From: Getachew Tesfaye
To: DAFLUCAS Ronda M.
Date: 1/22/2007 1:16:07 PM
Subject: Codes and Methods TR ANP-10263P - Draft RAI

Ronda,
Attached are the subject draft RAIs. Per our agreement, I have scheduled a post-submittal telecon for Friday February 2nd (1 to 3:30pm) to discuss these draft RAIs.

Bridge line: 301-231-5539 or 800-638-8081 and the passcode is 8715 followed by the # sign.

7 lines are available. 4 lines will be available for AREVA. Three lines are reserved for NRC staff.

Getachew Tesfaye
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NRO/DNRL/NAR1
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CC: Anthony Attard; Edward Throm; Joseph Colaccino; Larry Burkhart; Ralph Landry; Shih-Liang Wu

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DRAFT

REQUEST FOR ADDITIONAL INFORMATION
NUCLEAR PERFORMANCE AND CODE REVIEW BRANCH
DIVISION OF SYSTEMS SAFETY
OFFICE OF NUCLEAR REACTOR REGULATION

ANP-10263(P), REVISION 0
"CODES AND METHODS APPLICABILITY REPORT FOR THE U.S. EPR"
AUGUST 2006, AREVA NP INC.

TAC NO.: MD2803

Validation of Methodology for Small Break LOCA

The vertical and horizontal flow maps in S-RELAP5 are described in Section 3.1 of R1. Interphase friction is described in Section 3.2 of R1, including entrainment. The models have been assessed by AREVA and have been found acceptable for SBLOCA evaluations.

The EPR relies on steam generator crash cooling (including reflux condensation) to bring the primary system pressure down to the cutoff head of the medium head safety injection (MHSI) system pumps during SBLOCAs. The main steam relief train (MSRT) is used to depressurize the SG at a rate of 180 °F/hr, and is actuated following an SI signal. The MSRT is also used to manage an STGR event.

RAI 1: The description of the automatic depressurization method presented in ANP-10276 is clearer. The cooling rate is only an approximation of the process which is a pressure set-point reduction over a period of time. ANP-10263P should be modified to clarify this method.

The U.S. EPR SG design includes an economizer, a feedwater preheating section (Figure 2-5 does not appear to show this feature).

RAI 2: Provide a better pictorial representation of the economizer, both elevation and cross-section views, either replacement or additional figure. On modeling Figure 5-2, provide a cross-section view showing the economizer modeling.

AREVA used BETHSY test 9.1.b (R2) to evaluate the MHSI system (R3). It is also noted that the assessment for loop seal clearing used BETHSY as well as UPTF-A5RUN11E (R3). There is no mention of any adjustment to the physical loop seal model for UPTF in R3, "behavior is not particularly sensitive" to nodalization or time step. However, for BETHSY, an artificial adjustment was made based on observed results from the test. This adjustment carries over to the SBLOCA methodology.

RAI 3: Did the UPTF S-RELAP5 model include a bias in the loop seal? If so, the modeling description should be modified.

ENCLOSURE

RAI 4: Justify the bias in BETHSY as the correct method to address the observed uncertainties in the break flow rate, the uncertainties in the auxiliary feedwater flow control logic, and the uncertainties in predicting the flow regime in the U-tubes (water hold-up), which could also influence loop-seal clearing in a loop. These uncertainties could all be related to the calculated performance of the SGs and the resulting uncertainties in the RCS pressure and temperature.

Little information could be located concerning the scope of modeling studies of the SGs, beyond the number of axial nodes used to model the U-tubes. However, the effects of nodalization have been shown to influence the analytical results, R4.

Of particular concern, because of the importance of using the SGs to manage design basis accidents, is the treatment of the U-tubes which have varying tube lengths. There are a number of tests which show non-uniform conditions exist in the tube bundles.

Tests have shown the following:

1. Non-uniform flow conditions can be expected in the steam generator during reflux condensation. Some tubes may be in a condensing co-current two-phase flow pattern while others stagnate. This has been found to cause a reduction in the effective heat transfer area in the SG. (R5, R6, R7, R8 and R9)

2. Noncondensable gases can accumulate in the U-tubes. These noncondensables can originate from air initially dissolved in the primary coolant. Local condensation heat transfer coefficients are known to decrease as the noncondensable gas mass fraction increases (R10 and R11).

3. Secondary transient depressurization in one ROSA test (R11) was found to cause a significant relocation of the primary mass. Condensate accumulated in the crossover leg as well as in the SG tubes of the affected loop. Reactor pressure vessel mass decreased during this time, and core dryout progressed until it was later slowed by an increase in the reflux flow rate.

RAI 5: Provide additional nodalization and test comparison analyses to fully qualify the S-RELAP5 heat and mass transfer package for modeling the EPR SG performance during small-break LOCAs, including an STGR. These studies are to include both axial nodalization as well as multiple U-tube paths to address the observed non-uniform flow conditions, and the modeling of the U.S. EPR economizer. The results of these studies will be used to justify the S-REALP5 model to be used for licencing analyses.

RAI 6: Section 4.2.5 - It is not clear if it will be acceptable to terminate the calculation when the fuel temperature transient in the core has been reversed. How does this relate to the description presented in Section 4.1.1 for the length of the calculation? Justify this in consideration of the requirement to demonstrate acceptable cladding oxidation and core cooling if there are prolonged periods of high cladding temperatures.

Validation of S-RELAP5 Methodology for Non-LOCA Events

RAI 7: Section C.2, page C-3: It is not clear where the 1406.9 psia value comes from, the graphical output does not reach this value. The post-trip set-point for the MSRT is not this high. Where does this value come from? Modify the text, or graphical output, according.

RAI 8: Section 5.2.2 of ANP-10263P addresses nodal changes because of length change but not sensitivity studies. Provide additional nodalization studies to justify the S-RELAP5 model for the economizer. The results of these studies will be used to justify the S-RELAP5 model to be used for licencing analyses.

The staff is not sure what to do with, or what is meant by, statements typical of page 5-16 of ANP-10263NP (***emphasis*** added):

> "The significant differences between the U.S. EPR U-tube SG design and current PWR U-tube SG designs are the increased size/volume of the unit and the incorporation of an axial economizer with a split downcomer and lower tube bundle region. The difference in size of the unit has no effect on the ability of S-RELAP5 to simulate the related hydrodynamic and thermodynamic phenomena. The fluid flow and heat transfer phenomena within the axial economizer region (single- and two-phase fluid flow, convection and nucleate boiling heat transfer) ***are similar*** to those in other regions of current PWR U-tube SG designs modeled using the Reference 5-1 methodology. Explicit modeling of the axial economizer geometry in the U.S. EPR S-RELAP5 SG model is allowed by the Reference 5-1 methodology (page 3-1) and ***would be considered*** an acceptable plant-specific application of the currently approved methodology. The Reference 5-1 methodology is suitable for analyzing U.S. EPR SG primary/secondary heat transfer phenomena during moderate overcooling events. "

Page 5-24 of ANP-10263NP (***emphasis*** added):

> "The fluid flow and heat transfer phenomena within the axial economizer region (single and two-phase fluid flow, convection and nucleate boiling heat transfer) ***are similar*** to those in other regions of current PWR U-tube SG designs modeled using the Reference 5-1 methodology. The MSLB SG model outlined in Reference 5-1 (a single SG boiler node with "steam-only" connecting junction to the steam dome) ***is expected to remain*** a conservative approach for calculating SG heat removal for the U.S. EPR SG since it forces all energy to be removed by conversion of the SG liquid inventory to steam, with no liquid release or carryover. Therefore, the Reference 5-1 methodology is suitable for analyzing U.S. EPR SG primary/secondary heat transfer phenomena during the pre-scram period of MSLB events."

Page 5-26 of ANP-10263NP (***emphasis*** added):

> "<u>U-tube SG with Axial Economizer</u>: The MSLB SG model nodalization outlined in

Reference 5-1 (a single SG boiler node with "steam-only" connecting junction to the steam dome) ***is expected to remain*** a conservative approach for calculating SG heat removal for the U.S. EPR SG since it forces all energy to be removed by conversion of the SG liquid inventory to steam, with no liquid release or carryover. The Reference 5-1 methodology is suitable for modeling the U.S. EPR SG heat transfer during an MSLB event."

RAI 9: How will AREVA demonstrate that the current modeling approaches are actually representative of the U.S. EPR and remain conservative?

Page 5-33 of ANP-10263NP:

"Steam generators with axial economizers: The U.S. EPR steam generator design features an axial economizer which channels the feedwater through the 180° sector of the downcomer and lower boiler regions that corresponds to the cooler, downflow legs of the U-tubes. However, modeling this feature is not warranted for a Main Steam Line Break analysis, in which all of a steam generator's downcomer and boiler regions are lumped together into a single volume and the feedwater is injected into the bottom of that volume."

RAI 10: This needs further clarification. Is the statement based simply on using the previous modeling approach or has it been, or will it be, demonstrated though sensitivity studies? What is done with the additional SG structures which form the economizer? Why is it not important to consider the economizer for this event?

RAI 11: It is not clear from the text or from Figure 2-4 what is meant by a variable cross-section area in the downcomer. Elaborate and include a discussion of any changes needed to ensure adequate two-dimensional (θ,z) nodalization of the downcomer for licensing analyses.

RAI 12: Is equation 2.51 in R1, "S-RELAP5 Models and Correlation Code Manual," correct? Should it be similar to Eq. 2.52? Is the term properly coded? (See RAI 2.10 response in EMF-2328(P).)

A review of the informal PIRT discussed in the RAI responses in EMF-2328(P), suggested that the SG heat and mass transfer phenomena were ranked for the early phases (1, 2 and 3) of the SBLOCA and focused on loop seal clearing. In the U.S. EPR, SG mass and heat transfer is likely important to the later phases (4 and 5) as well.

RAI 13: The referenced benchmarks (Table 4-2) do not specifically address SG mass and heat transfer. Expand the PIRT to specifically address SG mass and heat transfer during all phases, including phenomena associated with reflux condensation. Expand the validation data base for SG mass and heat transfer, including reflux condensation, particularly to address the later phases of the event.

In addition to the larger RCS component volumes and SG component volumes, the U.S. EPR operates at a higher power level, with higher RCS temperatures and higher SG pressures than the typical U.S. PWR designs for which S-RELAP5 was previously accepted.

RAI 14: Verify that the mass and heat transfer correlations in S-RELAP5 adequate cover the ranges for the anticipated increases in the mass and energy transfer rates expected in the U.S. EPR, for both small break LOCA (including SGTR) and non-LOCA accidents.

Applicability of Other Approved Methodologies to U.S. EPR Design

RAI 15: The COPERNIC code demonstrated that the LOCA initial conditions were not necessarily limited in the beginning of life depending on the power histories. Please assess the situation for the EPR.

RAI 16: Provide the assembly bow and rod bow analyses for the EPR.

RAI 17: Provide the axial growth analyses for the rod and assembly to address the shoulder gap clearance.

RAI 18: Justify that the EPR 14-foot-core will not suffer from excessive vibrational fretting on fuel rods and grid spacers.

RAI 19: Provide analytical results of fuel melting, stain , rod pressure, and fuel stored energy for typical power histories for the EPR.

RAI 20: The maximum rod gas pressure is limited to below a value which would cause (1) the fuel cladding gap to re-open, and (2) extensive departure from nucleate boiling (DNB) propagation to occur. Does this imply that EPR allows for certain DNB failures and propagation?

RAI 21: Section 6 mentioned that various mechanisms could affect M5 performance including water-side and fuel-side corrosion. Please elaborate.

RAI 22: Please address the fuel assembly structural response to seismic and LOCA loading as described in the Appendix A to SRP 4.2.

Core Neutronics

RAI 23: Page A-1 of ANP-10263P discusses the subject of "Reflectors." Since this a new reflector design, will there be a separate topical report addressing the new design?

RAI 24: Page A-15 of ANP-10263P, section A.2.3, presents the methodology description and the validation process associated with these methodologies. However, no technical basis was provided to support these applications. For example, in sub-section A.2.4.1, it is simply stated that the critical experiments provided in SAV95 are still valid. No reason was given as to why they are still valid. Provide this justification.

RAI 25: Page A-26, Section A.3.0, Power Distribution Uncertainties for POWERTRAX/S, and subsequent sub-sections, allude to a new power distribution calculational method and uncertainties determination. The last sentence of the first paragraph in this section, states that this methodology will be discussed in a future topical. Will this be a separate topical to the DCD? What is the time-line for this topical? Additional discussions may be required.

RAI 26: On page A-33, Sub-Section A.3.3.2, the subject of Local Peaking Factor Uncertainty is discussed. The remain text of this sub-section and sub-sequent section provide the staff with the results of the uncertainties for the respective sections. However, the statistical method used to arrive at these results is not discussed. Please provide the statistical methodology used to arrive at these values, as well as references.

General Comment

RAI 27: On page 2-24 of the ANP-10263P, sub-section 2.2.4.2.1 discusses the subject of the "Aeroball System". Does AREVA intend to submit this methodology for NRC Staff approval prior to the submittal of the DCD?

RAI 28: In an SBLOCA, the RCS begins to depressurize and about 30 minutes later two-phase natural circulation is lost. Reflux condensation cooling begins and a slug of unborated water is formed in the descending half of the SG U-tubes, in the crossover leg, in the pump volume and possibly in the lower plenum of the vessel. Later this slug could be transported to the core in several ways. This transient is an important issue (Generic Safety Issue 185). How will GSI 185 be addressed for the U.S. EPR?

References:

R1. "S-REALP5 Models and Correlations Code Manual," EMF-2100(P) Rev 4, May 2001.

R2. ISP-27, "BETHSY Experiment 9.1.B - 2" Cold Leg Break Without HPSI and With Delayed Ultimate Procedure," November 1992, OECD/NEA/CSNI/R(92)20.

R3. "PWR Small Break LOCA Evaluation Model, S-REALP5 Based," EMF-2328(P), January 2000.

R4. "BETHSY Nodalization Study During Mid-Loop Operation," V. Segon, et al., International Conference, Nuclear Energy in Central Europe 2001, September 10-13, 2001.

R5. "Heat Transfer Characteristics of Reflux Condensation Phenomena in a Single Tube," G-H. Chou, J-C. Chem, Nuclear Science and Engineering: 127, 220-229 (1997).

R6. "Non-uniform flow distribution in steam generator U-tubes of a pressurized water reactor plant during single- and two-phase natural circulation," J-J. Jeong, et al., Nuclear Science and Engineering: 231, 303-314 (2004).

R7. "Nonuniform Steam Generator U-Tube Flow Distribution During Natural Circulation Tests in ROSA-IV Large Scale Test Facility," Y. Kukita, et al., Nuclear Science and Engineering: **99**, 289-298 (1988).

R8. "Intentional Depressurization of Steam generator Secondary Side during a PWR Small-Break Loss-of-Coolant Accident," H. Asaka, Y, Hukita, Journal of Nuclear Science and Technology: 32[2]. pp. 101-110 (February 1995).

R9. "Thermal-hydraulic characteristics of a next generation reactor relying on steam generator secondary side cooling for primary depressurization and long-term passive core cooling," Nucl. Eng. Design,185, pp. 83-96, (1998).

R10. Reflux condensation behavior in a U-tube steam generator with or without noncondensables," Tay-Jian Liu, Nuclear Engineering and Design, Volume 204, Issues 1-3, February 2001, Pages 221-232.

R11. "Reflux condenser mode with non-condensible gas: assessment of Cathare against Bethsy test 7.2C," B. Noel and R. Deruaz, Nuclear Engineering and Design, Volume 149, Issues 1-3, 1 September 1994, Pages 291-298.

R12. BETHSY Test 9.113. ISP-27, Clement, P., Chataing, T., Deruaz, R., OECD/NEA/CSNI/R(92)20, (1992).

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Loomis, G. G., and Soda, K., "Results of the Semiscale MOD-2A natural circulation experiments," NUREG/CR-2335, (1982).

Kukita, Y., Nakamura, H., and Gotou, H., "Nonuniform steam generator U-tube flow distribution during natural circulation tests in ROSA-IV large scale test facility," Nucl. Sci. Eng., 99, pp. 289-298, (1988).

Dumont, D., et al., "Loss of residual heat removal during mid-loop operation: BETHSY experiments," NURETH 6, Grenoble, (1993).

K. Umminger, R. Mandl and R. Wegner, " Restart of natural circulation in a PWR–PKL test results and 5 calculations," Nuclear Engineering and Design, Volume 215, Issues 1-2, June 2002, Pages 39-50.

Large Scale Separate Effects Tests

Howard, R. C., et al., "PWR FLECHT SEASET Steam Generator Separate Effects Task Data Report," NUREG/CR-1366, (1980).

Howard, R. C., and Hochreiter, L. E., et al., "PWR FLECHT SEASET Steam Generator Separate Effects Task Data Analysis and Evaluation Report," NUREG/CR-1534, (1982).

Additional SG Heat Transfer Tests for SBLOCA Qualification

Klaus Kochshkamper, "Validation of the Thermal-Hydraulic Computer Code S-RELAP5 for Performing Loss-of-Coolant Accident Analysis (LOCA) in Pressurized Water Reactors (PWRs)," Nuclear Society of Slovenia, 2nd Regional Meeting: Nuclear Energy in Central Europe, 11-14 September 1995. (LOFT L2-5, PKL III B.2 and BETHSY 6.2)