ISL-NSAD-TR-02-16

Technical Evaluation Report
of the
FTI-Lynchburg Appendix K LOCA Code, Rev. 5
BEACH Topical Report BAW-10166
Appendices H and I

by

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November 2002

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Prepared for

Division of Systems Safety and Analysis
Office of Nuclear Reactor Regulation
U. S. Nuclear Regulatory Commission
Washington, DC 20555

Under
Contract No. NRC-03-00-003, Task Order No. 21
JCN J2976

ABSTRACT

Information Systems Laboratories, Inc. (ISL) reviewed the proposed change to the FTI-Lynchburg Appendix K LOCA Code, Rev. 5, BEACH, Appendices H and I. The BEACH code computes the hot channel response during reflood following a large break LOCA and is part of a suite of codes employed to simulate the blowdown, refill, and reflood phases of a large break LOCA. The proposed change includes extending the reflood range of applicability for the BEACH code from the presently accepted reflood rate of 0.5 in/sec down to and including 0.3 in/sec. Framatome also proposes to extend the initial clad temperature range to include a maximum clad temperature of 2045 °F, an increase from the previously approved maximum clad temperature of 1640 °F. Framatome utilized the FLECHT-SEASET reflood test data and presented sensitivity studies to demonstrate BEACH is capable of bounding the PCT for reflood rates down to and including 0.3 in/sec. However, plant calculations for North Anna showed that the reflood system code, REFLOOD3B, terminated prior to completion of the run. As such, quench in the upper portion of the core was not predicted to occur while clad temperatures remained in excess of 1600 °F with a very slow rate of temperature decrease. The REFLOOD3B reflood system analysis code terminated because of bulk boiling in the vessel downcomer and lower plenum, which the code cannot accommodate. Because the analysis cannot be completed, clad oxidation cannot be assessed. As such, with the inability to complete the Appendix K licensing analysis of the North Anna plant, ISL recommends that the proposed model change to BEACH not be accepted at this time. Should Framatome, at a future date, correct the termination error in REFLOOD3B and complete the analysis, with other recommended modifications to BEACH, the review of the proposed changes to BEACH can be completed. As an alternative, ISL has included in this report a suggested course of action that could serve as an interim measure to support the licensing of the North Anna nuclear steam supply system. This interim approach includes substituting an alternate reflood system analysis code that can handle boiling. This approach is to be considered an interim measure that represents a viable alternative that would enable Framatome to commit to the Staff to either correct the deficiencies in the REFLOOD3B code or replace it with a working system code which would enable the reflood phase of the analysis to be completed through quench of the core.

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EXECUTIVE SUMMARY

This report documents the review of the FTI-Framatome BEACH reflood heat transfer code for use in performing Appendix K large break LOCA emergency core cooling performance assessments. The proposed change to the BEACH code includes extending the reflood rate range of applicability from the currently approved reflood rate of 0.5 in/sec down to and including 0.30 in/sec. Framatome also proposes to extend the initial clad temperature range to include a maximum clad temperature of 2045 °F, an increase from the previously approved maximum clad temperature of 1640 °F. Framatome compared the BEACH predictions with the FLECHT-SEASET reflood tests to demonstrate that the BEACH code can accommodate reflood rates down to 0.36 in/sec. Framatome demonstrated that the BEACH code over-predicted or conservatively bounded the high clad temperature responses for FLECHT tests 8037 and 0791 at all locations on the rod at the time of the peak clad temperature (PCT). These tests were performed at a reflood rate of 0.4 in/sec., where the PCT for these FLECHT tests were over-predicted by about 100 °F. To justify the lower reflood rate of 0.30 in/sec., Framatome showed that the PCT was captured when extrapolated beyond the 0.36 in/sec reflood rate. That is, the over-prediction in PCT at the 0.30 in/sec was greater than that for the same decrease in reflood rate in the range of slightly higher reflood rates where FLECHT data was available. The extrapolation from 0.36 in/sec to 0.30 in/sec is considered justified, however it is noted that only one FLECHT test included a system pressure at 15.0 psia. Benchmarking of BEACH at low system pressures is lacking for cases where plant calculations approach 14.7 psia.

Moreover, when a plant calculation was requested and performed, the results of the North Anna large break LOCA was transmitted to the Staff and showed a REFLOOD3B reflood system code termination when the system pressure achieved a low value of 14.7 psia when downcomer boiling ensued. As a consequence, the plant calculation could not be continued and ended with the clad temperature in excess of 1600 °F. Because the temperature decrease at the time of code failure was slow, quench would not occur for an extended period of time. Since clad oxidation continues, termination of the run precludes the total oxidation for the hot rod and core wide calculation from being determined. Because peak local and core wide oxidation could not be calculated and the core was not demonstrated to be returned to acceptably low temperatures, the proposed model changes and plant analyses are not recommended for approval.

The REFLOOD3B system code termination is due to the achievement of saturated conditions in the downcomer and lower plenum where bulk boiling developed. Since REFLOOD3B only accommodates single-phase flow, saturated bulk boiling conditions will cause the code to terminate. Recognizing this limitation, ISL suggests the following interim measures to enable the proposed changes to BEACH be recommended for approval and include:

1) Replace the REFLOOD3B system code with an equivalent system code, for example; RELAP5;

2) Include similar models, boundary conditions, geometry, and system resistance etc. to reproduce the REFLOOD3B reflood rates, system pressures, and temperatures up to the time of the REFLOOD3B failure.
3) Run the RELAP5 code beyond the REFLOOD3B failure to generate reflood heat transfer boundary conditions for use in BEACH to compute reflood heat transfer coefficients and the resultant PCT through and including quench of the core. This will enable the peak local and core wide clad oxidation rates to be computed as an interim measure, but will also demonstrate that the core can be reduced to acceptably low temperatures.

The above proposed method would enable Framatome to support the North Anna plant and would be considered an interim measure until Framatome could, at a later date, either correct the REFLOOD3B code deficiency or submit a replacement system reflood code capable of handling bulk boiling in the system. ISL suggests this approach and recommends the Staff consider this an alternative interim method. Framatome would then commit to correct the deficiency in REFLOOD3B or submit an alternative system code at some future agreed upon date with the Staff. Framatome would also have to address addition recommendations contained in this technical evaluation report.

Based on the overall review of the BEACH code and North Anna plant calculations, some additional recommendations and modifications to BEACH are further recommended. These include limiting the minimum drop size to 0.5 mm to preclude the BEACH code from artificially calculating drop sizes well below that supported by the FLECHT reflood test data. Small drop sizes produce high rates of interfacial heat transfer during reflood which can cause large reductions in PCT that are not justified by the reflood test data, especially at low system pressures approaching atmospheric conditions.

The recommendations contained in this technical evaluation report identify suggested changes to BEACH as well as an alternate approach that could be used to analyze the North Anna plant on an interim basis or until that time code deficiencies in the Framatome REFLOOD3B reflood code can be corrected or replaced.

PREFACE

This report was prepared for the U.S. Nuclear Regulatory Commission, Office of Nuclear Reactor Regulation, by Information Systems Laboratories, Inc.

Technical Evaluation Report
FTI-Lynchburg Appendix K LOCA Code, Rev. 5
BEACH Topical Report BAW-10166
Appendices H and I

1.0 INTRODUCTION

The Code of Federal Regulations in 10 CFR 50.46 and Appendix K to 10CFR Part 50 describe the requirements for computer codes used to analyze the loss-of-coolant accident in light water reactors using zircaloy clad fuel. The NRC Staff reviews and approves the computer codes for all licensing based applications. Often, the Office of Nuclear Reactor Regulation requests outside technical assistance to review such codes and methodologies and has asked Information Systems Laboratories, Inc. to provide assistance in the review of the proposed change to the Framatome BEACH reflood code used to assess the performance of the hot channel during reflood following a large break LOCA. Specifically the request for assistance includes evaluating the the proposed change to BEACH which extends the range of applicability of the BEACH reflood rate from the currently approved reflood rate of 0.5 in/sec to the proposed reflood rate of 0.3 in/sec. Framatome also proposes to extend the initial clad temperature range to include a maximum clad temperature of 2045 °F, an increase from the previously approved maximum clad temperature of 1640 °F. This section describes the review of the proposed changes to the BEACH code.

2.0 EVALUATION OF PROPOSED CHANGES TO BEACH

The BEACH code is one of several codes employed by Framatome to assess emergency core cooling performance following a large break LOCA. Specifically, BEACH computes the hot rod response during the reflood phase of the LOCA and requires boundary conditions, in particular, the reflood rate, calculated by the REFLOOD3B system code employed during reflood. The proposed change to be evaluated is to extend the range of applicability of the BEACH from the currently approved reflood rate of 0.5 in/sec down to and including 0.3 in/sec. This section describes the review of BEACH and the proposed change.

To demonstrate applicability of BEACH down to reflood rates of 0.30 in/sec, it is necessary to compare the BEACH predictions to the FLECHT-SEASET reflood test data. Since the FLECHT data only includes reflood tests down to reflood rates of 0.4 in/sec, extrapolation beyond 0.4 in/sec is necessary. Framatome compared the BEACH predictions with the FLECHT database for a large range of reflood rates and system pressures (See Refs. 5.1 and 5.2). Framatome also performed additional sensitivity studies to cover the low reflooding rate range by performing an analysis of FLECHT – SEASET Test 31805 with a reflood rate of 0.81 in/sec assuming a range of lower reflood rates down to and including the low reflood rate of 0.36 in/sec. The results of the study showed the following peak clad temperature (PCT) predictions:

Reflood Rate (in/sec)	Temperature Rise (°F)
1) 0.97 (Test 31504)	593 (Data) 715 (BEACH)
2) 0.81 (Test 31805)	687 (Data) 880 (BEACH)
3) 0.72	970.4 (BEACH)
4) 0.60	1165.2 (BEACH)
5) 0.45	1567.0 (BEACH)
6) 0.36	2048.0 (BEACH)
7) 0.30	failed (BEACH)

The power for these cases was the same (0.7 kw/ft) as was the pressure (40 psia). Cases 3) through 6) represent sensitivity cases relative to the base case FLECHT test 31805. Note that no additional FLECHT runs for Test 31805 were run for the reflood rates assumed in the study for Cases 3) through 6). The simulation at a reflood 0.30 in/sec failed because of clad temperatures in excess of 2500 °F, and the code terminated.

The BEACH predictions for two FLECHT tests 8037 and 0791 in Ref. 5.2 demonstrated that at the time of PCT, BEACH captured the clad temperature distribution along the entire axis of the rod while the PCT was over-predicted by 100 F at the PCT location for test 8037. These tests resulted in PCTs near 2500 °F and are considered challenging tests for a phenomenologically based reflood model. Of concern was the fact that BEACH predicted an early quench for test 8037 and when questioned in an RAI, Framatome responded that this was a very limited occurrence. When further questioned, Framatome was requested to review their reflood simulations for the FLECHT and FLECHT-SEASET data and noted that early quench was not predicted in their other benchmarks (Ref. 5.3), stating this was an "outlier" occurrence. ISL found this response acceptable.

ISL also requested plots of predicted versus PCTs for the FLECHT-SEATSET data comparisons. These responses to the RAIs (Ref. 5.3) showed that BEACH captured the PCT for approximately 80% of the data at all elevations. It is noted that when the initial clad temperatures were adjusted by the initial differences, differences between the measured and BEACH predictions were reduced and the peak reported temperatures were essentially the same as the BEACH prediction. While only a few temperatures were not captured by BEACH, these comparisons are considered reasonable predictions of reflood PCT behavior.

Lastly, Framatome provided comparisons to two gravity FLECHT Tests, 3215B and 3316B, which produced reflood rates between 0.3 and 0.5 in/sec covering this lower reflood rate range. Although the PCTs for these tests were only 1600 °F, they demonstrated that BEACH over-predicted these tests by 200 to 300 °F. Framatome also presented results of BEACH comparisons at the higher reflood rates to cover the range of conditions expected in the plant analyses (Tests 31701, 31203, and 34006). These tests also demonstrated adequate performance at the higher reflood rates. Framatome also noted that the inability of the BEACH code to capture the clad temperatures above the five foot elevation for tests 35807 and 35912 were due to questionable data caused by bundle distortion for the group 1 rods. The group 1 rods were lower power than the group 2 and 3 rods, which were captured by the BEACH simulation. ISL agrees with explanation.

Based on the sensitivity studies performed on Test 31805 above and the fact that Framatome captured the PCT for two high temperature tests with the BEACH predictions, ISL believes that BEACH can capture the PCT down to reflood rates of 0.3 in/sec. It is important to note that this conclusion needs to be confirmed in view of the concerns regarding the lack of a rod-to-rod thermal radiation model and its implications on dispersed flow film boiling model development discussed in Section 2.2 below.

2.1 Effect of Droplet Diameter

Because BEACH will be applied at very low reflood rates, it was necessary to understand the ability of the code to predict droplet size since the droplet diameter affects the degree of steam superheat and ultimately the PCT. When questioned in an RAI, Framatome demonstrated that the drop size for FLECHT-SEATSET test 31805 at the time of PCT remained consistent with the data. However, the droplet diameter for Test 31805, the lowest reflood rate test (0.81 in/sec) predicted by BEACH, achieved diameters approaching 0.5 mm, which is somewhat smaller than the average droplet diameter of the observed value of 0.75 mm presented in Ref. 5.4. While these results are considered acceptable, there are no constraints that the droplet diameter could not be calculated to be smaller than the minimum diameter for this, or other FLECHT tests (see Ref. 5.4), which is about 0.5 mm. When questioned Framatome stated that there are no limits placed on the drop size in BEACH.

To better understand the influence of droplet diameter on PCT, a sensitivity study on restricting the droplet diameter was suggested by ISL. The results of the study on Test 31805 revealed the following results:

Minimum Drop Diameter (mm)	PCT (°F)
1) no limit	1998
2) 0.1	1998
3) 0.2	1997
4)0.4	1992
5)0.5	2013
6)0.6	2026
7)0.8	2087
8)1.0	2155

Framatome noted that the case at 0.3 mm would not execute. The results of this study showed that employing a minimum droplet diameter of 0.5mm increases PCT by only 15

°F. Since this drop size of 0.5 mm is a lower limit for the drop sizes typical of the FLECHT-SEASET test data in Ref. 5.4, it is recommended that lower limit be imposed on the BEACH code to preclude the code from artificially computing low drop sizes that could significantly reduce the calculated PCT. Since the drop size is a strong function of the reflood vapor velocities, which can fluctuate heavily during reflood due to the hydraulic conditions as well as numerical oscillations, imposing the minimum drop size will preclude BEACH from predicting too low of a drop size during reflood. This limit represents a negligible change in PCT of 15 °F as noted in the above sensitivity study, but would preclude BEACH from predicting unrealistically low droplet sizes.

Framatome noted that the FLECHT bundle contained structural grids without mixing vanes in contrast to the Framatome bundles with mid span mixing grids. Framatome contends that these grids will produce drop sizes smaller than the 0.5mm size given in the FELCHT data. While ISL agrees that this may be the case, there is no data to demonstrate or support this benefit. A minimum drop size of 0.5 mm is recommended.

Also, the FLECHT database has limited data below 20 psia. Only one BEACH test simulation (FLECHT Test 0791 which captures the PCT) in Ref. 5.2 was performed at 14.7 psia by Framatome. As a result, there is limited data to demonstrate BEACH capabilities below 14.7 psia. As such, should plant calculations show the containment system pressure decreases below 14.7 psia prior to quench, additional justification of the applicability of BEACH to low pressure reflood would be needed. Under these conditions, RCS pressures could fall below the minimum pressure (i.e. 14.7 psia) of the FLECHT database.

2.2 Rod-to-Rod Thermal Radiation

ISL also questioned the comparison of the BEACH calculated reflood convection heat transfer coefficient to the FLECHT data since FLECHT includes rod-to-rod radiation and BEACH does not. That is, BEACH computed convection heat transfer coefficients without surface-to-surface radiation included. To compare BEACH convection heat transfer coefficients to the data in a proper manner, rod-to-rod radiation should be subtracted from the test data. Framatome responded that rod-to-rod radiation is negligible (See the response to RAIs in Ref. 5.3) since the power profile is flat in FLECHT-SEASET. ISL disagrees with Framtome and performed surface to surface radiation calculations that showed the radiation contribution in FLECHT test 31805 was 22.8% of the total heat transfer rate due to the location of the hot rod near the thimble tubes which are at 1800 °F while the hot rod at the time of PCT was 2101 °F. Although the radial power profile is flat, the thimbles represent appreciable thermal radiation heat sinks. If the immediate neighbors surrounding the hot rod are assumed to be on the average 25 °F cooler than the hot rod reflecting the variation in the rod temperatures during the tests, the thermal radiation is computed to be 33.9 percent of the total heat transfer rate. The Appendix presents a brief overview of the model used to compute the rod-to-rod radiation contribution, the computer program and model, which utilized a 5x5 rod array with the hot rod located in the center, and the results of specific assessments for two FLECHT-SEASET tests. Specifically, the Appendix presents an assessment of

FLECHT Tests 31805 and 31405. These calculations show that surface-to-surface radiation can be in the range 25-35% of the total heat for the hot rod in the FLECHT tests and is consistent with Hochreiter's assessment of the FLECHT facility given in Ref. 5.5 where he states thermal radiation can be as much as 35% of the total heat transfer rate. For FLECHT Skewed and Cosine series tests where a radial power was simulated in the tests, rod-to-rod radiation can even be higher.

ISL inquired that if radiation was subtracted from the FLECHT test data, how would this have influenced the model development? Would Framatome have chosen more limiting interfacial heat transfer models or tuned their droplet models to slightly higher droplet sizes to better predict the adjusted lower reflood heat transfer coefficient data (adjusted downward to reflect the removal of thermal radiation) for example since the heat transfer coefficient may now be overpredicted by BEACH? While Framatome was uncommitted as to how their model would have been developed in view of this consideration, ISL feels that such an approach would be consistent with good engineering practice. It certainly would be in the spirit of incorporating the correct physics into the methodology. It is even recommended in Regulatory Guide 1.157 that methods be employed to adjust for thermal radiation effects when benchmarking against reflood data. In any event, this issue was not properly addressed by Framatome in the RAI response (see Ref. 5.3) to the satisfaction of ISL. Since this is a deficiency that continues to plague both best-estimate and Appendix – K reflood model development, it is an issue that needs to be properly resolved since this oversight could appreciably affect the development of dispersed flow film boiling heat transfer models. Framatome, therefore, needs to address the impact of rod-to-rod radiation on the development of the dispersed flow film boiling model, and this issue remains an open item.

2.3 Extension of the Maximum Initial Clad Temperature

Framatome also requests extension of the initial maximum clad temperature range from 1640 °F to 2045 °F based on comparisons to FLECHT Test 34420. BEACH predictions of this test showed that the PCT was captured. Other key parameters (i.e. heat transfer coefficient, quench front advance, and quench time were also successfully predicted or bounded by the BEACH prediction. The simulation also captured temperatures along the upper portion of the fuel rod. As such, ISL finds the extension to the higher initial clad temperatures justified based on these comparisons.

2.4 Large Break LOCA Example Appendix K Analysis

Lastly, Framatome was requested in an RAI to present the results of an analysis of a nuclear steam supply system (NSSS) to show sample or representative results of BEACH at low reflood rates requested in the proposed change. The results (Ref. 5.6 and 5.7) for the North Anna NSSS for the limiting large break LOCA were presented however, the analysis was terminated at 400 seconds when the REFLOOD3B reflood system code failed when the fluid in the downcomer and lower plenum achieved saturation during late reflood. The PCT was calculated to be about 2000 °F at 200 seconds but only decreased to just above 1600 °F at 400 seconds where the temperature decay is very low or nearly flat. This suggests that quench of the upper portion of the core will not occur for an extended period of time since quench during reflood typically occurs at temperatures 850 to 900 °F. Since peak local and core wide clad oxidation is dependent on the time at temperature, an assessment of the oxidation cannot be made since quench has not been calculated. Furthermore, Criterion 5 of 10CFR50.46 states that the core temperatures should be reduced to acceptably low temperatures and was not demonstrated in this plant analysis. As a consequence, peak local and core wide oxidation percentages have not been shown to meet 10CFR50.46 limits. In view of these limitations, ISL recommends that the BEACH code proposed changes not be accepted for use in performing ECCS Appendix K licensing analyses at this time.

Because this finding will not allow Framatome to perform a completed ECCS licensing analysis, ISL suggests an interim approach described in the following section that could enable Framatome to support the North Anna NSSS.

2.5 Suggested Alternative or Interim Solution

As discussed above, the REFLOOD3B reflood code cannot handle saturated boiling in the system, an alternative approach is recommended. This approach includes applying another thermal hydraulic code. For example, the RELAP5 code or other suitable alternative that can accommodate boiling conditions could be used in place of the REFLOOD3B code to perform the system reflood calculation. The following approach is suggested:

1) Employ an alternate system code such as RELAP5 or TRAC or suitable alternative to represent the reactor coolant system during reflood.
2) Input similar geometries, boundary conditions, loop resistances, etc. to reproduce the reflood behavior predicted by REFLOOD3B up to the time of the code failure. Demonstrate that this alternative code reproduces the reflood rate, and system pressure computed by REFLOOD3B up to the time of failure. Show that the alternate code boundary conditions reproduce the same heat transfer coefficients and hence PCT response in BEACH that REFLOOD3B did up to the failure time.
3) Extend the alternate code out in time until the entire core has quenched, using the calculated boundary conditions and pertinent results from the alternate code as input to BEACH so the hot channel PCT and oxidation percentages can be computed.
4) If downcomer boiling in bulk occurs, justification for the downcomer modeling and nodalization both in the azimuthal and radial directions, and cross flow resistance modeling will also be necessary. Demonstrate that the worst single failure for cases without downcomer boiling remains the worst single failure. For example, if no failure is the worst failure when the PCT occurs during reflood without downcomer boiling, then a diesel failure or LPSI failure may be worse during downcomer boiling since pumped injection affects the subcooling and boiling in the downcomer during late reflood.

It is also mentioned that Framatome noted that the proposed change to extend the BEACH code application down to the 0.30 in/sec reflood rate does not occur until well after the PCT has been achieved. This was noted, but because the newly proposed code will be applied to cases where downcomer boiling ensues, it will be necessary to demonstrate quench and termination of the clad oxidation since downcomer boiling in the analyses will incur larger oxidation rates potentially approaching the limits in 10CFR50.46. As mentioned above, although the proposed extension does not appear to affect PCT, it does influence the oxidation calculated for peak local and core wide conditions, since the lower late reflood rates will cause the clad temperatures in the top of the core to remain at elevated temperatures for extended periods of time compared to those cases that do not incur downcomer boiling.

3.0 RESTRICTIONS AND BEACH CODE APPLICABILITY

Framatome has proposed changes to BEACH to extend the applicability of the code to reflood rates down to and including 0.3 in/sec. The following recommendations and restrictions are summarized.

1) A minimum drop size of 0.5 mm is recommended for implementation in BEACH.
2) The BEACH code is applicable to reflood rates down to and including 0.3 in/sec
3) The BEACH code can be applied down to and including containment system pressures of 14.7 psia. If containment pressures less than 14.7 are encountered, justification for the reflood response computed by BEACH at pressures lower than 14.7 is needed.
4) An alternate reflood code capable of accommodating boiling in the downcomer and lower plenum can be used providing the alternate code can reproduce the reflood behavior up until the time REFLOOD3B fails. This includes reproduction of the RCS pressure in the core, reflood rate, reflood heat transfer coefficients, and clad temperature responses. This model would then be considered an interim model until REFLOOD3B is corrected or a new alternative code can be defended and substituted.
5) If downcomer boiling dominates the late reflood period, justification for the downcomer model (nodalization of the walls and fluid including the cross flow resistances) will be needed.
6) Analyses should be carried out until the entire core has quenched and has been reduced to acceptably low cladding temperatures. Peak local and core wide oxidation percentages should be computed until the clad temperature response no longer contributes to oxidation.
7) Framatome needs to address the fact that rod-to-rod radiation is present in the FLECHT data and tuning a convective model to data that contains thermal radiation and convection is incorrect. The data should be corrected and the model re-tuned or thermal radiation should be accounted for in the BEACH dispersed flow film boiling model.

This interim approach is suggested to enable Framatome to provide support to North Anna while the deficiencies in the large break LOCA Appendix K methodology are corrected or replaced with a permanently defendable reflood system code and analysis approach.

The pertinent parameter ranges for BEACH which reflect the new reflood rate and lower pressure are (changes are indicated in bold):

Peak Power:	0.4-1.0 kw/ft
Containment Pressure:	15-73 psia
Maximum Initial Cladding Temperature:	950-2045 °F
Core Inlet Subcooling:	0. 0-180 °F

Flooding Rate:	0.30-10.0 in/sec
Grid Flow Blockage:	0.00-0.55
Rupture Flow Blockage:	0.0-0.60"

4.0 CONCLUSION

This report documents the review of the FTI-Framatome BEACH reflood heat transfer code for use in performing Appendix K large break LOCA emergency core cooling system performance assessments. The proposed change to the BEACH code includes extending the reflood rate range of applicability from the currently approved reflood rate of 0.5 in/sec down to and including 0.3 in/sec. Framatome also proposes to extend the initial clad temperature range to include a maximum clad temperature of 2045 °F. A review of the BEACH simulations against FLECHT reflood test data showed that the BEACH code could be applied successfully down to and including reflood rates of 0.4 in/sec. Sensitivity studies showed that BEACH can be applied down to 0.3 in/sec although the FLECHT data base only covers reflood rates down to 0.4 in/sec.. Framatome showed that the small extrapolation into this lower range is justified. Framatome also showed that extending the maximum initial clad temperature is justified based on comparison to FELCHT data at these initial temperatures.

Submittal of a plant sample large break LOCA analysis for the North Anna plant revealed that the REFLOOD3B code terminated once boiling developed in the downcomer and lower plenum. As a consequence, Framatome could not demonstrate fuel rod quench and the reduction of clad temperatures to acceptably low temperatures. Because the plant calculated clad temperatures in the top of the core remained at elevated values just in excess of 1600 °F when the REFLOOD3B code terminated, clad oxidation percentages for peak local and core wide conditions could not be determined. Since the decrease in clad temperature was slowed to very low values low at the end of the run, the core is expected to remain at elevated values for extended periods of time causing the oxidation to further increase. Since Framatome could not complete the evaluation to demonstrate the results remains within the limits defined by the criteria in 10CFR50.46, ISL does not recommend BEACH be approved for this application.

ISL does, however, suggest an interim approach that could provide support to the North Anna plant. This alternate approach consists of employing an alternate system code to continue the reflood simulation during the boiling phase. If Framatome can reproduce the REFLOOD3B results up to the code failure, this interim code could then be applied for the remainder of the reflood until the core has quenched and oxidation has been demonstrated to be terminated. The results of the interim code could then be used to provide input to BEACH to complete the hot channel clad temperature and oxidation analysis. These results would be considered an acceptable interim approach until Framatome later committed to correct the REFLOOD3B code deficiency or justified replacement with an alternative reflood systems code that is found to be acceptable to the Staff. It is important to note that in order for this approach to be technically justified, additional modifications and restrictions on BEACH and the analysis approach are also identified and recommended in this technical evaluation report.

5.0 REFERENCES

5.1 BAW-1066PA Revision 4, BEACH-Best Estimate Analysis Core Heat Transfer-A Computer Program for Reflood Heat Transfer During LOCA," B&W Nuclear Technologies, February 1996.

5.2 Letter J.F. Mallay to USNRC, "Request for Review of Appendices and H and I to BAW-10166, Rev.5" December 10, 2001.

5.3 Letter J.F. Mallay to USNRC, "Responses to RAI on Topical Report BAW-10166 Appendices H and I," July 15, 2002.

5.4 Lee, N. et al, PWR FLECHT-SEASET Unblocked Bundle, Forced and Gravity Reflood Task, Data Evaluation and Analysis Report," EPRI- NP-2013, NUREG/CR-2256, February 1982.

5.5 Hochreiter, L.E. and Ried, K., "Reflood Heat Transfer and Hydraulics in PWRs,"

5.6 Response to Informal NRC Questions, BAW-10166, BEACH, Rev. 5, December 2001.

5.7 Letter from L.N. Hartz, (VEPCO) to USNRC, Docket Nos. 50-338 & 50-339, VEPCO North Anna Power Station Units 1&2, RELOOD3B Code Update in Support of Proposed T.S. Changes and Exemption Request to Use Framatome ANP Advanced Mark-BW Fuel, July 25, 2002.

APPENDIX

Comments on Framatome Responses to RAI's on Rod-to-Rod Radiation

The rod-to-rod radiation in Tests 31504 and 31805 from the FLECHT-SEASET test series (NUREG/CR-2256) shows the rod-to-rod thermal radiation heat transfer to be 25 to 35% of the total heat transfer. The statement that radiation to unheated rods, thimbles, and adjacent rods is negligible is unjustified and incorrect. Framatome did not perform any thermal radiation calculations to support their contention that thermal radiation is non-negligible in the FLECHT tests.

A detailed multi-surface rod-to-rod radiation model was used to confirm the radiation heat transfer for the sample tests. Each of the tests was modeled as a 25-rod array (5x5) with the hot rod as the central rod and thimbles located in the appropriate positions. The following bounding conditions were assumed and the radiation heat transfer from the hot rod to the surrounding surfaces was calculated at the time of the PCT.

Test 31405

<u>Case 1 (see Fig 1)</u>
Hot rod location is rod 8K
Hot rod temperature = 2101 °F
Thimble temperature = 1800 °F
Immediate surrounding rods = 2101 °F
Fence (rods outside 5x5 array) temperature = 2076 °F (25 °F cooler than hot rod)

Equivalent heat transfer coefficient for hot rod = 1.52 Btu/hr-ft^2-°F

Total heat transfer coefficient at time of PCT is approximately 10 Btu/hr-ft^2-°F

Percent of total heat transfer 15.2%

<u>Case 2 (see Fig 1)</u>
Hot rod location is rod 8K
Hot rod temperature = 2101 °F
Thimble temperature = 1800 °F
Immediate surrounding rods = 2076 °F (average of 25 °F cooler)
Fence (rods outside 5x5 array) temperature = 2076 °F (25 °F cooler than hot rod)

Equivalent heat transfer coefficient for hot rod = 2.53 Btu/hr-ft^2-°F

Total heat transfer coefficient at time of PCT is approximately 10 Btu/hr-ft^2-°F

Percent of total heat transfer 25.3%

Test 31805

Case 1 (see Fig 2)
Hot rod location is rod 11K
Hot rod temperature = 2250 °F
Thimble temperature = 1800 °F
Immediate surrounding rods = 2250 °F
Fence (rods outside 5x5 array) temperature = 2225 °F (25 °F cooler than hot rod)

Equivalent heat transfer coefficient for hot rod = 2.28 Btu/hr-ft^2-°F

Total heat transfer coefficient at time of PCT is approximately 10 Btu/hr-ft^2-°F

Percent of total heat transfer 22.8%

Case 2 (see Fig. 2)
Hot rod location is rod 11K
Hot rod temperature = 2250 °F
Thimble temperature = 1800 °F
Immediate surrounding rods = 2225 °F (average of 25 °F cooler)
Fence (rods outside 5x5 array) temperature = 2225 F (25 °F cooler than hot rod)

Equivalent heat transfer coefficient for hot rod = 3.39 Btu/hr-ft^2-°F

Total heat transfer coefficient at time of PCT is approximately 10 Btu/hr-ft^2-°F

Percent of total heat transfer 33.9%

The method consists of supplying view factors and structure temperatures into the following equation which is solved for the net radiation heat transferred per unit time, Q_i, between the emitted radiation and the absorbed portion of the incident radiation. The following equation is solved for Q_i:

$$\sum_{j=1}^{n}(F_{ij}-\delta_{ij})\sigma T_i^4=\sum_{j=1}^{n}\left(F_{ij}\frac{1-\varepsilon_j}{\varepsilon_j}-\delta_{ij}\right)\frac{Q_j}{A_j} \qquad i=1,\dots,n$$

where

F_{ij} = view factor from surface i to surface j

σ = Stefan-Boltzmann constant (0.1712×10^{-8} BTU/hr-ft^2-°R)

ε_i = emissivity = 0.8

T_i = the surface absolute temperature (°R)

Q_i = net heat transferred per unit time from surface, i

A_i = surface, i, heat transfer area

δ_{ij} = Kronecker function = { 1 if i = j; = 0 if i ≠ j)

This equation is the general steady-state equation for determining radiation exchange in gray, diffuse enclosures consisting of n surfaces by the net radiation method. It represents a set of linear algebraic equations (i.e. linear in T^4) containing n surface temperatures and n heat fluxes. With the n known surface temperatures, the equation can be solved for the net heat transferred, Q_i, for the n surfaces in Figs. 1 and 2.
With Q_i computed for the above equation, the equivalent heat transfer coefficient for thermal radiation can be readily computed from

$$h_{rad} = \frac{Q_i}{\left[A_i(T_i - T_{sat})\right]}$$

where h_{rad} is in Btu/hr-ft^2-°F and is based on the FLECHT fluid saturation temperature T_{sat}.

Figure 1
FLECHT-SEASET Test
31504
Test Rod 8K

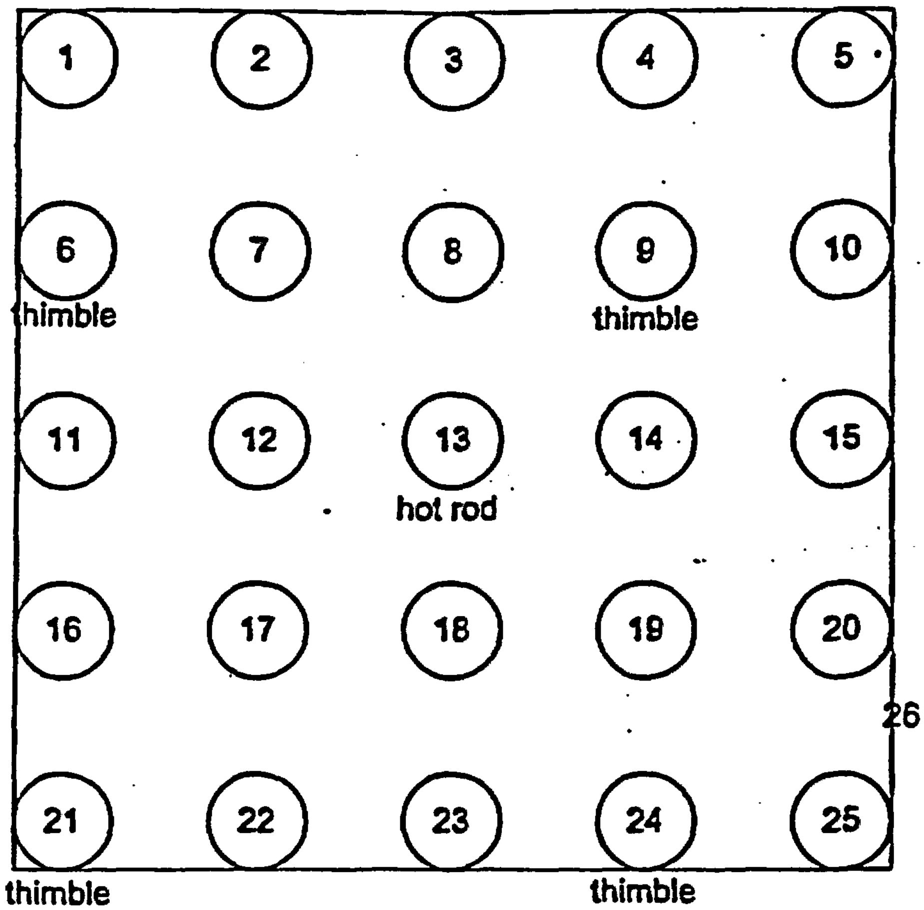

Figure 2
FLECHT-SEASET Test
31805
Test Rod 11K