FRAMATOME ANP
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FRAMATOME ANP, Inc.

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

Downcomer Boiling in Framatome ANP PWR ECCS Evaluation Models

Ref.: 1. Letter, Stephen Dembek (NRC) to James F. Mallay (Framatome ANP), "Potential Non-Conservative Modeling of Downcomer Boiling in the Approved Framatome ANP Emergency Core Cooling System Evaluation Model for Application to Certain Westinghouse and Combustion Engineering Designed Pressurized Water Reactors," June 3, 2002.

Ref.: 2. Letter, James F. Mallay (Framatome ANP) to Document Control Desk (NRC), "Potential Non-Conservative Modeling in Approved Appendix K Evaluation Models," NRC:02:035, July 11, 2002.

Ref.: 3. EMF-2103(P) Revision 0, "Realistic Large Break LOCA Methodology for Pressurized Water Reactors," Framatome ANP, Inc., August 2001.

Ref.: 4. Letter, James F. Mallay (Framatome ANP) to Document Control Desk (NRC), "Responses to a Request for Additional Information on EMF-2103(P) Revision 0, 'Realistic Large Break LOCA Methodology for Pressurized Water Reactors' (TAC No. MB2865)," NRC:02:062, December 20, 2002.

The NRC requested that Framatome ANP evaluate the impact of downcomer boiling and the need to model downcomer boiling on its Appendix K LBLOCA evaluation models in Reference 1. Framatome ANP responded to this request (Reference 2) and stated that its current evaluation models comply with the pertinent regulations on ECCS analysis and are acceptable for continued use in licensing applications. In addition, Framatome ANP performed evaluations of the impact of downcomer boiling on ECCS performance using its realistic LBLOCA model (Reference 3). The results of these evaluations are provided in Attachment A. Additional studies related to downcomer boiling were performed in response to an RAI from the NRC regarding the realistic LBLOCA model and are described in Reference 4. This response is included as Attachment B. Non-proprietary versions of Attachments A and B are also provided.

The evaluation in Attachment A demonstrates that the impact of downcomer boiling is small. Moreover, that impact is significantly less than the conservatism between the calculated results for a large break LOCA obtained using an Appendix K model and the conservative 95/95 PCT calculated from the realistic model.

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Framatome ANP concludes from its review of the regulations and the detailed evaluation described in Attachment A that the Framatome ANP Appendix K evaluation models comply with the pertinent regulations on ECCS analysis and are acceptable for continued use in licensee applications.

Framatome ANP considers some of the information contained in the enclosures to be proprietary. An affidavit is provided which satisfies the requirements of 10 CFR 2.790(b) to support the withholding of this information from public disclosure.

Very truly yours,

Jerald S Holm for

James F. Mallay, Director
Regulatory Affairs

Enclosures

cc: R. Caruso (w/enclosures)
D. G. Holland (w/enclosures)
Project 728

AFFIDAVIT

STATE OF WASHINGTON)
) ss.
COUNTY OF BENTON)

1. My name is Jerald S. Holm. I am Manager, Product Licensing, for Framatome ANP ("FANP"), and as such I am authorized to execute this Affidavit.

2. I am familiar with the criteria applied by FANP to determine whether certain FANP information is proprietary. I am familiar with the policies established by FANP to ensure the proper application of these criteria.

3. I am familiar with the FANP attachments to letter NRC:03:011 Rev. 1 regarding Downcomer Boiling in Framatome ANP PWR ECCS Evaluation Models dated April 4, 2003, and referred to herein as "Documents." Information contained in these Documents has been classified by FANP as proprietary in accordance with the policies established by FANP for the control and protection of proprietary and confidential information.

4. These Documents contain information of a proprietary and confidential nature and is of the type customarily held in confidence by FANP and not made available to the public. Based on my experience, I am aware that other companies regard information of the kind contained in these Documents as proprietary and confidential.

5. These Documents have been made available to the U.S. Nuclear Regulatory Commission in confidence with the request that the information contained in these Documents be withheld from public disclosure.

6. The following criteria are customarily applied by FANP to determine whether information should be classified as proprietary:

(a) The information reveals details of FANP's research and development plans and programs or their results.

(b) Use of the information by a competitor would permit the competitor to significantly reduce its expenditures, in time or resources, to design, produce, or market a similar product or service.

(c) The information includes test data or analytical techniques concerning a process, methodology, or component, the application of which results in a competitive advantage for FANP.

(d) The information reveals certain distinguishing aspects of a process, methodology, or component, the exclusive use of which provides a competitive advantage for FANP in product optimization or marketability.

(e) The information is vital to a competitive advantage held by FANP, would be helpful to competitors to FANP, and would likely cause substantial harm to the competitive position of FANP.

7. In accordance with FANP's policies governing the protection and control of information, proprietary information contained in these Documents have been made available, on a limited basis, to others outside FANP only as required and under suitable agreement providing for nondisclosure and limited use of the information.

8. FANP policy requires that proprietary information be kept in a secured file or area and distributed on a need-to-know basis.

9. The foregoing statements are true and correct to the best of my knowledge, information, and belief.

[signature]

SUBSCRIBED before me this 4th day of April, 2003.

[signature]

Susan K. McCoy
NOTARY PUBLIC, STATE OF WASHINGTON
MY COMMISSION EXPIRES: 1/10/04

SUSAN K. McCOY
COMMISSION EXPIRES
NOTARY PUBLIC
1-10-04
STATE OF WASHINGTON

Attachment A Evaluation of Downcomer Boiling

Framatome ANP notes the following facts concerning the matter of potential downcomer boiling:

- Framatome ANP is not familiar with any NRC-approved Appendix K evaluation model that models the downcomer during the reflood stage of a large break LOCA in sufficient detail to simulate boiling. In the absence of such a model, it is not possible to perform sensitivity studies on downcomer behavior, as suggested in Reference A.1.

- Downcomer boiling will be enhanced with decreased containment pressure. The net effect of downcomer boiling is to increase the core bypass and to increase the amount of water lost out the break. Appendix K includes a specific conservatism that addresses ECCS bypass by requiring that all ECCS water remaining in the core at the end of blowdown be discarded. The origin of this requirement was the uncertainty about the amount of ECCS water that is actually lost out the break, regardless of the timing of this phenomenon. Adding a specific requirement to address one part of this ECCS bypass, namely downcomer boiling, is effectively double accounting and is unnecessary to provide an adequate level of safety.

- No part of the NRC regulations (or its supplemental regulatory guidance) addresses the matter of downcomer modeling or downcomer behavior. The original criteria contained in 10 CFR 50.46 and Appendix K were based on assumptions that clearly provided significant conservatisms to account for uncertainties and unidentified phenomena. Specifically, Framatome ANP believes that the potential effect of downcomer boiling is more than compensated for by these intentional conservatisms to the extent that this particular phenomenon should not have to be accounted for in Appendix K evaluation models. On the other hand, realistic and best estimate models should include sufficient detail to address downcomer noding and the associated fluid behavior.

Information concerning the phenomenon of downcomer boiling is very limited, and published documents by the NRC consist of two internal memos. One memo is from S. M. Bajorek to J. E. Rosenthal of May 22, 2002. This same information is summarized in Attachment 4 to another memo from A. C. Thadani to S. J. Collins of June 20, 2002. The former memo relies on the analytical results contained in the FSAR for the Watts Bar nuclear power plant using a best estimate model. Information about this model and its application to Watts Bar are not available to Framatome ANP to evaluate. Based on our own evaluations, however, these results from Watts Bar appear to reflect modeling difficulties or inaccuracies and do not fairly represent the limited effect that downcomer boiling is expected to have on peak cladding temperature. Downcomer boiling is expected to have its primary effect on cladding temperature behavior following the initial peak and may or may not create a second peak as high as or higher than the first.

The first NRC memo reviews available experimental information, but these experiments do not support the PCT impact shown by the Watts Bar case. This lack of experimental validation may be due to inadequacies in the experiments or how they were instrumented, or it may reflect the limited or null effect this phenomenon has on cladding temperature.

Returning to the matter of the overall conservatism of Appendix K evaluation models, the following quote is taken from the end of the first internal memo cited above:

> *The findings discussed in this report are not meant to imply that calculations made using Appendix K Evaluation Models underestimate the peak cladding temperature (PCT) or equivalent clad reacted (ECR) in a large break LOCA. Appendix K requires the use of the 1971 ANS decay heat standard, which is known to be very conservative. Appendix K also requires several other conservative modeling assumptions. The conservatism associated with the 1971 decay heat model and these other Appendix K requirements* ***sufficiently compensates*** *for the downcomer boiling effect.* [Bolding added.]

Framatome ANP documented an evaluation of the impact of downcomer boiling using a realistic LBLOCA evaluation model during the NRC review of this methodology. This evaluation can be characterized as a study of the true physical impact of downcomer boiling on the PCT expected during a LOCA. This evaluation is documented as RAI #27 in Reference A.3. Five studies were performed to evaluate the impact of downcomer boiling in a PWR. The conclusions from the five studies are:

Study 1: The difference in PCT between a particular case with and without the modeling of downcomer boiling is about [ ] for a PWR with dry containment (containment pressure is about 30 psia). This difference is only applicable to an individual case and is not indicative of the change in the limiting PCT. [

]

Study 2: The evaluation of the influence of containment pressure during a LOCA on downcomer boiling shows that the net impact on PCT for an ice condenser or sub-atmospheric containment PWR (low containment pressure) is about [ ].

Study 3: The available experimental evidence confirms that the realistic LBLOCA model simulates downcomer boiling adequately. However, no experimental data exist for those conditions in which the model predicts downcomer boiling is most important; that is, low containment pressure during a LOCA.

Study 4: A sensitivity study was performed with respect to the impact of downcomer nodalization on downcomer boiling. The study concluded that downcomer boiling is adequately modeled by the nodalization used in the realistic LBLOCA methodology. The use of an increased number of nodes in the downcomer leads to lower PCTs, but this result is related to a better modeling of the fluid exiting the core and is not due to an improvement in the modeling of downcomer boiling.

Study 5: A sensitivity study was performed on the loss coefficients used in the downcomer. This was shown to have little impact on the PCT.

Following is a discussion of the evaluations performed to determine the effect of downcomer boiling using the realistic LBLOCA model. Two situations are addressed: a typical dry containment and a low pressure containment.

Evaluation of a Three-Loop Dry Containment PWR

An analysis was performed for a three-loop Westinghouse designed PWR with a minimum containment pressure greater than 30 psia. The analysis used the realistic LBLOCA methodology described in Reference A.2. The analysis produced the results summarized in Study 1 provided in Attachment B.

The realistic LBLOCA methodology models the boiling in the downcomer in a conservative manner. To assess the impact of downcomer boiling, the limiting realistic LBLOCA calculations from the analysis of a three-loop PWR were repeated by disabling the wall heat transfer within the downcomer and lower plenum. This effectively eliminates downcomer boiling from the calculation.

The methodology presented in Reference A.2 calculates the highest PCT among a randomly sampled set of 59 cases with a 95% probability at a 95% confidence level. Figure 1 shows the PCT as a function of time for the 59 calculations performed for a three-loop PWR. The results show a distinct temporal preference for the occurrence of the PCT: during blowdown (~15s), at the end of refill (~30s), and during late reflood (~100s). This behavior is relevant because the Appendix K methodology accounts for downcomer boiling through the end of bypass (~22s).

Figure 2 shows a comparison of the amount of vapor generation for the limiting PCT calculation (i.e., with downcomer boiling) and for the same calculation without downcomer boiling. These results show that boiling in the downcomer occurs during blowdown and in late reflood only. During the refill phase, little or no boiling occurred in the downcomer.

The first and third traces in Figure 3 show the PCT versus time for the limiting case (28) with and without downcomer boiling. Eliminating downcomer boiling reduces the late PCT from 1826 °F to [

]

To quantify the conservatism that inherently exists in the Appendix K methodology, a realistic LBLOCA analysis was performed using the same peaking factors as the limiting Appendix K three-loop LBLOCA analysis for the example plant. (The peaking factors for the analysis described in the preceding paragraphs are higher than can be supported by an Appendix K analysis.) [

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Evaluation of a Three-Loop Low Pressure Containment PWR

A similar study to that described above was done by simulating a three-loop PWR with a sub-atmospheric containment design. This analysis was performed to evaluate the effect of the downcomer boiling phenomenon for low minimum containment pressures during a LOCA. The minimum containment pressure for the realistic LBLOCA calculation presented here is about 10 psia. [

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An equivalent case for the simulated low pressure containment plant with a Framatome ANP Appendix K evaluation model is not currently available. It can be seen from the evaluation for a dry containment plant that the conservatism from the Appendix K required features is much larger than the impact of downcomer boiling in a low pressure containment plant.

Conclusions

The conclusions from these two evaluations are:

1. The PCT impact of downcomer boiling is shown to be between [ ]
2. The PCT impact of downcomer boiling is only significant for low pressure containment plants.
3. The PCT impact of downcomer boiling, even for low pressure containment plants, is not sufficient to offset the conservatism shown to exist in the Appendix K model.

Framatome ANP concludes that no adjustments are necessary to its Appendix K models to account for downcomer boiling. The Appendix K models are adequately conservative.

Figure 1 Scatter Plot of PCT vs. Time of PCT from Realistic LBLOCA Three-Loop Sample Problem

Figure 2 Vapor Generation Rate in Downcomer Broken Loop Sector

Figure 3 PCT Trends for the Limiting PCT Case (#28) with Downcomer Boiling

Figure 4 PCT vs. Time of PCT from Realistic LBLOCA Three-Loop Sample Problem at Current Appendix K Power Limits

Figure 5 Cladding Temperature from the Realistic LBLOCA Analysis Using Current Appendix K Power Limits

References:

A.1 Letter, Stephen Dembek (NRC) to James F. Mallay (Framatome ANP), "Potential Non-Conservative Modeling of Downcomer Boiling in the Approved Framatome ANP Emergency Core Cooling System Evaluation Model for Application to Certain Westinghouse and Combustion Engineering Designed Pressurized Water Reactors," June 3, 2002.

A.2 EMF-2103(P) Revision 0, "Realistic Large Break LOCA Methodology for Pressurized Water Reactors," Framatome ANP, Inc., August 2001.

A.3 Letter, James F. Mallay (Framatome ANP) to Document Control Desk (NRC), "Responses to a Request for Additional Information on EMF-2103(P) Revision 0, 'Realistic Large Break LOCA Methodology for Pressurized Water Reactors' (TAC No. MB2865)," NRC:02:062, December 20, 2002.

Attachment B Downcomer Boiling

Downcomer Boiling

Question 27: *The brief overview and description of large break LOCA behavior on Page 3-4 does not mention the potential for downcomer boiling. Downcomer boiling has been shown to be important in the transport of coolant to the core in the LBLOCA. Discuss the basis for the applicability of the S-RELAP5 simulation of the effects of downcomer boiling and the manner in which downcomer boiling has been treated in the RLBLOCA methodology. Include in the discussion the roll of the downcomer wall initial temperature in downcomer boiling.*

The PIRT in Table 3.3 does not include downcomer boiling. Please include in the discussion the exclusion of downcomer boiling from the PIRT.

Response 27: The downcomer boiling issue is included in the Framatome ANP PIRT under the label "Hot wall" phenomenon; in addition, downcomer boiling is also highly dependent on containment pressure, which is also a phenomenon appearing on the PIRT. Unlike many 10 CFR 50, Appendix K methodologies, S-RELAP5 simulates this phenomenon and its detrimental effects on core reflooding. [

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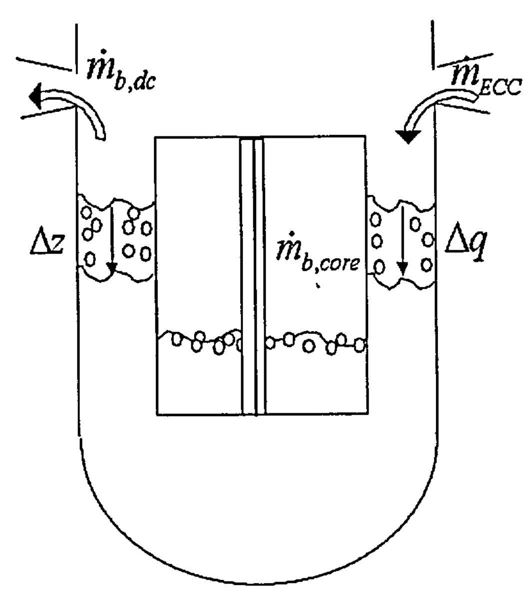
Downcomer wall temperature is initialized both in input and by a long steady-state calculation (800 s). Examination of wall temperatures following the steady-state calculation has shown good convergence.

Boiling is a phenomenon that codes like S-RELAP5 have been developed to predict and boiling in the downcomer is an observed phenomenon in S-RELAP5 LBLOCA simulations. Downcomer boiling is the result of the release of stored energy in vessel metal mass. Unlike many legacy LBLOCA methodologies, surface boiling is a modeled phenomenon for all components in an RLBLOCA analysis. Specifically, downcomer boiling is in the nucleate boiling regime and in S-RELAP5, nucleate boiling heat transfer is modeled using the Chen correlation. The implementation of the nucleate boiling model in S-RELAP5 has been validated through the prediction of several assessments on boiling phenomenon provided in the S-RELAP5 Code Verification and Validation document (EMF-2102).

Hot downcomer walls penalize PCT by two mechanisms: reducing subcooling of coolant entering the core and by the loss of coolant mass out the break from boiling along the downcomer ($\dot{m}_{b,dc}$, see figure at right). These processes reduce the density of the downcomer fluid and effectively lower the height of the liquid column in the downcomer which reduces the pressure driving force for reflooding the core. While boiling in the downcomer may occur at anytime during a LBLOCA transient, the biggest impact on clad temperatures will occur during late



reflood following the end of accumulator injection. At this time, there is a large step reduction in coolant flow from the ECC system ($\dot{m}_{ECC}$ in figure) and, at this same time, the coolant subcooling is being lost due to heat input from the downcomer metal mass. When this coolant becomes saturated, boiloff occurs which further reduces the effective downcomer level. With the reduction of the downcomer liquid level, the core reflood rates will be reduced and the clad temperatures will increase.

While this phenomenon can impact clad temperatures, it is a self-limiting process. As the downcomer liquid level decreases, less energy is released from the downcomer walls and the liquid level eventually stabilizes. (Note: The core liquid level will move with the downcomer level which will further contribute to this stabilizing effect.) This stable level is a function of the total energy release to the coolant. The largest component of the total energy is not from the downcomer but, rather, from the core to the coolant.

To what extent the liquid level decreases to a new stable level is dependent on the same characteristics that encourage boiling. Many of these factors, such as geometry, coolant flow rates, and power, are dependent on plant design and operation. Phenomenologically, boiling is most dependent on coolant properties, of which pressure is the key characteristic. (Note: Calculations with S-RELAP5 show that heat transfer from the downcomer metal mass becomes conduction-limited, resulting in heat fluxes that are insensitive to hydraulic variations.) The extent of the downcomer liquid level reduction is strongly correlated to the amount of coolant at the beginning of downcomer boiling, i.e., the maximum liquid level following the step change in ECCS flow and prior to boiling. Downcomer liquid level (collapsed) is directly related to how much coolant mass is lost out the break. This implies that the smaller breaks will have the higher pre-downcomer boiling liquid level and the larger downcomer liquid level reduction during downcomer boiling. Thus, downcomer boiling will have the largest impact on clad temperatures for the smaller breaks.

Several sensitivity studies have been performed using S-RELAP5 to demonstrate the primary simulation sensitivities to downcomer boiling phenomena and to establish a pedigree for S-RELAP5's capability to simulate downcomer boiling. These studies are summarized in the table below.

Study #	Description
1	With vs. Without DC Walls
2	Low Containment Pressure Plant RLBLOCA Analysis
3	SemiScale S-06-3 Benchmark
4	Finer Azimuthal Nodalization (6 axial x 9 azimuthal)
5	DC Cross Flow Form Loss (based on Idelchek formulation)

Study #1

Heat structures attached to the downcomer and lower plenum fluid volumes were decoupled so that heat released from these heat structures would not contribute to heating liquid in these regions (the decoupling was assumed to occur following accumulator discharge). Removing the heat structures will both prevent the reduction in subcooling and the boiling of coolant entering the reactor vessel. The base calculation was extracted from a preliminary RLBLOCA analysis of a three-loop plant. Figure 27.1 compares the PCT from these calculations for the condition with and without downcomer boiling for the case with the highest PCT, 1826 °F. This break is best described as a 93% double-end guillotine break to a dry containment. (Note: Generally, dry containment pressures during LBLOCAs are usually greater than 30 psia.)

Shortly after the accumulator discharges, boiling was observed along the downcomer sector adjacent to the broken loop, as seen in Figure 27.2; however, sustained downcomer boiling was not observed in the other two sectors until after 100 s. These two sectors received LPSI driven ECCS coolant that offset some of the heatup in the downcomer in this area. In comparing the "W/ DC walls" case to the "W/O DC walls" case, the collapsed liquid level shown in Figure 27.3 for the "W/ DC walls" case changes very little; however, it is obvious from the divergence in the liquid level results that at about 100 s downcomer boiling is removing a significant amount of liquid from the downcomer. This level differential represents the dominant condition influencing core reflood rate, and it is obvious in Figure 27.1 that downcomer boiling is a factor in raising clad temperature beginning after accumulator discharge. In fact, in this sensitivity study, the PCT contribution from downcomer boiling is about [ ].

Figure 27.1 PCT Trends with Downcomer Boiling

Figure 27.2 Vapor Generation Rate in Downcomer Broken Loop Sector

Figure 27.3 Core Collapsed Liquid Level Trends with Downcomer Boiling

It is Framatome ANP's experience that the PCT impact of downcomer boiling is predominantly the consequence of plant type, break size, and containment pressure. In the above sensitivity study on a three-loop plant, containment pressure was no lower than 30 psia at anytime during the late reflood period. This is relatively high compared to plants that incorporate ice condensers or more aggressive containment spray systems.

Study #2

To evaluate the effect of containment pressure, a complete RLBLOCA analysis was performed for a three-loop plant designed with a very aggressive containment cooling system capable of rapidly returning the containment pressure to near atmospheric conditions following a LBLOCA. To demonstrate the downcomer boiling sensitivity to break size, the worst split break and the worst guillotine break were identified. The break size of these cases was determined to be 36% and 89% for the split and guillotine break, respectively. The worst case guillotine break calculation was modified in a special calculation to be similar to the "W/O DC walls" calculation in Study #1. This calculation also modeled an increase in the ECCS coolant temperature to simulate the loss of subcooling that would occur from the downcomer walls.

Figure 27.4 shows a comparison of the PCT response from the limiting LBLOCA simulation (89% DEGB) for the low containment pressure plant and a "No Downcomer Boiling" calculation (no wall heat structures, elevated ECCS coolant temperature). The effect of downcomer boiling is dramatic; however, it only accounts for about a [ ] impact on PCT. The most noticeable difference is the time-at-temperature condition of the base case. For this reason, the effect of downcomer boiling and the low containment temperature will likely have a significant impact on oxidation. Figure 27.5 shows the collapsed liquid level response from these two calculations. In these calculations, the accumulator discharge ends near 60 s. At that time, both calculations show a dramatic decrease in collapsed liquid level as a result of the drop in coolant flow. (Note: The liquid level is also depressed somewhat from the nitrogen bubble that flows from the accumulator to the break.) After this initial drop, both calculations recover somewhat until subcooling is lost in the base case. At that time, the downcomer collapsed liquid level drops to about 9 ft and stabilizes. The calculation without the wall heat structures shows a relatively consistent increase in the liquid level.

Figure 27.6 shows the PCT response for the limiting split break. Through the end of accumulator discharge, clad temperature remains lower than the DEGB, as would be expected for smaller LOCAs that leave more coolant in the reactor vessel. After this time, there is a significant heat up of the hot pin (300 °F over the early reflood peak). In this calculation, the downcomer collapsed liquid level drops to about 12.5 ft, prompting the temperature excursion observed during the late reflood.

Figures 27.7 and 27.8 show PCT vs. Time of PCT graphs for the three-loop sample problem and the low containment pressure RLBLOCA analyses. The key distinction between these two graphs is in the preferences for the Time of PCT. For the dry containment, there are two distinct groupings around the early (30 s) and late (90 s) reflood periods. In the low pressure containment analysis, there is a distinct grouping during the early reflood period; however, an effect of the low pressure containment is an apparent spreading out of the late reflood grouping. Comparing the early reflood grouping between the two graphs, calculated PCTs are similar (although the dry containment results tend to be higher). However, there is little similarity between the late reflood groupings. The delayed cooldown predicted for the low containment pressure analysis clearly contributes to higher PCTs. In particular, split breaks are noticeably higher.

Figure 27.4 PCT from Worst Guillotine and "W/O DC Walls" Calculation

Figure 27.5 Collapsed Liquid Level from Calculations on Worst Guillotine Break

Figure 27.6 PCT from Worst Split Break Calculation

Figure 27.7 PCT vs. Time of PCT for Three-Loop Sample RLBLOCA Analysis

Figure 27.8 PCT vs. Time of PCT for Low Containment Pressure RLBLOCA Analysis

Framatome is aware of a LBLOCA simulation for the four-loop Westinghouse Watts Bar plant that attributes about 400 °F to a PCT penalty from downcomer boiling. We are unaware of all the assumptions applied in this simulation; however, there are a couple of aspects to this calculation that are unique: specifically, low pressure and break sizes that approach the small break region. As shown in this RLBLOCA analysis on the low containment pressure plant, S-RELAP5 has predicted similar characteristics with a downcomer boiling penalty as high as [ ] or more for smaller break sizes and low pressure. To date, none of these calculations have been a limiting analysis; however, the design of this RLBLOCA methodology does not preclude this possibility.

Study #3

No specific test program has explicitly addressed downcomer boiling; however, CCTF, LOFT, and SemiScale have all performed tests with hot downcomer walls. All the CCTF, LOFT, and SemiScale assessments performed for the "Evaluation of Code Bias" include hot downcomer walls. In addition, such scaled tests tend to over emphasize metal mass since it is impossible to scale down such structure without distorting hydraulic scaling. Generally, S-RELAP5 has been shown to match or bound clad temperature predictions. The main limitation of these tests is that the minimum pressure among these tests is about 30 psia. Similar containment pressure profiles were used in the PWR sample problems.

Possibly the best benchmark available for examining downcomer boiling is the SemiScale S-06-3 test. This test was included in the S-RELAP5 Code Verification and Validation. Unfortunately, that calculation as presented did not show significant downcomer boiling. For this reason, the modeling of this calculation was re-evaluated with the aid of one of the original SemiScale engineers (Tom Larson). His suggestion was to reexamine the modeling of the downcomer filler component and its contact with the downcomer vessel wall. This is primarily concerned with how to model the "filler gap," a space located between a filler mass and the vessel wall. Original documentation indicated that this filler gap was filled with air; however, according to the SemiScale engineer and verified through thermocouple measurements, this space filled with water during the transient and greatly enhanced the release of metal mass energy to the downcomer inventory.

Figures 27.9 and 27.10 show a calculation vs. test comparison of the peak clad temperature and liquid level (in terms of differential pressure) response, respectively. The liquid level specifically shows the post-accident refill, followed by a rapid boil off that stabilizes to about 2.5 psid. The downcomer boiling phenomena does not actually contribute to a higher peak clad temperature; however, it does extend the cool down period.

Figure 27.9 Semiscale S-06-3 Peak Clad Temperature Comparison to Data

Figure 27.10 Semiscale S-06-3 Downcomer Liquid Level Comparison to Data

Study #4

This sensitivity study consists of four calculations examining clad temperature sensitivity to downcomer nodalization. The base model, with 6 axial by 3 azimuthal regions (Figure 27.11), has been expanded to 6 axial by 9 azimuthal regions (Figure 27.12). The first calculation simulated is designed to be equivalent to the limiting PCT calculation given for the three-loop sample problem. The second calculation simulated increases the vessel side break flow discharge coefficients. The third and fourth calculations repeat the first two calculations using a low containment pressure plant (three-loop sample problem).

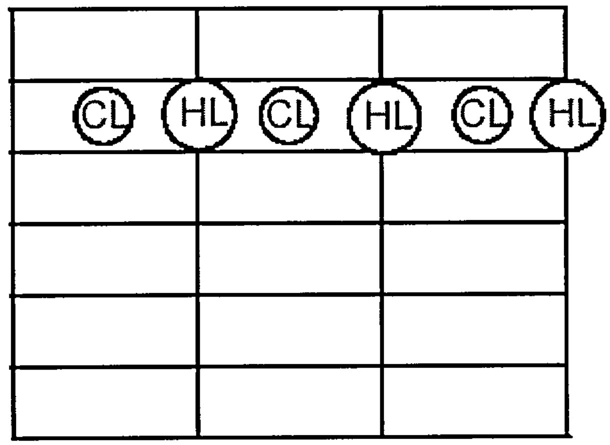


Figure 27.11 Base Model Nodalization Around Cold Leg Nozzles

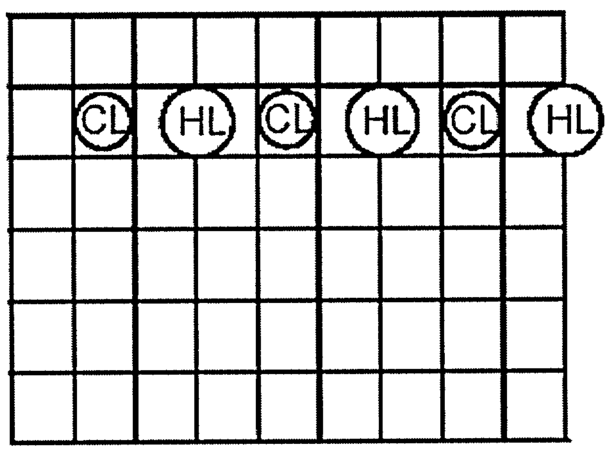


Figure 27.12 Renodalized Model Around Cold Leg Nozzles

Figure 27.13 presents the peak clad temperature responses for the conditions representing the three-loop sample problem from the renodalized and base models. The renodalized model has a significantly different response beginning at the end of blowdown. The clad temperature response shows a distinct blowdown peak in the sensitivity study that was not present in the base case. From the break flow and downcomer liquid level plots (Figure 27.15 and 27.15), it is obvious that in the sensitivity study that less RCS and ECCS coolant is going out the break during the early phases of the transient and is staying in the downcomer instead.

With basically equivalent models except for the nodalization in the downcomer, the source of this discrepancy is found in understanding how the nodalization influences the result. Referring to the Figures 27.11 and 27.12, the pathways from the intact loops to the broken loop can be traced out by following each optional pathway from the two sources to the one sink. In the base model, the pathways are few; flow moves from the source volumes in the downcomer to either up or down, then over to the broken loop sector, and out the sink volume. In the renodalized model, there are more pathways possible. The effect is an increase in the mean free path between the source to the sink volumes for the model with the finer nodalization. By moving to finer and finer nodalization, the change in the mean free path would evidently become negligible; however, there is a penalty in code runtime.

For LBLOCA applications, the remarkable characteristics of the simpler nodalization scheme is that it contributes to a conservative clad temperature bias. Downcomer phenomena impacting clad temperatures are many, including hotwall, boiling, CCFL, condensation, and multi-dimensional effects, and the relative contributions of each of these phenomena are difficult to separate and assess. This was the conclusion of the Technical Program Group that developed the CSAU methodology. Like the TPG, the Framatome RLBLOCA methodology has demonstrated the conservatism of the simple nodalization through assessment (primarily against full-scale UPTF tests) and sensitivity study (this nodalization study). By consistently applying this nodalization in assessments and in licensing calculations, the code bias and uncertainty associated with nodalization is passed to all similar calculations. This was the conclusion of the TPG.

Nonetheless, maintaining the simpler nodalization does not fully address downcomer boiling sensitivity to nodalization. For this reason, a second calculation was performed using the renodalized model in which the break flow discharge coefficients were increased so that the break flow during the early phase of the transient would be nearly equivalent to that in the base model calculation. By doing this, downcomer inventory at the beginning of reflood would be approximately the same as the base case, thus, providing for the key boundary condition for assessing boiling in the downcomer. Figure 27.16 provides the peak clad temperature response from this calculation compared to the base case. Figures 27.17 and 27.18 present break flow and downcomer liquid level plots that demonstrate that similar beginning of reflood conditions for downcomer inventory exist as the result of increased break flow.

From the peak clad temperature plot, it is seen that the two cases present very similar results. The finer nodalization model is still impacted by the longer mean free paths as observed in the first sensitivity calculation; hence clad temperatures are still lower. Relevant to the downcomer boiling issue was whether having more modeled heat structure surfaces cooled by ECCS (i.e., not directly under the cold leg nozzles) would in some way influence how the bulk rate of boiling in the downcomer was calculated. The key measures addressing this concern are downcomer liquid level, downcomer temperatures, and, by virtue of the application, clad temperatures.

No indication of a phenomenological discrepancy is discernable from the downcomer liquid level response in Figure 27.18 and the clad temperature response shown in Figure 27.16. Figure 27.19 shows the coolant liquid temperature vs. saturation temperature for an azimuthal slice in the downcomer between the broken loop and the intact loop. It can be seen that as one moves away from the broken loop, the subcooling of the liquid increases. Comparison of this figure to Figure 27.20 presenting the same temperatures for the base case shows that in the simpler nodalization subcooling is less for the nodes directly under the intact loops and more for the nodes directly under the broken loop; hence, on the average, the same amount of heat is being removed in both calculations. In both calculations it is shown that boiling diminishes with time.

Heat transfer out of the downcomer walls becomes conduction-limited and despite the large amount of stored energy remaining in the heat structures, the heat transfer at the wall surface is adequately handled by the flow of LPSI-supplied ECC and subcooling returns.

Figure 27.13 Peak Clad Temperature Comparison of the Renodalization Model to the Base Model

Figure 27.14 Break Flow Comparison of the Renodalization Model and the Base Model

Figure 27.15 Downcomer Collapsed Liquid Level Comparison of the Renodalization Model and the Base Model

Figure 27.16 Peak Clad Temperature Comparison of the Modified Renodalization Model to the Base Model

Figure 27.17 Break Flow Comparison of the Renodalization Model and the Base Model

Figure 27.18 Downcomer Collapsed Liquid Level Comparison of the Modified Renodalization Model and the Base Model

Figure 27.19 Downcomer Saturation and Liquid Temperatures in Second Renodalization Sensitivity Study Calculation

Figure 27.20 Downcomer Saturation and Liquid Temperatures in the Base Case

Downcomer boiling is known to be highly sensitive to containment pressure. For this reason, the two nodalization sensitivity calculations were performed for a plant with an aggressive containment cooling system. Figure27.21 provides the peak clad temperature response from the "renodalized-only" calculation (74) compared to the low containment pressure base case (16) for this separate RLBLOCA analysis. As with the first calculation, the break flow and downcomer liquid level plots (Figure 27.22 and 27.23) show that less RCS and ECCS coolant is going out the break during the early phases of the transient and staying in the downcomer.

Figure 27.24 compares the peak clad temperature response for the "renodalized + flow" calculation (75) with that from the low containment pressure base case (16). Like the second calculation, the key measures addressing this concern are downcomer liquid level, downcomer temperatures, and clad temperatures. Comparison of these measures provided in Figures 27.24-27.26 to those provided for the three-loop sample problem show similar characteristics. There is no indication of any phenomenological discrepancies related to the prediction of downcomer boiling between these calculations.

Figure 27.21 Peak Clad Temperature Comparison of the Renodalization Model to the Base Model (Low Pressure Plant Analysis)

Figure 27.22 Break Flow Comparison of the Renodalization Model and the Base Model (Low Pressure Plant Analysis)

Figure 27.23 Downcomer Collapsed Liquid Level Comparison of the Renodalization Model and the Base Model (Low Pressure Plant Analysis)

Figure 27.24 Peak Clad Temperature Comparison of the "Renodalized + Flow" Model to the Base Model (Low Pressure Plant Analysis)

Figure 27.25 Break Flow Comparison of the "Renodalized + Flow" Model and the Base Model (Low Containment Pressure Plant)

Figure 27.26 Downcomer Collapsed Liquid Level Comparison of the "Renodalized + Flow" Model and the Base Model (Low Containment Pressure Plant)

Study #5

Two calculations have been performed to determine clad temperature sensitivity to best-estimate cross flow form loss resistances (friction is inherently treated in S-RELAP5). The form loss calculation applies the Idelchek reference for flow through a curved pipe or rectangular duct. Using an angle of curvature of 120°, this results in a form loss of 0.1167. This loss is applied along the junctions of the three azimuthal sectors in the base case model (not the renodalized model). The two calculations are derived from the limiting calculations for the three-loop sample problem (in figures, case 66 vs. 41) and from a RLBLOCA analysis of a low containment pressure plant (in figures, case 80 vs. 16). Figures 27.27 and 27.28 show the clad temperature results for these two calculations.

The dominant result in the first calculation is that beginning-of-reflood occurs earlier as a result of less fluid lost from the break. Outside of the clad temperature and downcomer liquid level plots, other key variables are very similar to the base case. The early beginning-of-reflood was not observed in the second calculation. This may be related to differences in the influence of steam binding related to the different containment pressures. A comparison of reflood rates between the two calculations shows that during the early reflood period, the reflood rate from the low pressure plant calculation is significantly lower. The lower reflood rate is indicative of a greater resistance to flow from the downcomer to the upper plenum and out the break. This resistance is likely the dominant resistance to flow into the reactor vessel rather than the effect of the added cross sectional form losses. As a consequence, the effect of the added cross sectional form loss on clad temperatures is minimal, about 14 F.

The sensitivity calculation does show a later quench time. However, comparison of the total oxidation actually shows that the base case is somewhat higher than the sensitivity calculation. This suggests that for the majority of the transient, the calculations are very similar. There is an accumulative effect from the inclusion of the cross flow form losses that limits how much heat is being removed from the downcomer walls in the form of steam. The result is a delayed quench. This can be seen in the downcomer collapsed liquid level (Figure 27.29). The base case calculation clearly shows that near the end of the calculation, the rise in the downcomer liquid level is more rapid than in the sensitivity calculation. Measuring the importance of these differences relative to the primary acceptance criteria, PCT, for a LBLOCA, these differences are minor.

Figure 27.27 Peak Clad Temperature Results from Cross Flow Resistance Study

Figure 27.28 Peak Clad Temperature Results from the Cross Flow Resistance Study on the Low Pressure Containment Plant

Figure 27.29 Downcomer Collapsed Liquid Level Responses for the Cross Flow Resistance Sensitivity Study and the Base Case for a Low Containment Pressure Plant

<u>Downcomer Boiling Summary</u>

The key sensitivities for downcomer boiling are break size and containment pressure. Sensitivity studies have been done for both of these parameters during the development of this RLBLOCA methodology. In all the studies performed for lowered containment pressure, clad temperature increased. Studies on break size showed that there tends to be a break size that minimizes blowdown heat transfer and that tends to provide the highest clad temperatures. Sensitivity studies on interfacial drag have not shown a strong influence on clad temperatures. Injection subcooling is considered a Plant Parameter that is treated on a plant specific basis. In sample problems, it has been conservatively treated (minimized). A time step sensitivity study is presented in Appendix C of EMF-2103 Revision 1.