FRAMATOME ANP

July 5, 2001
NRC:01:027

Document Control Desk
ATTN: Chief, Planning, Program and Management Support Branch
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555-0001

Non-Proprietary Copies of LOCA Documents

Ref: References are listed on page 3.

The NRC staff had requested non-proprietary copies of each of the LOCA submittals currently being reviewed by the NRC for Framatome ANP. Some of this information has already been provided, and the remainder is either enclosed or will be provided later, as indicated below.

Three LOCA-related submittals are being reviewed by the NRC:

- SBLOCA top and side breaks (BAW-10168, Revision 3),
- Volume-averaged fuel temperature uncertainties (BAW-10164, Revision 4, and supporting documents), and
- The 'standalone' RELAP5 LBLOCA (BAW-10164, Revision 5, and supporting documents).

The SBLOCA submittal was transmitted to the NRC by Reference 1 and is non-proprietary.

The volume-averaged fuel temperature uncertainty submittal consists of two parts, which are contained in References 2 and 3. The Reference 2 submittal included both proprietary and non-proprietary versions. The Reference 3 submittal is non-proprietary. References 4 and 5 provided supporting information regarding the uncertainty submittals. Reference 4 is non-proprietary. Reference 5 is proprietary, and the non-proprietary version is enclosed. A copy of this document has been sent directly to Stewart Bailey.

The 'standalone' RELAP5 LBLOCA encompasses three submittals, References 6, 7, and 8. Reference 6 is non-proprietary. Reference 8 is being revised; proprietary and non-proprietary versions will be submitted to the NRC later this year. If this new information

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continues to rely on Reference 7, and Framatome requests specific acceptance of this document, a non-proprietary version will be provided at that time.

Very truly yours,

James F. Mallay, Director
Regulatory Affairs

cel

Enclosure

cc: Stewart N. Bailey

Ref.: 1. Framatome Technologies Letter: J. J. Kelly, FTI, to Document Control Desk, NRC, "A Request to Rescind FTI's Commitment to Analyze Top and Side SBLOCAs for T_{hot} Recirculating Steam Generator Plants--BAW-10168P-A, Revision 3, Volume II, December 1996," FTI-98-3797, December 10, 1998.

Ref.: 2. Framatome Cogema Fuels Letter: T. A. Coleman, FCF, to U. S. Nuclear Regulatory Commission, GR99-194.doc, September 24, 1999 (BAW-10164P, Revision 4, "RELAP5/MOD2-B&W--An Advanced Computer Program for Light Water Reactor LOCA and Non-LOCA Transient Analysis," September 1999).

Ref.: 3. Framatome Technologies Letter: J. J. Kelly, FTI, to Document Control Desk, NRC, "Modeling Refinements to Framatome Technologies' RELAP5-Based, Large Break LOCA Evaluation Models--BAW-10168 for Non-B&W-Designed, Recirculating Steam Generator Plants and BAW-10192 for B&W-Designed, Once-Through Steam Generator Plants," FTI-00-551, February 29, 2000.

Ref.: 4. Framatome Technologies Letter: J. J. Kelly, FTI, to Document Control Desk, NRC, "Additional Information on Modeling Updates to Framatome Technologies' RELAP5-Based, Large Break LOCA Evaluation Models--BAW-10168 for Non-B&W-Designed, Recirculating Steam Generator Plants and BAW-10192 for B&W-Designed, Once-Through Steam Generator Plants," FTI-00-2225, September 5, 2000.

Ref.: 5. Framatome ANP Letter: R. W. Ganthner, FRA-ANP, to Document Control Desk, NRC, "Additional Information on Use of the Void-Dependent Cross-Flow Model Implemented in RELAP5/MOD2-B&W Code (BAW-10164, Rev. 4 P) for B&W Plant SBLOCA Applications Performed Using the BWNT LOCA EM (BAW-10192PA)," FANP-01-915, March 23, 2001.

Ref.: 6. Framatome Technologies Letter: J. J. Kelly, FTI, to Document Control Desk, NRC, "Methodology Revision (Revision 4) to Framatome Technologies' RELAP5-Based, Large Break LOCA Evaluation Model--BAW-10168, Volume I for Non-B&W-Designed, Recirculating Steam Generator Plants," FTI-00-1972, July 31, 2000.

Ref.: 7. Framatome Technologies Letter: J. J. Kelly, FTI, to Document Control Desk, NRC, "Methodology Revision (Revision 1) to Framatome Technologies' RELAP5-Based, Large Break LOCA Evaluation Model--BAW-10192, Volume I for B&W-Designed, Once-Through Steam Generator Plants," FTI-00-1914, July 31, 2000.

Ref.: 8. Framatome Technologies Letter: J. J. Kelly, FTI, to Document Control Desk, NRC, "Methodology Revision (Revision 5) to Framatome Technologies' RELAP5 Computer Program for LOCA and Non-LOCA Transient Analysis, BAW-10164," FTI-00-1968, July 31, 2000.

bc: NRC:01:027
(via e-mail)
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Attachment

Response to a Verbal Request for Additional Information on the RELAP5/MOD2-B&W Void-Dependent Core Cross-Flow Model Used in B&W-Plant SBLOCA Applications

Table of Contents

List of References

1. FTI Topical Report BAW-10192PA-00, "BWNT LOCA – BWNT Loss-of-Coolant Accident Evaluation Model for Once-Through Steam Generator Plants", June 1998.

2. FTI Topical Report BAW-10164PA-03, "RELAP5/MOD2-B&W An Advanced Computer Program for Light Water Reactor LOCA and Non-LOCA Transient Analysis," July 1996.

3. FCF Topical Report BAW-10227P-A, "Evaluation of Advanced Cladding and Structural Material (M5) in PWR Reactor Fuel," February 2000.

1.0 Background and Introduction

Framatome Advanced Nuclear Power (FRA-ANP), previously Framatome Technologies Inc., has used the BWNT LOCA Evaluation Model (EM) documented in BAW-10192P-A (Reference 1) for small break loss of coolant accident (SBLOCA) licensing analyses for the B&W-designed 177-fuel assembly lowered-loop (177-FA LL) and raised-loop (177-FA RL) plants. These analyses have been performed in accordance with the EM descriptions and they have complied with the EM and code limitations and restrictions imposed via the NRC safety evaluation reports (SERs). During the course of analysis, FRA-ANP has discovered that the SBLOCA core cross-flow form loss modeling requirements are cumbersome for the analysts to use when analyzing the spectrum of SBLOCA transients with core uncovering. FRA-ANP has remedied these problems by standardizing the current EM cross-flow implementation methods via RELAP5/MOD2-B&W code automation improvements. The extent of the FRA-ANP code improvements and plans for using this improved implementation are provided to the NRC through this documentation.

The EM describes the philosophy and physical cross-flow modeling approach used in SBLOCA analyses (Reference 1, Volume II, Section A.4). A high cross-flow resistance is used in the pool region to stabilize the void gradients or mixture levels between the hot and average channels. This pool void gradient results in a slightly higher hot channel mixture level than that of the average core. Above the mixture level, the cross-flow resistance from the hot-to-average channel is conservatively reduced to allow steam flow diversion out of the hot channel. The average-to-hot channel resistance is increased in the steam region to restrict the flow of cooler steam from the average channel. The cross-flow resistance model that represents this stated approach is shown as the "Base Case" model in Table A-3 of the SBLOCA EM (Reference 1). Demonstration cases provided characteristic behavior when this segmented flow resistance model is used with low resistances in the upper core region and a high resistance in the lower core or pool region. Section

A.4 of the SBLOCA EM (Volume II) states that the discontinuity in the resistances must be near or below the elevation of the minimum core mixture level obtained in the analysis. If the user specifies the transition elevation between the wrong two volumes, then an iteration on the cross-flow resistance input model might be required. This iteration is both burdensome to the user and it can introduce a variation of roughly +/- 40 F in the maximum peak clad temperature (PCT) prediction related to the degree of conservatism that the user imposed via specification of the elevation of the cross-flow resistance step change. This type of variation has been noted in SBLOCA analyses with limiting PCTs in the 1300 to 1450 F range for B&W-designed plants.

FRA-ANP reviewed the EM modeling philosophy and devised a simple code model that could be made responsive to the SBLOCA cross-flow resistance model requirements and change dynamically with the actual mixture levels. This variable resistance model will eliminate any potential user iteration associated with the specification of the fixed cross-flow resistance change. This standardization of the resistance modeling will also eliminate any PCT variations associated with the user's specification of the fixed-resistance transition elevation.

The new RELAP5/MOD2-B&W code (Reference 2) cross-flow model option alters the cross-flow resistance based on the local volume upstream conditions. At void fractions less than the pool region cutoff, the high cross-flow loss coefficients are used. At void fractions greater than the steam region cutoff, the low form loss coefficients are used. A smoothing region with linear interpolation between the two cutoff values is included to smooth the transition between the two resistance factors. This improved implementation method remains consistent with current EM discussions, therefore it is not considered to be an EM change. Nonetheless, FRA-ANP has notified the NRC of the implementation method differences, because of the slight alteration of the interpolation region and code automation of the cross-flow resistance model. The RELAP5/MOD2-B&W cross-flow code formulation changes were included in the documentation provided in the Revision 4 code updates supplied with the M5 licensing documentation in Appendix K of Reference 3. That information, with the void fractions at which the transitions occur, clearly defines the model that Framatome ANP will use in BAW-10192 SBLOCA EM applications.

2.0 Void-Dependent Cross-Flow Model

The basic principles described in Section A.4 of the SBLOCA EM volume describe a relationship between the cross-flow form loss and the upstream fluid conditions. If the upstream fluid is representative of the pool region (i.e. below the mixture level), then the resistance should be high. Use of the higher pool resistance supports the variations in the mixture region void fraction related to power differences between the hot and average channels. These resistances are reduced [ ] above the top of the mixture region to allow for steam flow diversion out of the hot channel. The steam region resistance factor from the average-to-hot channel is increased [ ] to restrict steam flow from the average-to-hot channel. The pool or steam region can be defined within the code via use of an upstream volume void fraction. Based on simple changes in code logic, the cross-flow resistance was modified based on the upstream void fraction for any junction that is designated as a void-dependent cross-flow junction.

The new code option allows the user to specify the core cross-flow junctions as void-dependent cross-flow paths via a specialized flag on the junction-input cards. The user also provides the void fractions that define the steam region and the pool region. The pool region cross-flow resistance is specified for the junctions. If the upstream volume void fraction is below the pool region void fraction, then the high void fraction form loss factor [ ] is unmodified. If the upstream

volume void fraction is above the steam region void fraction, then the hot-to-average pool resistance is reduced [ ] to the steam form loss [ ] for the hot-to-average resistance. A lower multiplicative factor [ ] is used to adjust the pool resistance value to the average-to-hot steam form loss [ ]. All of these form loss coefficients are unmodified from the original fixed cross-flow EM modeling concepts. The only difference with the void-dependent model implementation is that a smoothing integral is used when the void fraction falls between the pool and steam void fractions. A linear interpolation on upstream void fraction will be used to define the multiplicative adjustments for both the forward and reverse form loss coefficients under these conditions.

This new code option forces the cross-flow resistance to be similar to that described in the EM at the time of minimum core inventory. It has the added benefit of providing a smooth transition from the higher pool region resistance to that of the steam region both during both the uncovering and refill phases. Without this new code option, the user was limited to a fixed cross-flow resistance specification at a predefined core elevation. This fixed modeling could be modified via code restarts in the transient, although this approach provides another way that the user can affect the overall calculation of PCT.

The new void-dependent user-input options for the pool void fraction cutoff value are obtained by observing the maximum pool-region void fraction in the worst break size range for the SBLOCA spectrum analyses. Generally, the highest PCT is predicted for B&W-plant analyses when the break size is between 0.024 and 0.15 ft^2. The highest core void fractions in the pool regions vary [ ] for these break sizes, with the void fraction increasing with break size. The pool-region cutoff void fraction [ ] will cover all of these break sizes and should be reasonable for the typically non-limiting analyses at larger break sizes. In fact, its use on the largest SBLOCAs will likely reduce the cross-flow over the entire channel, causing the PCTs to increase slightly for these break sizes. These breaks should remain non-limiting, however, because the uncovering duration is short.

The steam-region void-fraction cutoff should be set close to 1.0 during the core-uncovering phase. Consideration of the refill phase suggests that the steam-region void-fraction cutoff should be slightly less than 1.0 to prevent an increase in the resistance before there is a mixture level re-established in the volume. Accordingly, a void fraction [ ] was selected as a reasonable value that is appropriate for both the initial uncovering and refill periods for all SBLOCA transients.

In equation form, the form losses are defined for the positive flow direction (forward flow) from the average channel to the hot channel (i.e. Volume K is the average channel volume, Volume L is the hot channel volume).

Void fraction Check		Form Loss Factor	For Flow From
$\alpha_g(K) \le \alpha_{pool}$	Then,	$K_{forward} = K_{forward\ input}$ [ ]	average-to-hot
$\alpha_g(L) \le \alpha_{pool}$	Then,	$K_{reverse} = K_{reverse\ input}$ [ ]	hot-to-average
$\alpha_g(K) \ge \alpha_{stm}$	Then,	$K_{forward} = K_{forward\ input} * M_{forward\text{-}stm}$ [ ]	average-to-hot
$\alpha_g(L) \ge \alpha_{stm}$	Then	$K_{reverse} = K_{reverse\ input} * M_{reverse\text{-}stm}$ [ ]	hot-to-average

$\alpha_{pool} \le \alpha_g(K) \le \alpha_{stm}$	Then,	$K_{forward} = K_{forward\ input} * M^{Interpolated}_{forward-stm}$	average-to-hot
$\alpha_{pool} \le \alpha_g(L) \le \alpha_{stm}$	Then,	$K_{reverse} = K_{reverse\ input} * M^{Interpolated}_{reverse-stm}$	hot-to-average

where

$$M^{Interpolated}_{forward-stm} = 1-(1-M_{forward-stm})*\left[\frac{\alpha_{pool}-\alpha_g(K)}{\alpha_{pool}-\alpha_{stm}}\right],$$

$$M^{Interpolated}_{reverse-stm} = 1-(1-M_{reverse-stm})*\left[\frac{\alpha_{pool}-\alpha_g(L)}{\alpha_{pool}-\alpha_{stm}}\right],$$

[ ](average-to-hot)

[ ] (hot-to-average)

[ ]

[ ]

3.0 Summary and Conclusion

The void-dependent cross-flow option implemented in RELAP5/MOD2-B&W Revision 4 standardizes the SBLOCA cross-flow modeling approach used in BAW-10192PA. It is an improved code implementation that was developed from the original EM methods with a resistance model that responds mechanistically to the actual core mixture level. It preserves the three major conservatisms that were targeted or imposed by the EM cross-flow model selections. These conservatisms entailed (1) limiting the difference in the hot and average mixture levels to roughly one volume height or less, (2) forcing a low cross-flow resistance in the uncovered or steam region to maximize flow diversion out of the hot channel, and (3) restricting the average-to-hot channel steam region flow. These three conservatisms are preserved with the new void-dependent model.

A small set of limiting SBLOCA plant cases have been run with the new void-dependent cross-flow option, and these have been compared with the original fixed-resistance method application results. The PCTs have increased in some cases and decreased in others, but the general variation in PCTs is primarily influenced by the degree of conservatism imposed by the user-specified fixed cross-flow resistance step change location in the original application. The representative plant cases examined showed that the void-dependent cross-flow model PCT falls within the PCT range that can be produced by different user-selected locations of the fixed cross-flow resistance model. Therefore, based on this examination of these current SBLOCA application cases, FRA-ANP has concluded that this new void-dependent standardization will not provide any significant increase or decrease in the BAW-10192PA calculated SBLOCA PCTs for limiting SBLOCA analyses performed with a loss of offsite power (LOOP). Therefore, the void-dependent model will be included in future B&W-designed EM applications performed with Reference 1.

The new model has the added benefit in that it is responsive to faster transients with dynamic mixture level transitions and applications such as those with manual reactor coolant pump trip within the first several minutes after loss of subcooling margin. These applications, which are being performed as a result of Preliminary Safety Concern (PSC) 2-00, were not considered when the fixed resistance model was developed. The void dependent cross-flow model is well suited for applications such as these; therefore it was used for the PSC 2-00 analyses that will be submitted to the NRC in April, 2001.

The void-dependent cross-flow model with the inputs prescribed in this letter represents an automated form of the fixed core cross-flow resistance model that the NRC approved for use for SBLOCA applications with BAW-10192PA. The automated model retains the prescribed EM conservatisms from the original SBLOCA EM approach and standardizes the PCT predictions for LOOP or no LOOP transients for B&W-designed plants. Therefore, FRA-ANP intends to use the void-dependent model in all future SBLOCA applications performed with the BAW-10192PA EM.