AREVA

ANP-10300Q2NP
Revision 0

AURORA-B: An Evaluation Model for Boiling Water Reactors; Application to Transient and Accident Scenarios

Response to NRC Request for Additional Information

June 2016

AREVA Inc.

ANP-10300Q2NP
Revision 0

AURORA-B: An Evaluation Model for Boiling Water Reactors; Application to Transient and Accident Scenarios

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Nature of Changes

Item	Section(s) or Page(s)	Description and Justification
1	All	Initial Issue

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Nomenclature

Acronym	Definition
ABWR	Advanced Boiling Water Reactor
AE	Absolute Error
AFC	Automatic Flow Control
AOO	Anticipated Operational Occurrence
APRM	Average Power Range Monitor
ARI	Alternate Rod Insertion
ARQ	Acceptance Review Question
ASME	American Society of Mechanical Engineers
ATWS	Anticipated Transient without Scram
ATWSP	ATWS Peak Pressure Event with Main Steam Isolation Valve Closure
BOC	Beginning of Cycle
BT	Boiling Transition
BWR	Boiling Water Reactor
CCD	Component Calculational Device
CFD	Computational Fluid Dynamics
CFR	Code of Federal Regulations
CHF	Critical Heat Flux
CoA	Continuity of Assessment
CPR	Critical Power Ratio
CRDA	Control Rod Drop Accident
ECCS	Emergency Core Cooling System
EFW	Extended Flow Window
EM	Evaluation Model
EOC	End of Cycle
EOOS	Equipment Out Of Service
EPFOD	Extended Power/Flow Operating Domain
EPRI	Electric Power Research Institute
EPU	Extended Power Uprate
FGR	Fission Gas Release
FIST	Full Integral Simulation Test
FoM	Figure of Merit

Nomenclature

(Continued)

Acronym	Definition
FSAR	Final Safety Analysis Report
FWCF	Feedwater Controller Failure
HPCI	High Pressure Coolant Injection
HPCS	High Pressure Core Spray
HTFS	Heat Transfer and Fluid Flow Service
ICF	Increased Core Flow
INEL	Idaho National Engineering Laboratory
ISP	International Standard Problem
[	]
[	]
LAR	License Amendment Request
LFWH	Loss of Feedwater Heater
LHGR	Linear Heat Generation Rate
LHGRFACp	Power dependent Linear Heat Generation Rate Reduction Factor
LHS	Left Hand Side
LOCA	Loss of Coolant Accident
LPRM	Local Power Range Monitor
LRNB	Load Reject No Bypass
LTP	Lower Tie Plate
LTR	Licensing Topical Report
MCPR	Minimum Critical Power Ratio
[	]
MOC	Middle of Cycle
MSIV	Main Steam Isolation Valve
MSIVF	Main Steam Isolation Valve Closure - High Flux Scram Event
NEOC	Near End of Cycle
NEM	Nodal Expansion Method
NFT	Nuclear Fuel Type
NRC	Nuclear Regulatory Commission

Nomenclature

(Continued)

Acronym	Definition
OLMCPR	Operating Limit MCPR
OOS	Out Of Service
PB	Peach Bottom
PHTF	Portable Hydraulic Test Facility
PIRT	Phenomena Identification and Ranking Table
PLUOOS	Power Load Unbalance System Out of Service
PPD	Plant Parameters Document
PPR	Pin Power Reconstruction
PRFO	Pressure Regulator Failed Open with no Scram
PWR	Pressurized Water Reactor
RAI	Request for Additional Information
RCIC	Reactor Core Isolation Cooling
RE	Relative Error
RHS	Right Hand Side
RIA	Reactivity Insertion Accident
RLBLOCA	Realistic Large Break Loss of Coolant Accident
RMS	Root Mean Square
RPT	Recirculation Pump Trip
SE	Standard Error
SER	Safety Evaluation Report
[	]
SLCS	Standby Liquid Control System
SLMCPR	Safety Limit Minimum Critical Power Ratio
SLO	Single Loop Operation
SRP	Standard Review Plan
SRSS	Square Root of the Sum of the Squares
TAF	Top of Active Fuel
TIP	Traversing Incore Probe
TTNB	Turbine Trip No Bypass
TT1	Turbine Trip Test 1

Nomenclature

(Continued)

Acronym	Definition
UTP	Upper Tie Plate
V&V	Verification and Validation
ΔCPR	Transient Change in CPR for a Fuel Assembly
ΔMCPR	Transient Change in MCPR

INTRODUCTION

This document comprises AREVA's response to the Nuclear Regulatory Commission (NRC's) Request for Additional Information (RAIs) for the Licensing Topical Report (LTR) ANP-10300P, "AURORA-B: An Evaluation Model for Boiling Water Reactors; Application to Transient and Accident Scenarios." The RAIs were transmitted in Reference 1.

References

1 U.S. Nuclear Regulatory Commission letter to AREVA, "REQUEST FOR ADDITIONAL INFORMATION RE: AREVA NP, INC TOPICAL REPORT ANP-10300P, REVISION 0, "AURORA-B: AN EVALUATION MODEL FOR BOILING WATER REACTORS; APPLICATION TO TRANSIENT ACCIDENT SCENARIOS" (TAC NO. ME2979)" NRC:15:009, February 25, 2015.

Comment 1:

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

RAI-1a:

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.

AREVA Response 1a:

The errors described in Attachment B of Reference 1-1 can be grouped into three categories:

1. Input errors:

[ ]

[

]

[ ]

2. Data extraction errors:

[ ]

3. Typographical, grammatical, and transcription errors.

[ ]

RAI-1b:

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.*

AREVA Response 1b:

In addition to the changes to ANP-10300P identified in RAI-1a, several code changes have been made to address current RAIs. AREVA proposes the following:

1. The foundational S-RELAP5 code version for the AURORA-B AOO methodology is [ ]. It contains modifications to the code version used for the original submittal. It improves some separate effect test results (separator carryunder for example), provides new data edits to better enable response to RAIs, and facilitates the use of non-parametric ordered statistics.
2. The foundational MB2-K code version for the AURORA-B AOO methodology is [ ]. It contains improvements to the decay heat model.
3. Responses to these RAIs are performed withS-RELAP5 version UOCT14 which has modules of MB2-K version [ ] installed within it. Data comparisons and descriptions reflect the level of agreement of those code versions with test data. Biases and uncertainties in the model predictions that are presented in these RAIs reflect the performance of those code versions.
4. AREVA proposes that select sections of ANP-10300P be updated to ensure the final methodology is sufficiently captured by the approved version of the LTR to minimize human performance errors association with misinterpreting the document. Included in the updates are those changes specifically identified in Attachment B of Reference 1-1 as well as the replacement of Section 6.8.5 with the non-parametric statistical approach contained in the response to RAI-49b. The revision will also include clarifying language regarding the utilization of the non-parametric statistical approach throughout the document.

An approved LTR for a methodology is not updated for minor changes associated with code maintenance. These minor changes are tracked within the code maintenance process described in RAI-19. The code modifications performed must stay within the terms, conditions and limitations of the approved method such that the changes do not constitute an adverse change (consistent with allowed changes under 10 CFR 50.59). When a major change to the methodology is made, such as adopting a new fuel lattice code, the methodology would be resubmitted to the USNRC for review and approval.

RAI-1 References

1-1 AREVA letter to U.S. Nuclear Regulatory Commission, "Response to a Draft Request for Additional Information Regarding ANP-10300P, Revision 0, 'AURORA-B: An Evaluation Model for Boiling Water Reactors; Application to Transient Accident Scenarios,'" NRC:11:081, August 3, 2011.

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

Comment 2:

[ ]

RAI-2:

How does this relate to EMF-2100(P)? Is there a [ ] Model and Correlation Manual that would provide a delta-review for EMF2100P?

AREVA Response 2

In general, the S-RELAP5 Models and Correlations Code Manual, [ ], has a specific revision number that corresponds to a specific code version. Consequently, [ ] provides the basis for the code version used in the AURORA-B methodology and previous revisions to [ ] apply to code versions used in the realistic Pressurized Water Reactor (PWR) Realistic Large Break Loss of Coolant Accident (RLBLOCA) [ ] methodology.

The realistic PWR RLBLOCA [ ] methodology was submitted with the code version associated with [ ]. Through PWR LOCA refinement, BWR code development, fuel model development, and resolution of code errors, the S-RELAP5 Models and Correlations Code Manual has evolved from [ ] without substantial change to the models common to all methodologies. The specific models for AURORA-B and PWR RLBLOCA are activated through input and do not affect the calculated results unless activated. The BWR models are the jet pump and BWR separator components. Optional models for BWR wall friction and local form loss models, as well as special treatment for the BWR upper plenum and the BWR Critical Heat Flux (CHF) correlations are activated through model options in existing component and heat structure input. [ ]

[

]

Comment 3:

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

RAI-3:

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

AREVA Response 3

Current S-RELAP5 version UOCT14 uses *IAPWS-IF97 thermodynamic properties for water and steam* (References 3-1 and 3-2) for steam tables. Instead of approximating with lookup tables, steam/water properties are evaluated directly with the IAPWS-IF97 formulations of polynomial expressions. Accordingly, the uncertainties are close to those described in Section 12 of Reference 3-1. For BWR operating ranges, the uncertainties of specific volume are within $\pm$0.015% for water and within $\pm$0.1% for steam. These uncertainties are insignificant compared to uncertainties in other code parameters, such as those identified in the PIRT (Section 3.4 of LTR).

RAI-3 References

3-1 *Revised Release on the IPAWS Industrial Formulation 1997 for the Thermodynamic Properties of Water and Steam, August 2007*. This release and other releases issued by IAPWS can be obtained from http://www.iapws.org.

3-2 *ASME International Steam Tables for Industrial Use*, ASME Press, 2000.

Comment 4:

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

RAI-4:

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

AREVA Response 4

The major function of the control systems and boundary condition inputs to the evaluation model (EM) is to simulate actuation of valves, pump trips, scram, etc. for transients. Virtually all of the analysis inputs described or alluded to in Table 5-4 are defined and documented by the utility in plant, reload and/or analysis-specific controlled documents jointly prepared by the utility and AREVA. In addition to the Plant Parameter Document (PPD) a plant-reload-specific calculation plan is jointly prepared, reviewed and issued to specify additional analysis details. An overview of this process along with general AOO and accident analysis considerations is described in Section 6.8.

Section 6.8.3 provides [

]

[

]

[ ]

The following paragraphs provide more discussion of the Table 5-4 features and inputs to the AURORA-B analysis process relative to control systems modeling.

There are two major BWR control systems currently modeled in the AURORA-B system analysis, [

]

For licensing analyses, the reactor protection systems and their response are specified in a conservative manner, the key parameters controlled by the plant technical specifications (Tech Specs for short) and/or analytical limits that have been defined by various setpoint methodology documents. [

]

[ ]

Comment 5:

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 [ ]

RAI-5a:

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

<u>AREVA Response 5a:</u>

[ ]

RAI-5b:

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?

<u>AREVA Response 5b:</u>

[ ]

RAI-5 References

5-1 Framatome ANP letter to NRC Document Control Desk, Request for Review of EMF-2310(P) Revision 1, "SRP Chapter 15 Non-LOCA Methodology for Pressurized Water Reactors," August 12 2003, NRC:03:044.

5-2 [ ]

5-3 [ ]

Comment 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 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:

RAI-6a:

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

AREVA Response 6a:

The definition of a significant departure from the SRP is a subjective topic. It is the intent for the AURORA-B EM to be applicable to all jet-pump BWRs, however, that applicability must be demonstrated on a plant specific basis when the EM is introduced through the License Amendment Request (LAR) process.

The plant Licensee must add the AURORA-B references to their Technical Specification and this change is accomplished through an NRC review of the plant LAR. In the LAR the Licensee provides justification for why the generically approved AURORA-B methodology is applicable for performing licensing analyses at the plant. Part of this justification would include demonstrating that the plant conforms to the SRP within the bounds of applicability of the methodology. The NRC then reviews the LAR and either accepts that the AURORA-B EM is applicable to the plant or requires modification on a plant specific basis to make it applicable for the specific plant.

RAI-6b:

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?

AREVA Response 6b:

When a plant transitions to AREVA fuel and methods an extensive investigation of the current licensing basis is conducted. AREVA reviews the Final Safety Analysis Report (FSAR) and other applicable licensing analysis reports. Events and analyses are classified as a) not impacted by a change in fuel or core design, b) bounded by the consequences of another event, or c) potentially limiting – reanalyze using the AURORA-B AOO methodology. This disposition considers both rated and off-rated operating conditions. For each selected event and operating condition, an assessment is made as to whether it can be adequately simulated by AURORA-B. Questions that would be addressed include:

- Does the plant configuration, co-resident fuel or event scenario introduce phenomena that have not been evaluated in the context of the already approved methods or models?
- Are new closure models needed that have not been approved?
- Are nodalization changes necessary that are inconsistent with what is described in ANP-10300P?

If new modeling is needed that is not approved, the results of the review would be provided to the affected plant licensee(s) as part of the process for making code and methodology modifications and the changes would be submitted for NRC review and approval either in a LTR or a plant specific methodology submittal in support of the fuel transition LAR.

Comment 7:

The discussion in Section 3.1.2.7 of the applicability of the AURORA-B EM to SRP 15.8 transients (ATWS), 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;

RAI-7a:

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?

<u>AREVA Response 7a:</u>

Boron cannot be injected into the reactor unless the SLCS is actuated. Since peak pressure is reached well before the SLCS is actuated (see response 7b), the assumptions of boron concentration as a function of time have no impact on the computed peak pressure. With respect to the fuel integrity analyses, no credit is taken for the negative reactivity insertion due to boron transport into the core and therefore the computed power response is conservative.

RAI-7b:

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?

AREVA Response 7b:

The MSIV closure without scram is the limiting or near limiting event for peak pressure during an ATWS (Reference 7-1, Sect. 2.2).

[ ]

RAI-7 References

7-1 NEDO-24222, "Assessment of BWR Mitigation of Anticipated Transients Without Scram Volume II (NUREG 0460 Alternate No. 3)," February 1981.

Comment 8:

Plant nodalization is discussed 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)

RAI-8:

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

AREVA Response 8:

Nodalization sensitivity studies were performed for the steam lines. The results are summarized in AREVA's response to the NRC Acceptance Review Questions (ARQ) (Reference 8-1, question 24). Results of the study form the technical basis for the modeling guidelines (Reference 8-2, e.g., Tables 6-6 and 6-7, and Section 7.4), which are summarized in ANP-10300P, Section 5.2.8.2.

For the fuel region, [

]

Nodalization for the reactor vessel [

]

[

]

The modeling guidelines (Reference 8-2) establish [

]

[ ]

Figure 8-1: Typical PWR Steam Generator Nodalization with S-RELAP5

RAI-8 References

8-1 ANP-10300Q1P, Revision 0, "AURORA-B: An Evaluation Model for Boiling Water Reactors; Application to Transient and Accident Scenarios, Responses to NRC Acceptance Review Questions," AREVA, July 2011.

8-2 [ ]

8-3 EMF-2310(P)(A), Revision 1, "SRP Chapter 15 Non-LOCA Methodology for Pressurized Water Reactors," Framatome ANP, May 2004.

Comment 9:

Comment - The discussion in Section 5.2.9.1 (p. 5-28) summarizes the process for determining the 'event MCPR' 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.

RAI-9:

Justify the use of [ ] response.

AREVA Response 9:

During an AOO event, the change in power and flow cause a change in the CPR of an assembly. The change in the MCPR in the core is used to establish the operating limit MCPR that is required for the event. During the analysis process, [

]

[

]

The purpose of the operating limit MCPR is to ensure that during an AOO, critical power or dryout is not attained during the event. [

]

RAI-9 References

9-1 ANP-10307PA, Revision 0, *AREVA MCPR Safety Limit Methodology for Boiling Water Reactors*, AREVA NP, June 2011.

Comment 10:

The discussion in Section 5.2.9.1 (p. 5-29) states that [ ] As formulated, this statement cannot be objectively assessed by an independent reviewer.

RAI-10:

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

AREVA Response 10:

With the AURORA-B AOO EM analysis system, [ ]

[ ]

[ ]

The approach described by above Items [ ]

Comment 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.

RAI-11:

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.

AREVA Response 11:

The MICROBURN-B2 code is a three-dimensional steady state nodal reactor simulator which is used to perform core nuclear design calculations and NRC approved steady state safety analyses, including steady state MCPR analysis. It is described in more detail in Reference 11-1, with additional information provided in Reference 11-2, Question 15 and Section A.4.

[ ]

While there was no direct interaction between S-RELAP5 itself and the MICROBURN-B2 steady-state core simulator for the LTR calculations, the MICROBURN-B2 core model did serve as the basis for the S-RELAP5 core model. As

described in Reference 11-2, Question 15, the MICROBURN-B2 simulator [

]. All certified automation tools developed for licensing AURORA-B will fall under the same software quality assurance practices as those discussed in RAI-19.

RAI-11 References:

11-1 EMF-2158(P)(A) Revision 0, *Siemens Power Corporation Methodology for Boiling Water Reactors: Evaluation and Validation of CASMO-4/MICROBURN-B2,* Siemens Power Corporation, October 1999.

11-2 ANP-10300Q1P, Revision 0, "AURORA-B: An Evaluation Model for Boiling Water Reactors; Application to Transient and Accident Scenarios, Responses to NRC Acceptance Review Questions," AREVA, July 2011.

Comment 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 [

] 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.

RAI-12a:

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.

AREVA Response 12a:

To evaluate the fuel-to-clad gap conductance and gap-conductance uncertainty, AREVA examined the fuel behavior of [

]

[ ]

Power uncertainties

[ ]

Manufacturing uncertainties

[ ]

Pellet property/model uncertainties

[ ]

[

]

Three RODEX4 rod depletion input decks have been provided on the attached CD and provide the depletion information for [

]

Table 12-1 Average Rod Parameter Statistics

[

]

[ ]

Figure 12-1 Individual Trial Results and Histogram for [ ]

[

]

Figure 12-2 Individual Trial Results and Histogram for [

]

[ ]

Figure 12-3 Individual Trial Results and Histogram for Average [ ]

RAI-12b:

Also provide a distribution plot of predicted gap conductance.

AREVA Response 12b:

See response RAI-12a above.

RAI-12c:

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

AREVA Response 12c:

Rod average and maximum planar average power values are readily available from the MICROBURN-B2 calculations. The rod average exposure corresponding to the maximum planar average power is not easily obtained, however the assembly and maximum planar average exposure values are readily available.

The available data was extracted from two cycle depletions to present results for both the ATRIUM 10XM and the ATRIUM-10A fuel designs currently in operation in the US. The data was generated from core follow analyses based on actual core operation. The first analysis was for a core where the fresh fuel was ATRIUM 10XM and the second cycle fuel was ATRIUM-10A fuel. Figure 12-4 presents the assembly average data and Figure 12-5 presents the maximum planar average data for the MCPR limiting assembly of the fresh fuel and the second cycle fuel at each cycle exposure statepoint. The second analysis was for a plant that contained only ATRIUM-10A fuel so both the fresh fuel and the second cycle fuel are ATRIUM-10A. These are presented in Figure 12-6 and Figure 12-7.

[ ]

Figure 12-4 Assembly Average Data for MCPR Limiting Assembly ATRIUM 10XM

Figure 12-5 Maximum Planar Average Data for MCPR Limiting Assembly ATRIUM 10XM

[ ]

Figure 12-6 Assembly Average Data for MCPR Limiting Assembly ATRIUM 10A

[ ]

Figure 12-7 Maximum Planar Average Data for MCPR Limiting Assembly ATRIUM 10A

RAI-12 References:

12-1 BAW-10247PA, Rev 0, Realistic Thermal-Mechanical Fuel Rod Methodology for Boiling Water Reactors, Framatome ANP, Inc., February 2008.

Comment 13:

[

] in ANP-10300Q1P Rev.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.

RAI-13:

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 [

].

AREVA Response 13:

The assumption in question is consistent with the current licensing basis for BWRs. Unlike PWR methods that utilize local CHF correlations based on sub-channel analyses, BWR methods use correlations based on [

]

[

]

Comment 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 FWCF and MSIV events. It appears that this correction may alter Table 32-1 of earlier responses to RAIs.

RAI-14:

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.

AREVA Response 14:

The AREVA responses to the ARQs and the corrections to LTR ANP-10300P were provided in letter **[** **]**. The text in the LTR was corrected to more accurately state the analysis results that support Table 32-1. Both the responses to the ARQs and the corrections to the LTR are based on the same analyses and Table 32-1 of the AREVA response to the ARQs is correct.

Comment 15:

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

RAI-15:

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.

AREVA Response 15:

In addition to the four models noted in the RAI, The RODEX4 models for [

] The RODEX4 thermal property formulations for fuel and cladding are described in detail in Section 7 of Reference 15-1.

RAI-15 Reference

[ ]

Comment 16:

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

RAI-16:

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

AREVA Response 16:

[ ]

[

]

Figure 16-1 Stable Fission Gas Release Data as a Function of Peak Fuel Enthalpy Increase from Simulated RIA Tests in CABRI, NSRR, and BIGR Test Reactors

[

]

Table 16-1 Fission Gas Release for Short Hold Time Experiments

Figure 16-2 Fission Gas Release for Short Hold Time

[ ]

RAI-16 Reference

[ ]

Comment 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.

RAI-17a:

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

AREVA Response 17a:

Please see Response to 17b.

RAI-17b:

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.

AREVA Response 17b:

The cycle exposure (or time) that is limiting varies for each AOO transient and accident. The primary core-wide factors relating to transient response are [

]

For AURORA-B licensing evaluations, the entire fuel cycle is considered for each AOO transient and accident analyzed. [

]

[ ]

Comment 18:

In Section 9.3, criteria are established defining an "insignificant change" in three figure of merits (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.

RAI-18a:

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

<u>AREVA Response 18a:</u>

The term [ ] The definitions of significance in Section 9.3 are used to characterize the importance of sensitivity study evaluations of code input parameters or physical models as presented in ANP-10300P Section 6.8 or in the evaluation of code changes or errors described in Section 9.4. These evaluations are [ ]

RAI-18b:

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

AREVA Response 18b:

The definitions of significance in Section 9.3 [

]

RAI-18c:

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?

AREVA Response 18c:

MCPR is always calculated at full machine precision and typically printed out to at least 4 decimal places. When specifying core operating limits, MCPR limits are generally only specified to two decimal place (0.01) precision, [

] When assessing sensitivity studies, code modifications or errors, using more significant digits provides a smoother response to the changes being studied.

Comment 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 [

]

The reviewers acknowledge that three of these [

] might reasonably fall within the purview of a quality program that is compliant with 10 CFR 50 Appendix B requirements. Therefore, changes of these three types should not require further NRC approval, provided the effects on relevant 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.

RAI-19:

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 signinificant 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.*

<u>AREVA Response 19</u>:

AREVA's Software Quality Assurance Procedures for NRC approved methods require both the verification and validation (V&V) of code modifications and the assessment of the changes on the approved methodology results. These are two separate steps in the code release process.

1. The V&V of a code modification ensures the modification functions as intended. It includes new validation against data or higher order methods when the particular update modifies physical models and the existing test suite is inadequate to assess the change in performance.
2. In addition to the modification specific V&V described in item 1, AREVA evaluates the impact of the code modifications on the EM performance through a series of tests referred to as the Continuity of Assessment (CoA) process. The CoA process recalculates a sufficient cross section of the analyses included in the methodology LTR to assess the impact of modifications relative to both the previous code version and to the final results (i.e. results updated as a result of RAIs) presented in the approved LTR. Table 19-1 identifies the assessments and sample problems from ANP-10300P currently included in the CoA process for AURORA-B AOO. As additional AURORA-B methods are finalized, the CoA test suite will be expanded to represent the entire qualification and application space represented in the associated LTRs. With respect to the concerns identified in the RAI:
   a) With a broad spectrum of CoA test cases, the detection of compensating changes, whether due to errors or model changes, can be identified. Any compensating change in the CoA assessments to restore a "desired level of performance" would be detected since the CoA test materials are controlled in the same manner as the AURORA-B source code which is compliant with 10 CFR 50 Appendix B requirements.
   b) The CoA process includes an assessment against the final results in the approved LTR to ensure accumulated changes fall below the criteria in Sections 9.3 and 9.4 to preclude reporting the changes to the NRC.

c) The breadth of the combined CoA test suite (AOO, Control Rod Drop Accident (CRDA) and LOCA) will detect adverse interactions and incompatibilities with other models used within the methodologies.

d) Table 19-1 identifies the assessments and sample problems from ANP-10300P included in the CoA process for AURORA-B AOO.

e) When new data is added for verification, [

]

Table 19-1: ANP-10300P Assessments and Sample Problems in CoA Test Suite

[

]

Comment 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., > 90%. 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.

RAI-20a:

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.

<u>AREVA Response 20a:</u>

The MICROBURN-B2 and MB2-K codes do not assume that the bypass flow and active channel (assembly) flow have the same void fraction. [

]

AREVA models BWR fuel assemblies within the CASMO-4 lattice code with [

]

RAI-20b:

MICROBURN-B2 use a fitting function for cross-sections. Figure A-15 in ANP-10300Q1P rev 0, suggests that the fitting function starts to under-predict reactivity after ~80 to ~85% 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 > 80% void for pin power reconstruction?

AREVA Response 20b:

The core response in a transient is based upon the entire core reactivity as no region responds in isolation to its environment. The comparison between MICROBURN-B2 and [

]

Comment 21:

The calculation of 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.

RAI-21:

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.

AREVA Response 21:

The relative differences, in %, between the MICROBURN-B2 and MB2-K calculated assemblywise **[ ]** power distributions for a BWR4 at full power, near BOC Extended Power Uprate (EPU) conditions are presented in Figure 22-1.

[

]

The MB2-K calculated steady-state relative pin powers and relative differences from the MICROBURN-B2 relative pin powers for the maximum LHGR node for this same reactor and operating conditions are presented in Figure 22-2.

Figure 21-1: MICROBURN-B2/MB2-K Assemblywise [ ] Power Distribution Differences (% Relative)

Figure 21-2: MICROBURN-B2/MB2-K Nodal Relative Pin Power Comparison for BWR4

Comment 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.

RAI-22a:

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.

AREVA Response 22a:

[ ]

The extension of steady-state neutronics solution methods to the time dependent case is standard industry practice, provided that all time-dependent inputs and outputs are updated with every time step. This is the case with MB2-K.

RAI-22b:

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?

AREVA Response 22b:

[ ]

RAI-22 References:

22-1 EMF-2158(P)(A) Revision 0, *Siemens Power Corporation Methodology for Boiling Water Reactors: Evaluation and Validation of CASMO-4 / MICROBURN-B2*, Siemens Power Corporation, October 1999.

[ ]

Comment 23:

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

RAI-23:

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

AREVA Response 23:

[ ]

[ ]

RAI-23 References

23-1 Allis-Chalmers Atomic Energy Division, *Joint US/EURATOM R&D Program AT (11-1)-1186; Steam Separation Technology Under the Euratom Program; Topical Report – Part I, Primary Separation of Steam from Water by Natural Separation*, ACNP-65002, April 15, 1965.

23-2 Allis-Chalmers Atomic Energy Division, *Joint US/EURATOM R&D Program AT (11-1)-1186; Steam Separation Technology Under the Euratom Program; Quarterly Progress Report; October 1, 1963-December 31, 1963*, ACNP-63035, January 10, 1964.

Comment 24:

Section 6.2.5 states "Since USNRC approval in Reference 5, qualification of the code system has been confirmed for EPU 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.

RAI-24a:

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?

<u>AREVA Response 24a:</u>

See response to RAI-20a.

RAI-24b:

MB2-K uses a fitting function for cross-sections. Figure A-15 in ANP-10300QP rev 0, suggests that the fitting function starts to under-predict reactivity after ~80 or ~85% 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.

<u>AREVA Response 24b:</u>

See response to RAI-20b.

RAI-24c:

How are cross sections determined for > 80% void?

<u>AREVA Response 24c:</u>

See response to RAI-20b

Comment 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.

RAI-25:

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.

AREVA Response 25:

[ ]

Table 25-1 Relative Differences, in %, Between MB2-K and CUBBOX Local Relative Power Densities, 1.0 Second MB2-K Time Steps

[ ]

Table 25-2 Relative Differences, in %, Between MB2-K and CUBBOX Local Relative Power Densities, 0.5 Second MB2-K Time Steps

[

]

Table 25-3: Relative Differences, in %, Between MB2-K and ISQBOX Assembly Power Distributions

[ ]

Table 25-3: Relative Differences, in %, Between MB2-K and ISQBOX Assembly Power Distributions (continued)

Table 25-3: Relative Differences, in %, Between MB2-K and ISQBOX Assembly Power Distributions (continued)

Table 25-3: Relative Differences, in %, Between MB2-K and ISQBOX Assembly Power Distributions (continued)

[ ]

RAI-25 References:

[ ]

Comment 26:

Section 6.6.2.1 discusses distortions in LPRM measurements and the time to achieve peak power.

RAI-26:

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?

AREVA Response 26:

Table 26-1 provides the sensitivity of the peak and integral power results of the PB turbine trip test results due to changes of [ ] in the delayed neutron yields. The change of [ ] in the delayed neutron yields is the two-sigma uncertainty in delayed neutron yields utilized in the uncertainty analysis provided in the response to RAI-49b.

Table 26-1: Peach Bottom Turbine Trip Test Sensitivity to Delayed Neutron Yield Changes

[ ]

[

]

Comment 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, and the [
>
>]

RAI-27a:

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

<u>AREVA Response 27a:</u>

Of 172 individual local power range monitors (LPRMs) in the core, 77 valid measurements are available for turbine trip test 1 and 76 measurements are available for turbine trip tests 2 and 3. In Tables 27-1 through 27-3 the measured and predicted relative powers are shown with the corresponding prediction error. Individual LPRMs are identified with prefixes that indicate their axial positions. Levels A (LA), B (LB), C (LC), and D (LD) correspond to 18, 54, 90, and 126 inches above the bottom of active fuel, respectively.

The prediction errors of the individual LPRMs, normalized to the core average, [

]

Table 27-1 Normalized LPRM Signals for Peach Bottom Turbine Trip Test 1

[ ]

Table 27-1 Normalized LPRM Signals for Peach Bottom Turbine Trip Test 1 continued

[ ]

Table 27-1 Normalized LPRM Signals for Peach Bottom Turbine Trip Test 1 continued

[

]

Table 27-2 Normalized LPRM Signals for Peach Bottom Turbine Trip Test 2

[ ]

Table 27-2 Normalized LPRM Signals for Peach Bottom Turbine Trip Test 2 continued

[ ]

Table 27-2 Normalized LPRM Signals for Peach Bottom Turbine Trip Test 2 continued

[ ]

Table 27-3 Normalized LPRM Signals for Peach Bottom Turbine Trip Test 3

[

]

Table 27-3 Normalized LPRM Signals for Peach Bottom Turbine Trip Test 3 continued

[ ]

Table 27-3 Normalized LPRM Signals for Peach Bottom Turbine Trip Test 3 continued

[ ]

[ ]

Figure 27-1 [ ]

[ ]

Figure 27-2 Prediction Error in Normalized LPRM Signals at Level D for Turbine Trip Test 1 [ ]

[ ]

Figure 27-3 Prediction Error in Normalized LPRM Signals at Level C for Turbine Trip Test 1 [ ]

[ ]

Figure 27-4 Prediction Error in Normalized LPRM Signals at Level B for Turbine Trip Test 1 [ ]

Figure 27-5 Prediction Error in Normalized LPRM Signals at Level A for Turbine Trip Test 1 [ ]

Figure 27-6 Prediction Error in Normalized LPRM Signals at Level D for Turbine Trip Test 2 [ ]

Figure 27-7 Prediction Error in Normalized LPRM Signals at Level C for Turbine Trip Test 2 [ ]

Figure 27-8 Prediction Error in Normalized LPRM Signals at Level B for Turbine Trip Test 2 [ ]

[ ]

Figure 27-9 Prediction Error in Normalized LPRM Signals at Level A for Turbine Trip Test 2 [ ]

[ ]

Figure 27-10 Prediction Error in Normalized LPRM Signals at Level D for Turbine Trip Test 3 [ ]

[ ]

Figure 27-11 Prediction Error in Normalized LPRM Signals at Level C for Turbine Trip Test 3 [ ]

[ ]

Figure 27-12 Prediction Error in Normalized LPRM Signals at Level B for Turbine Trip Test 3 [ ]

[ ]

Figure 27-13 Prediction Error in Normalized LPRM Signals at Level A for Turbine Trip Test 3 [ ]

RAI-27b:

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

<u>AREVA Response 27b:</u>

[ ]

[ ]

Table 27-4 Key Transient Parameters for Turbine Trip Test 1

[ ]

Figure 27-14 Comparison of Initial Power Distributions for TT1

RAI-27c:

How is the assumption that [ ] validated?

<u>AREVA Response 27c:</u>

[ ]

[ ]

Table 27-5 PB2 Turbine Trip Tests RMS Relative Calculated/Measured Differences (%) for Available LPRMs Surrounding Hot Channel

[ ]

See also the response to RAI-83 for further discussion of assembly and pin power distribution uncertainties.

RAI-27d:

How is the assumption that [ ] validated?

AREVA Response 27d:

[ ]

RAI-27 References:

27-1 P. N. Somerville, *Tables for Obtaining non-Parametric Tolerance Limits*, The Annals of Mathematical Statistics, Vol. 29, November 1958.

27-2 Core Design and Operating Data for Cycles 1 and 2 of Peach Bottom 2, EPRI NP-563, June 1978.

27-3 Transient and Stability Tests at Peach Bottom Atomic Power Station Unit 2 at End of Cycle 2, EPRI NP-564, June 1978.

27-4 ANP-10300Q1P, Revision 0, "AURORA-B: An Evaluation Model for Boiling Water Reactors; Application to Transient and Accident Scenarios, Responses to NRC Acceptance Review Questions," AREVA, July 2011.

Comment 28:

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

RAI-28:

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

AREVA Response 28:

[ ]

RAI-28 References

28-1 ANP-10300Q1P, Revision 0, "AURORA-B: An Evaluation Model for Boiling Water Reactors; Application to Transient and Accident Scenarios, Responses to NRC Acceptance Review Questions," AREVA, July 2011.

Comment 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 [ ] (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 +/- 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 p. 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.

RAI-29a:

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.

AREVA Response 29a:

Table 29-1 FRIGG-2 Experiment Conditions for Figure 29-1 through Figure 29-7

[ ]

[ ]

Figure 29-1 Calculated and Measured Void Axial Profile for FRIGG-2 Test 313007

[ ]

Figure 29-2 Calculated and Measured Void Axial Profile for FRIGG-2 Test 313010

[ ]

Figure 29-3 Calculated and Measured Void Axial Profile for FRIGG-2 Test 313016

[ ]

Figure 29-4 Calculated and Measured Void Axial Profile for FRIGG-2 Test 313017

[ ]

Figure 29-5 Calculated and Measured Void Axial Profile for FRIGG-2 Test 313020

[ ]

Figure 29-6 Calculated and Measured Void Axial Profile for FRIGG-2 Test 313030

Figure 29-7 Calculated and Measured Void Axial Profile for FRIGG-2 Test 313060

Table 29-2 FRIGG-3 Experiment Conditions for Figure 29-8 through Figure 29-18

[ ]

Figure 29-8 Calculated and Measured Void Axial Profile for FRIGG-3 Test 413102

[ ]

Figure 29-9 Calculated and Measured Void Axial Profile for FRIGG-3 Test 413107

[ ]

Figure 29-10 Calculated and Measured Void Axial Profile for FRIGG-3 Test 413111

[ ]

Figure 29-11 Calculated and Measured Void Axial Profile for FRIGG-3 Test 413116

[ ]

Figure 29-12 Calculated and Measured Void Axial Profile for FRIGG-3 Test 413117

[ ]

Figure 29-13 Calculated and Measured Void Axial Profile for FRIGG-3 Test 413118

[ ]

Figure 29-14 Calculated and Measured Void Axial Profile for FRIGG-3 Test 413122

[ ]

Figure 29-15 Calculated and Measured Void Axial Profile for FRIGG-3 Test 413124

Figure 29-16 Calculated and Measured Void Axial Profile for FRIGG-3 Test 413125

Figure 29-17 Calculated and Measured Void Axial Profile for FRIGG-3 Test 413140

[ ]

Figure 29-18 Calculated and Measured Void Axial Profile for FRIGG-3 Test 413141

Table 29-3 ATRIUM-10A Experiment Conditions for Figure 29-20 through Figure 29-21

[ ]

Table 29-4 ATRIUM-10A Data for Figures 29-22 through 29-24

[ ]

[ ]

Figure 29-19 Calculated and Measured Void Axial Profile for ATRIUM-10A Test 25

[ ]

Figure 29-20 Calculated and Measured Void Axial Profile for ATRIUM-10A Test 214

Figure 29-21 Calculated and Measured Void Axial Profile for ATRIUM-10A Test 323

Figure 29-22 Calculated and Measured Void Fractions for ATRIUM-10A Void Fraction Tests with Measurements at Level 1

[ ]

Figure 29-23 Calculated and Measured Void Fractions for ATRIUM-10A Void Fraction Tests with Measurements at Level 2

[ ]

Figure 29-24 Calculated and Measured Void Fractions for ATRIUM-10A Void Fraction Tests with Measurements at Level 3

RAI-29b:

Discuss the significance of 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, addressing in particular 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.)

AREVA Response 29b:

[ ]

Table 29-5 Rod Array Data Binned According to Pressure, Subcooling and Mass Flux

[ ]

Table 29-6 ATRIUM 10XM gamma tomography test characteristics

Axial Power Shape	Downskew
Radial Power Peaking	[ ]
Bundle Design	[ ]
Pressure (psi)	[ ]
Inlet Subcooling (°F)	[ ]
Mass Flow Rate (lbm/s)	[ ]
Equilibrium Quality at Measurement Plane (fraction)	[ ]
Max Void at Measurement Plane (fraction)	[ ]
Reported Measurement Uncertainty (fraction)	[ ]

Figure 29-25 Calculated vs. Measured Results for ATRIUM 10XM Void Fraction Tests

Figure 29-26 Comparison of Means, Variance in Means and Number of Data Points for S-RELAP5 Benchmarks Binned by Pressure

RAI-29c:

Examining the plots in Figures 6-1 through 6-3, it appears that the uncertainty in the void fraction predictions compared to measured data [ ] 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 [ ] applications of the EM [ ]

<u>AREVA Response 29c:</u>

[ ]

Table 29-7 ATRIUM-10A Selection of Valid Data

[ ]

Table 29-7 ATRIUM-10A Selection of Valid Data (continued)

Table 29-7 ATRIUM-10A Selection of Valid Data (continued)

[ ]

Table 29-8 ATRIUM-10A Void Prediction Error

[ ]

[ ]

Figure 29-27 ATRIUM-10A Void Measurements

Figure 29-28 Calculated vs. Measured Results for ATRIUM-10A Void Fraction Tests

RAI-29d:

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 + 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 + experimental) uncertainties based on experience or other applicable data sets that contain replicate tests. These estimates of the total uncertainty (measurement + 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.

AREVA Response 29d:

Table 29-9 Measurement Uncertainties for FRIGG Tests

[ ]

Table 29-10 Measurement Uncertainties for ATRIUM-10A Tests

[ ]

RAI-29e:

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

]

AREVA Response 29e:

[

]

Table 29-11 Rod Array Void Prediction Errors

Figure 29-29 Calculated vs. Measured Results for FRIGG-2 Void Fraction Tests

Figure 29-30 Calculated vs. Measured Results for FRIGG-3 Void Fraction Tests

[ ]

Figure 29-31 Calculated vs. Measured Results for ATRIUM-10A Void Fraction Tests

[ ]

Figure 29-32 Calculated vs. Measured Results for Christensen Tests

RAI-29 References:

29-1 O. Nylund, et. al., *Hydrodynamic and Heat Transfer Measurements on a Full-Scale Simulated 36-Rod Marviken Fuel Element with Uniform Heat Flux Distribution*, ASEA and AB Atomenergi, FRIGG-2, R4-447/RTL-1007, 1968

29-2 O. Nylund, et. al., *Hydrodynamic and Heat Transfer Measurements on a Full-Scale Simulated 36-Rod Marviken Fuel Element with Non-Uniform Heat Flux Distribution*, ASEA and AB Atomenergi, FRIGG-3, R4-494/RL-1154, 1968

29-3 ANP-10300Q1P, Rev. 0, "AURORA-B: An Evaluation Model for Boiling Water Reactors; Application to Transient and Accident Scenarios, Responses to NRC Acceptance Review Questions," July 2011.

Comment 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.

RAI-30a:

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.

AREVA Response 30a:

The Christensen tests are used to [

]

Table 30-1 Statistics of Measured vs. Predicted Void Fraction for Christensen Tests

[ ]

Figure 30-1 Calculated vs. Measured Results for Christensen Tests with 400 psi Outlet Pressure (6 gpm Inlet Flow Rate)

[ ]

Figure 30-2 Calculated vs. Measured Results for Christensen Tests with 600 psi Outlet Pressure (9 gpm Inlet Flow Rate)

Figure 30-3 Calculated vs. Measured Results for Christensen Tests with 800 and 1000 psi Outlet Pressure (9 gpm Inlet Flow Rate)

[ ]

Figure 30-4 Calculated vs. Measured Results for Christensen Tests with Inlet Subcooling 5.2 - 6.0 °F

[ ]

Figure 30-5 Calculated vs. Measured Results for Christensen Tests with Inlet Subcooling 13.0 - 15.6 °F

[ ]

Figure 30-6 Calculated vs. Measured Results for Christensen Tests with Inlet Subcooling 21.8 - 25.9 °F

RAI-30b:

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 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.

AREVA Response 30b:

[ ]

Table 30-2 Christensen Experiment Conditions

[ ]

[ ]

Figure 30-7 Void Fraction Comparison for Christensen Test 9

[ ]

Figure 30-8 Void Fraction Comparison for Christensen Test 10

Figure 30-9 Void Fraction Comparison for Christensen Test 11

Figure 30-10 Void Fraction Comparison for Christensen Test 12

Figure 30-11 Void Fraction Comparison for Christensen Test 13

Figure 30-12 Void Fraction Comparison for Christensen Test 15

[ ]

Figure 30-13 Void Fraction Comparison for Christensen Test 16

RAI-30c:

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 + 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 + experimental) uncertainties based on experience or other data sets that contain replicate tests. These estimates of the total uncertainty (measurement + 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.

AREVA Response 30c:

[ ]

[

]

Figure 30-14 Christensen Tests at 600 psia with Varying Subcooling

RAI-30d:

Explain the source and derivation of [

] , and address their relationship to the total uncertainty in the measured void fraction values. Discuss the significance of [

]

AREVA Response 30d:

Please refer to AREVA Response 29e.

RAI-30 Reference:

30-1 H. Christensen, *Power-to-Void Transfer Function, Doctoral Dissertation*, Massachusetts Institute of Technology, September 1961 (and ANL-6385, July 1961).

Comment 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 [

]

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.

RAI-31a:

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

<u>AREVA Response 31a:</u>

[

]

[

]

RAI-31b:

How is the [ ] prediction uncertainty determined? Since the [ ]

AREVA Response 31b:

[ ]

Table 31-1 Statistics for Measured vs. Calculated Void Fraction for the Allis Chalmers Tests

[

]

RAI-31c:

In what sense is this a 'bounding' estimate, when the primary reference shows a prediction uncertainty of ±20% for the Kataoka-Ishii correlation, 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 + 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 [ ] in Figures 6-6, 6-7, and 6-8.

AREVA Response 31c:

[ ]

Table 31-2: [ ]

[ ]

RAI-31d:

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

AREVA Response 31d:

[ ]

[ ]

RAI-31 References:

31-1 Allis Chalmers Atomic Energy Division, *Joint US/EURATOM R&D Program AT(11-1)-1272: Investigation of Vapor Volume Fraction and Slip Velocity Under the Euratom Program; Final Report*, ACNP-64029, November, 1964

31-2 Allis Chalmers Atomic Energy Division, *Joint US/EURATOM R&D Program AT(11-1)-1186: Steam Separation Technology Under the Euratom Program; Quarterly Progress Report*; April 1, 1963-June 30, 1963, ACNP-63021, July 10, 1963

31-3 Allis Chalmers Atomic Energy Division, *Joint US/EURATOM R&D Program AT(11-1)-1186: Steam Separation Technology Under the Euratom Program; Quarterly Progress Report*; October 1, 1963-December 31, 1963, ACNP-63035, January 10, 1964

31-4 I. Kataoka, M. Ishii, *Drift Flux Model for Large Diameter Pipe and New Correlation for Pool Void Fraction*, International Journal of Heat Mass Transfer, 30, No. 9, pp. 1927-1939, 1987.

31-5 [

]

31-6 Allis Chalmers Atomic Energy Division, *Joint US/EURATOM R&D Program AT(11-1)-1186: Steam Separation Technology Under the Euratom Program; Topical Report - Part 1*; ACNP-65002, April 15, 1965

Comment 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 ALTAS and KATHY databases [ ] 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.

RAI-32a:

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.

AREVA Response 32a:

The requested information is provided in Table 32-1.

Table 32-1 Assembly Data Pertaining to Two-phase Pressure Drop

[ ]

RAI-32b:

Separate plots of the [

] How was it determined that the two datasets could be combined to obtain a meaningful overall relative prediction error?

AREVA Response 32b:

[

]

[

] for the ATLAS data are not significantly different from those of the KATHY data.

Table 32-2 Statistical Comparison of ATLAS and KATHY Data

[ ]

RAI-32c:

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.

AREVA Response 32c:

[ ]

Table 32-3 Pressure Drop Benchmark Statistics by Exit Flow Quality (calculated-measured) / measured

[ ]

Figure 32-1 Relative Error vs. Exit Flow Quality

[ ]

Figure 32-2 Absolute Error vs. Exit Flow Quality

[ ]

Table 32-4 Relative Error F-test

[ ]

Table 32-5 Absolute Error F-test

[ ]

[ ]

Table 32-6 Relative Error Student's t-test

[ ]

Table 32-7 Absolute Error Student's t-test

[ ]

RAI-32d:

The listing of means and standard deviations in Table 6-10 does 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.

AREVA Response 32d:

See conclusion in response to RAI-32c.

RAI-32e:

> *Figure 6-18 shows [ ] A simple homogeneity of variance assessment of the SDs in Table 6-10 that we performed shows [ ] 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.*

AREVA Response 32e:

See conclusion in response to RAI-32c.

Comment 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.

RAI-33a:

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

AREVA Response 33a:

For each grid configuration, [ ]. Essentially, they are determined [ ] to fit its individual results in terms of minimizing the overall mean of RE. Additionally, [ ].

For production fuel designs tests in the PHTF the single phase loss coefficients are determined by regression analysis. The following steps are performed:

1. Differential pressure drop measurements are collected for each axial segment of interest (depending on the design specific axial geometry) as a function of the test conditions (Reynolds number).
2. The differential pressure drops are reduced to the spacer pressure drop by subtracting the computed values for the friction, density head, and changes in cross sectional area.
3. The pairs of grid pressure drops and Reynolds numbers are used to obtain the loss coefficients based on standard non-linear regression analyses such as the function available within MathCad.

RAI-33b:

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

AREVA Response 33b:

The requested information is provided in Table 33-1.

Table 33-1 Pressure Drop Statistics by Fuel Design and Grid Spacer Design Combination

Comment 34:

The process for determining the 'correction factor' of [ ] and 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, and the [ ] and an inappropriate means of capturing the effect of the [ ] in this region.

RAI-34:

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

<u>AREVA Response 34:</u>

The factor of [ ] is determined based on [ ]. After a factor of [ ], the comparison results for [ ] are shown in Table 34-1, Figure 34-1 and Figure 34-2. Figure 34-2 provides the graphical comparison of the computed pressure drop above the part-length rods with and [ ]

[

] Based on these comparison results, it is concluded that the factor of [ ] is appropriate.

Table 34-1 PHTF Pressure Drop Benchmark Statistics

[ ]

[ ]

Figure 34-1 PHTF Test Data Comparisons

[ ]

Figure 34-2 PHTF Test Data: Relative Error vs. Reynolds Number

Comment 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.

RAI-35:

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

<u>AREVA Response 35:</u>

The interfacial friction multiplier, *f*, is proposed [ ], as shown in Figure 35-1, while it has [ ] on the overall pressure drop calculation, as demonstrated in Table 35-1.

[

]

Figure 35-1 Increase f to [

]

Table 35-1 Effect of f on the ATRIUM-10A/B Pressure Drop Comparisons

[

]

Comment 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.

RAI-36:

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?

AREVA Response 36:

For grid configurations not included in the combined ATLAS and KATHY databases,

[

]

Comment 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. However, 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;

RAI-37a:

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?

AREVA Response 37a:

[

]

RAI-37b:

What effect does [

] 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?

AREVA Response 37b:

[

]

RAI-37c:

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.

<u>AREVA Response 37c:</u>

[

]

RAI-37d:

Discuss the characteristics of the tests where the EM is [

] does it have in the overall applicability of the EM to transient conditions in operating BWRs?

<u>AREVA Response 37d:</u>

[

]

Comment 38:

Section 6 (p. 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, and 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 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, (p. 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 p. 6-97) that a [ ] and when it is added, and 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.

RAI-38a:

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".

AREVA Response 38a:

The acceptance criteria presented in Section 6.0 of the LTR [

]

[

]

RAI-38b:

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.

AREVA Response 38b:

The following table lists the assessment cases, the page number where the assessment statement is located, the revised assessment statement based the acceptance criteria listed in RAI- 38a, and the basis for the revised assessment statement.

Table 38-1 Revised Assessment Analysis

[

]

Table 38-1 Revised Assessment Analysis continued

[ ]

Table 38-1 Revised Assessment Analysis continued

Table 38-1 Revised Assessment Analysis continued

[ ]

RAI-38c:

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.

<u>AREVA Response 38c:</u>

[ ]

[ ]

RAI-38 References

[ ]

Comment 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.

RAI-39:

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.

<u>AREVA Response 39:</u>

The issue of uncertainty is addressed in the responses to several RAIs. Table 39-1 summarizes the biases and random uncertainties for both the measurements and

predictions for the tests of ANP-10300P, Sections 6.2 and 6.5. Also listed are the RAIs in which the uncertainties are discussed. The comment column indicates the purpose for the assessment.

Table 39-1: Experiment and Prediction Biases and Uncertainties

Table 39-1: Experiment and Prediction Biases and Uncertainties (continued)

[ ]

Table 39-1: Experiment and Prediction Biases and Uncertainties (continued)

[ ]

Table 39-1: Experiment and Prediction Biases and Uncertainties (continued)

Comment 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 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.

RAI-40:

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.

AREVA Response 40:

Prediction uncertainty bands are [

]

Further discussion about the prediction uncertainties is given in the response to RAI-49b.

Table 40-1 Prediction Uncertainty Bands

[ ]

Comment 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.

RAI-41a:

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.

AREVA Response 41a:

[ ]

Figure 41-1 NM Plot of 1/6 Scale Jet-Pump Data with Analytic and S-RELAP5 Models

Figure 41-2 Calculated minus Measured N-Ratio in 1+ Flow Regime

Figure 41-3 Calculated minus Measured N-Ratio in 1- Flow Regime

Figure 41-4 Calculated versus Measured N-Ratio in 1+ Flow Regime

[ ]

Figure 41-5 Calculated versus Measured N-Ratio in 1- Flow Regime

[ ]

Figure 41-6 NM Plot of 1/6 Scale Jet-Pump Data with S-RELAP5 with 2σ Upper and Lower Bounds

Figure 41-7 Calculated minus Measured N-Ratio from the Plant 1 Data

Figure 41-8 Calculated minus Measured N-Ratio from the Plant 2 Data

Figure 41-9 Calculated minus Measured N-Ratio from the Plant 3 Data

Figure 41-10 NM Plot of Plant 1 Jet pump Data with S-RELAP5 with 2σ Upper and Lower Bounds

[ ]

Figure 41-11 NM Plot of Plant 2 Jet pump Data with S-RELAP5 and Approximated Uncertainties

[ ]

Figure 41-12 NM Plot of Plant 3 Jet pump Data with S-RELAP5 with 2σ Upper and Lower Bounds

RAI-41b:

Explain how the "2σ 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 + 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.

<u>AREVA Response 41b:</u>

[ ]

All jet pump results [

]

RAI-41c:

The error bars in Figure 6-21 represent the measurement uncertainties and were supplied with the data.

> *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.*

AREVA Response 41c:

[ ]

RAI-41d:

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 percentage of predicted values agree with measured values (when accounting for data and model-prediction uncertainties as addressed in previous comments). Please provide this information.

AREVA Response 41d:

[ ]

RAI-41 References

41-1 [

]

41-2 NUREG/CR-4606, Statistical Methods for Nuclear Material Management, December 1988.

41-3 Crapo, H. S., LOFT Test Support Branch Data Abstract Report: INEL One-Sixth Scale Model Jet Pump Test, Idaho National Engineering Lab, EGG-LOFT-5063, 1979.

Comment 42:

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.

RAI-42a:

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.

<u>AREVA Response 42a:</u>

[ ]

[

]

RAI-42b:

Discuss measurement and modeling uncertainties associated with the measured pressures, and carryover and carryunder fractions reported for this data. Specifically address how is it 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.

AREVA Response 42b:

[

]

[ ]

[ ]

Figure 42-1 [ ]

[ ]

Figure 42-2 [ ]

[ ]

Figure 42-3 [ ]

[ ]

Figure 42-4 [ ]

[

]

Figure 42-5 [

]

[ ]

Figure 42-6 [ ]

Carryover is not a highly ranked phenomenon (not in Table 5.6 of LTR). Most of the liquid carried out of the separator by steam falls back, either from the steam exit region or from the dryer, into the bulk water region outside the separator-standpipe forests, where the liquid returns directly from the separator discharge passages. Also the impact on the pressure from condensing/vaporizing the carryover liquid present in the region above the separator exit, including steam line, is insignificant. Therefore, code uncertainty analysis for carryover is not made. However, a carryover multiplier is provided. The measurement uncertainty estimation of 20% for carryover may be used with the carryover multiplier for performing sensitivity studies or for validating that the carryover is not an important phenomenon for AOO events, if necessary.

Comparison plots of carryover are shown in Figures 42-7 and 42-8 for 2-stage separator and in Figures 42-9 and 42-10 for 3-stage separator. Good agreement between calculations and experimental data is seen, as the calculated values are close to the data or within the scatter of the data.

[ ]

Figure 42-7 [ ]

[ ]

Figure 42-8 [ ]

[ ]

Figure 42-9 [ ]

[ ]

Figure 42-10 [ ]

RAI-42 References:

[ ]

42-4 Y. K. Cheung, V. Parameswaran and J.C. Shaug, BWR Refill-Reflood Program: Model Development – TRAC-BWR Component Models, NP-2376, NUREG/CR-2574, GEAP 22052, Interim Report, February 1984.

[ ]

Comment 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.

RAI-43a:

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.

AREVA Response 43a:

[ ]

RAI-43b:

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

AREVA Response 43b:

[ ]

RAI-43c:

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

AREVA Response 43c:

[ ]

[ ]

RAI-43d:

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.

AREVA Response 43d:

[ ]

RAI-43e:

The portion of Table 6-13 for [ ] classifies [ ]

calculations. However, Figure 6-32 shows at most [ ]. Please explain this apparent inconsistency.

AREVA Response 43e:

[ ]

RAI-43 References

[ ]

Comment 44:

In Section 6.6.1.1, discussion of the natural recirculation test states that "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.)

RAI-44:

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 **[**

]

<u>AREVA Response 44:</u>

[

]

[ ]

[ ]

Figure 44-1 Downcomer Level vs Downcomer Flow for 6PNC2-1

[ ]

Figure 44-2 Downcomer Level vs Core Bypass Flow for 6PNC2-1

[ ]

Figure 44-3 Downcomer Level vs Heated Assembly (DC-Bypass) Flow for 6PNC2-1

RAI-44 References

44-1 NUREG/CR-4128, *BWR Full Integral Simulation Test: Phase 2 Test Results and TRACBWR Model Qualification*, U.S. Nuclear Regulatory Commission, June 1985. (Also issued as EPRI NP-3988 and GEAP-30876).

Comment 45:

The presentation of 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.

RAI-45:

Discuss the significance of the [

]

AREVA Response 45:

[

]

[ ]

Table 45-1 Key Transient Parameters for the Turbine Trips
[ ]

[ ]

Table 45-2 Key Transient Parameters for the Turbine Trips
[ ]

[ ]

Figure 45-1 Comparison of Pressure Responses in Steam Dome for TT1

Figure 45-2 Comparison of Relative Core Power Responses for TT1

[ ]

Figure 45-3 Comparison of Pressure Responses in Steam Dome for TT2

[ ]

Figure 45-4 Comparison of Relative Core Power Responses for TT2

Comment 46:

Section 6.8 (p. 6-152) states that "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.

RAI-46:

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.

<u>AREVA Response 46:</u>

[ ]

Table 46-1 Allowable Ranges for EM Structure Parameters

[ ]

[ ]

Comment 47:

Section 6.8 (p. 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.

RAI-47:

Provide a discussion showing how it is determined where the EM yields biased predictions, the directions of the biases, and 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".

AREVA Response 47:

In general, the overall EM summarized in Section 5 of the LTR [

]

[

]

Comprehensive studies of the sensitivities of the medium to highly ranked phenomena from the PIRT process have been performed to identify the truly medium-to-high sensitivity parameters and quantify their effects for the key types of transients. The transients studied include [

]

RAI-47 References

[ ]

Comment 48:

Section 6.8, (p. 153), states that [

] 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.

RAI-48a:

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 of 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.

AREVA Response 48a:

The propagation of uncertainties is [

]

RAI-48b:

Propagating biases and uncertainties through a model/code is typically done via Monte Carlo methods. 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.

AREVA Response 48b:

Random uncertainties in the EM are now being treated [

]

RAI-48c:

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.

AREVA Response 48c:

The propagation of uncertainties [

]

Comment 49:

Section 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.

RAI-49a:

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.

<u>AREVA Response 49a:</u>

[ ]

For the EM structure, the concept is that the parameters are defined such that the user effect results in a limited and acceptable range of variation in the predicted FoMs. Please see the response to RAI-46 for further explanation.

[ ]

[ ]

The combination of the constraints on the EM structure, the conservative application of plant parameters and operating conditions, and the assessment of the FoM penalty through non-parametric statistical analyses ensures the reported values for the FoMs are conservative.

To summarize, the application of the EM will proceed as follows: [ ] Table 49-1 describes how each highly ranked phenomenon in the PIRT is addressed.

Table 49-1 Treatment of Uncertainties for Highly Ranked Phenomena

[ ]

Table 49-1 Treatment of Uncertainties for Highly Ranked Phenomena continued

[ ]

Table 49-1 Treatment of Uncertainties for Highly Ranked Phenomena continued

Table 49-1 Treatment of Uncertainties for Highly Ranked Phenomena continued

[ ]

Table 49-1 Treatment of Uncertainties for Highly Ranked Phenomena continued

[ ]

[ ]

Figure 49-1 [ ]

[ ]

Figure 49-2 [ ]

[ ]

Figure 49-3 Prediction Error in Peak to Average Normalized LPRM String Signals for Turbine Trip Test 1 [ ]

[ ]

Figure 49-4 Prediction Error in Peak to Average Normalized LPRM String Signals for Turbine Trip Test 2 [ ]

[ ]

Figure 49-5 Prediction Error in Peak to Average Normalized LPRM String Signals for Turbine Trip Test 3 [ ]

[ ]

Figure 49-6 Comparison of Select Hot Channel Nodal Powers With and Without Neighboring Control Blade Operable

Figure 49-7 Comparison of Hot Channel Total Power and Heat Flux With and Without Neighboring Control Blade Operable

RAI-49b:

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

<u>AREVA Response 49b:</u>

[ ]

49.1 ***Description of Non-Parametric Uncertainty Analysis Process***

[ ]

[ ]

Table 49-2 [ ]

[ ]

[

]

[ ]

Table 49-3 Uncertainty Parameters for AOO BWR-4 Sample Problem Non-parametric Uncertainty Analyses

[ ]

Table 49-4 Example of Ordered FoM Results from Non-Parametric Statistical Process

[ ]

49.2 *Example Results from AURORA-B Non-Parametric Process*

[ ]

[ ]

Table 49-5 Sample BWR-4 Test Case Results from Non-Parametric Statistical Process

[ ]

49.3 Application of Non-Parametric Statistics for Licensing Analyses

[ ]

49.4 Determination of Uncertainty Parameter Sampling Ranges

[ ]

49.4.1 [ ]

[ ]

[

]

49.4.2 [ ]

[

]

[ ]

49.4.3 [ ]

[ ]

[ ]

49.4.4 [ ]

[ ]

Figure 49-8 Example of Data Uncertainty as a Function of Fuel Temperature

[ ]

Figure 49-9 Correlation Comparison for AREVA Fuel

49.4.5 [ ]

[ ]

49.4.6 [ ]

[ ]

49.4.7 [ ]

[ ]

[

]

49.4.8 [ ]

[

]

[ ]

Figure 49-10 Void Fraction Changes vs. Randomly Sampled Parameter

49.4.9 [ ]

AREVA has analyzed the EPICURE critical experiments (Reference 49-8) where the moderator density reactivity was evaluated. These results are presented in Table 49-6. These results show comparisons [ ]

Sensitivity studies have been performed on the core power distribution results by varying the [ ] correlation in MICROBURN-B2 to correct the mean to match the measured ATRIUM-10 void fraction data. The modified [ ] correlation parameters were then modified to generate two bounding correlations for the

ATRIUM-10 of [ ]. The results of this modified correlation are presented in Figure 49-11.

Modified [ ] correlations in MICROBURN-B2 were approximated with [ ]. Figure 49-12 shows a comparison of the [ ] ratio results compared to the ATRIUM-10 test data. This approach allowed for reasonable variations of equivalent void fractions as determined by the [ ] correlation.

Analyses were based on modifications to the void-quality correlation that resulted in a new nominal fit and offsets that were on average [ ]. The information included the impact of the fuel depleted with the changes in the void-quality correlation. The difference in depletion changes the sensitivity of void fraction modifications considerably due to the feedback of modified power distributions on exposure distribution.

The change in the void-quality correlation was imposed over all fuel in the core from beginning of life. No changes were made to the fuel loading and rod patterns.

It should be noted that a [ ] perturbation of the void correlation used in the sensitivity studies is substantial. For example, the [ ] void scenario is equivalent to a [ ]. The measure of void correlation uncertainty used in the sensitivity analyses was somewhat arbitrarily defined as a value that would bound the ATRIUM-10 test data. In a BWR, the core power and power distribution are tightly coupled with the void fraction and a large error in predicted core void fraction would have a significant effect on the predicted power distribution measurements obtained from operating reactors. If the error in void fraction was as large as assumed in sensitivity studies, the effect would be observed in comparisons of predicted to measured power distributions obtained from operating reactors.

Additional calculations were performed [ ]

[ ]

Changes in the void fraction in the manner described above are similar to changes in the void coefficient. The critical experiment indicated that CASMO-4 [ ]

Table 49-6 Result of EPICURE Core Analysis

[ ]

[ ]

Figure 49-11 Modified Void Fraction Correlation Comparison to ATRIUM-10 Test Data

[ ]

Figure 49-12 [ ] Void Fraction Results Comparison to ATRIUM-10 Test Data

[ ]

Figure 49-13 Representative 2D TIP Statistic Comparison for Variations of the Void Quality Correlation

[ ]

Figure 49-14 Representative 3D TIP Statistic Comparison for Variations of the Void Quality Correlation

49.4.10 [ ]

49.4.11 [ ]

49.4.12 [

]

49.4.13 [

]

49.4.14 [

]

49.4.15 [

]

RAI-49 References

49-1 University of Cincinnati, The Applicability of the Homogeneous Flow Model to Pressure Drop in Straight Pipe and Across Area Changes, A. Husain, W.G. Choe, J. Weisman, COO-2152-16.

49-2 Paul N. Somerville, Tables for Obtaining Non-Parametric Tolerance Limits", Annals of Mathematical Statistics, Vol. 29, Number 2, 1958.

49-3 J. L. Jaech, On the Use of Tolerance Intervals in Acceptance Sampling by Attributes, Journal of Quality Technology, Vol. 4, No. 2, April 1972.

49-4 EMF-2103P, Rev 3, Realistic Large Break LOCA Methodology for Pressurized Water Reactors, Topical Report, AREVA NP Inc., September 2013.

49-5 BAW-10247PA, Rev 0, Realistic Thermal-Mechanical Fuel Rod Methodology for Boiling Water Reactors, Framatome ANP, Inc., February 2008.

49-6 [ ]

49-7 PHYSOR 2002, A Review of Delayed Neutron Data for Calculating Effective Delayed Neutron Fractions, Antonio D'Angelo and John L Rowlands, October 2002.

49-8 J. P. Chauvin and P. Fougeras, "Technical Note: EPICURE Programme, Experimental Results Related to the UH1.2 Configuration", CEA, NT – SPRC – 96-002, 1996.

Comment 50:

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.

RAI-50:

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.

AREVA Response 50:

Table 51-1 in the response to RAI-51a lists the ranges for the perturbations and their bases for the approach that was taken in ANP-10300P. [

] The sensitivity cases of Section 6.8.3 and 6.8.4 are now being used for general information only.

Comment 51:

In Section 6.8.4, (p. 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.

RAI-51a:

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.

AREVA Response 51a:

The sensitivity cases of Section 6.8.3 and 6.8.4 [ ] the sensitivity cases of Section 6.8.3 and 6.8.4 are now being used for general information only. Please see the response to RAI-49b for discussion of biases and uncertainties of parameters that affect highly ranked phenomena.

The range for each of the parameters in the sensitivity cases is presented in the response to Question 20 in Reference 51-1. The basis for each of the parameter ranges is presented in Table 51-1.

Table 51-1: Treatment of Uncertainties in Predicting Highly Ranked Phenomena

Table 51-1: Treatment of Uncertainties in Predicting Highly Ranked Phenomena continued

[ ]

Table 51-1: Treatment of Uncertainties in Predicting Highly Ranked Phenomena continued

[ ]

RAI-51b:

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.

AREVA Response 51b:

The following response addresses sensitivity cases of ANP-10300P, Section 6.8.3 and 6.8.4 which were used to evaluate the ability of the EM to predict highly ranked phenomena and to determine the uncertainty of the EM for predicting FoMs. [

] The sensitivity cases of Section 6.8.3 and 6.8.4 are now being used for general information only.

When a parameter is perturbed, a "positive response" means the predicted FoM moved in the adverse (less safe) direction, e.g. ΔMCPR or peak pressure increased as a result of the perturbation. "Negative response" is the opposite. [

]

RAI-51c:

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>AREVA Response 51c:</u>

The statement is intended to mean that for several of the parameters perturbed, engineering judgment was used to set the range of the perturbation. That range is intended to span the bias plus and minus random uncertainty. Table 51-1 in the response to RAI-51a lists the ranges for the perturbations and their bases for the approach that was taken in ANP-10300P. [

] The sensitivity cases of Section 6.8.3 and 6.8.4 are now being used for general information only.

RAI-51 References

51-1 ANP-10300Q1P, Revision 0, AURORA-B: An Evaluation Model for Boiling Water Reactors; Application to Transient and Accident Scenarios, Responses to NRC Acceptance Review Questions, July 2011.

51-2 A. K. Kudirka and C. L. Swan, Performance of Production Steam Separators for the 1967 Production Line, NEDE-13060, General Electric, December 1969.

Comment 52:

In Section 6.8.4, Table 6-36 (p. 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).

RAI-52a:

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.

AREVA Response 52a:

Table 51-1 in the response to RAI-51a lists the ranges for the perturbations and their bases for the approach that was taken in ANP-10300P, [

] The sensitivity cases of Section 6.8.3 and 6.8.4 are now being used for general information only. The revised model predictions that are presented in the RAI responses do not exhibit significant biases relative to data.

RAI-52b:

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.

AREVA Response 52b:

Table 52-1 condenses the information in ANP-10300P, Table 6-36. Table 52-1 lists the highly ranked PIRT phenomena and where the respective biases and random uncertainties are addressed. The random uncertainties for several of the phenomena are addressed with the sensitivity studies described in Section 6.8.4 of ANP-10300P. Uncertainties for other phenomena are addressed elsewhere, for example, in upstream methodologies. Table 52-1 also indicates whether the sensitivity to a particular phenomenon was included in the determination of conservative measures (ANP-10300P, Section 6.8.5).

It may be helpful to refer to AREVA's response to ARQ 32 (Reference 52-1) for a list of specific sensitivity cases that were included in the determination of conservative measures. Tables 32-1 and 32-2 of Reference 52-1 identify the connection between the sub-sections of ANP-10300P, Section 6.8.4 and the specific sensitivity cases.

Table 52-1: [ ]

[ ]

Table 52-1: [

] continued

[

]

RAI-52 Reference:

52-1 ANP-10300Q1P, Revision 0, "AURORA-B: An Evaluation Model for Boiling Water Reactors; Application to Transient and Accident Scenarios; Responses to NRC Acceptance Review Questions," July 2011.

Comment 53:

Section 6.8.4.1 (p. 6-164) states [ ] How this was done is not explained, nor is the [ ] of confidence defined in a quantitative sense. The LTR further states that [ ] 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 (pp. 6-164 and 6-165) adjustments up and down [ ] 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.

RAI-53a:

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

AREVA Response 53a:

The intention was to cover the range of prediction uncertainty in void fraction as shown in FRIGG and ATRIUM-10A tests of Section 6.2.1 (see Table 51-1). [ ] The sensitivity cases of Section 6.8.3 and 6.8.4 are now being used for general information only.

RAI-53b:

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

AREVA Response 53b:

The following discussion applies to the uncertainty treatment explained in ANP-10300P, Sections 6.8.3 through 6.8.5. [

] The sensitivity cases of Section 6.8.3 and 6.8.4 are now being used for general information only.

Table 53-1 shows the sensitivities of the EM for the BWR/4 sample problem. [

] The beneficial change relative to the baseline calculation is what is meant when the topical report refers to a "less severe response than the baseline analyses."

[

]

Table 53-1 Sensitivity Results for Interfacial Drag in the Core Region

[ ]

RAI-53c:

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.

<u>AREVA Response 53c:</u>

As stated in the response to RAI-51a, the intention was to cover the range of prediction uncertainty in void fraction as shown in FRIGG and ATRIUM-10A tests of Section 6.2.1 (see Table 51-1). [ ]

[

] The sensitivity cases of Section 6.8.3 and 6.8.4 are now being used for general information only.

Comment 54:

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

RAI-54:

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 a [ ] to appropriately encompass estimates of bias and the uncertainty. Please provide your response in relation to RAI-12 above.

<u>AREVA Response 54:</u>

[ ]

Comment 55:

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

RAI-55a:

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.

AREVA Response 55a:

[ ]

[

]

RAI-55b:

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.)

AREVA Response 55b:

[

]

RAI-55 References:

55-1 BAW-10247PA, Rev 0, Realistic Thermal-Mechanical Fuel Rod Methodology for Boiling Water Reactors, Framatome ANP, Inc., February 2008.

Comment 56:

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

RAI-56:

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.

<u>AREVA Response 56:</u>

The [ ] perturbation on Doppler reactivity feedback is chosen [

]

RAI-56 References:

56-1 E. Hellstrand, et al., "The Temperature Coefficient of the Resonance Integral for Uranium Metal and Oxide," Nuclear Science and Engineering, Vol. 8, 497-506 (1960).

56-2 ANP-10300Q1P, Revision 0, "AURORA-B: An Evaluation Model for Boiling Water Reactors; Application to Transient and Accident Scenarios, Responses to NRC Acceptance Review Questions," AREVA, July 2011.

Comment 57:

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

RAI-57:

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.

AREVA Response 57:

[ ]

Figure 57-1 Calculated –Measured N-ratio Comparison with Plant Data

Comment 58:

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

RAI-58:

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.

AREVA Response 58:

[ ]

Comment 59:

The discussion in Section 6.8.4.8 (p. 6-167, 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).

RAI-59:

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.

AREVA Response 59:

[ ]

[ ]

Figure 59-1 [ ]

[ ]

Figure 59-2 [ ]

RAI-59 References:

[ ]

Comment 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.

RAI-60a:

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 [ ] that appears to be used in this section.

AREVA Response 60a:

The SRSS approach is no longer used to determine the conservative measures to be applied for the three FoMs. Instead, the estimate of the appropriate conservatism will be determined by [ ] RAI-49b presents the foundation for the revised process as well as example applications.

RAI-60b:

Justify the assumption used in the [ ] 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 [ ]. 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.

AREVA Response 60b:

As described in RAI-60a, the SRSS approach is no longer used. [

]

RAI-60c:

Include a discussion of why the [ ], 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.

AREVA Response 60c:

[

]

RAI-60d:

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.

AREVA Response 60d:

[

]

[ ]

RAI-60e:

> *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."*

AREVA Response 60e:

See response to RAI-49b.

Comment 61:

In Section 6.8.5, under the un-numbered heading "Measures applied to ΔMCPR analyses" (pp. 6-170 to 6-171), the LTR states [

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

RAI-61:

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.

AREVA Response 61:

[

]

Comment 62:

Section 8.1.4 (p. 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.

RAI-62a:

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.

<u>AREVA Response 62a:</u>

This RAI is similar to RAI-47. The following response should be taken as a supplement to the response to RAI-47.

[ ]

[ ]

RAI-62b:

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

AREVA Response 62b:

[ ]

Comment 63:

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.

RAI-63:

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.

AREVA Response 63:

[ ]

[

]

RAI-63 References

[

]

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

Comment 64:

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".

RAI-64:

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

AREVA Response 64:

The PIRT evaluation process that supported the generation of ANP-2831 evolved over a significant period of time involving several groups of contributing individuals. The following summarizes the key early and final phases of that effort:

A. Preliminary PIRT Development for AURORA-B

The first iteration in the phenomena identification and ranking table (PIRT) process for the AURORA-B project was led by [ ] in 2003-2004. The in house committee developed the preliminary PIRT based on the applicable plant designs, events (working through the NUREG-0800 Chapter 15 transient events for BWRs) and the figures-of-merit applicable to AOO analyses. In addition to [ ] the committee included [ ], RELAP5 expert; [ ], TH testing and methods; [ ], BWR analysis applications; [ ], BWR transient methods; with >175 years of total applicable experience.

This PIRT was reviewed by another in-house committee of BWR application engineers ([ ], with >110 years total applicable experience), and updated to reflect their feedback.

B. Final PIRT Development Process and Documentation

In 2008-2009, concise phenomena descriptions were prepared by the methodology developers (with [ ] in the lead), and the preliminary phenomena rankings were reviewed for consistency between events. Available experimental data and preliminary code simulations and sensitivity cases were evaluated for consistency with the preliminary rankings. The result of this iteration defined the draft phenomena identification and ranking.

This draft was reviewed by an in-house committee of BWR application and methods experts ([ ], with >150 total applicable BWR analysis experience) to further refine the phenomena descriptions and rankings and develop consensus agreement for the phenomena identification and rankings that are published in Reference 64-1.

RAI-64 Reference:

64-1 ANP-2831P, Revision 1, "Phenomenon Identification and Ranking for BWR Events," AREVA NP, November 2015.

Comment 65:

EMF-2102(P), Rev. 0 is referenced by ANP-2831P. AREVA staff identified that Revision 1 is the current version applicable to the AURORA-B EM.

RAI-65a:

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?

AREVA Response 65a:

EMF-2102(P) Revision 1, "S-RELAP5: Code Verification and Validation," November 2010 provides supporting documentation for the RLBLOCA methodology EMF-2103(P) Revision 2, and is not applicable to the ANP-10300P Revision 0 methodology submittal.

RAI-65b:

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

AREVA Response 65b:

EMF-2102(P) Revision 0, "S-RELAP5: Code Verification and Validation," August 2001 provides supporting documentation for the RLBLOCA methodology EMF-2103(P)(A) Revision 0, and is not applicable to the ANP-10300P Revision 0 methodology submittal.

RAI-65c:

If EMF-2102(P), Rev. 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?

AREVA Response 65c:

As previously stated, EMF-2102(P) Revision 0 and Revision 1 are not applicable to the ANP-10300P Revision 0 methodology submittal. The purposes for referencing this document are for the test descriptions of BWR specific assessment cases (FRIGG-2 and 1ft GE Level Swell) and to support the claim that S-RELAP5 is a mature code and there have been extensive assessments performed using it.

RAI-65d:

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

AREVA Response 65d:

The revisions to EMF-2102(P) Revision 1 consist of rerunning the Revision 0 assessment cases with the EMF-2103(P) Revision 2 methodology plus additional test cases that had been requested after Revision 0 was released. Rerunning the assessment cases required minor input deck modifications for some problems since the RLBLOCA multipliers for reflood heat transfer and interphase friction were modified for the new RLBLOCA methodology.

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

Comment 66:

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

RAI-66a:

Clarify whether these were developed for the 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.

AREVA Response 66a:

[ ]

[ ]

[

]

RAI-66b:

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.

AREVA Response 66b:

[

]

RAI-66 Reference:

[ ]

Comment 67:

The text leading to Equations 3.214 and 3.219 identifies that [

]

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

and

$$\tau_w = \lambda_{Darcy} * \frac{\rho V^2}{8} = \frac{\lambda_{Darcy}}{4} * \frac{\rho V^2}{2}$$

[

] , using what appears to be the Fanning friction factor.

RAI-67:

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

<u>AREVA Response 67:</u>

The pressure drop across a flow length L is

$$\Delta p = \lambda_{darcy} \frac{L}{D} \frac{\rho v^2}{2} = \lambda_{fanning} \frac{L}{D} 2 \rho v^2$$

where D is hydraulic diameter. For laminar flow, the Fanning friction factor is

$$\lambda_{fanning} = \frac{16}{Re},$$

and the Darcy friction factor is

$$\lambda_{darcy} = \frac{64}{Re}.$$

For turbulent flow, the Darcy friction factor is given by the Colebrook equation

$$\frac{1}{\sqrt{\lambda_{t,darcy}}} = -2\log_{10}\left(\frac{\varepsilon}{3.7D} + \frac{2.51}{Re\sqrt{\lambda_{t,darcy}}}\right)$$

[ ]

In the above discussion, the equation numbers are from Reference 67-1.

RAI-67 Reference:

[ ]

Comment 68:

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

RAI-68:

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

<u>AREVA Response 68:</u>

Reference 68-1 shows a table of comparison of values calculated from the Colebrook equation and [ ] for the turbulent friction factor. It states:

"The explicit relationship for friction factor proposed in Equation 7 [ ] was checked for accuracy with the Colebrook-White equation, Equation 3, and it was found that for the relative roughness, $10^{-6} \leq \varepsilon/D \leq 10^{-2}$, and Reynolds number, $5 \times 10^{3} \leq R \leq 10^{8}$, the errors involved in the computation of f [ ] using Equation 7 are within $\pm$ 1.0%. For the most practicable of ε/D $(10^{-5} \leq \varepsilon/D \leq 10^{-3})$ and $(10^{4} \leq R \leq 10^{7})$, the error was, however, within $\pm$0.5%."

Accordingly, [ ] is sufficiently accurate for computing the Colebrook friction factor.

RAI-68 References

68-1 A. K. Jain, "*Accurate Explicit Equation for Friction Factor,*" ASCE J. Hydraulics Division, Volume 102, pp. 674-677, 1976.

Comment 69:

Section 3.6.1 limits to the local form loss correlation to [ ]

RAI-69a:

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

<u>AREVA Response 69a:</u>

The input guidelines (Reference 69-1) prescribe that [ ]

RAI-69b:

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

<u>AREVA Response 69b:</u>

[ ]

As noted in RAI-33a, the single-phase coefficients for production fuel designs tested in the PHTF are fit to the measured differential pressure drop for use in licensing calculations.

RAI-69c:

> *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?*

AREVA Response 69c:

The V&V of the coefficients a, b, c, d, and e are presented in Section 6.5.1 of the LTR. For the undefined fuel designs, [ ] The actual loss coefficients would need to be refined based on the fuel specific pressure drop information available. The coefficients, a, b and c, are derived from the [ ] pressure drop data, and the coefficients, d and e, are derived from the [ ] pressure drop data. Essentially, they are determined [ ]. Additionally, [ ]

RAI-69 References

[ ]

Comment 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 [ ]. However, in Equation 3.232 if [ ] (which appear to be reasonable possibilities), these equations are not 'fundamentally' identical.

[ ]

Also, based on a review of [ ] for the local loss term, Eq. 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.

RAI-70:

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

AREVA Response 70:

[ ]

Comment 71:

The Moody correlation, Equation 3.241, is presented as a separate reference (1.14). The Moody correlation 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).

RAI-71:

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

AREVA Response 71:

As discussed in the RAI-86 and RAI-87 response, the Moody correlation is part of the [ ] correlation methodology.

Comment 72:

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

]

RAI-72:

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.

AREVA Response 72:

[

]

Comment 73:

Equation 6.19, is defined as [ ] .

RAI-73:

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.

AREVA Response 73:

[ ]

Comment 74:

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

RAI-74:

Provide the definitions/equations for calculating Adg and Ath.

AREVA Response 74:

[ ]

Comment 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 (pg. 6-3) states that pressure ratio is determined from [

] Equations 6.21 and 6.22 include the elevation head.

RAI-75:

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

<u>AREVA Response 75:</u>

[

]

RAI-75 References:

75-1 Crapo, H. S., LOFT Test Support Branch Data Abstract Report: INEL One-Sixth Scale Model Jet Pump Test, Idaho National Engineering Lab, EGG-LOFT-5063, 1979.

Comment 76:

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

RAI-76a:

Define the operating envelope for the jet pump model.

AREVA Response 76a:

[ ]

RAI-76b:

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 [ ]. What is the

specific Mach limit for applicability of the [ ] model [ ] ?

<u>AREVA Response 76b:</u>

[ ]

RAI-76c:

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).

<u>AREVA Response 76c:</u>

[ ]

RAI-76d:

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.).

<u>AREVA Response 76d:</u>

[ ]

[ ]

RAI-76e:

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.).

<u>AREVA Response 76e:</u>

[ ]

RAI-76 References:

76-1 [ ]

76-2 Ransom, V. H., Course A – "Numerical Modeling of Two-Phase Flow" for Presentation at Ecole d'ETE d'Analyse Numerique, EGG-EAST-8546, May 1989.

76-3 Crane, Flow of Fluids through Valves and Fittings, Technical paper No. 410, (1988).

Comment 77:

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

RAI-77a:

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

<u>AREVA Response 77a:</u>

[ ]

Table 77-1 K-Loss Input Values for Jet Pumps

[ ]

RAI-77b:

[ ]

AREVA Response 77b:

[ ]

RAI-77 References:

[ ]

Comment 78:

Equation 6.100 has a different form in other RELAP5 Volume 1 references.

RAI-78:

Confirm which is the correct formulation or supply the correct formulation.

[ ]

versus

[ ]

<u>AREVA Response 78:</u>

[ ]

RAI-78 References

78-1 Information Systems Laboratories, *RELAP5/MOD3.3 Code Manual Volume I: Code Structure, System Models*, and Solution Methods, December 2001.

78-2 Y. K. Cheung, V. Parameswaran and J.C. Shaug, BWR Refill-Reflood Program: Model Development – TRAC-BWR Component Models, NP-2376, NUREG/CR-2574, GEAP 22052, Interim Report, February 1984.

Comment 79:

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

RAI-79:

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

AREVA Response 79:

Comment 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".

RAI-80:

Identify the specific equations used to create Eq. 6.111.

<u>AREVA Response 80:</u>

[

]

[ ]

RAI-80 Reference

[ ]

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

Comment 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. Are there accidents where the reflector response coefficients change?

RAI-81:

Provide the data used to verify that the reflector response coefficients are not sensitive to changes in the core conditions during a rapid transient.

AREVA Response 81:

[ ]

Comment 82:

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

RAI-82:

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.

AREVA Response 82:

[ ]

Comment 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.

RAI-83a:

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)?

AREVA Response 83a:

The uncertainties in the calculated and measured bundle and pin powers [

]

RAI-83b:

How do rapid power transients impact the pin power reconstruction?

AREVA Response 83b:

[

]

RAI-83 References:

83-1 EMF-2158(P)(A) Revision 0, *Siemens Power Corporation Methodology for Boiling Water Reactors: Evaluation and Validation of CASMO-4 / MICROBURN-B2*, Siemens Power Corporation, October 1999.

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

Comment 84:

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

RAI-84:

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

AREVA Response 84:

All BWR/4 and BWR/6 baseline analyses presented in ANP-10300P were initiated from nominal full power conditions and did not exhibit transitions to SLO. However, SLO is a valid operating mode and will be analyzed with AURORA-B both as an initial condition (to set SLO OLMCPRs) and as a terminal event from two-loop operation. The only significant difference that arises for SLO is the [

].

Clarification Questions

Comment 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 **[ ]**.

RAI-85:

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

AREVA Response 85:

The code version UOCT09 was the final version of S-RELAP5 that was submitted with both ANP-10300P Revision 0 and EMF-2103 Revision 2 methodologies. The AURORA-B development began several years earlier, but since the specialized PWR and BWR models are invoked by user input, the development did not affect or impact the approved methodologies that use S-RELAP5. As outlined in Response 2, the constitutive models are invoked by the methodology identifier BWRNL for ANP-10300P Revision 0, and PWRLBRV2 for EMF-2103 Revision 2.

Comment 86:

The report indicates that [ ]

RAI-86:

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

AREVA Response 86:

Two users' options for wall friction calculations are implemented in S-RELAP5. [ ]. Both wall-friction models are formulated with the Darcy friction factor (see the RAI-67 response).

[ ]

[ ]

Comment 87:

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

RAI-87:

Clarify where the [ ] are used.

AREVA Response 87:

As discussed in the RAI-86 response, there are [

].

Comment 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.

RAI-88:

Clarify this discrepancy.

AREVA Response 88:

The comment refers to Reference 4 in ANP-2831P, Revision 0, "Phenomenon Identification and Ranking for BWR Events." The correct callout for Reference 4 is ANP-2830P, Revision 0, "Control System and Reactor Protection System Requirements for Modeling BWR Events," December 2009.

Comment 89:

Section 3.6 of EMF-2100 identifies that the [ ] for the GE adiabatic test data.

RAI-89:

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

AREVA Response 89:

[ ]

Comment 90:

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

RAI-90:

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

AREVA Response 90:

[ ]

In the above discussion, the equation numbers are as presented in Reference 90-1. The revised theory manual will have the same modification with different equation numbers.

RAI-90 References

[ ]

Comment 91:

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

RAI-91:

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?

AREVA Response 91:

EMF-2102(P) was compiled for the realistic LBLOCA revision submittal. It does not include BWR specific validation cases. All BWR AURORA-B EM specific validation cases are presented in ANP-10300P. ANP-10300P is not a supplement to EMF-2102(P).

Comment 92:

From Figure A-19 in ANP-10300Q1P Rev. 0, Appendix A, it appears that the assumed TIP axial standard deviation is [ ] for D-lattice and [ ] for C-lattice.

RAI-92:

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.

AREVA Response 92:

The data provided in Figure A-19 in ANP-10300Q1P represents the nodal (includes axial and radial) TIP uncertainties. The values referenced come from Table 2.2 of Reference 92-1 for "Cycle Average 3-D Nodal TIP Relative Standard Deviation Including Limited Measurement Uncertainty" ([ ] for C-Lattice Plants and [ ] for D-Lattice Plants). The axial power uncertainty presented in Table 2.3 of Reference 92-1 is derived from this nodal power uncertainty and the radial power uncertainty based upon the equation $[\delta P^{n}_{ijk}]^2 = [\delta P_{ij}]^2 + [\delta P_k]^2$. These values are independent of the local pin power uncertainty ([1.48%]) from Table 2.3 of Reference 92-1. The local pin power uncertainty value discussed in section 9.3 of Reference 92-1 includes the pin-power reconstruction uncertainty since those calculation were performed with pin-power reconstruction.

RAI-92 References:

92-1 EMF-2158(P)(A) Revision 0, *Siemens Power Corporation Methodology for Boiling Water Reactors: Evaluation and Validation of CASMO-4 / MICROBURN-B2*, Siemens Power Corporation, October 1999.

Comment 93:

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

RAI-93:

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.

AREVA Response 93:

[ ]

Comment 94:

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

RAI-94:

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.

AREVA Response 94:

The AURORA-B EM will be used to assess Chapter 15 BWR AOO events for both two loop and SLO across the licensed power/flow operating domain. This also includes Increased Core Flow (ICF), Extended Flow Window (EFW) and Coastdown operation. Table 94-1 provides a summary of Chapter 15 events and the most likely events to be analyzed with AURORA-B, but AURORA-B is generally applicable to all Chapter 15 AOO scenarios.

It should be noted that AURORA-B licensing analyses also support multiple Equipment Out Of Service (EOOS) scenarios, including but not limited to Feedwater Heaters, Power Load Unbalance, Pressure Regulator, Recirculation Pump Trip, Safety Relief Valves, Turbine Bypass Valves, Turbine Control Valve (OOS or slow closure) and Turbine Stop Valve.

SLO differs from two loop operation primarily in the range of possible flow conditions (SLO cannot achieve full core flow) and in the initial flow condition for the idle loop. It should be noted that when a single recirculation pump trips or seizes from current operating conditions the event terminal condition is the single loop operating state point with reverse flow through the idle loop. The AURORA-B EM is applicable to both initial and terminal SLO conditions since the jet pump model has been validated for all combinations of drive, suction and discharge flow rates as presented in Section 6.5 of ANP-10300P.

Table 94-1 Summary of SRP Event Classifications and Typical AURORA-B Analyses

SRP Event Classification	Typical AURORA-B Analyses
15.1 Cool Down Events	Loss of feedwater heating, FWCF (increasing flow), steam pressure regulator failure - open
15.2 Heat Up Events	Loss of external load (generator load rejection), turbine trip, steam pressure regulator failure - closed, loss of stator cooling, closure of MSIV (one or more)
15.3 Loss of Coolant Flow Events	Loss of forced reactor coolant flow, reactor coolant pump rotor seizure
15.4 Reactivity Events	Startup of an idle recirculation pump, recirculation flow controller malfunction resulting in ICF
15.5 Increasing Inventory Events	Inadvertent operation of Emergency Core Cooling System (ECCS), High Pressure Core Spray (HPCS), HPCI or Reactor Core Isolation Cooling (RCIC))
15.6 Decreasing Inventory Events	Inadvertent opening of a pressure relief valve
15.7 Anticipated Transients Without Scram	Closure of MSIV, steam pressure regulator failure - open

Comment 95:

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

RAI-95:

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.

AREVA Response 95:

[ ] effects considered by the RODEX4 code in its fuel thermal/mechanical calculation are listed in Sections 6.2 and 6.3 of Reference 95-1 as follows:

[ ]

From all of these effects, calculation [ ]

[ ]

RAI-95 Reference

95-1 [ ]

Issue With Adequate References

Comment 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.

RAI-96:

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

[ ]

In Section 6.5.1 Rod Bundle Pressure Drop, cite references

[ ]

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

> 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]
>
> 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

[ ]

In Section 6.5.4 *Critical Power Tests*, cite reference

[ ]

<u>AREVA Response 96:</u>

It is not AREVA practice to cite internal calculation notebooks in LTRs. Instead, AREVA maintains a Source Reference Record associated with the LTR that provides the cross-reference between the LTR contents and the internal calculation notebooks. The internal calculation notebooks are available for audit. The requested references for Section 6.5.2.1 EGG-LTSF 1/6 Scale Tests will be added to ANP-10300P.