framatome

# AURORA-B: An Evaluation Model for Boiling Water Reactors; Application to Loss of Coolant Accident Scenarios

ANP-10332Q1NP
Revision 0

## Response to NRC Request for Additional Information

April 2018

Framatome Inc.

ANP-10332Q1NP
Revision 0

# AURORA-B: An Evaluation Model for Boiling Water Reactors; Application to Loss of Coolant Accident Scenarios

# Response to NRC Request for Additional Information

## Nature of Changes

| Item | Section(s) or Page(s) | Description and Justification |
|---|---|---|
| 1 | | New Document |

# Table of Contents

# Table of Contents

# Table of Contents

# Table of Contents

# Table of Contents

## List of Tables

# List of Tables

## List of Figures

## List of Figures

## List of Figures

## List of Figures

## List of Figures

## List of Figures

# List of Figures

## Nomenclature

| Acronym | Definition |
|---|---|
| ADS | Automatic Depressurization System |
| AOO | Anticipated Operational Occurrence |
| APF | Axial Peaking Factor |
| BATT | Battery |
| BWR | Boiling Water Reactor |
| CCFL | Counter-Current Flow Limit |
| CHF | Critical Heat Flux |
| CPR | Critical Power Ratio |
| DEG | Double-Ended Guillotine |
| ECCS | Emergency Core Cooling System |
| EM | Evaluation Model |
| FCTF | Fuel Cooling Test Facility |
| FIST | Full Integral Simulation Test |
| FLECHT | Full Length Emergency Cooling Heat Transfer |
| FoM | Figure of Merit |
| HEM | Homogeneous Equilibrium Model |
| HPCI | High Pressure Coolant Injection |
| HPCS | High Pressure Core Spray |
| HTC | Heat Transfer Coefficient |
| JP | Jet Pump |
| LAR | License Amendment Request |
| LBLOCA | Large Break Loss of Coolant Accident |
| LHGR | Linear Heat Generation Rate |
| LOCA | Loss of Coolant Accident |
| LOFT | Loss of Fluid Test |
| LOOP | Loss of Offsite Power |

| | |
|---|---|
| LP | Lower Plenum |
| LPCI | Low Pressure Coolant Injection |
| LPCS | Low Pressure Core Spray |
| LTR | Licensing Topical Report (ANP-10332P) |
| LUT | Lookup Table |
| MAPLHGR | Maximum Average Planar Linear Heat Generation Rate |
| MCPR | Minimum Critical Power Ratio |
| MLO | Maximum Local Oxidation |
| MSIV | Main Steam Isolation Valve |
| NRC | Nuclear Regulatory Commission |
| PCT | Peak Cladding Temperature |
| PIRT | Phenomenon Identification and Ranking Table |
| PWR | Pressurized Water Reactor |
| RDIV | Recirculation Discharge Isolation Valve |
| RPF | Radial Peaking Factor |
| SBLOCA | Small Break Loss of Coolant Accident |
| SEO | Side Entry Orifice |
| SET | Separate Effects Test |
| SF | Single Failure |
| SRP | Standard Review Plan (NUREG-0800) |
| SRV | Safety Relief Valve |
| SSTF | Steam Sector Test Facility |
| THTF | Thermal Hydraulic Test Facility |
| TLTA | Two Loop Test Apparatus |
| TR | Topical Report (ANP-10332P) |
| UP | Upper Plenum |
| UTP | Upper Tie Plate |

## Introduction

This document comprises Framatome's* response to the Nuclear Regulatory Commission (NRC's) Request for Additional Information (RAIs) for the Licensing Topical Report (LTR) ANP-10332P, "AURORA-B: An Evaluation Model for Boiling Water Reactors; Application to Loss of Coolant Accident Scenarios." The RAIs were transmitted in References 1 and 2.

References

1 Letter, Jonathan G. Rowley (NRC) to Gary Peters (Framatome), "Request for Additional Information Regarding AREVA Inc. Topical Report ANP-10332P, Revision 0, "AURORA-B: An Evaluation Model for Boiling Water Reactors; Application to Loss of Coolant Accident Scenarios," (TAC NO. MF3829), October 24, 2017.

2 Letter, Jonathan G. Rowley (NRC) to Gary Peters (Framatome), "Request for Additional Information Regarding AREVA Inc. Topical Report ANP-10332P, Revision 0, AURORA-B: An Evaluation Model for Boiling Water Reactors; Application to Loss of Coolant Accident Scenarios," (TAC NO. MF3829/EPID: L-2014-TOP-0004), Undated, Received January 23, 2018.

* Framatome Inc. formerly known as AREVA Inc.

**RAI-1**

*Please clarify the following statement on Page 4-3 of Topical Report (TR) ANP-10332P:*

> *Provided that the licensing basis of the plant does not significantly depart from the SRP [Standard Review Plan] bases, the AURORA-B LOCA [loss-of-coolant accident] EM [evaluation model] supports the licensing basis of each plant to which it is applied by analyzing the plant-specific scenarios, consistent with the criteria defined in the licensing basis documents for the plant.*

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

**Framatome Response 1:**

The definition of a significant departure from the SRP is **[ ]**. It is the intent for the AURORA-B LOCA EM to be applicable to **[ ]**, 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 LOCA 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 LOCA EM is applicable to the plant or requires modification on a plant specific basis to make it applicable for the specific plant.

**RAI-2**

*On Page 6-21 of ANP-10332P, Table 6-1* [ ]. *Please confirm this information is beyond the intended scope of the TR's application or justify its inclusion.*

**<u>Framatome Response 2:</u>**

[ ] are beyond the scope of the topical report's application. [ ]

**RAI-3**

*How do the predictions of the proposed AURORA-B LOCA EM compare to those of the existing approved EM for the spectrum of BWR loss-of-coolant accidents (LOCAs)? Please provide comparison cases using similar initial conditions for a large- and a small-break LOCA scenario.*

**Framatome Response 3:**

The following plots compare results from the BWR/4 demonstration case from Section 7.7.4 to those from an equivalent EXEM BWR-2000 analysis for the same plant based on RELAX and HUXY for the high PCT LTR case, the small recirculation line 0.1 $ft^2$ split break in the pump discharge piping with battery single failure and a top-peaked axial shape. The available EXEM analysis was performed prior to the [ ]. The first figure compares the PCT from S-RELAP5 version USEP12 [ ] to the PCT result from HUXY (EXEM BWR-2000). Results are [ ].

The remaining plots show [ ].

[ ]

**Figure R3-1 EM Comparison of Small Break PCT**

[ ]

**Figure R3-2 EM Comparison of Small Break Upper Plenum Pressure**

[ ]

**Figure R3-3 EM Comparison of Small Break Total Break Flow**

[ ]

**Figure R3-4 EM Comparison of Small Break Upper Plenum Liquid Mass**

Figure R3-5 EM Comparison of Small Break Bypass Liquid Mass

[ ]

**Figure R3-6 EM Comparison of Small Break Lower Plenum Liquid Mass**

The following figures show similar comparisons of S-RELAP5 version USEP12 to the prior RELAX/HUXY method for [ ] large break case from Section 7.7.4, the 1.0 DEG pump suction recirculation line break with LOCA single failure and a mid-peaked axial shape.

[ ]

**Figure R3-7 EM Comparison of Large Break PCT**

**Figure R3-8 EM Comparison of Large Break Upper Plenum Pressure**

**Figure R3-9 EM Comparison of Large Break Total Break Flow**

[ ]

**Figure R3-10 EM Comparison of Large Break Upper Plenum Liquid Mass**

**Figure R3-11 EM Comparison of Large Break Bypass Liquid Mass**

**Figure R3-12 EM Comparison of Large Break Lower Plenum Liquid Mass**

The following table shows key conditions for the EXEM BWR-2000 and AURORA-B LOCA cases are equivalent.

**Table R3-1 Key Conditions for EM Comparison**

[ ]

**RAI-4**

*Please correct the apparently misstated sentence on Page 4-8 or justify that it is correct:*

[

].

*Clarify whether the intended meaning is:*

[

].

**Framatome Response 4:**

The intended meaning is: [

] Requirements that disallow a return to nucleate boiling are lifted after end of blowdown.

## RAI-5

*ANP-10332P presents a single phenomenon identification and ranking table (PIRT) for the spectrum of postulated LOCA events. The PIRT and accompanying textual descriptions appear to focus* [ ]. *Whereas, the importance of PIRT phenomena may vary substantially depending upon the location and size of the piping rupture, as well as the plant type. Furthermore,* [ ]. *In light of the discussion above, please provide the following information supporting development of the PIRT in ANP-10332P:*

a. *Please clarify how AREVA's PIRT process considered the full range of possible LOCA break locations and sizes, such that confidence exists that all applicable phenomena have been captured and appropriately ranked. If* [ ] *were used to develop the PIRT in Table 4-1 of ANP-10332P, then please provide these documents.*

b. *Please provide an analogous discussion to part a. regarding how the full range of BWR plant types was considered in the PIRT.*

c. *What method is used to determine overall ranking in cases of disagreement between phenomenon rankings for LOCAs of different break location, break size, or plant type?*

**<u>Framatome Response 5a.:</u>**

[ ] break sizes and locations.

**<u>Framatome Response 5b.:</u>**

The range of plant types [ ] was considered during the PIRT process as illustrated by comments in Table 4-1 [ ] for some phenomena [ ]. The [ ] prior to rankings being established.

**Framatome Response 5c.:**

The [ ] break location, break size or plant type is listed for each phenomenon in Table 4-1.

**RAI-6**

*Section 6.3.3 of ANP-10332P states that the primary thermal-hydraulic, thermal conduction, and neutron kinetics processes and closure relations for modeling highly ranked PIRT phenomena are summarized in Table 6-3 of the TR. However, the* [

] *is unclear and should be documented such that the NRC staff can be confident that AREVA has fully accounted for all important physical phenomena and processes associated with the spectrum of postulated BWR LOCA events. If all highly ranked PIRT items in* [

] *of ANP-10332P, then please provide justification.*

**<u>Framatome Response 6:</u>**

The highly ranked phenomena from PIRT [

]. All highly ranked phenomena are [ ].

[

]

**RAI-7**

*Please clarify the following issues concerning items in the PIRT:*

a. *Explain the meaning of PIRT item* [ ].
   *Please further explain why this item is ranked low for refill and reflood.* [ ].

b. *Explain specifically the flowpath or flowpaths referred to by PIRT item* [ ]

c. *The ranking for* [ ], *but the rationale for importance states* [ ]. *Please clarify this apparent contradiction.*

d. *Explain why* [ ]*?*

e. *Provide justification for* [ ].

f. *Although Section 5.4.6 of ANP-10332P discusses* [ ].

**<u>Framatome Response 7a.:</u>**

The PIRT item for [ ] refers to [ ] which are listed separately in Table 4-1. They are [ ] phenomena and include the [ ]. This item is ranked low during refill and reflood because [ ] are addressed by other PIRT items.

**Framatome Response 7b.:**

This refers to [ ] the flow paths listed below. ECCS contributes [ ]. The regional [ ].

[ ]

**Framatome Response 7c.:**

The rationale for importance describes [ ] by the PIRT team. [ ] because it does not influence [ ] is more significant and ranked high. [ ] is also ranked high because it affects [ ].

**Framatome Response 7d.:**

The [ ] of the recirculation discharge line. [ ] an important phenomenon. [ ].

**Framatome Response 7e.:**

[ ] during the LOCA transient would only apply for [ ].

[ ] which is small in the [ ] volume. Consequently, there is no significant influence on the [ ] and it does not have a significant impact on the figures of merit.

**Framatome Response 7f.:**

[ ] important to the LOCA figures of merit, [ ]. They influence the [ ].

**RAI-8**

*Please clarify whether it is necessary to validate and assess any* [

].

**Framatome Response 8:**

Medium-ranked phenomena from Table 4-1 are listed in the following table. [

].

**Table R8-1 Medium Ranked Phenomena**

[

]

[ ]

[ ] – These phenomena occur due [ ] Validation for [ ] and was performed by SET comparisons as noted in Table 5-1 or by IET comparisons as discussed in the response to RAI-47. These [ ]. The SSTF test simulations (Sections 7.7.1

and 7.9.6.2) are good examples. In those simulations the [ ]. Therefore, these phenomena are evaluated to be calculated appropriately because the important TH behaviors and histories in the IET simulations are reasonably well predicted.

[ ] models in S-RELAP5 are [ ] validated by the existing two-phase assessments.

[ ] are validated by the [ ] which were performed to address the highly-ranked, [ ] phenomena.

## RAI-9

*How is the pressure drop associated with recirculation pumps modeled in AURORA-B for both forward and reverse flow, and what is the technical basis? Furthermore, regarding Item II.3 in Appendix K, please clarify whether sensitivity analyses have been performed that are sufficient to determine a generically limiting condition with respect to whether a recirculation pump that has coasted down should be assumed to freespin or become locked in place?*

## Framatome Response 9:

Pump Pressure Drop

The pressure drop associated with recirculation pumps modeled in AURORA B for both forward and reverse flow is from the S-RELAP5 PUMP component model which is modified from RELAP5/MOD3 to apply two-phase pump degradation based on the EPRI two-phase pump performance program (Reference 14). As detailed in Section 6.2 of the S-RELAP5 theory manual (Reference 6), the single-phase pump performance model is based on 4-quadrant homologous pump curves using pump rated speed, flow, head, fluid density and torque in addition to pump inertia and pump/piping design data representative of the actual pumps as provided by the utility in the plant specific parameters document. The two-phase pump performance model is based on fully degraded two-phase head difference multiplier tables derived from EPRI two-phase pump performance tests and applied to the 4-quadrant single-phase homologous curve.

## Pump Coastdown

The AURORA-B LOCA EM assumes the recirculation pump is [ ]. The following table summarizes the results of sensitivity calculations [ ].

**Table R9-1 [ ] Sensitivity**

[ ]

**RAI-10**

*During an audit held on May 16-18, 2017, AREVA stated its intention* [

].

**Framatome Response 10:**

Framatome confirms [

].

The clad swelling and rupture model is based on NUREG-0630 as used in previously approved LOCA topical reports, for example EXEM BWR-2000 and PWR RLBLOCA. Clad swelling and/or rupture only occurs when the cladding temperatures are high and the rod pressure is greater than the coolant pressure. It depends on the [

].

Fuel relocation occurs when fuel fragments from upper locations move into the swollen, ruptured location. Fuel relocation [

].

Fuel relocation is [

]

[

].

[ ]

**Figure R10-1 [ ] Size Distribution**

These tests show [

].

Framatome implemented the [

].

To confirm [

].

**RAI-11**

*Please describe the modeling of fuel pellet thermal conductivity in RODEX4 as a function of exposure and summarize the basis for concluding that the concerns raised in Information Notice 2009-23 have been adequately addressed.*

**Framatome Response 11:**

Information Notice 2009-23 addresses fuel thermal conductivity degradation caused by irradiation, and recommends this effect be included in modern fuel codes. It also indicates that the NRC confirmatory code, FRAPCON, has been updated to include this degradation effect based on Halden high burnup tests.

The fuel conductivity correlation used in RODEX4 is a [

].

This RODEX4 thermal conductivity correlation [

].

**Figure R11-1 RODEX4 UO2 Thermal Conductivity by Exposure**

**RAI-12**

*In light of the facts that (1) the S-RELAP5 code contains a kernel taken from the RODEX4 code,* [

]. *If AREVA does not agree to such a commitment, please provide an alternative approach with adequate justification.*

**<u>Framatome Response 12:</u>**

Framatome [

].

**RAI-13**

*The AURORA-B LOCA EM incorporates a "kernel" of routines from the RODEX4 code (Reference 9 of ANP-10332P) into S-RELAP5 to calculate* [

] *The following questions seek to clarify the coupling between the RODEX4 kernel and the master code, S-RELAP5.*

a. *Explain the guidance and justification* [

].

b. *How does RODEX4 account for the effect of cladding and fuel dimensional changes (e.g., thermal expansion, creep, cladding swelling/rupture, etc.) in the calculation of gap conductance?*

c. *In calculating an* [ ], *how does RODEX4 account for the non-uniformity of the fuel-cladding gap size in the axial and azimuthal directions?*

d. *Fuel pellet* [

].

*Explain the impact of the timing of this change in fuel thermal conductivity on the conservative prediction of peak cladding temperature (PCT) for time-in-life LOCA analyses of different break sizes.*

**<u>Framatome Response 13a.:</u>**

The [ ] used in the RODEX4 kernel within S-RELAP5 are described below in the response to RAI-14c. Fuel and cladding [

]

[ ].

**Framatome Response 13b.:**

The kernel transient gap conductance is calculated [ ] RODEX4 gap conductance formulation. This formulation is based on current transient values of [ ]. The transient gap width calculation [ ]. In addition, the gap width calculation includes [ ]. These permanent strains are acquired from the stand-alone RODEX4 exposure calculation through a data file imported to initialize S-RELAP5.

The LOCA methodology also makes use of the NRC approved NUREG-0630 Appendix K clad swelling and rupture model (Reference 25) to evaluate swelling and rupture at high cladding temperatures. Pre-rupture and post-rupture cladding strains predicted by this model are [ ]. After rupture occurs, the [ ].

**Framatome Response 13c.:**

The RODEX4 calculation in S-RELAP5 uses [ ]. Each of these axial levels has its own linear heat generation rate and fluid conditions, resulting in calculated fuel and cladding thermal properties, gap width and gap conductance. The S-RELAP5 fuel heat structures use [ ] model implemented in S-RELAP5.

[ ].

The RODEX4 kernel in S-RELAP5 adjusts gap width based [ ]. To account for [ ] based on the NUREG-0630 rupture model. Pre-rupture and rupture [ ] are calculated in S-RELAP5 using [ ]. These [ ].

RODEX4 assumes the pellet [ ].

[ ]

**Figure R13-1 RODEX4 [ ]**

**Framatome Response 13d.:**

The thermal conductivity is [ ] with the stored energy requirement of Appendix K I.A.1 under the heading: "The Initial Stored Energy in the Fuel." Appendix K [ ].

Sensitivity calculations were performed for a large break (1.0 DEG) and a small break LOCA (0.1 $ft^2$). PCT results are shown in the following plots which compare the EM model with [

].

**Figure R13-2 PCT Impact of Thermal Conductivity for a Large Break LOCA**

**Figure R13-3 PCT Impact Thermal Conductivity for a Small Break LOCA**

**RAI-14**

*The NRC staff has previously reviewed a number of aspects of the AURORA-B LOCA EM for other applications.*

a. *Please highlight and, as necessary, either cite or provide justification for* **[**

**]**.

b. Please identify and justify the **[**

**]**.

c. *Please identify and justify any major changes between the RODEX4 kernel and the approved methodology described in BAW-10247PA, Revision 0, and approved supplements thereto. Please further describe whether AURORA-B test problems exist that verifies that the RODEX kernel in AURORA-B predicts behavior equivalent to the stand-alone code for transient conditions.*

**Framatome Response 14a.:**

The latest NRC staff review was performed for the **[** **]** based on S-RELAP5 version UOCT09. Changes from UOCT09 to the USEP12 version used in the AURORA-B LOCA LTR are listed below. **[** **]**.

[ ]

[ ]

**Framatome Response 14b.:**

The major changes that transformed S-RELAP5 [ ].

S-RELAP5 has been [ ].

**Framatome Response 14c.:**

The RODEX4 kernel in S-RELAP5 contains a subset of the RODEX4 physical models presented in BAW-10247. The full RODEX4 code calculation of cladding and fuel deformation includes the following effects.

[ ]

From all of these effects, calculation [ ]. Baker-Just metal-water reaction is implemented in S-RELAP5.

The [ ] in S-RELAP5 are then:

- [ ]

- [ ]

These [ ] during transient analyses and are used to update [ ] to current transient values.

The portions of the full RODEX4 code used to calculate these [ ] have been incorporated intact in the RODEX4 kernel in S-RELAP5, and will [ ].

All maintenance or error correction changes to the parent RODEX4 code are implemented in the S-RELAP5 RODEX4 kernel if they impact the physical models included in that kernel. There have been no changes to RODEX4 since the original incorporation of the approved version of RODEX4 in S-RELAP5 which affect the fuel rod physical models used in S-RELAP5 for AURORA-B analysis.

The code maintenance process for S-RELAP5 includes a [ ]. This confirms that the kernel in S-RELAP5 is accurately duplicating the RODEX4 calculation of the fuel rod effects which impact transient LOCA analyses.

## RAI-15

*During an audit on May 16-18, 2017, AREVA stated that it seeks the NRC staff's review and approval of AURORA-B* [

]. *In light of this voluntarily implemented change in S-RELAP5 code version, additional information is necessary to describe the changes in the new code version, as well as its impact on the validation and demonstration analyses in ANP-10332P:*

a. *Please provide description, at a level of detail commensurate with a TR, of any changes to the AURORA-B LOCA EM resulting from the change in S-RELAP5 code version and provide justification for the acceptability of the changes.*

b. *Please provide an updated version of the validation and assessment analyses demonstrating that the AURORA-B code system's validation and assessment results using the* [ ] *version of S-RELAP5 are acceptable. Please confirm that the discussion and conclusions expressed in ANP-10332P regarding the validation and assessment results remain accurate, or provide an updated discussion and conclusions.*

c. *Please provide updated demonstration case (i.e., BWR plant analysis) results that illustrate how the AURORA-B code system with the* [

].

*Please confirm that the discussion and conclusions expressed in ANP-10332P regarding the demonstration case results remain accurate, or provide an updated discussion and conclusions.*

**<u>Framatome Response 15a.:</u>**

The S-RELAP5 code changes [

]:

[ ]

[ ]

The following code changes for intermediate code versions since USEP12 [ ].

[ ]

**Figure R15-1 [ ] Bromley Film Boiling Attenuation Factor**

**Figure R15-2 Bromley Attenuation Factor [ ]**

[

]

**Figure R15-3 Shape Factor vs Velocity [ ]**

[ ]

**Figure R15-4 Shape Factor vs Void Fraction [ ]**

[ ]

[ ]

**Framatome Response 15b.:**

A [ ] was provided to the NRC staff to document updated assessment results and discussion.

The principle differences in calculated results between [ ] and USEP12 are the changes required from the NRC staff review of ANP-10300P for AURORA-B AOO. In all cases, the overall conclusions from the original assessments are unchanged. There are no adverse results that would negate use of [ ]. For the majority of the assessments, the differences between the code versions are quite small.

The change to [ ] and the change to [ ]. The impact of both changes is illustrated in the [ ].

[ ]

**Figure R15-5 CCTF Run 62 Cladding Temperature at 2.035 m Elevation**

[ ]

**Figure R15-6 THTF Steady-State Film Boiling Calculated vs Measured HTC**

**Framatome Response 15c.:**

The break spectrum calculations for the LTR demonstration cases were repeated using the updated S-RELAP5 code version [ ]. Results are shown in the following tables and include BWR/6 cases [ ].

The updated BWR/4 sample analysis produced the highest PCT for a [ ].

**Table R15-1 PCT Summary – BWR/4 SF-BATT Updated Code and Model**

[ ]

**Table R15-2 PCT Summary – BWR/4 SF-LPCI Updated Code and Model**

[ ]

**Table R15-3 PCT Summary – BWR/4 SF-LOCA Updated Code and Model**

[ ]

The updated BWR/6 sample analysis produced the highest PCT for a [

]. The worst small recirculation line break was [

].

**Table R15-4 PCT Summary – BWR/6 SF-LPCI Updated Code and Model**

[

]

**Table R15-5 PCT Summary – BWR/6 SF-LPCS Updated Code and Model**

[ ]

**Table R15-6 PCT Summary – BWR/6 SF-HPCS Updated Code and Model**

[ ]

**RAI-16**

*The AURORA-B LOCA EM chose to use the Groeneveld 2006 CHF look-up table (LUT) over other steady-state correlations deemed acceptable in Appendix K to 10 CFR Part 50. The following questions seek clarification of the implementation of the CHF LUT in the EM.*

a. *Section 6.4.10 of ANP-10332P states that eight rod-bundle correction factors may be applied to the Groeneveld CHF LUT used in AURORA-B. These correction factors appear to contain fuel-design-specific aspects. To illustrate AREVA's use of these factors, please provide a table that identifies the values of these correction factors for the ATRIUM 10 fuel design.*

b. *According to Section 6.4.10 of ANP-10332P, applying only the hydraulic diameter factor to the CHF LUT results in an underprediction of the critical power for the ATRIUM 10 fuel bundle. However,* [

]

*Please further (1) explain quantitatively the impact of the other* [

], *and (2) provide justification that implementation of the method used for the AURORA-B LOCA EM would result in an overall conservative prediction.*

c. *Section 6.4.10 of ANP-10332P states that* [

]

[

]. *How does the determination of the* [

] *account conservatively for the uncertainty of the fuel-specific CHF/CPR correlations? Furthermore, which method does the EM use to determine the CHF value during transient and the value of the* [

]*?*

d. *The functional forms of the eight rod-bundle correction factors for the CHF LUT are summarized in* [

]. *Explain the rationale for the selection of* [

].

**<u>Framatome Response 16a.:</u>**

Values of the eight correction factors are computed from both geometric and thermal-hydraulic quantities that vary in time and space. [

]. The eight correction factors are referred to as K1 through K8 in the following discussion.

The equations for the correction factors are presented first, followed by plotted results. Values are given in the equation for constant correction factors. The time varying correction factors are plotted and shown in Figure R16-1 through Figure R16-4.

Figure R16-1 shows the time histories of each correction factor, K1 through K7. The reverse flow correction for K8 is embodied in a modified form of the LUT-CHF given by Equation 4.64 in Reference 6 and is included in the LUT-CHF value in Figure R16-3 and Figure R16-4. The product of the correction factors K1 through K7 is shown in Figure R16-2. The [

].

[

]

[ ]

**Figure R16-1 Groeneveld Factors K1 through K7 [ ]**

[ ]

**Figure R16-2 Product of Groeneveld Factors K1 through K7 [ ]**

[ ]

**Figure R16-3 Groeneveld LUT-CHF with Factors [ ]**

[ ]

**Figure R16-4 LUT-CHF and Calculated Heat Flux [ ]**

**Framatome Response 16b.:**

**[**

**]**.

The caption **[**

**]**.

CHF prediction for bundle geometries requires the tabular CHF value be multiplied by the correction factors. The quantitative impact of those factors is discussed in the response to RAI-16a. This response presents demonstration calculations to show their cumulative effect on the effective CHF value yields a conservative prediction when applied to a Framatome fuel bundle.

For this demonstration, the [ ]. The calculation is repeated with the [ ]. The resulting [ ] indicates a conservative CHF value.

Table R16-1 compares the [ ]. They show the Groeneveld LUT [ ] conservative CHF when applied to a Framatome fuel bundle.

**Table R16-1 [ ] Groeneveld LUT**

[ ]

**<u>Framatome Response 16c.:</u>**

The [ ].

In S-RELAP5, the transient equilibrium quality used in the LUT is calculated from the conservation equations that are advanced in time and space. This incorporates [ ].

**Framatome Response 16d.:**

The reference citations are [ ] provided to the NRC staff. The reference numbers in this response apply to the S-RELAP5 theory manual rather than the LTR.

Of the eight correction factors, [ ].

In Lee's article, he also presents other research and experience [ ].

Groeneveld discusses the methods of determining the accuracy of the CHF-LUT in the 1995 table article [ ].

Groeneveld then discusses the process of determining the CHF prediction [

].

In S-RELAP5 when using the Groeneveld CHF-LUT, the transient thermodynamic quality that is supplied to the LUT is [

].

The correction factors for the 2006 CHF-LUT were listed in a 2005 article and, [

].

**RAI-17**

*ANP-10332P proposes that* [

].

*Please clarify the following regarding this approach:*

a. *Under what circumstances does* [

]

b. *AREVA explained in ANP-10332P that the* [

]. *However,*

i. [

]

ii. [

]

[ ]

iii. *The Opinion of the Commission on the 10 CFR 50.46 rulemaking, dated December 28, 1973, on Page 1116 appears to* [ ]. *In particular, the Opinion stated disagreement with a proposal that critical heat flux exceedances on the order of milliseconds may be neglected. In light of the Commission's Opinion, please justify that the proposed approach is compliant with Appendix K or revise it to be compliant.*

c. *In light of the large, well-curated database associated with the Groeneveld 2006 CHF LUT and* [ ]. *In doing so, please discuss the qualification data for the* [ ] *and justify that the model and its qualification database are applicable to the spectrum of BWR LOCA events, particularly around* [ ]. *Please discuss in particular whether, prior to reaching* [ ]. *Justification should be provided if the* [ ] *is being applied under such conditions, since it is not clear that it is applicable.*

**<u>Framatome Response 17a.:</u>**

[ ] when using the Groeneveld look-up table (LUT) [ ].

Other NRC approved Appendix K methods have used a [

].

An example of the impact is shown in LTR Figure 7-544 where the [ ]. Another example follows for two cases [

].

[ ]

**Figure R17-1 Cladding Temperatures at Time of CHF**

**Figure R17-2 Void Fractions at Time of CHF**

**Figure R17-3 Critical Heat Flux at Time of CHF**

The following figures demonstrate that the [

].

CHF from the LUT [

].

**Figure R17-4 Heat Flux and CHF [ ]**

**Figure R17-5 [ ] Heat Transfer Mode [ ]**

**Figure R17-6 Heat Flux and CHF [ ]**

**Figure R17-7 [ ] Heat Transfer Mode [ ]**

**Figure R17-8 Heat Flux and CHF [ ]**

**Figure R17-9 [ ] Heat Transfer Mode [ ]**

[

]

**Figure R17-10 [ ] Rod Temperatures**

**<u>Framatome Response 17b.:</u>**

i. The [

]. The Groeneveld LUT [

]. Other approved Appendix K methods have applied a [

].

ii. The native [

].

iii. The [

]. Other approved Appendix K methods have used a [

].

**Framatome Response 17c.:**

The database [

].

**RAI-18**

*Appendix K states that*

> *After CHF is first predicted at an axial fuel rod location during blowdown, the calculation shall not use nucleate boiling heat transfer correlations at that location subsequently during the blowdown even if the calculated local fluid and surface conditions would apparently justify the reestablishment of nucleate boiling. Heat transfer assumptions characteristic of return to nucleate boiling (rewetting) shall be permitted when justified by the calculated local fluid and surface conditions during the reflood portion of a LOCA.*

*and*

> *Transition boiling heat transfer shall not be reapplied for the remainder of the LOCA blowdown, even if the clad superheat returns below 300 °F, except for the reflood portion of the LOCA when justified by the calculated local fluid and surface conditions.*

*Although in both cases Appendix K explicitly speaks of implementing these heat transfer lockouts during the blowdown phase and releasing them during the reflood phase,* [ ]. *Therefore,* [ ] *is not clear and requires justification:*

a. *Please provide a more detailed description regarding the* [ ] *as used in the AURORA-B LOCA EM. In addition, for one small- and one large-break demonstration case audited by the NRC staff, please identify the times in the calculation that correspond to the* [ ].

b. *Please describe the expected* [ ]

[

]

c. *Please either revise ANP-10332P to comply with the requirements of Appendix K or justify that the current approach is compliant with Appendix K.*

**Framatome Response 18a.:**

A PWR has [ ] because ECCS enters the core from the lower plenum. For a BWR, [

] BWR/4 large break and [ ] BWR/4 small break demonstration cases audited by the NRC staff. PCTs occur at [ ], respectively.

**Framatome Response 18b.:**

Results would be [

]. Release of the heat transfer lockouts only allows a return to transition or nucleate boiling when the coolant conditions warrant. As the NRC staff noted [

].

**Framatome Response 18c.:**

The EM is compliant with Appendix K. RAI-18 refers to the nucleate boiling lockout from Appendix K I.C.4.e and the transition boiling lockout from I.C.5.b.3. [

].

This conclusion is [

].

**RAI-19**

*ANP-10332P states that the Groeneveld-Stewart correlation is less conservative than the Appendix K criterion for minimum film boiling temperature (i.e., $T_{min}$) below approximately 0.26 MPa (~ 38 pounds per square inch absolute (psia)). Please discuss the relevance of this observation relative to the pressure range associated with BWR LOCA scenarios for large and small breaks for Mark I, II, and III containment designs and justify that the Groeneveld-Stewart correlation is appropriate. Please explicitly address the observation that,* [

].

**<u>Framatome Response 19:</u>**

The Appendix K 300 °F wall superheat criteria is always used to prevent the return to transition boiling heat transfer during blowdown as required by Appendix K. [

].

G-S was developed from data for Inconel 600. Application of G-S to Zircaloy or zirconium oxide is conservative because those materials have a higher minimum film boiling temperature than Inconel 600 or stainless steel as discussed in Section 6.4.12 (Pages 6-71 to 6-72) and shown in the following figures from Peterson and Bajorek (Reference 48). The minimum film boiling temperature is higher for Zircaloy than Inconel 600 which has properties comparable to stainless steel. Zirconium oxide is substantially higher as shown in the second figure. The conservative impact of cladding material exceeds the non-conservatism in Figure 6-19 so G-S is conservative overall for Zircaloy and its oxide.

[ ]

**Figure R19-1 $T_{min}$ vs Pressure from Peterson and Bajorek**

**Figure R19-2 $T_{min}$ by Material from Peterson and Bajorek**

**RAI-20**

*Regarding the information presented in Figure 6-20 of ANP-10332P:*

a. *Please provide an additional, zoomed-in plot to supplement the information in Figure 6-20 that better resolves the* [ ] *(this range is of significant interest for BWR LOCA events post-blowdown).*

b. *Please explain the* [ ]

c. *Please further explain* [ ]. *Which of these conditions is most applicable for the spectrum of BWR LOCA events, as predicted by the AURORA-B LOCA methodology? In responding, please reference one of the demonstration cases audited by the NRC staff, since, as noted above, it is not clear* [ ]

**<u>Framatome Response 20a.:</u>**

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

[ ]

**Figure R20-1 Calculated and Measured $T_{min}$ at Low Pressures**

**<u>Framatome Response 20b.:</u>**

Figure 6-20 and the zoomed figure above shows a comparison of the Groeneveld-Stewart correlation of $T_{min}$ to the data from their experiments and data from Winfrith. At low pressures (200 and 500 kPa), the Winfrith data are lower than the Groeneveld and Stewart's data as well as their correlation.

Based on a review of Reference 45 for Groeneveld-Steward and Reference 46 for Winfrith, there are [ ].

In addition, Groeneveld-Steward used [ ]

Otherwise, the both experiments were conducted with a similar test procedure using a "hot patch technique" that permits film boiling conditions to be maintained in a heat flux controlled system at heat flux level well below the CHF.

**Framatome Response 20c.:**

The basis for the Groeneveld-Stewart correlation is Reference 45. For saturated water, the correlation defines $T_{min}$ (K) based on pressure (MPa) using:

$$T_{min} = 557.85 + 44.1P - 3.72P^2; \qquad X > 0$$

For subcooled water, expressed as a negative steam quality (X < 0), the correlation includes an additional term that increases $T_{min}$ for the subcooled region:

$$T_{min} = 557.85 + 44.1P - 3.72P^2 - \frac{10^4 X}{2.82 + 1.22P}; \quad X < 0$$

The BWR/6 1.0 DEG, PS, SF-LPCS, mid-peaked power shape case from Section 7.7.6 was audited by the NRC and used to assess impact of saturated and subcooled conditions.

As noted by the NRC, Figure 7-501 shows that the calculation was terminated prior to hot rod quench at the PCT node. That calculation was extended to beyond the time when the PCT node on the hot rod (HR) quenched as shown in the following figure.

**Figure R20-2 Extended Run to Hot Rod Quench**

To assess the impact of fluid conditions, the S-RELAP5 calculation was rerun with [ ].
This differs from the EM where the code [ ] however, this approach is available by input changes and is sufficient to show the sensitivity. One case used the saturated Groeneveld-Stewart equation while the second used the equation for subcooled conditions. The following figure shows the impact of the subcooled term which [ ]. The sudden decrease in temperature [ ] as shown in Figure R20-5 and Figure R20-6.

[ ]

**Figure R20-3 Impact of Subcooling on Groeneveld-Stewart $T_{min}$**

The following figure shows the calculated $T_{min}$ values with and without the subcooling term. Subcooled conditions [ ].

[ ]

**Figure R20-4 Groeneveld-Stewart $T_{min}$ Saturated and Subcooled Components**

[ ]

**Figure R20-5 Hot Rod Temperature at $T_{min}$ [ ]**

**Figure R20-6 Void Fraction for $T_{min}$ [ ]**

**RAI-21**

*Please provide adequate basis that* **[**

**]**.

**<u>Framatome Response 21:</u>**

The request **[**

**]**.

**RAI-22**

*Regarding the CCFL testing in the mini-loop described in Section 5.4.8 of TR, please clarify how the testing was scaled geometrically so as to represent the actual plant condition. In particular, the flow area distribution along the upper tie plate surface is not uniform, and it is not clear how the scaling was done to ensure applicability to the full-size condition.*

**Framatome Response 22:**

A [ ] was used. The test section and experimental procedures were qualified by verifying the [

].

**RAI-23**

*ANP-10332P states in Section 6.2.5 that "The suitable calculation for gamma energy deposited in the fuel is AREVA's BWR fuel management reactor physics code used for reload licensing analysis."* [

]. *Please either (1) confirm that the generic methodology in ANP-10332P will* [

], *including:*

a. *Identification of the current BWR fuel management reactor physics code and the extent to which this code been reviewed by the NRC staff for* [ ].

b. *Description of the* [ ].

c. *Discussion of the* [ ].

**Framatome Response 23a.:**

Gamma deposition will be [

].

Framatome has performed [

]

[

].

**Framatome Response 23b.:**

After the [ ], gamma sources from neutron capture, fission, inelastic scattering and radioactive decay are calculated for all regions of the problem, and a gamma transport calculation is performed using [

].

Figure R23-1 compares the normalized gamma [

]:

[ ]

where [

].

[

].

**Figure R23-1 Normalized Gamma [ ]**

The gamma transport calculation is [ ]. Gamma fluxes are calculated for [ ]

[

].

Figure R23-2 presents the fuel exposure dependence of the delayed gamma energy deposition fraction outside of the fuel pellet and clad regions for [

].

[

]

**Figure R23-2 Delayed Gamma Energy Fractions Deposited Outside of Fuel Rods**

Table R23-1 through Table R23-4 below present the delayed gamma energy deposition fractions at [

].

**Table R23-1 Delayed Gamma Energy Deposition for [ ]**

[

]

**Table R23-2 Delayed Gamma Energy Deposition for [ ]**

[

]

**Table R23-3 Delayed Gamma Energy Deposition for [ ]**

[

]

**Table R23-4 Delayed Gamma Energy Deposition for [ ]**

[

]

The preceding tables present the gamma energy deposition fractions at [

]. Figure R23-2 indicates the

gamma energy deposition fractions outside the fuel [

]. In general, the non-fuel gamma energy deposition is [

].

The effect of [

].

The [ ] was used to calculate the fraction of radioactive decay power which is emitted as gamma radiation. The [

]. Table R23-5 through Table R23-7 present the fractions of decay heat emitted as gamma radiation [

].

**Table R23-5 Fraction of Decay Heat from Gamma Emission at [ ]**

[ ]

**Table R23-6 Fraction of Decay Heat from Gamma Emission at [ ]**

[ ]

**Table R23-7 Fraction of Decay Heat from Gamma Emission at [ ]**

[ ]

These tables show that gamma energy emission accounts for [ ]. Coupled with the results presented in Table R23-1 through Table R23-4, this results in the conclusion that, after reactor shutdown, [ ]. As a result, it may be concluded that [ ].

When applied in S-RELAP5, the gamma heat source outside the fuel rods [ ].

**Framatome Response 23c.:**

The [ ] has been experimentally validated by Framatome via comparisons between measurements of gamma-sensitive [ ]. This validation has been previously provided to the NRC in topical report EMF-2158(P)(A) where [ ]. All of this data was collected at normal operating conditions. It should be observed that, [ ].

The decay heat calculations were performed with [ ].

**RAI-24**

*Appendix K to 10 CFR Part 50 states that if the results indicate that the maximum clad temperature for the LOCA is to be found at an even lower value of the discharge coefficient than 0.6, then the lower range shall be extended until the maximum clad temperature has been achieved. Please provide the following information to justify the statement in ANP-10332P that* [

]:

a. *Clarify why* [

]?

b. The TR states that [

].

**Framatome Response 24a.:**

Experimental data for open pipe flow has shown that discharge coefficients [

].

**Framatome Response 24b.:**

The [ ] for all cases.

Variation in discharge coefficient and split break area [ ].

**RAI-25**

*ANP-10332P indicates that the Moody model* **[**

**]**

**Framatome Response 25:**

The Moody model **[** **]**.

**RAI-26**

*Please describe how [ ] is modeled in the AURORA-B LOCA EM for the primary system safety/relief valves (SRVs), which may be opened in some LOCA scenarios at high pressure when the automatic depressurization system is activated. Please include a description of the [*

*].*

**Framatome Response 26:**

[ ] at the SRVs is modeled [

].

**RAI-27**

*ANP-10332P does not define which* [

]. *Therefore, please provide the following information:*

a. *Identify the* [

] *in conformance with Appendix K.*

b. *Either (1) confirm that the* [

] *were used when performing each of the analyses included in ANP-10332P (e.g., those used for code assessment and validation, demonstration cases, etc.), (2) provide additional simulations with the* [ ]*, or (3) identify* [

].

c. *When performing* [ ] *analyses in accordance with the methodology described in ANP-10332P, please explain* [

] *will be implemented and verified in a way that minimizes the potential for human error and unintended variation. For example, having a* [

]

[

]

**Framatome Response 27a.:**

The following [ ] must be used to perform calculations under the AURORA-B LOCA EM in conformance with Appendix K.

[

]

[ ]

**Framatome Response 27b.:**

The LTR demonstration cases used the [ ] in conformance with Appendix K. All Appendix K requirements are [ ].

Code validation against test data [ ].

The assessments used [ ].

[ ]

[ ]

Sections 7.9.1 and 7.9.2 clarify and demonstrate the substantial impact some of those Appendix K conservatisms have on TLTA and FIST cases. This question and these cases are also discussed in the responses to RAIs 53, 90, 92, 93, 94 and 95. In addition, the response to RAI-58 illustrates the conservative PCT impact of Appendix K options on demonstration cases.

**<u>Framatome Response 27c.:</u>**

The [ ] will be implemented [ ].

The [ ].

## RAI-28

*Chapter 15 of the SRP and Regulatory Guide 1.203 both specify that an analytical EM submitted for NRC review should be "frozen" (i.e., placed in a controlled, unchangeable state). These guidance documents further indicate that the code assessment and validation process should be performed with the frozen version of the EM that has been submitted for review. The NRC staff likewise expects that the demonstration analyses submitted in the TR should be performed with this same frozen version to demonstrate expected performance of the EM under review. However,* [

]*. Therefore, please provide the following information:*

a. *Identify the frozen code version associated with the AURORA-B LOCA EM proposed in ANP-10332P.*

b. *Identify the code version that AREVA has used to perform the assessment and validation simulations in the TR . Either (1) confirm it is the same as the frozen code version associated with the AURORA-B LOCA EM, (2) provide additional simulations with the appropriate frozen code version, or (3) provide justification that additional simulations with the frozen code version are not necessary.*

c. *Identify the code version that AREVA has used to perform the demonstration case simulations in the TR. Either (1) confirm it is the same as the frozen code version associated with the AURORA-B LOCA EM, (2) provide additional simulations with the appropriate frozen code version, or (3) provide justification that additional simulations with the frozen code version are not necessary.*

**<u>Framatome Response 28a.:</u>**

S-RELAP5 version USEP12 is the code version associated with the original TR. As discussed during the May 16-18, 2017 audit, Framatome is seeking approval for [

] as described in the response to RAI-15. The impact of [

] was presented during the audit and is addressed by responses to other RAIs (e.g. RAI-15, RAI-51 and RAI-126).

**Framatome Response 28b.:**

The USEP12 code version was used to perform the assessment and validation simulations in the TR. The impact of [ ] is addressed by responses to RAI-15, RAI-51 and RAI-126.

**Framatome Response 28c.:**

The USEP12 version was used to perform the demonstration case simulations in the TR. The impact of [ ] is addressed by responses to RAI-15 and RAI-126.

**RAI-29**

*ANP-10332P primarily focuses upon concerns associated with code development and validation. A number of relevant aspects of the broader EM are not treated. Therefore, please discuss the following aspects of the framework for applying the AURORA-B LOCA EM to plant-specific analysis and provide justification. For each item, specify whether plant-specific determinations must be made, or whether a generic basis exists to disposition the item in the present review.*

a. *Which break locations on which systems must be considered in the LOCA analysis, and how are the analyzed breaks selected?* [

]

b. *What are the required extent and resolution of the break spectrum for selection of the limiting break and single failure combination? In responding, please provide adequate justification for (1) the resolution used for intermediate breaks* [

] *and (2) the selection of the minimum analyzed break size in the small-break range* [

]

c. *For split breaks,* [

]*? In responding, please consider conditions during blowdown where the break flow is choked, as well as conditions later in the event after the break has unchoked.*

d. *Should a split break occur on the recirculation discharge piping for the BWR/3-4 design, low-pressure coolant injection flow pumped into the broken recirculation discharge piping may have the potential to enter the reactor vessel. Please clarify if credit is taken for safety injection flow to the broken loop in the case of a split break. If credit is taken, then please describe the governing phenomena, the applicable modeling practices (including modeling of break azimuth) in AURORA-B, and the validation basis for the associated AURORA-B models. As applicable, please also* *clarify the impacts of loop-select logic (including the possibility for this logic to experience a single-failure and the minimum break size for which it is effective).*

e. *Can a single simulation simultaneously achieve limiting conditions for peak cladding temperature, maximum local oxidation, and core-wide oxidation, or are separate analysis cases, potentially with different initial conditions, different break locations, and single failures, necessary to achieve the limiting results for each of the relevant criteria from 10 CFR 50.46? Please clarify in particular, how the limiting oxidation results* [

].

f. *How is the most-limiting single failure for each analysis determined? Does the method recognize that the limiting single failure is generally scenario dependent?*

g. *What key initial conditions will be specified in each analysis* [

]? *In each case, please identify whether nominal conditions will be used or whether a conservative assumption will be used, and provide a technical basis. If a single set of initial conditions is insufficient to ensure that limiting results are calculated for each of the relevant criteria from 10 CFR 50.46 (e.g., if multiple points on the power-flow map must be considered), then please provide information for all relevant cases that would need to be simulated.*

h. *Discuss assumptions regarding the availability of offsite power, the response of non-safety-related equipment, and operator actions.*

i. *Please clarify whether* [

].

j. *In large-break LOCA scenarios,* [

].

k. *How is the limiting* [ ]? *In particular, because of the potential for bottom-up and top-down quench fronts in the BWR design,* [ ] *Therefore, please provide adequate justification for the adequacy of the existing method or commit to performing a plant-specific* [ ]. *Please further ensure that the response considers the requirements for* [ ].

l. *Please discuss the modeling of the linear heat generation rate, decay heat, and stored energy for* [ ], *and explain how AREVA has conservatively modeled these parameters in an overall sense for* [ ].

**<u>Framatome Response 29a.:</u>**

Recirculation line breaks and non-recirculation line breaks are considered. For the recirculation line, [ ]. Special analysis considerations are required when the break is postulated to occur in a pipe that is used as the injection path for an ECCS (e.g. core spray line). Although these breaks are relatively small, their existence disables the function of an ECCS. The extent of the break spectrum analysis is discussed in the response for Item g.

The [ ] steam line and feedwater line breaks [ ].

Feedwater line breaks [ ]

[ ].

**Framatome Response 29b.:**

An [ ], similar to those in Table 7-37, are analyzed for each [ ].

The required break size resolution for the [ ] is specified in guidelines as follows. The break geometries analyzed for recirculation line breaks are double-ended guillotine (DEG) and split. The DEG break [ ].

- DEG breaks – The largest contraction coefficient is 1.0 and the [ ].
- Large split breaks – The area of the largest split break analyzed is [ ].
- Small split breaks – The break area for transition between large and small breaks is [ ].
- The minimum break size is [ ]."

**Framatome Response 29c.:**

[ ] are used to model the containment and [ ]. Break modeling is discussed in Sections 6.2.13 and 6.4.6.

The split break flow discharges at a rate based on the Appendix K required Moody critical flow model [ ].

After the break is [ ].

**Framatome Response 29d.:**

Low-pressure coolant injection (LPCI) flow [ ].

**Framatome Response 29e.:**

The limiting PCT and oxidation [ ].

**Framatome Response 29f.:**

Each single failure is considered [ ]. Single-failures are prescribed on a plant-specific basis and [ ]. Examples include failures of an ECCS pump, battery and diesel generator systems.

**Framatome Response 29g.:**

[ ] initial conditions. The feedwater [ ]. Initial core flow is [ ].

The following parameters and assumptions are conservatively chosen based on Appendix K and AURORA-B LOCA as listed in Section 3.3:

- The 2% power uncertainty unless lower is justified.
- Maximum linear heat generation rate [ ] based on technical specifications.
- All permitted axial shapes addressed.
- Initial stored energy conservatively calculated.
- Appropriate analysis support credit taken for control rod insertion.
- Analysis conservatively addresses the operation of the reactor coolant pump.
- A conservatively low minimum containment pressure is used.

**Framatome Response 29h.:**

[ ] during the LOCA event. Modeling of plant systems, such as those in Table R29-1, [ ].

Loss of offsite power (LOOP) is [ ] offsite power available (OPA). The following table describes the differences in operation

[

].

**Table R29-1 Offsite Power Available vs Loss of Offsite Power**

[

]

[ ]

**Framatome Response 29i.:**

[ ] as discussed in the response to RAI-87.

**Framatome Response 29j.:**

The potential for [ ] in the AURORA-B LOCA EM.

**Framatome Response 29k.:**

The axial power profile is [ ]. Example profiles are shown in Figure 6-1.

The product of the [ ], or

[ ]

This equation is used [ ].

Section 6.2.1 discusses [ ]

[

].

The above method [

].

[ ]

**Figure R29-1 Thermal Limits History for an Operating Plant**

In addition, assembly axial shapes [

].

[

]

**Figure R29-2 Axial Offset History for an Operating Plant**

Framatome may [

].

Plant operation is [

]

[

].

Framatome [

].

[

]

An example result for an operating plant is shown in the following figure, which demonstrates [

].

[

]

**Figure R29-3 Thermal Limits [ ] Assembly**

Sensitivity calculations [

].

The BWR/6 large break cases [

].

**Table R29-2 Peak Cladding Temperatures [ ]**

[ ]

The resulting power distributions shall comply with the Appendix K I.A. requirement that the range of power distribution shapes and peaking factors representing power distributions that may occur over the core lifetime be studied and the limiting shape identified.

**<u>Framatome Response 29I.:</u>**

The hot rod is [ ]. Decay heat and maximum stored energy are used [ ] as specified in Appendix K.

**RAI-30**

*In Section 3.3 of ANP-10332P, AREVA indicates* [

]

**Framatome Response 30:**

If a calculation [

].

Oxidation is [

] provided based on Baker-Just metal-water reaction [

].

**Table R30-1 [ ] Baker-Just [ ]**

[ ]

**Figure R30-1 [ ] Baker-Just [ ]**

**RAI-31**

*In Section 3.3 of ANP-10332P, AREVA states* [

]

**<u>Framatome Response 31:</u>**

The hot rod [

].

The quench height [

].

The question [ ] is discussed in the response to RAI-32 and the question [ ] is also discussed in the response to RAI-107 and RAI-108.

**RAI-32**

*ANP-10332P did* [

]. *Therefore, please address the following requests:*

a. *Page 6-37 of ANP-10332P states that* [

]

b. *From a simulation perspective,* [

]. *The basis for these predictions, as well as other similar examples in Tables 7-62 through 7-65, is not obvious, nor is it explained in ANP-10332P.*

i. *Please provide an explanation for the* [

].

ii. *Please clarify and provide justification for AREVA's position regarding* [

]

c. *The* [ ] *proposed in ANP-10332P for plant analysis* [

]. *In light of the discussion above, please clarify whether sensitivity studies have been performed to demonstrate that significant changes in the prediction of (1)* [ ] *and (2) the figures of merit from 10 CFR 50.46 for the full-size plant application would not occur if*

i. [ ]

ii. [ ]

d. *Please clarify whether AREVA has performed* [ ]

[

]

e. *Discuss assumptions for* [

]. *Have sensitivity studies been performed to show the effects of variations in these factors and their impact on whether* [
]?

f. *Upper plenum conditions* [

]

i. *Please discuss how inaccuracy in predicting* [
].

ii. *Please discuss how inaccuracy in predicting* [
].

iii. *Please discuss the basis for limiting* [

]. 

g. *Discuss the intent and significance of [*

].

i. *Which of the* [
]*?*

ii. Provide justification if [
].

iii. *ANP-10332P states that it is anticipated that only* [

]

h. *Please identify whether any of the demonstration cases* [

].

i. *Please confirm that the* [
].

**<u>Framatome Response 32a.:</u>**

This is addressed by the response to RAI-32h.

**Framatome Response 32b.:**

This is addressed by the response to RAI-32h.

**Framatome Response 32c.:**

This is addressed by the response to RAI-32h.

**Framatome Response 32d.:**

This is addressed by the response to RAI-32h.

**Framatome Response 32e.:**

This is addressed by the response to RAI-32h.

**Framatome Response 32f.:**

This is addressed by the response to RAI-32h.

**Framatome Response 32g.:**

This is addressed by the response to RAI-32h.

**Framatome Response 32h.:**

Sensitivity calculations were performed to [

].

Small and large break [

].

The phasic superficial velocities at the UTP, side-entry office (SEO) and inlet to the PCT node [

].

[

]

**Figure R32-1 Large Break Hot Channel Superficial Velocities at the UTP**

**Figure R32-2 Large Break Hot Channel Superficial Velocities at the SEO**

**Figure R32-3 Large Break Hot Channel Superficial Velocities at the PCT Node**

The phasic superficial velocities at the UTP, SEO and inlet to the PCT node [

].

[

]

**Figure R32-4 Small Break Hot Channel Superficial Velocities at the UTP**

Figure R32-5 Small Break Hot Channel Superficial Velocities at the SEO

Figure R32-6 Small Break Hot Channel Superficial Velocities at the PCT Node

Three sets of sensitivities were run [

].

**Table R32-1 Sensitivity 1 – [ ]**

[

]

The second sensitivity [

].

**Table R32-2 Sensitivity 2 – [ ]**

[ ]

A third sensitivity [ ].

**Table R32-3 Sensitivity 3 – [ ]**

[ ]

These sensitivity cases [ ].

Plotted results for the PCT, void fraction [ ] and collapsed liquid level [ ] are shown for large and small break cases and each of the three sensitivities in the following figures.

**Figure R32-7 Large Break PCTs for Sensitivity 1**

**Figure R32-8 Large Break Void Fractions for Sensitivity 1**

[ ]

**Figure R32-9 Large Break HC Liquid Level for Sensitivity 1**

[ ]

**Figure R32-10 Small Break PCTs for Sensitivity 1**

[ ]

**Figure R32-11 Small Break Void Fractions for Sensitivity 1**

[ ]

**Figure R32-12 Small Break HC Liquid Level for Sensitivity 1**

[ ]

**Figure R32-13 Large Break PCTs for Sensitivity 2**

[ ]

**Figure R32-14 Large Break Void Fractions for Sensitivity 2**

**Figure R32-15 Large Break HC Liquid Level for Sensitivity 2**

**Figure R32-16 Small Break PCTs for Sensitivity 2**

**Figure R32-17 Small Break Void Fractions for Sensitivity 2**

**Figure R32-18 Small Break HC Liquid Level for Sensitivity 2**

[ ]

**Figure R32-19 Large Break PCTs for Sensitivity 3**

[ ]

**Figure R32-20 Large Break Void Fractions for Sensitivity 3**

**Figure R32-21 Large Break HC Liquid Level for Sensitivity 3**

**Figure R32-22 Small Break PCTs for Sensitivity 3**

**Figure R32-23 Small Break Void Fractions for Sensitivity 3**

**Figure R32-24 Small Break HC Liquid Level for Sensitivity 3**

The phasic superficial velocities at the UTP, SEO and inlet to the PCT node [

].

[

]

**Figure R32-25 Large Break HC Superficial Velocities at UTP for Sensitivity 1**

**Figure R32-26 Large Break HC Superficial Velocities at SEO for Sensitivity 1**

**Figure R32-27 Large Break HC Superficial Velocities at PCT Node for Sensitivity 1**

**Figure R32-28 Small Break HC Superficial Velocities at UTP for Sensitivity 1**

**Figure R32-29 Small Break HC Superficial Velocities at SEO for Sensitivity 1**

[ ]

**Figure R32-30 Small Break HC Superficial Velocities at PCT Node for Sensitivity 1**

[ ]

**Figure R32-31 Large Break HC Superficial Velocities at UTP for Sensitivity 2**

**Figure R32-32 Large Break HC Superficial Velocities at SEO for Sensitivity 2**

**Figure R32-33 Large Break HC Superficial Velocities at PCT Node for Sensitivity 2**

[ ]

**Figure R32-34 Small Break HC Superficial Velocities at UTP for Sensitivity 2**

[ ]

**Figure R32-35 Small Break HC Superficial Velocities at SEO for Sensitivity 2**

[ ]

**Figure R32-36 Small Break HC Superficial Velocities at PCT Node for Sensitivity 2**

[ ]

**Figure R32-37 Large Break HC Superficial Velocities at UTP for Sensitivity 3**

[

]

**Figure R32-38 Large Break HC Superficial Velocities at SEO for Sensitivity 3**

[

]

**Figure R32-39 Large Break HC Superficial Velocities at PCT Node for Sensitivity 3**

[ ]

**Figure R32-40 Small Break HC Superficial Velocities at UTP for Sensitivity 3**

[ ]

**Figure R32-41 Small Break HC Superficial Velocities at SEO for Sensitivity 3**

[ ]

**Figure R32-42 Small Break HC Superficial Velocities at PCT Node for Sensitivity 3**

**Framatome Response 32i.:**

[ ].

## RAI-33

*Bypass leakage flowpaths are important in determining BWR LOCA behavior. Please provide the following information regarding bypass leakage paths:*

a. *Which specific bypass leakage paths (e.g., between bypass region, fuel bundle, lower plenum, guide tubes) are explicitly modeled in the AURORA-B LOCA EM?*

b. *What are the characteristics of these flowpaths? Which are the most significant (i.e., in terms of flow area or flow rate under nominal design conditions)? Please further clarify the method used to determine the characteristics for all leakage paths (e.g., measurements, calculations), especially for the fit-up gaps, which are more difficult to determine analytically in an accurate manner.*

c. *Clarify language on Page 6-37 of ANP-10332P. Reference is made to four leakage paths,* **[ ]***:*

> *There are four leakage paths for which reverse flow (also called backflow) is important in the LOCA evaluation. These leakage paths are included as junctions in the LOCA modeling of the reactor. These leakage paths are between the bypass and core regions, the bypass and lower plenum, and the control rod guide tubes and lower plenum.*

d. *Discuss whether any significant bypass leakage paths are neglected in the AURORA-B LOCA EM, and, as applicable, the resulting impacts on the output of the EM.*

e. *Please show the bypass leakage paths discussed above on an illustrative diagram (e.g., Figure 6-13 of Lahey and Moody, The Thermal-Hydraulics of a Boiling Water Nuclear Reactor, Second Edition).*

f. *Describe how hot wall effects are modeled, and provide a basis for the models used.*

**Framatome Response 33a.:**

The following figure shows the modeled leakage paths between the bypass, fuel bundle and lower plenum [

].

A fourth leakage path (not shown) models the flow from the guide tubes into the lower plenum [ ].

**Figure R33-1 Bundle and Bypass Leakage Paths**

**Framatome Response 33b.:**

Paths 2 and 3 described above in the response to RAI-33a are determined from [

].

The leakage flows [

].

**Framatome Response 33c.:**

Four leakage paths are modeled. [

].

**Framatome Response 33d.:**

[ ].

**Framatome Response 33e.:**

A diagram of the leakage paths is shown in the response to RAI-33a.

**Framatome Response 33f.:**

The hot wall effect [

].

The hot wall [

].

**RAI-34**

*[ ], could the reactor pressure be temporarily reduced below the containment pressure (e.g., due to the spraying of cold water in the upper plenum), [ ]? In addressing this question, please provide the following information:*

a. *Describe the modeling of the [ ].*

b. *If AREVA concludes that [ ].*

c. *If AREVA concludes that [ ].*

**<u>Framatome Response 34a.:</u>**

The S-RELAP5 model [ ].

**<u>Framatome Response 34b.:</u>**

The [ ] as demonstrated by the response to RAI-34c.

**Framatome Response 34c.:**

The following [

].

[ ]

**RAI-35**

*Section 6.3.7 of ANP-10332P provides nodalization diagrams* [

]. *If additional systems will be explicitly simulated in the AURORA-B EM, then please provide applicable n*odalization diagrams and justify that the credit taken for these systems is appropriate.

**Framatome Response 35:**

The feedwater and ECCS systems [

].

For ECCS line breaks, [

].

The HPCS and LPCS breaks [

].

Other line breaks [

].

**RAI-36**

*Heat structure modeling for the recirculation system [*

*] is accurate for the recirculation system and other systems such as the feedwater system.*

**Framatome Response 36:**

Heat structures are [

].

**RAI-37**

*Page 6-29 of ANP-10332P states that the vessel nodalization scheme for AURORA-B is similar to the 3-region TRAC model used in the U.S. NRC sponsored SSTF assessment of Reference 64 (J.A. Findlay, "BWR Refill-Reflood Program Task 4.4 – CCFL / Refill System Effects Tests (30° Sector), Evaluation of Parallel Channel Phenomena," NUREG/CR-2566, GEAP-22044, EPRI NP-2373, Nov. 1982.) However, the NRC staff could not find the cited TRAC model in Reference 64. Please clarify.*

**Framatome Response 37:**

The 3-region TRAC-BWR model used in the NRC sponsored SSTF assessment of Reference 64 was documented under Program Task 4.8. The reference is "BWR Refill-Reflood Program Task 4.8 – TRAC-BWR Model Qualification for BWR Safety Analysis Final Report, M. Alamgir, NUREG/CR-2571, GEAP-22049, EPRI NP-2377, R2, Oct. 1983."

**RAI-38**

*In the AURORA-B EM, AREVA has [*

**]**

**Framatome Response 38:**

The [

].

Even [ ], the EM model uses [

].

BWR/5-6 designs have significant core ECCS flow rates, [ ].

The response to RAI-29k provides [ ].

[ ]

**Figure R38-1 BWR/6 Large Break [ ] Flow Rate**

**RAI-39**

*Please clarify AREVA's modeling practices for the fuel bundle represented by the hot channel in Section 6.3.8 and Figure 6-10 of ANP-10332P.*

a. *In the* [

]?

b. *Please provide a more-detailed diagram for an* [

].

c. *If AREVA's modeling practices would allow the* [

].

**<u>Framatome Response 39a.:</u>**

The [ ] to model the fuel bundle –
[

].

**<u>Framatome Response 39b.:</u>**

The following figure shows a diagram of the [

].

**Figure R39-1 [ ] Rod Location**

[ ].

**<u>Framatome Response 39c.:</u>**

[ ].

**RAI-40**

*Please justify the alternative to the [*

*]. It is not clear to the NRC staff whether sufficient benchmarking and validation has been performed for this case. Please provide adequate justification that the alternative model has been conservatively compared to an adequate quantity of experimental data, or commit to providing such justification for plant-specific applications.*

**Framatome Response 40:**

The alternative approach [

].

Rather than model [

].

**RAI-41**

*Section I.C.1.d of Appendix K requires that the nodalization in the vicinity of and including the broken or split sections of pipe and the points of ECCS injection shall be chosen to permit a reliable analysis of the thermodynamic history in these regions during blowdown. Section 6.2.13 of ANP-10332P* [

] *address the specific requirement of I.C.1.d of Appendix K. Provide evidence demonstrating compliance of the EM with this Appendix K requirement.*

**Framatome Response 41:**

[ ] the nodalization near the break and ECCS injection locations provide a reliable analysis. The following table shows [

].

**Table R41-1 Break and ECCS Injection Nodalization [ ]**

[ ]

**RAI-42**

*Describe the process for determining* [

]

**Framatome Response 42:**

The break spectrum calculations [

].

Two cases are compared to demonstrate [

].

**Table R42-1 [ ] Sensitivity**

[ ]

**RAI-43**

*Discuss the process and criteria for the determination of* [

]

**Framatome Response 43:**

The [

]:

[

]

[

].

With respect to RODEX4, all thermal-mechanical exposure history effects [

].

In the course of [

].

**RAI-44**

*ANP-10332P states on Page 1-3 that the AURORA-B LOCA EM will use a point kinetics model with input or modeling parameters based on an appropriate core simulator code; for example, MICROBURN-B2.*

a. *How does AREVA determine whether a core simulator is appropriate for use with the AURORA-B LOCA EM, and that the point kinetics inputs will be conservative? Is prior NRC approval of the core simulator code required?*

b. *Please describe the specific inputs from MICROBURN-B2 to the AURORA-B LOCA EM or reference where they have been described.*

c. *ANP-10332P states that inputs from XCOBRA may be used for determining steady-state flow distributions, in lieu of MICROBURN-B2.* **[**

**]**. *In the case that XCOBRA is used, how are the point kinetics inputs to AURORA-B determined?*

**<u>Framatome Response 44a.:</u>**

MICROBURN-B2 and the underlying cross section generation code, CASMO-4, **[** **]** and XCOBRA **[** **]** are used as NRC approved core simulators (Reference 7, EMF-2158(P)(A) and Reference 23, XN-NF-80-19(P)(A)). Any future replacement for the current codes used in the AURORA-B LOCA EM would be subject to NRC approval.

Bounding neutronic parameters for the AURORA-B LOCA EM S-RELAP5 point kinetic model have been established that result in **[**

**]**.

**Framatome Response 44b.:**

The point kinetics inputs from MICROBURN-B2 and the underlying cross section generation code, CASMO-4, are shown in Figure 6-2 of the LTR and are listed as follows:

[ ]

The inputs are described in the context of the point kinetics model in Section 11.0 of the S-RELAP5 theory manual (Reference 6, FS1-0009406, Revision 2).

**Framatome Response 44c.:**

Neutronic models and reactivity feedback [

].

Regardless of whether XCOBRA or MICROBURN-B2 are used [

].

**RAI-45**

*It is noted in Section 6.2.3 of ANP-10332P that AREVA will use* [

]

**Framatome Response 45:**

The BWR/4 large break [

].

[

]

**Figure R45-1 Cladding Temperatures [ ]**

**RAI-46**

*Please describe the process of performing calculations [*

*].*

**Framatome Response 46:**

The break spectrum analysis [

].

The RODEX4 calculations use a [

].

Gadolinia rods [

].

**Figure R46-1 [ ] Gadolinia [ ] vs Exposure**

In the statistical methodology (BAW-10247PA) [

].

RODEX4 calculations [

].

**RAI-47**

*After a PIRT has been generated, the EM development and assessment process calls for a validation matrix that lists separate effects tests (SETs) and integral effect tests (IETs) for validating each [*

*]. The validation descriptions, while listing the phenomena that are considered by AREVA to be validated by each individual test/facility, do not provide any evidence or discussion of how the validation [*

*]. Therefore, additional information is needed to complete the validation description and conclusions for [*

*].*

**<u>Framatome Response 47:</u>**

The following table lists the high-ranked phenomena from Table 4-1 that are [

]. Medium-ranked phenomena are discussed in the response to RAI-8. The validation for each of these high-ranked phenomena is discussed below [

].

**Table R47-1 High Ranked Phenomena [ ]**

[

]

[ ]

**Figure R47-1 [ ] UP Temperatures [ ]**

[ ]

**RAI-48**

*A significant proportion of the tests and test facilities* [

]

**Framatome Response 48:**

[

].

The AURORA-B LOCA code, correlations and modeling options were applied in the
[ ].

**RAI-49**

*A number of the models incorporated into the AURORA-B LOCA EM are required or acceptable features, as defined in Appendix K.* [

]. *Appendix K states that, to the extent practicable, predictions of the EM, or portions thereof, shall be compared with applicable experimental information.*

a. *Please explain how the assessment and validation performed for the AURORA-B LOCA EM is compliant with Appendix K to 10 CFR Part 50, which requires (under Part I) a comparison with experimental data for certain phenomena and further stipulates (under Part II) that, to the extent practicable, predictions of the EM, or portions thereof, shall be compared with applicable experimental information.*

b. *In making valid comparisons against experimental data, consideration of experimental uncertainty and scaling may be important in assessing conclusions regarding the applicability of the tests and the level of agreement between the code and the data. In this regard, the brief summary discussion in Section 5.6 of TR is not sufficiently clear. Please explain in more detail how experimental uncertainty is handled* [ ] *and provide examples.*

**Framatome Response 49a.:**

The assessment and validation in Section 7 includes comparisons to experimental information for a wide variety of tests and phenomena as summarized in the assessment matrix in Table 5-1 and in compliance with Appendix K. The response to RAI-47 clarifies how phenomena [ ].

**Framatome Response 49b.:**

Section 7.9 clarifies: "The AURORA-B LOCA EM is based on Appendix K criteria; therefore, it is a conservative method and does not rely on uncertainty analysis." [

]

[

].

The [

] to satisfy the following requirements of Appendix K:

- I.A.1. *The Initial Stored Energy in the Fuel.* The steady-state temperature distribution and stored energy in the fuel before the hypothetical accident shall be calculated for the burn-up that yields the highest calculated cladding temperature (or, optionally, the highest calculated stored energy.)

- I.C.4. *Critical Heat Flux*. a. Correlations developed from appropriate steady-state and transient-state experimental data are acceptable for use in predicting the critical heat flux (CHF) during LOCA transients.

- I.C.5. Post-CHF Heat Transfer Correlations. a. Correlations of heat transfer from the fuel cladding to the surrounding fluid in the post-CHF regimes of transition and film boiling shall be compared to applicable steady-state and transient-state data using statistical correlation and uncertainty analyses. Such comparison shall demonstrate that the correlations predict values of heat transfer co-efficient equal to or less than the mean value of the applicable experimental heat transfer data throughout the range of parameters for which the correlations are to be used. The comparisons shall quantify the relation of the correlations to the statistical uncertainty of the applicable data.

**RAI-50**

*[ ] during the refill phase are important phenomena that [ ]. The introduction of cold liquid from the ECCS (particularly for BWRs where LPCI injects into the recirculation discharge line) into a [ ] Therefore, please either provide a specific comparison of the AURORA-B model's prediction of these phenomena in the [ ], or provide more detailed justification that the existing integral effects comparisons demonstrate an acceptably accurate prediction.*

**Framatome Response 50:**

Section 7.7.1.1 documents the results of the EM simulation for the SSTF BWR/4 LOCA test. The full scale, 30-degree sector test facility (SSTF) includes 58 individual fuel bundles, the surrounding peripheral and interstitial bypass region, upper plenum (UP) and lower plenum (LP), guide tubes, jet pump flow paths, downcomer, and ECCS injection systems.

SSTF Test EA3.1 Run 111 is the reference test for a BWR/4 LOCA and is used to assess the impact of the BWR/4 ECCS configuration on the refill-reflood responses. The test was performed with one LPCS and two LPCI systems. [

].

**RAI-51**

*The NRC staff's audit review of the* [

], *as well as (2) AREVA's rationale for implementing this change, are not clear. Please provide this additional information.*

**<u>Framatome Response 51:</u>**

The [

]. These conditions apply for [
], as seen in the heat transfer coefficient comparisons. [

].

**RAI-52**

*Discuss the practice of* [

], *and further clarify the impact that this practice has on gauging the overall assessment of EM accuracy.*

**Framatome Response 52:**

Choking was validated by Marviken separate effects tests. [

].

**RAI-53**

*Please address the AURORA-B [ ] prediction of FIST Test 6SB2C in Section 7.7.3.2 of ANP-10332P, and [ ]. The NRC staff made several observations concerning the AURORA-B [ ] prediction of this test:*

- *The predicted heatup rate appeared to be approximately [ ].*
- *The predicted heatup time appeared to be approximately [ ].*
- *The predicted bundle mass is [ ].*
- *The experimental data showed [ ]*

*Although Section 7.9.2.2 of ANP-10332P contains an [ ]*

**Framatome Response 53:**

FIST Test 6SB2C cladding temperatures [

]

TRACE cladding surface temperatures for FIST 6SB2C are [

]

[

]

**Figure R53-1 TRACE Rod Temperatures at 77-in for FIST 6SB2C**

[ ]

**Figure R53-2 TRACE Rod Temperatures at 77-in for FIST 6SB2C**

The following figure shows the nominal prediction from TRACG [

].

[

]

**Figure R53-3 TRACG Rod Temperatures for FIST 6SB2C**

The figure below shows TRAC-BD1 [

].

[ ]

**Figure R53-4 TRAC-BD1 Rod Temperatures at 117-in for FIST 6SB2C**

The following figure from a GE pre-test TRAC prediction [

].

[

]

**Figure R53-5 GE TRAC Rod Temperatures for FIST 6SB2C**

FIST 6SB2C is [ ] TRAC-BF1 [ ] as shown in the following figure:

[ ]

**Figure R53-6 TRAC-BF1 Rod Temperatures for FIST 6SB2C**

The following figure shows the PCT results [

].

[

]

**Figure R53-7 [ ] PCTs for FIST 6SB2C**

**RAI-54**

*Results for split breaks have been calculated in ANP-10332P up to a size [*

*]. Please explain the differences in behavior and clarify that the modeling of critical flow in each case is being performed in an acceptable manner.*

**Framatome Response 54:**

[ ] are used to model the containment and [

]. Break modeling is discussed in Sections 6.2.13 and 6.4.6. Break nodalization sensitivities are discussed in the response to RAI-41.

Split and DEG breaks are [

].

The difference between split and guillotine breaks [

].

Figure R54-1 below shows [

]. A break spectrum is performed to find the limiting break size, type and conditions.

[ ]

**Figure R54-1 Break Flow Rates for DEG and Split Breaks [ ]**

**RAI-55**

*Please clarify why* [

]

**Framatome Response 55:**

[

].

**RAI-56**

*Demonstration cases for the BWR/6 ECCS configuration with a [*

*]*

**Framatome Response 56:**

Demonstration cases for the BWR/6 with a [

]:

**Table R56-1 PCT Summary – BWR/6 SF-LPCI [ ]**

[

]

**Table R56-2 PCT Summary – BWR/6 SF-LPCS [ ]**

[ ]

**Table R56-3 PCT Summary – BWR/6 SF-HPCS [ ]**

[ ]

**RAI-57**

*On Page 7-340, ANP-10332P states that the* [

]

**Framatome Response 57:**

Figures 7-392 and 7-393 show the [

].

**RAI-58**

*For limiting small-break and large-break demonstration cases, please provide a calculation to illustrate the impact of the conservatism imposed by the Appendix K EM by* [

]

**Framatome Response 58:**

The [ ] demonstration cases from the LTR are repeated using S-RELAP5 [

]:

[ ]

PCT results are compared in the following table and plots. [

].

**Table R58-1 Appendix K Conservatism**

[ ]

**Figure R58-1 Appendix K Impact for LBLOCA Example**

**Figure R58-2 Appendix K Impact for SBLOCA Example**

**RAI-59**

*Please explain the* **[** **]** *behavior observed during the audit in the* **[**

**]**

**<u>Framatome Response 59:</u>**

The **[** **]** behavior is explained by **[**

**]**.

The following table shows break spectrum results **[**

**]**.

**Table R59-1 [ ] Break Spectrum for BWR/6 [ ]**

**RAI-60**

*The NRC staff audited S-RELAP5 output for the case* [

]

**Framatome Response 60:**

The cladding temperature at [

]

Sensitivity calculations [

].

* [

]

**Figure R60-1 Cladding Temperatures [ ]**

**Figure R60-2 Cladding Temperatures [ ]**

**RAI-61**

*Table 7-54 of ANP-10332P reports a value of* [

]

a. *Please clarify whether the results* [ ].

b. *Please describe how AREVA determines* [

]

**Framatome Response 61a.:**

The values in Table 7-54 [

].

**Framatome Response 61b.:**

The PCT and MLO [

].

**RAI-62**

*Please describe how detailed component* [

]

**Framatome Response 62:**

[

].

**RAI-63**

*The AURORA-B code system is used in a [ ]. When the computer codes constituting AURORA-B (i.e., S-RELAP5, RODEX4, MB2-K) are further taken into account, the [ ], it is possible that changes to AURORA-B or its subsidiary codes in support of [ ].*

a. *How does AREVA's quality assurance program for AURORA-B and its constituent codes provide reasonable assurance that adverse impacts from changes in [ ]*

b. *Have criteria been established to confirm that, when there is no impact expected from a change on [ ]?*

c. *Describe how quality assurance is performed on the [ ] calculations to ensure that errors are not introduced, and that if errors are introduced, they can be identified and corrected.*

d. *What is the full suite of validation problems that must be reanalyzed when updates are made to the AURORA-B code system? Does the validation suite contain suitable analyses for [ ]?*

**Framatome Response 63a.:**

The S-RELAP5 version [ ].

Framatome [ ] under their quality assurance program. [

].

[

]

**Figure R63-1 [ ] GE Level Swell**

[ ]

**Figure R63-2 [ ] FLECHT-SEASET**

**Framatome Response 63b.:**

The preparer and reviewer use [ ] as discussed in the responses to RAI-63a and RAI-63d.

**Framatome Response 63c.:**

The [ ] is reviewed by an independent analyst. [ ].

**Framatome Response 63d.:**

The code release [

].

**RAI-64**

*According to Chapter 15.0.2 of the SRP, required input settings should be hardwired into the input processor so that the code stops with an error message when the required input is not provided or the input is not within an acceptable range, or administrative controls should be established to accomplish the same purpose. Further guidance is provided therein that all models should be assessed over the entire range of conditions encountered in the event scenario.*

a. *Provide an overview of how input checking is performed for the AURORA-B LOCA EM. If required input is missing or in an unacceptable range, is the code automatically halted, or have administrative controls been established which serve the same purpose?*

b. *If, during code execution, parameters passed to a given model or correlation are outside of its qualified and validated range of applicability, are error messages generated by the code? Is code execution halted, or does the code continue to execute, producing potentially non-physical or otherwise unacceptable results?*

**Framatome Response 64a.:**

The code checks [

].

**Framatome Response 64b.:**

[

].

Appendix K I.C.4 states: "Critical Heat Flux. a. Correlations developed from appropriate steady-state and transient-state experimental data are acceptable for use in predicting the critical heat flux (CHF) during LOCA transients. The computer programs in which these correlations are used shall contain suitable checks to assure that the physical parameters are within the range of parameters specified for use of the correlations by their respective authors."

[ ]

**RAI-65**

*The use of revised analysis methods in lieu of those described in an approved TR is viewed by the NRC staff as a change to an EM that may, in general, require additional NRC staff review to ensure acceptability. For example, revised analysis methods may affect validation and assessment comparisons, code stability, and the results of demonstration analyses. In its present review of ANP-10332P, the NRC staff does not intend to authorize such changes absent future specific reviews. Therefore, please provide adequate justification for any conditions under which AREVA believes it has the authority to revise the AURORA-B LOCA EM, as described in ANP-10332P [ ], and continue to apply the revised EM as a generically approved method.*

**Framatome Response 65:**

Section 12.4 discusses code modifications and states: "modifications will not be made unless they are reported to the NRC." [

].

Framatome makes all error corrections [

].

## RAI-66

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

## Framatome Response 66:

The trend is referring to the [ ]. Also, as discussed on Page 7-31, [ ].

**RAI-67**

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

**Framatome Response 67:**

It is based on the estimated location of dryout from the void fraction data in Figure 7-23 when liquid is no longer available to keep the vapor at the saturation temperature. The criteria, start of the superheated region and uncertainty in measured flow for Test K are discussed on Page 7-34.

**RAI-68**

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

**Framatome Response 68:**

The natural circulation flowpath for TLTA System Configuration 5A (Figure 7-33) is as follows: **[**

**]**.

**RAI-69**

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

**<u>Framatome Response 69:</u>**

[

].

The test did not [

].

**RAI-70**

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

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

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

**Framatome Response 70a.:**

The predicted timescale was [

].

**Framatome Response 70b.:**

The original calculation used [

].

[

]

**Figure R70-1 Void Fractions at DP Cell 31 (THL) for TLTA Test 6441-7**

[

]

**Figure R70-2 Downcomer Void Fractions for TLTA Test 6441-7**

[ ]

**Figure R70-3 Bypass Void Fractions for TLTA Test 6441-7**

[ ]

**Figure R70-4 Bundle Void Fractions at DP Cell 27 for TLTA Test 6441-7**

[ ]

**Figure R70-5 Bundle Void Fractions at DP Cell 28 for TLTA Test 6441-7**

[ ]

**Figure R70-6 Bundle Void Fractions at DP Cell 29 for TLTA Test 6441-7**

[ ]

**Figure R70-7 Bundle Void Fractions at DP Cell 30 for TLTA Test 6441-7**

[ ]

**Figure R70-8 Cladding Temperatures at 107" Elevation for TLTA Test 6441-7**

**Figure R70-9 Cladding Temperatures at 115" Elevation for TLTA Test 6441-7**

**Figure R70-10 Cladding Temperatures at 120" Elevation for TLTA Test 6441-7**

[ ]

**Figure R70-11 Cladding Temperatures at 130" Elevation for TLTA Test 6441-7**

[ ]

**Figure R70-12 Cladding Temperatures at 135" Elevation for TLTA Test 6441-7**

**Figure R70-13 Cladding Temperatures at 140" Elevation for TLTA Test 6441-7**

**RAI-71**

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

**Framatome Response 71:**

A nodal diagram of the S-RELAP5 model for FCTF is shown in the following figure.

**Figure R71-1 S-RELAP5 Nodal Diagram for FCTF**

**RAI-72**

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

**<u>Framatome Response 72:</u>**

Heat transfer is primarily in [

].

[ ]

**Figure R72-1 Heat Transfer Mode at 75-in for FCTF Test 79**

**RAI-73**

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

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

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

**Framatome Response 73a.:**

[ ].

**Framatome Response 73b.:**

The two figures below show heat transfer modes predicted for the cases of Figure 7-98 for THTF and Figure 7-119 for FLECHT Skewed. [ ].

S-RELAP5 allows any heat transfer mode [

].

[

]

**Figure R73-1 Heat Transfer Mode for THTF Test 3.09 at Level G**

[ ]

**Figure R73-2 Heat Transfer Mode for FLECHT Skewed Test 13609 at 84-in**

**RAI-74**

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

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

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

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

**<u>Framatome Response 74a.:</u>**

The S-RELAP5 calculated PCTs for the non-skewed tests are **[**

**]**

[

].

**Framatome Response 74b.:**

The [ ] temperatures from the FLECHT Skewed tests [

].

**Framatome Response 74c.:**

PCT impact due to reflood rate is shown by the maximum clad temperature (MCT) profiles from Tests 31805, 31504, 31203, 31302 and 31701 in Figures 7-134, 7-132, 7-130, 7-131 and 7-133, respectively. The reflood rates from these tests are 0.81, 0.97, 1.51, 3.01, and 6.10 in/s, respectively. [

].

PCT impact due to system pressure is determined from the MCT profiles from Tests 34209, 31504 and 32013 in Figures 7-136, 7-132 and 7-135, respectively. The system pressures from these tests are 20, 40 and 60 psia, respectively. [

].

PCT impact due to inlet subcooling is determined from the MCT profiles from FLECHT Skewed Tests 13609 and 13914 in Figures 7-137 and 7-138, respectively. The inlet subcooling used in these tests are 144 and 8 °F, respectively. [

].

S-RELAP5 [

].

**RAI-75**

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

**Framatome Response 75:**

All these phenomena **[** **]**. The response to RAI-47 clarifies how phenomena **[** **]**.

**RAI-76**

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

**<u>Framatome Response 76:</u>**

Measurement locations are at [ ] in the first nodal diagram shown below for Test 10 Run 080 and plotted in Figure 7-169. It is taken [ ] in the second nodal diagram for Test 10 Run 081 for Figure 7-173.

[ ]

**Figure R76-1 UPTF Nodalization for Test 10 Run 080**

[

]

**Figure R76-2 UPTF Nodalization for Test 10 Run 081**

**RAI-77**

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

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

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

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

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

**<u>Framatome Response 77:</u>**

UPTF Tests 6 and 7 show [ ]. UPTF Test 10 and 12 verifies [ ].

**RAI-78**

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

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

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

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

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

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

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

**Framatome Response 78a.:**

The flow area [

].

**Framatome Response 78b.:**

Significant [

].

**Framatome Response 78c.:**

[ ] measure the differential pressures across the SEOs of the bundles [

].

**Framatome Response 78d.:**

Figure R78-1 below shows the comparisons of the measured and predicted DP1 and DP2 differential pressure measurements in [ ]. Pressure transducer DP2 measures the pressure difference between a location near the side entry orifice and the lower region of the fuel bundle (22.3 inches). The initial test measurement is [ ].

The initial values of other pressure cells in the same configuration are [

].

If DP2 was [

].

This information leads Framatome to conclude [

].

[ ]

**Figure R78-1 Pressure Differentials for Bundle B54**

**<u>Framatome Response 78e.:</u>**

Condensate and cold LPCI liquid is [ ].

The impact [ ].

**<u>Framatome Response 78f.:</u>**

The phenomena [ ].

**RAI-79**

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

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

]*?*

b. *The transition to* [

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

].

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

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

**Framatome Response 79a.:**

The water level in [

].

**Framatome Response 79b.:**

When the spray spargers [

].

The predicted mass flows [

].

**Framatome Response 79c.:**

Higher liquid subcooling in the upper plenum (UP) leads to [

].

**Framatome Response 79d.:**

Time zero in the simulation matches [ ].

**RAI-80**

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

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

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

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

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

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

**Framatome Response 80a.:**

The system pressure decreases and flashing occurs in the lower plenum as coolant is discharged through the break. Early in the event, [

].

The TLTA prediction [

].

This is [

].

**Framatome Response 80b.:**

The two-phase and temperature distribution in the system [

].

**Framatome Response 80c.:**

This is caused by the [
]. However, Figures 7-267 to 7-277 show the predicted heater wall temperatures are [

].

**Framatome Response 80d.:**

As shown in Figures 7-267 through 7-274, [

].

**Framatome Response 80e.:**

The phenomena are listed because [

]

**RAI-81**

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

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

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

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

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

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

**<u>Framatome Response 81a.:</u>**

Page 7-256 references a good comparison of break flow. The measured break flow [ ].

## Framatome Response 81b.:

As the upper plenum water starts flowing downward [

].

## Framatome Response 81c.:

Measured and predicted event times for TLTA Test 6432-1 are shown in the following table. The impact of the [

].

**Table R81-1 Major Event Timings for TLTA Test 6432-1**

[

]

**Framatome Response 81d.:**

The measured non-zero LPCI flow from [

].

**Framatome Response 81e.:**

The [ ] upper plenum mass accumulation [

].

The general behavior of the predicted upper plenum mass is [

].

**RAI-82**

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

**Framatome Response 82:**

The initial bundle power, steam dome pressure, water level, recirculation line flow rates, jet pump flow rates and core flow were [

].

Key initial conditions for each test are shown in Table 7-21 for Test 6DBA1, Table 7-23 for 6SB2C, Table 7-25 for 6LB1 and Table 7-27 for 4DBA1.

**RAI-83**

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

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

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

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

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

**Framatome Response 83a.:**

Yes.

**Framatome Response 83b.:**

The narrow downcomer in FIST is [ ].

**Framatome Response 83c.:**

The ADS orifice size used for large break test 6DBA1 [ ].

Figures 7-331 (BWR/6 SBLOCA), 7-370 (BWR/6 LPCI line break), and 7-421 (BWR/4 LBLOCA) show [

].

**Framatome Response 83d.:**

The prediction of the upper plenum (UP) inventory shown in Figure 7-312 [

].

**RAI-84**

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

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

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

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

**<u>Framatome Response 84a.:</u>**

The reference for the [ ].

**<u>Framatome Response 84b.:</u>**

The [ ] on calculated PCTs as shown in Figures 7-351 to 7-353. Figure 7-335 shows the predicted [ ].

The PCTs become [

].

Related discussion is provided in the response to RAI-53.

**<u>Framatome Response 84c.:</u>**

FIST Test 6SB2C was [
]. Figure R84-1 confirms the [
]. The original ADS flow rate (black line) is also shown.

Steam dome pressures and break flow rates of the two simulations are compared in Figure R84-2 and Figure R84-3, respectively. Steam dome pressure [

].

Figure R84-4 compares the predicted PCTs and measured highest cladding temperature at the mid-point. The peak cladding temperature (PCT) is [

].

In summary, FIST Test 6SB2C was [

].

**Figure R84-1 ADS Flow Rates – FIST Test 6SB2C**

**Figure R84-2 Steam Dome Pressures – FIST Test 6SB2C**

[ ]

**Figure R84-3 Break Flow Rates – FIST Test 6SB2C**

[ ]

**Figure R84-4 Peak Cladding Temperatures – FIST Test 6SB2C**

[ ]

**Figure R84-5 Void Fractions in PCT Nodes – FIST Test 6SB2C**

[ ]

**Figure R84-6 LPCS Flow Rates – FIST Test 6SB2C**

[ ]

**Figure R84-7 Mass Flow Rates from UP to Bundle – FIST Test 6SB2C**

**RAI-85**

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

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

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

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

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

**<u>Framatome Response 85a.:</u>**

The ADS delay is **[ ]**.

**<u>Framatome Response 85b.:</u>**

The test values for jet pump (JP) discharge uncovery and recovery **[ ]**.

The measured timing of L1 is [

].

**Framatome Response 85c.:**

Void fractions were measured at three points, 37, 57 and 117-in, [

].

**Framatome Response 85d.:**

The three void fraction measurements are being compared to the integrated mass. The early difference in bypass mass is [

] than the calculated value consistent with the void fraction measurements at 37, 71 and 117-in.

**RAI-86**

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

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

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

c. *As reflooding occurs due to upflow from the bottom of the rod bundle, lower plenum conditions are important. S-RELAP5 predicts earlier fill-up of the lower plenum than in the test (e.g., Figure 7-398 shows void fraction at the top of lower plenum and Figure 7-405 shows the liquid mass in lower plenum). S-RELAP5 also predicts more liquid in the bottom of the rod bundle* **[ ]** *(Figure 7-399). Please explain the phenomena that lead to the overprediction of liquid in the lower plenum and bottom of rod bundle, and explain the impact of the S-RELAP5 overprediction on the conservativism of calculated peak cladding temperatures and other figures of merit.*

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

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

**Framatome Response 86a.:**

The offset between the measured and predicted mass in Figure 7-405 is [

].

**Framatome Response 86b.:**

ECCS is initiated at 30 seconds [

] predictions of cladding temperatures in Figures 7-414 to 7-416. The L1 timing is also discussed in the response to RAI-84 and RAI-85.

**Framatome Response 86c.:**

Figure 7-398 shows the predicted lower plenum void fraction [

].

Even with the [

] at upper elevations as shown in Figures 7-411 and 7-412. This leads to [

] shown in Figures 7-414 to 7-416. [

].

**Framatome Response 86d.:**

The calculation predicts [ ] at those elevations as shown in Figure 7-409 and 7-411 leading to [ ].

**Framatome Response 86e.:**

The calculated and measured [ ].

**RAI-87**

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

**Framatome Response 87:**

Delays for [

].

**RAI-88**

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

**Framatome Response 88:**

The discharge pipe area in Table 7-47 [

].

**RAI-89**

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

**Framatome Response 89:**

The SRVs are [

].

**RAI-90**

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

**<u>Framatome Response 90:</u>**

The Appendix K **[** **]** for the two small break cases in Section 7.9.2. **[** **]**.

The demonstration problems applied all Appendix K options, as required. The response to RAI-58 shows **[** **]**.

**RAI-91**

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

**Framatome Response 91:**

For a component, the **[**

**]**.

**RAI-92**

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

**<u>Framatome Response 92:</u>**

The primary cause of the [ ] for the case in Section 7.9.2.1 and Figure 7-531 for this single bundle assessment. [ ]. This is confirmed by following figure that compares the upper tie plate liquid superficial velocities [ ] during the period for the two cases.

[ ]

**Figure R92-1 Upper Tie Plate Superficial Liquid Velocity**

**RAI-93**

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

**<u>Framatome Response 93:</u>**

A [ ] FIST Test 6SB2C with Appendix K changes in Section 7.9.2.2 as shown in the following figure.

[ ]

**Figure R93-1 Bundle Inlet Flow Rate for FIST 6SB2C with Appendix K Options**

**RAI-94**

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

**<u>Framatome Response 94:</u>**

The [ ] in the FIST 6SB2C case with Appendix K assumptions in Section 7.9.2.2. This single bundle test [ ] was requested by the NRC staff and is discussed in the response to RAI-53.

**RAI-95**

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

**<u>Framatome Response 95:</u>**

The **[** **]** impact on PCT followed by the **[** **]** and then the **[** **]**.

**RAI-96**

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

**Framatome Response 96:**

Figure 7-181 shows **[**

**]**.

**RAI-97**

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

**<u>Framatome Response 97:</u>**

The [ ] shown in Figure 7-184 and 7-185 are computed values based on the [ ].

**RAI-98**

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

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

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

**Framatome Response 98a.:**

The boundary conditions [

].

**Framatome Response 98b.:**

Reference to the figure and section [ ]."

**RAI-99**

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

**Framatome Response 99:**

The impact of [ ] carryunder only affects the [

]

**RAI-100**

*For the CCFL Mini Loop Test (Section 7.6.5):*

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

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

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

**Framatome Response 100a.:**

These variables are from the software used [

].

**Framatome Response 100b.:**

The mini-loop [

].

**Framatome Response 100c.:**

[ ] Kutateladze correlation parameters [

].

The SEO uses [

].

**RAI-101**

*Section 6.4.2 of ANP-10332P cites its Reference 15 (RODEX2 ECCS Comparisons for a BWR dated September 6, 1983) as establishing the basis for the selection of the limiting power history in making a conservative determination of fuel stored heat. However, the basis supporting application of this methodology with the AURORA-B LOCA EM is unclear, particularly in light of the facts that (1) Reference 15 predates the recent reappraisal of the impact of thermal conductivity degradation, (2) the RODEX2 code used in Reference 15 has long been supplanted by enhanced analytical methods, such as the RODEX4 code used in the AURORA-B LOCA EM, (3) core design and operating cycle strategies have significantly changed across the industry since 1983, and (4) fuel designs have also evolved significantly since 1983 (e.g., incorporation of part-length rods, water channels, and burnable absorbers). Hence, it is not clear that any conclusions regarding the conservatism of power histories drawn from Reference 15 would be relevant to future application of the AURORA-B LOCA methodology. Therefore, in light of the points raised by the NRC staff, please either (1) justify the continued applicability of the Reference 15 methodology for determining a limiting power history for the computation of fuel stored heat or (2) provide a revised determination of the limiting power history along with justification for its conservatism.*

**Framatome Response 101:**

The power history calculations are [ ] as discussed in the responses to RAI-46, RAI-116 and RAI-117. The power history [ ]

The reference [ ].

**RAI-102**

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

**<u>Framatome Response 102:</u>**

The steady-state **[** **]** the S-RELAP5 calculation.

**RAI-103**

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

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

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

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

**Framatome Response 103a.:**

The two plots below compare the measured with the calculated void fraction distribution for the GE Level Swell Test 1004-3 at 140 s and 180 s [ ]. The measured pressure was approximately [ ].

**Figure R103-1 Void Fraction for GE 1ft 1004-3 Test at 140 seconds**

**Figure R103-2 Void Fraction for GE 1ft 1004-3 Test at 180 seconds**

**Framatome Response 103b.:**

The pressure range for the Christensen tests is 400-1000 psia. [ ].

**Framatome Response 103c.:**

Those phenomena occur during the tests. FLECHT-SEASET [ ].

**RAI-104**

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

**<u>Framatome Response 104:</u>**

The following LTR demonstration cases were examined to determine reflood rates and powers for comparison to the THTF tests:

[ ]

Reflood rates ranged from [ ]. Peak node linear heat rates ranged from [ ].

**RAI-105**

*The pressure range for the THTF tests in Section 7.3.11 of ANP-10332P used to derive the [ ] is [ ] psia. Please clarify whether [ ] has been validated at pressures less than [ ] psia and justify why [ ] should be applied at pressures below this range. In so doing, please address in particular the following points:*

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

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

**Framatome Response 105a.:**

The lower pressure range was validated by [ ].

Heat transfer coefficients (HTC) were calculated [ ] for test conditions in Columbia and THTF [ ]. The following figure compares the calculated and measured HTCs for the two tests. [ ] the THTF data as shown in Figures 7-66 and 7-67.

Values appear [ ].

[ ]

**Figure R105-1 THTF and Columbia Test Heat Transfer Predictions**

**<u>Framatome Response 105b.:</u>**

The [ ] used in the FLECHT validation assessments as noted in the response to RAI-105a.

**RAI-106**

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

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

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

**Framatome Response 106a.:**

The prediction [

].

In the prediction, [

].

Quenching [ ]. Figures 7-275, 7-274, 7-273, and 7-272 show that quenching starts [

].

Figure R106-2 shows the predicted lower plenum mass. [

].

The restriction of water [

].

[ ]

**Figure R106-1 Wall Temperatures at Lower Elevations – TLTA Test 6425-2**

Figure R106-2 Lower Plenum Fluid Mass History – TLTA Test 6425-2

**Framatome Response 106b.:**

The FIST and TLTA facilities have [

].

These differences [ ] LOCA transient comparisons between FIST and TLTA. Two sensitivity cases were run [

].

The following figure shows that applying the [

].

[

]

**Figure R106-3 Effect of [ ] Liquid Volume on TLTA 6425-2**

**RAI-107**

*In RAI 61, the NRC staff requested that AREVA address the observation that, in one of the audited demonstration cases, [ ] that was reported in ANP-10332P as the PCT for that case. Further review by the NRC staff regarding the three audited demonstration cases has resulted in related observations that should likewise be addressed by AREVA:*

a. *For the predicted results of the BWR/4 large-break case (i.e., 1.0 double-ended guillotine break on the pump suction line with the "LOCA" single-failure), the [ ] of the core exhibits a PCT and local oxidation in [ ]. The NRC staff found this result unexpected, inasmuch as the models used by AREVA for the [ ] have been described in ANP-10332P as conservative. In light of the discussion above, please explain why the cladding temperature and local oxidation for the [ ], and further justify that the modeling* of the [ ] in the AURORA-B LOCA EM are conservative.

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

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

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

**<u>Framatome Response 107a.:</u>**

The PCT on the [ ].

The power in the hot rod is [ ].

**Table R107-1 [ ] Sensitivity**

[ ]

Only the [

] because it includes all the Appendix K requirements [

] as demonstrated in the response to RAI-58 and discussed in the response to RAI-107d.

**Framatome Response 107b.:**

The [

].

The [ ] are only used to provide a conservative [

].

This is demonstrated by sensitivity calculations summarized in the following table where the [

].

**Table R107-2 [ ] Model Sensitivities**

[

]

The hot rod is [

] as discussed in the response to RAI-40. In addition, the audited cases have [

] as shown in Table R107-2 above.

[ ] peak cladding temperature and local oxidation. [

].

**Framatome Response 107c.:**

The sensitivity calculation in Section 7.9.5 [

].

**Framatome Response 107d.:**

[ ] for reporting peak cladding temperature and local oxidation. The [

]

[

].

**RAI-108**

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

**Framatome Response 108:**

Items (1) to (3) are addressed in the response to RAI-107 [ ]. The response to RAI-107b [ ].

The EM approach is [ ] for the following reasons:

[ ]

- The EM model is [

  ], which are confirmed by testing:

[

]

- The EM model [

  ], which occurs in testing and [

  ].

[

]

**RAI-109**

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

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

b. *It is not clear to the NRC staff that the models described in ANP-10332P for fuel rod swelling, rupture, and blockage are the same as those previously approved in XN-NF-82-07(P)(A), Revision 1. Please provide sufficient explanation of what parts of the modeling in ANP-10332P are the same as those used in XN-NF-82-07(P)(A), Revision 1, and which parts of the model (if any) are different from that previously approved and used in EMF-2361(P)(A).*

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

**<u>Framatome Response 109a.:</u>**

The current BWR cladding material [

].

The current NUREG-0630 model approved for Framatome fuel is applied to current Framatome BWR fuel.

**Framatome Response 109b.:**

The swelling and rupture model for Framatome's zircaloy cladding is given in
[

] for the swelling and rupture model discussion.

The discussion begins with the formulation of the hoop stress. [

].

The dimensionless cladding heatup rate ($H_c$) is [

].

Therefore, the S-RELAP5 model is consistent with XN-NF-82-07(P)(A), Revision 1 (Reference 25) and EMF-2361(P)(A).

**Framatome Response 109c.:**

[

].

**RAI-110**

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

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

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

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

**Framatome Response 110a.:**

The flow blockage **[**

**]**.

**Framatome Response 110b.:**

[ ] audited by the NRC staff
[

].

**Framatome Response 110c.:**

The flow blockage model was [

].

The calculated rupture temperature, blockage and heat-up rate [

].

Appendix K (I.C.7.a and I.D.5.b) states the flow blockage model is only required for PWRs and Section 6.4.5 cites References 24, 30 and 31 to conclude the impact of flow blockage is not significant for BWRs. [

].

**RAI-111**

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

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

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

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

**Framatome Response 111a.:**

The impact of the [ ] for large and small break events is discussed in the response to RAI-32h. The [

]

[

].

The normal [

].

**Framatome Response 111b.:**

The [ ] in the FCTF assessments. The actual calculated [

] as shown and discussed in the response to RAI-39b.

**Framatome Response 111c.:**

[ ] limiting once an issue with the [

]. Both cases were executed with [

] used in the response to RAI-15c. Results in the following table show the [

].

**Table R111-1 BWR/4 SF-LOCA PCTs [ ]**

[

]

**RAI-112**

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

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

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

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

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

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

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

**Framatome Response 112a.:**

Time step sensitivity results are discussed in the response to RAI-126d.

**Framatome Response 112b.:**

The axial noding sensitivity for the large break case from Figure 7-542 was [ ]. Results are [ ] axial fluid nodes in the core.

[ ]

**Figure R112-1 Core Node Sensitivity for Large Break Result**

**Framatome Response 112c.:**

The radial power [ ] for the large break case from Figure 7-545 [ ]. Results are [ ].

[ ]

**Figure R112-2 Uniform vs Non-Uniform Radial Power for Large Break**

**Framatome Response 112d.:**

The [ ] after eliminating [ ] time steps. The results for the [ ] as discussed in the response to RAI-111c.

**Framatome Response 112e.:**

The validation analysis cases used [ ] nodes consistent with the nominal value.

**Framatome Response 112f.:**

The sensitivity studies are [

].

**RAI-113**

*Please address the treatment of mixed core configurations.*

**<u>Framatome Response 113:</u>**

A LOCA analysis for a [

].

**RAI-114**

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

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

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

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

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

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

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

**Framatome Response 114a.:**

The rupture strain [

].”

[

]

**Framatome Response 114b.:**

This expression was [

].

**Framatome Response 114c.:**

The model was [

].

**Framatome Response 114d.:**

The S-RELAP5 theory manual was updated in [ ]. Excerpts from Section 7.4.10 follow with highlighted changes.

[

]

[

]

**Framatome Response 114e.:**

Only the BWR/4 reduced ECCS demonstration case in Section 7.7.5 [

].

The reduced ECCS case [

]. Results are provided in the response to RAI-115. [

].

**Framatome Response 114f.:**

The rupture, swelling and fuel relocation models were [

].

**RAI-115**

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

**Framatome Response 115:**

The BWR/4 reduced ECCS demonstration case from Section 7.7.5 was [ ], add plot parameters ECET and FGPRES [ ]. The requested ECBURST plot parameter is [ ]. The additional demonstration case was provided to the NRC staff for audit review.

PCT, rupture and oxidation results are compared in the following table. [ ].

**Table R115-1 BWR/4 Reduced ECCS Additional Case Results**

[ ]

**RAI-116**

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

**Framatome Response 116:**

The AURORA-B LOCA evaluation model consists of a multi-physics computational framework (code system) which is used to perform the LOCA analysis. The analyst performs the following steps, which are briefly listed and further explained below:

## RAI-117

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

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

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

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

**<u>Framatome Response 117a.:</u>**

The limiting [ ] then used in the exposure study [ ]. Further details are discussed in the response to RAI-46.

**<u>Framatome Response 117b.:</u>**

As discussed in the response to RAI-42, [ ] for the exposure study [

].

**Framatome Response 117c.:**

[

]. The hot channel [

].

**RAI-118**

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

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

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

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

**Framatome Response 118a.:**

Figure 7-72 compares the average rod model to an average powered rod in the all-rod model and was used to [ ] from hot rod comparisons as shown in Figure 7-73 where the temperature of hot rod in the all-rod model is plotted [ ].

**Framatome Response 118b.:**

The [ ] varied by test. However, the test [ ] on the hot rod as shown in Figure 7-73.

**Framatome Response 118c.:**

The [ ] was validated by comparison of the S-RELAP5 predicted [ ].

[ ]

**Figure R118-1 S-RELAP5 Hot Rod Temperatures [ ] for FCTF**

**RAI-119**

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

**Framatome Response 119:**

Reference 84 was provided to the NRC staff as requested.

**RAI-120**

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

**Framatome Response 120:**

The Marviken tests are used to assess the critical flow performance of S-RELAP5. Tables 7-13 and 7-14 show statistical comparisons of the [

]. Table 7-14 shows the resulting statistics when the Moody critical flow model is invoked.

The measured temperature profile for each test [

].

**RAI-121**

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

**Framatome Response 121:**

The final sentence in Section 7.6.2.2 is [

].

**RAI-122**

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

**Framatome Response 122:**

The PCT is 752 °F as stated. Figure 7-322 is [

].

**Figure R122-1 Peak Temperature Node History – FIST Test 6DBA1**

**RAI-123**

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

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

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

**<u>Framatome Response 123a.:</u>**

The [ ] shows the flow regime [ ]. In the last time period, the [ ].

**Framatome Response 123b.:**

[

].

Shortly after the transient begins, the [

].

Shortly after the transient begins, some [

].

In the calculations, the [

].

**RAI-124**

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

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

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

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

**<u>Framatome Response 124a.:</u>**

[ ].

**Framatome Response 124b.:**

[ ].

**Framatome Response 124c.:**

A [ ] single-phase vapor occurs at a [ ] as a factor in the enhancement.

**RAI-125**

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

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

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

**<u>Framatome Response 125a.:</u>**

Reflood rates ranged from [ ] as discussed in the response to RAI-104.

**<u>Framatome Response 125b.:</u>**

Preliminary computations indicated that the initial steady-state heater-rod temperatures were [ ].

**RAI-126**

*The [ ] results audited by the NRC staff do not indicate significant differences between the UMAR16 and USEP12 versions of S-RELAP5 for many of the cases considered therein. However, comparing the demonstration case results associated with the UMAR16 code version against those of the USEP12 version did reveal substantive differences. For example, when comparing the results calculated for specific failure scenarios, the calculated peak cladding temperatures were seen to be generally reduced, in some cases by [ ]. (During the May 2017 audit, AREVA noted that [ ] were also implemented in the UMAR16 calculations, although the specific impact of these changes relative to the code version and evaluation model changes was not determined.) In addition, the integral test comparison presented in the [ ] results for FIST Test 6SB2C that was audited by the NRC staff appears less favorable with the UMAR16 code version. Furthermore, the NRC staff observed that the validation comparisons in ANP-10332P are not directly applicable to the revised AURORA-B LOCA evaluation model AREVA now proposes that would incorporate the UMAR16 version of S-RELAP5 and additional evaluation model changes (e.g., [ ] etc.). Therefore, please provide the following information:*

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

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

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

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

**Framatome Response 126a.:**

The [ ] results for FIST Test 6SB2C show [ ].

The following figure compares the temperatures at the predicted PCT locations. [ ] discussed in the response to RAI-15b.

[ ]

**Figure R126-1 Cladding Temperatures at PCT Locations for FIST Test 6SB2C**

The integral tests were executed using the UMAR16 version of S-RELAP5 with [ ] identical input files used for the LTR simulations. Of the EM changes as listed in the response to RAI-15a, [ ].

The following table compares predicted PCTs from S-RELAP5 USEP12 to UMAR16 [ ].

SSTF calculations [ ].

**Table R126-1 Integral Test PCTs with UMAR16 and EM Changes**

[ ]

**Framatome Response 126b.:**

The demonstration case in Section 7.7.5 with the EM changes and corrections using S-RELAP5 version UMAR16 [ ].

**Framatome Response 126c.:**

The [ ] maximum time step was used [ ] as discussed in the response to RAI-15a where the EM changes are described.

**Framatome Response 126d.:**

The time step sensitivities shown in Figures 7-538 to 7-541 were repeated using S-RELAP5 version UMAR16 and the updated models. [ ].

**Figure R126-2 Time Step Study, LB MID Result for 1.0 DEG PS SF-LOCA**

**Figure R126-3 Time Step Study, LB TOP Result for 1.0 DEG PD SF-BATT**

**Figure R126-4 Time Step Study, SB MID Result for 0.1 ft2 PD SF-BATT**

**Figure R126-5 Time Step Study, SB TOP Result for 0.1 ft2 PD SF-BATT**

**RAI-127**

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

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

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

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

**Framatome Response 127a.:**

All important phenomena from Table 5-1 are addressed by [ ] in the response to RAI-63d. [ ].

**Framatome Response 127b.:**

[ ]. Updated time step and noding sensitivities are discussed in the responses to RAIs 41, 112 and 126.

**Framatome Response 127c.:**

[

]

results are examined and analyzed to determine if the conclusions drawn from the new results are unchanged from the original assessment conclusions. Then, the code modifications can be considered acceptable.