UNITED STATES
NUCLEAR REGULATORY COMMISSION
ADVISORY COMMITTEE ON REACTOR SAFEGUARDS
WASHINGTON, DC 20555 - 0001

January 31, 2011

Mr. R. W. Borchardt
Executive Director for Operations
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001

SUBJECT: REVIEW OF RAMONA5-FA FOR USE IN BWR STABILITY CALCULATIONS

Dear Mr. Borchardt:

During the 579th meeting of the Advisory Committee on Reactor Safeguards, January 13-15, 2011, we reviewed the staff's draft safety evaluation of AREVA's Licensing Topical Report EMF-3028(P), "RAMONA5-FA: A Computer Program for BWR Transient Analysis in the Time Domain," Revision 2. Our Power Uprates subcommittee also reviewed this matter on November 17, 2010. The staff's evaluation and our reviews were limited to the use of RAMONA5-FA to generate the correlations between the change in critical power ratio (**D**elta CPR) over **I**nitial CPR **V**ersus the **O**scillation **M**agnitude (referred to as the DIVOM correlations), rather than a complete review of the code for application to transient analyses. During these reviews, we had the benefit of presentations by and discussions with representatives of the NRC staff, AREVA and a member of the public. We also had the benefit of the documents referenced.

CONCLUSION AND RECOMMENDATION

1. The staff's recommendation to remove the interim 10 percent penalty on the DIVOM correlation slope calculated using RAMONA5-FA for extended flow window (EFW) operating domains is acceptable, subject to satisfactory resolution of issues associated with Recommendation 2.

2. Before the interim penalty is removed, the staff should review Volume 2 of the revised RAMONA5-FA Topical Report EMF-3028(P), to ensure that all errors have been corrected and that the documentation errors do not reflect errors in the source code.

BACKGROUND

Boiling water reactors are licensed to operate within specific power and core flow conditions referred to as "operating domains" in power-flow maps. In recent years, the industry has been moving towards expanded operating domains with increasing power densities and power-to-flow ratios. This trend is, in principle, detrimental to the stability characteristics of the reactor, inasmuch as it increases the probability of instability events and increases the severity of such events, if they were to occur.

During the past 15 years, the BWR Owners Group has developed, and the Staff has approved, three different long-term stability options. Among these long-term stability solutions is the Option III, which is a "Detect and Suppress" (D&S) system that relies on signals from the Local Power Range Monitors (LPRMs). Small numbers of closely spaced LPRMs are grouped into Oscillation Power Range Monitor (OPRM) cells. The OPRM signals are analyzed on-line; if instability is detected and confirmed, automatic action is taken to suppress the oscillations before the safety margins are compromised.

DIVOM is an acronym that stands for **D**elta CPR over **I**nitial CPR **V**ersus **O**scillation **M**agnitude. It correlates the loss in critical power ratio (CPR) in the hot channel corresponding to the power oscillation amplitude measured by the OPRM. The DIVOM correlation is used to define the OPRM amplitude scram setpoint for D&S long term stability solutions. Evaluations by General Electric in 2001 identified a non-conservative deficiency in the generic DIVOM curve developed by the BWR Owners Group; this resulted in a Part 21 notification. For high radial peaking and high peak bundle power-to-flow ratios, the regional mode DIVOM slopes were found to be significantly higher than the licensed generic correlation. The generic DIVOM correlation was subsequently eliminated and substituted with a cycle-specific DIVOM analysis.

AREVA's Enhanced Option III (EO-III) methodology, documented in Licensing Topical Report ANP-10262(P), is a proprietary extension of the Option III D&S solution for use in EFW domains. The EO-III methodology was approved by the NRC staff in 2008.

Our December 27, 2007 letter documents our review of the EO-III methodology including Topical Report BAW-10255(P), Revision 2, which describes AREVA's methodology for evaluating a cycle-specific DIVOM correlation for regional oscillations using the transient system code RAMONA5-FA. The topical report was submitted to the NRC for review in January 2006 by Framatome ANP (now known as AREVA). The NRC staff issued a safety evaluation report on AREVA's DIVOM methodology, which required a review of RAMONA5-FA before it could be used to calculate DIVOM correlations in EFW operating domains. Until this review is completed, AREVA must include an interim 10 percent penalty on the DIVOM correlation slopes calculated by RAMONA5-FA. To this end, the Staff has undertaken a review of RAMONA5-FA. The review is limited to the generation of DIVOM correlations, rather than a complete review of the code for generic transient analyses.

DISCUSSION

The RAMONA series of codes is based on RAMONA-3B originally developed by Brookhaven National Laboratory, which was modified by Studsvik-Scandpower to become RAMONA5 V2.4, and further modified by AREVA to become RAMONA5-FA. The codes use a four-equation, non-homogeneous, non-equilibrium, one-dimensional, two-phase flow model. Modifications made by Studsvik-Scandpower include the addition of an improved jet pump model, reverse flow models, and alternative correlation options. Additional enhancements were made in the transition from RAMONA5 V2.4 to RAMONA5-FA. These include: (1) new modules for adaptive three dimensional (3-D) neutron kinetics, modal neutron kinetics, and automatic input generation from the core simulator MICROBURN-2; and (2) updated closure relations including an improved fuel pin model from STAIF and AREVA's hydraulic and dryout correlations.

To develop the DIVOM correlation, the code needs to correctly model a self-consistent power-flow oscillation and evaluate the loss of CPR margin due to the power oscillation. AREVA qualified the RAMONA5-FA code for decay ratio and frequency calculations by comparing the code predictions against actual plant stability test data. The RAMONA5-FA decay ratio and frequency calculations were also benchmarked against data from the Karlstein Thermal Hydraulic (KATHY) loop tests; these comparisons demonstrated the ability of RAMONA5-FA to calculate self-consistent void-flow oscillations.

The current CPR correlations in RAMONA5-FA were independently reviewed and approved by the NRC. In our December 27, 2007, letter regarding our review of AREVA's EO-III methodology, we noted that "the limited data included in topical report BAW-10255(P) suggest a non-conservative bias in the predicted CPR values at the onset of dryout." This issue has been addressed satisfactorily by AREVA during the current review. The apparent non-conservative bias in the predicted CPR values is attributed to instrument damping of the inlet flow measurements for the KATHY oscillatory dryout-rewetting tests. When the data are corrected for flow meter damping, the apparent non-conservative bias in the CPR correlation is eliminated. The results show that all three dryout correlations available in the RAMONA5-FA code can adequately predict the onset of dryout under oscillatory flow conditions.

The staff reviewed the AREVA DIVOM methodology documented in BAW-10255(P), as well as the RAMONA5-FA user and theory manuals documented in EMF-3028, Volumes 1 and 2. Additionally, the staff conducted a one-week on-site audit of the RAMONA5-FA code. The staff's evaluations focused on the following questions:

- Does the AREVA calculation procedure comply with the approved DIVOM methodology?
- Can RAMONA5-FA correctly model the growing unstable power oscillations required in the calculation procedure?
- Given a power oscillation, can RAMONA5-FA correctly estimate the corresponding reduction in CPR?

The reviews encompassed the cross section generation methodology, neutronic and thermal-hydraulic models, and closure relations used in the RAMONA5-FA code. During the audit, the benchmarks and sensitivity analyses performed by AREVA were reviewed. The RAMONA5-FA steady-state predictions were compared against the results of MICROBURN-B2, AREVA's 3-D simulator code, which is regularly benchmarked against plant data. The performance of the RAMONA5-FA neutronic models was also evaluated for three transients: a pressure perturbation, a subcooling perturbation, and a control rod perturbation. Based on these evaluations, limitations were imposed on the use of one of the three neutronics models in RAMONA5-FA. Sensitivity calculations were performed where the void-quality correlation was biased to reflect the void data measured in the KATHY test facility for ATRIUM-10 fuel. The sensitivity calculations indicate that uncertainties in the void-quality correlations result in insignificant changes in the DIVOM slope and do not introduce errors in the decay ratio or oscillation frequency. Pressure drop values calculated with RAMONA5-FA agree with experimental data obtained in the KATHY test facility for ATRIUM-10 fuel.

Based on the review and on-site audit, the staff concluded that the RAMONA5-FA code is qualified to model the growing unstable power oscillations required for the DIVOM calculation procedures. Additionally, the code can correctly predict the onset of dryout conditions, during power oscillations representative of instabilities. The staff has, therefore, concluded that the 10 percent penalty previously imposed on DIVOM slopes calculated by RAMONA5-FA for EFW domains can be removed.

Our review of the RAMONA5-FA Licensing Topical Report EMF-3028(P) has identified numerous documentation errors. These errors were apparently introduced in the transitions to RAMONA5 V2.4 and RAMONA5-FA. A list of errors in the RAMONA5-FA Topical Report prepared by our consultant was provided to the staff. A revised version of the RAMONA5-FA theory manual (Topical Report EMF-3028(P), Volume 2) was prepared by AREVA in January 2011. AREVA stated that a subsequent review of the RAMONA5-FA source code indicated that the documentation errors in the theory manual had not been introduced into the source code. We recommend that, before the interim penalty is removed, the staff should review the revised RAMONA5-FA Topical Report EMF-3028(P), Volume 2, to ensure that all errors have been corrected and that the documentation errors do not reflect errors in the source code.

Sincerely,

/RA/

Said Abdel-Khalik
Chairman

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SUBJECT: REVIEW OF RAMONA5-FA FOR USE IN BWR STABILITY CALCULATIONS

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