An AREVA and Siemens company

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Revision 0

Response to Request for Additional Information – BAW-10255(P)

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AREVA

AREVA NP Inc.

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Question 1:

BAW-10255(P) states that "...to generate the DIVOM data consistent with their intended application as part of the long term stability solution Option III ..." Is the Framatome ANP DIVOM methodology restricted exclusively to Option III, or is it applicable to any generic detect and suppress application?

Response 1:

The DIVOM methodology under review is intended for application to any Detect & Suppress methodology where a relationship between critical power and oscillation magnitude is required.

Question 2:

BAW-10255(P) includes references to older DIVOM methodology models, including RAMONA3 and XCT-MODES. While the results from analyses using these codes provide useful insight, no detailed information is provided. We assume that Framatome ANP is not intending to license these codes for DIVOM calculation.

Response 2:

The assumption is correct; the DIVOM methodology under review supersedes older methodologies and codes.

Question 3:

In Section 2.2.2, BAW-10255(P) mentions a "A new modal neutron kinetics module has been installed in RAMONA5-FA, similar to the module used for the XCT-MODES study, which allows better user control over the oscillation mode and improved DIVOM curve calculation quality and efficiency." Provide a short (about 1 page) description of the model implementation.

Response 3:

A reference is made in Section 2.2.4 of BAW-10255(P) to the modal kinetics model implemented in RAMONA5-FA. A short description follows:

- The 3-D steady state cross sections and fluxes in two energy groups are obtained from a MICROBURN-B2 solution. These are **[** **]** parameters are used as basis for the kinetics model.
- The **[** **]** balance equation is an eigenvalue problem. This equation is solved using a **[** **]** technique to produce a sequence of flux eigenfunctions and their respective eigenvalues. The fundamental mode flux (first eigenfunction) distribution is identical to the MICROBURN-B2 solution **[** **]**. The fundamental mode eigenvalue is also identical to the effective multiplication factor of the MICROBURN-B2 solution. The higher harmonics form a sequence of spatial modes where their associated eigenvalues are sorted in decreasing order reflecting their respective subcriticality. Degenerate modes, with equal eigenvalues, are allowed and often encountered due to core symmetry.
- The modal neutron kinetics model based on **[** **]** is constructed by expanding the flux and the delayed neutron precursor concentrations into weighted 3-D functions (harmonics) using the steady state eigenfunctions. The orthogonality property of the eigenfunctions allows the weighting coefficients of the modal flux and delayed neutron precursors to form a linear set of first order differential equations. The initial values of all the weight coefficients are zero except for the fundamental mode. Spatial flux and power changes with time are results of nonzero weighting coefficients introducing higher order harmonic contributions.
- The modal kinetics method is particularly suited to stability problems such as DIVOM analysis, where its numerical efficiency is only a side benefit. Examples:
    - **[** **]**
    - **[** **]**

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Question 4:

BAW-10255(P) mentions that RAMONA5-FA can use two critical heat flux correlations (ANFB-10 or SPCB). Specify the rationale for not choosing a single correlation.

Response 4:

At the time of the DIVOM methodology development, there was AREVA fuel loaded in some plants where the licensing analysis was based on ANFB-10, and for other plants based on SPCB. It was felt that the same dryout correlation should be used for DIVOM analysis so that the Option III setpoint analysis remains strictly consistent. When new dryout correlations, such as ACE / ATRIUM-10A, are approved, they will be applicable to DIVOM analysis. The comprehensive research performed to support the DIVOM methodology under review included investigation of various phenomena contributing to sensitivity of the DIVOM curve. This included other dryout correlation forms such as the X-L type. **[**

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Question 5:

Figure 3.4 appears to imply that different oscillation frequencies (+/-20%) were used for the simulation; however, the three lines in the plot appear to have the same period. Please, explain.

Response 5:

The horizontal axis in Figure 3.4 is not time, but the oscillation cycle number. Essentially it is the time normalized to the respective period of oscillation for each of the curves. The choice of normalized time, i.e. cycle number, as the independent variable in the figure helps in the visualization of the differences in CPR.

Question 6:

Please explain Figure 3-3. How were the correlations "adjusted"?

Response 6:

The DIVOM curve is based on the relative change in CPR, not the absolute change. The XL correlation, used for the verification of correlation effect, produced a slightly different initial value of CPR. In order to make a valid comparison of the relative CPR response with the other two correlations (ANFB-10 and SPCB critical heat flux correlations), the initial CPR of the XL correlation was brought to the same value of the other correlations by adjusting its so-called R-factor, which is an empirical correction of the effect of pin power distribution on critical quality.

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Question 7:

In Section 4.6 "Closing Relations and Correlations," BAW-10255(P) states that RAMONA5-FA correlations are a consistent combination of the original RAMONA5-2.4 and MICROBURN-B2 correlations that were successfully tested against pressure drop and void fraction data available at FANP. Does the correlation database cover the proposed operations at EPU and MELLA+ power/flow ratios? Provide the void fraction levels covered by the THRP set qualification database.

Response 7:

The correlation database covers the expected operating domain. The pressure drop database bounds the power/flow ratios arising from operation at the EPU power level and in the flow window created by the MELLLA+ rod line. The database of ATRIUM-10™* void data contains data in the quality range of [ ] The increase of void fraction with increasing quality is very slow beyond this upper range, which was verified by performing an ATRIUM-10 test at high power/flow ratio resulting in steam quality of [ ] in agreement with void-quality correlations including the [ ] Figure 7-1 indicates the range of all predicted void data versus reported quality for the ATRIUM-10 void database used in qualifying RAMONA5-FA.

* ATRIUM-10 is a trademark of AREVA NP Inc.

Figure 7-1 Range of all Predicted Void Data versus Reported Quality for the ATRIUM-10 Void Database

Question 8:

BAW-10255(P) states that RAMONA5-FA is a very flexible code that offers a number of possibilities and user settings for DIVOM calculations. When these options are discussed in the LTR, a preferred setting for DIVOM calculations is mentioned. Provide a single table where all the RAMONA5-FA optional settings for DIVOM calculations are summarized. Verify that the DIVOM qualification database is consistent with the recommended settings.

Response 8:

The RAMONA5-FA settings for DIVOM analysis are given in Table 8.1 below.

Table 8.1 Standard RAMONA5-FA Correlations and Models for DIVOM Analysis

The DIVOM qualification database applies the set given in Table 8.1. The LTR also includes sensitivity studies where correlation and model options as well as several input variables were varied in order to examine their respective effects on DIVOM slope.

Question 9:

In Section 4.6.3, BAW-10255(P) states that a consistent set of non-equilibrium phase change parameter settings is used. These parameters were based on comparisons with KATHY loop results for Atrium-10 fuel. Provide one example of void fraction benchmark.

Response 9:

Figure 9-1 provides a comparison of the predicted and measured void fractions for the measurement station located near the exit of the ATRIUM-10 test bundle. Figure 9-2 provides a comparison of RAMONA5-FA calculations against ATRIUM-10 void data that were collected in the subcooled boiling region. This figure demonstrates the performance of the **[** **]** parameter settings used in RAMONA5-FA for predicting **[** **]**. Both figures were generated using the **[** **]**

Figure 9-1 Predicted and Measured Void Fraction versus Quality Near the Exit of the ATRIUM-10 Test Bundle

Figure 9-2 Predicted and Measured Void Fraction versus Quality in the Sub-Cooled Boiling Region from the ATRIUM-10 Test Bundle

Question 10:

Section 7.0 "DIVOM Methodology Application Procedure." This section is very sketchy. Please define the procedure options with more detail, including:

a. *Define the procedure that is used if the hot channel is found unstable in the STAIF calculation (step 3)*

b. *Define the procedure that is used to correct the DIVOM point (step 7)*

c. *Define the input biases in case the regional oscillation is not excited.*

Response 10:

The application procedure provided in Section 7.0 is a general summary of a detailed AREVA internal procedure. More details are provided below.

The DIVOM calculation procedure includes the following elements:

1. Definition of the state points to be analyzed.

    - Exposure: At least 3 representative points including beginning, peak hot excess, and end of each operating cycle.
    - Control rod pattern: Nominal step through
    - Xenon level: representative of 100% power operation
    - Core inlet subcooling: At thermal equilibrium conditions of the analyzed power/flow
    - Power and flow base and branch points for application to Option III:
        - Base point: Natural circulation flow at highest rod line power
        - Branch points: Increased flow in steps of 5% of rated along the highest rod line until oscillations cannot be excited, and [ ]
    - Power and flow points for application to Enhanced Option III:
        - Same as Option III with the exception that the base power/flow point is replaced by two points defining the boundary of the single channel instability exclusion region. One point is defined at natural circulation, and the other defined along the highest rod line and flow higher than natural circulation.

2. MICROBURN-B2 runs for the selected state points to generate cross section and hydraulic data for input into RAMONA5-FA and STAIF codes.

3. [

] For Enhanced Option III, STAIF is used to define the single channel instability exclusion region corner points.

4. RAMONA5-FA runs producing growing regional oscillations. The transient should continue until the hot channel power oscillation magnitude exceeds a preset limit of 0.4 (peak-to-peak), the calculated MCPR is less than unity, or oscillations are no longer increasing (stable limit cycle reached).

5. State point or input data modifications as needed for the purpose of exciting the regional mode oscillations while damping the global mode.

6. Post-processing of RAMONA5-FA output with the DIVOMPLT code to generate and plot DIVOM points.

7. [

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Clarification of the specific elements requested is given below.

a. Optional scoping calculations are recommended using the STAIF frequency domain code. STAIF runs help the analyst to define and anticipate transient calculation features and problems. One of these problems is that a particular exposure point may be too stable, i.e. decay ratio < 0.8, and can therefore be substituted with the next exposure step to generate a DIVOM set. For other cases where a marginally stable core can be destabilized, e.g. [

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The procedure places a limiting condition on the magnitude of destabilizing biases needed

for exciting regional oscillations in that [ ]. In the case single channel instabilities are encountered [ ] regardless of whether they were identified by STAIF or confirmed by RAMONA5-FA results, the action depends on whether the subject plant applies Option III or Enhanced Option III. For Option III plants (no extended flow windows), unstable single channels are unlikely. In the case the single channel instability is sufficiently large to cause decoupled hydraulic oscillations, loading pattern or control rod pattern modifications to reduce the radial peaking are recommended. [ ] It is important to notice that single channel instabilities are likely to be encountered for EPU with extended flow windows, and are excluded by a scram region as part of the Enhanced Option III solution.

b. [ ]

c. Biases are required in the case regional oscillations are not excited, but are possible when uncertainties are applicable, i.e. when the condition of 0.8 < regional decay ratio < 1.0 is encountered. Actually, regional decay ratios need to be 1.05 or larger in order to obtain regional oscillations that grow sufficiently to fill the required range of DIVOM oscillation magnitude. Several biasing options are available, and it is important that they do not

qualitatively alter the stability configuration in the sense of biasing the DIVOM slope of the state point being analyzed. A brief list is provided:

- [ ]
- [ ]
- [ ]

Question 11:

Provide detailed analysis to determine the DIVOM slope in the mixed core conditions with respect to any uncertainties in the void reactivity feedback for the legacy bundles which may impact the DIVOM curve for the mixed core applications.

Response 11:

The hydraulic design of legacy bundles, including other vendor designs, has an effect on the void reactivity mainly due to the differing cross section area of the water rods or the equivalent moderator structures. Due to the co-resident fuel requirements of compatibility, the variation of void-reactivity coefficients of fuel designs by different vendors is limited.

The slope of the DIVOM curve is inversely proportional to the magnitude of the void reactivity coefficient. The transient fluctuation of the flow rate during a density wave oscillation is the main parameter responsible for the CPR response (the y-axis of the DIVOM curve) and the power response (the x-axis of the DIVOM curve). The flow oscillation produces a corresponding void fraction oscillation, which results in a power response proportional to the void-reactivity coefficient. With the x-axis stretched in proportion to the void-reactivity coefficient, the slope of the DIVOM curve becomes inversely proportional to it. It is interesting to observe that the effect of void reactivity is self-limiting in the sense that void-reactivity coefficient magnitudes that are sufficiently low to cause elevation of the DIVOM slope beyond the current experience will also make the core so stable that oscillations are unlikely to develop in the first place.

The DIVOM sensitivity to the variation in void-reactivity coefficient, which includes all causes and mechanisms attributed to core loading and operating state as well as fuel type, is best addressed as a cycle-specific variation as stated in Table 3.1 of the LTR. AREVA has accumulated experience with performing cycle-specific DIVOM analysis, where cores with exclusively ATRIUM-10 fuel bundles are loaded, as well as mixed cores. **[**

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Figure 11-1 Example DIVOM Points [ ]

Figure 11-2 Example DIVOM Points [
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Figure 11-3 Example DIVOM Points [
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