VIRGINIA ELECTRIC AND POWER COMPANY
RICHMOND, VIRGINIA 23261

August 16, 2002

U. S. Nuclear Regulatory Commission
Attention: Document Control Desk
Washington, D.C. 20555

Serial No. 02-167D
Docket Nos. 50-338/-339
License Nos. NPF-4/-7

Gentlemen:

VIRGINIA ELECTRIC AND POWER COMPANY
NORTH ANNA POWER STATION UNITS 1 AND 2
LARGE BREAK LOCA ANALYSIS IN SUPPORT OF
PROPOSED TECHNICAL SPECIFICATIONS CHANGES AND EXEMPTION REQUEST
TO USE FRAMATOME ANP ADVANCED MARK-BW FUEL

In a March 28, 2002 letter (Serial No. 02-167), Virginia Electric and Power Company (Dominion) requested: 1) an amendment to Facility Operating License Numbers NPF-4 and NPF-7 for North Anna Power Station Units 1 and 2, and 2) associated exemptions from 10 CFR 50.44 and 10 CFR 50.46. The amendments and exemptions will permit North Anna Units 1 and 2 to use Framatome ANP Advanced Mark-BW fuel. This fuel design has been evaluated by Framatome and Dominion for compatibility with the resident Westinghouse fuel and for compliance with fuel design limits.

The attachment to this letter provides the assessment of large break LOCA phenomena for the Advanced Mark-BW fuel. The assessment is presented in the form of a supplement to the evaluation report provided in our March 28, 2002 letter (specifically, report Section 7.0). It is provided in accordance with the proposed documentation for the transition effort as stated in our June 19, 2002 letter (Serial No. 02-305A) and completes our documentation to establish compliance with the emergency core cooling system (ECCS) requirements of 10 CFR 50.46.

As indicated in our June 19, 2002 letter, the approach taken relies upon application of the existing Framatome ANP recirculating steam generator (RSG) LOCA evaluation model (Reference 1). For specific application to North Anna, the analyses performed with the RSG LOCA model have incorporated the two model changes and the minimum containment pressure evaluation. Also, the current small break LOCA assessment in the UFSAR was demonstrated to remain valid for the NAPS fuel reloads supplied by Framatome ANP. Each of these items has been previously submitted by the references indicated in parentheses.

- BEACH Reflood Heat Transfer Modifications (Reference 2)
- REFLOD3B Carryout Rate Fraction (Reference 3)
- Minimum Containment Backpressure Calculation (Reference 4)
- SBLOCA Evaluation (Reference 5)

The description in the attachment to this letter also provides an estimate of the impact on peak cladding temperature (PCT) and cladding oxidation to account for downcomer boiling

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during the reflood portion of the transient. The analysis results, as adjusted for these effects, comply with the acceptance criteria of 10 CFR 50.46.

The attached analysis provides the basis for licensing the initial reload batches of Framatome ANP Advanced Mark-BW fuel for North Anna Unit 1, Cycle 17 and North Anna Unit 2, Cycle 17. In addition, Dominion will reevaluate the large break LOCA for North Anna using an NRC-accepted ECCS evaluation model that includes appropriate features to address downcomer boiling. The model to be used for that reevaluation is expected to be the Framatome ANP realistic LOCA evaluation model. This reanalysis will be conducted prior to operation of either North Anna unit with the second batch of Advanced Mark-BW fuel. The specific cycles involved are North Anna Unit 1, Cycle 18 and North Anna Unit 2, Cycle 18.

As noted in previous correspondence, the initial reload batch of Advanced Mark-BW fuel is currently planned for North Anna Unit 1 Cycle 17, which is scheduled to begin operation in April 2003. We continue to request your assistance to achieve this reload schedule.

If you have any questions or require additional information on this, please contact us.

Very truly yours,

E. S. Grecheck
Vice President - Nuclear Support Services

Attachment

Commitments made in this letter:

Reanalyze the large break LOCA using an NRC-accepted ECCS model that includes appropriate features to address downcomer boiling prior to operation of either North Anna unit with the second batch of Advanced Mark-BW fuel.

References:

1. BAW-10168P-A, Revision 3, "RSG LOCA – BWNT Loss-of-Coolant Accident Evaluation Model for Recirculating Steam Generator Plants," December 1996.

2. Letter, James F. Mallay to USNRC, "Request for Review of Appendices H and I to BAW-10166," NRC:01:050, December 10, 2001.

3. Letter, L. N. Hartz to USNRC, "Virginia Electric and Power Company North Anna Power Station Units 1 and 2 – REFLOD3B Code Update in Support of Proposed Technical Specifications Changes and Exemption Request to Use Framatome ANP Advanced Mark-BW Fuel," Serial No. 02-167B, July 25, 2002.

4. Letter, L. N. Hartz to USNRC, "Virginia Electric and Power Company North Anna Power Station Units 1 and 2 – Minimum Containment Pressure Analysis to Support Proposed Technical Specifications Changes and Exemption Request Use of Framatome ANP Advanced Mark-BW Fuel," Serial No. 02-167A, July 9, 2002.

5. Letter, L. N. Hartz to USNRC, "Virginia Electric and Power Company North Anna Power Station Units 1 and 2 – Small Break LOCA Evaluation In Support Of Proposed Technical Specifications Changes And Exemption Request Use of Framatome ANP Advanced Mark-BW Fuel," Serial No. 02-167C, dated August 2, 2002.

cc: U.S. Nuclear Regulatory Commission
Region II
Sam Nunn Atlanta Federal Center
61 Forsyth Street, SW
Suite 23T85
Atlanta, Georgia 30303

Mr. J. E. Reasor, Jr.
Old Dominion Electric Cooperative
Innsbrook Corporate Center
4201 Dominion Blvd.
Suite 300
Glen Allen, Virginia 23060

Commissioner
Bureau of Radiological Health
1500 East Main Street
Suite 240
Richmond, VA 23218

Mr. M. J. Morgan
NRC Senior Resident Inspector
North Anna Power Station

COMMONWEALTH OF VIRGINIA)
)
COUNTY OF HENRICO)

The foregoing document was acknowledged before me, in and for the County and Commonwealth aforesaid, today by Eugene S. Grecheck, who is Vice President - Nuclear Support Services, of Virginia Electric and Power Company. He has affirmed before me that he is duly authorized to execute and file the foregoing document in behalf of that Company, and that the statements in the document are true to the best of his knowledge and belief.

Acknowledged before me this 16TH day of August, 2002

My Commission Expires: May 31, 2006.

Vicki L. Hull
Notary Public

(SEAL)

7.0 LOCA Analysis

Framatome ANP will be delivering Advanced Mark-BW reload fuel to the North Anna Power Station (NAPS) Units 1 and 2 starting in the first quarter of 2003. These units are Westinghouse-designed, three-loop plants operating at a rated thermal power of 2,893 MWt. The plants have conventional ECCS and dry, sub-atmospheric containment buildings. In accordance with 10CFR50.46 and 10CFR50, Appendix K, an evaluation of emergency core cooling system (ECCS) performance was done for the Framatome ANP reload fuel. The evaluation is discussed in the text that follows, and its results are summarized. All analysis results and evaluations confirm that the acceptance criteria of 10CFR50.46 are met. The assessment serves as a basis for licensing the use of Framatome ANP Advanced Mark-BW fuel at NAPS.

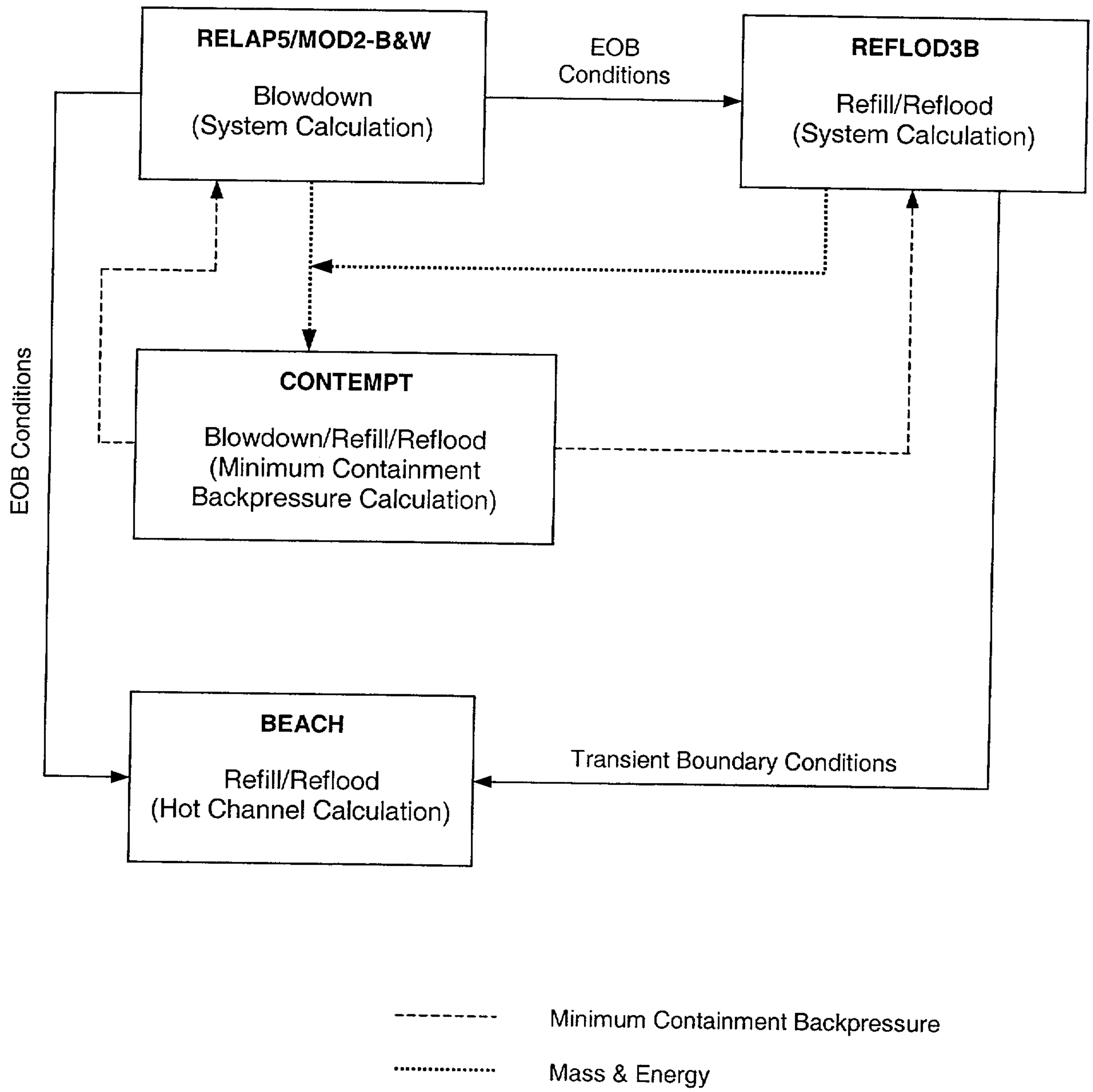
Section 7.1 presents a description of the computer codes and calculation methods used in the NAPS analyses. Analysis parameters and modeling for the large break calculations are discussed in Section 7.2. Generic and plant-specific sensitivity studies are documented in Section 7.3. Section 7.4 presents the LOCA limit calculations that demonstrate compliance with the peak clad temperature (PCT) and local clad oxidation criteria of 10CFR50.46. Compliance with the remaining three 10CFR50.46 criteria (maximum hydrogen generation, coolable geometry, and long-term cooling) is presented in Section 7.5, 7.6, and 7.7, respectively. Transition cores are addressed in Section 7.8, and Section 7.9 covers post-AOR (analysis of record) evaluations. The SBLOCA evaluation is presented in Section 7.10, and Section 7.11 summarizes the LOCA results. References are provided in Section 7.12.

7.1 Computer Codes and Methods

The recirculating steam generator (RSG) LOCA evaluation model (Reference 7-1) consists of computer codes and input models for performing LBLOCA calculations. The evaluation model is NRC-approved and is described below.

For large break predictions, the RSG LOCA evaluation model (EM) consists of two computer codes, RELAP5/MOD2-B&W (including its BEACH subroutines) and REFLOD3B. Figure 7.1-1 illustrates the interrelation of the computer codes. The RELAP5/MOD2-B&W code (Reference 7-2, hereafter referred to as RELAP5) calculates system thermal-hydraulics, core power generation, and core thermal response during blowdown. The calculation of the thermal-hydraulic transient is continued through the refill and reflood periods using the REFLOD3B system code (Reference 7-3). Of importance, REFLOD3B predicts the refill time and a transient, average core flooding rate. BEACH (Reference 7-4) is a set of reflood thermal-hydraulic and heat transfer subroutines within RELAP5. A BEACH model is created by taking the RELAP5 blowdown model and deleting all volumes and junctions except those representing the hot fluid channel. Hence, BEACH calculations are performed by restarting the RELAP5 blowdown run. The hot fluid channel composing the BEACH model is driven by transient boundary conditions (the core flooding rate and core inlet and outlet pressure and temperature) from the REFLOD3B prediction. BEACH calculates the thermal response of the hot pin and the hot bundle, both of which are modeled in the hot fluid channel and determine PCT. For the NAPS application, it was necessary to perform a specific analysis of minimum containment backpressure since UFSAR (Reference 7-17) predictions were of insufficient duration. The CONTEMPT code (Reference 7-5) in combination with the methods described in the Framatome ANP once-through steam generator (OTSG) LOCA EM (Reference 7-6), both of which were previously approved by the NRC, was used to determine the minimum containment backpressure.

Figure 7.1-1: LBLOCA Computer Code Interface



7.2 Calculation Inputs and Assumptions

The following are the major fuel and plant operating parameters used in the LOCA analysis:

1. Power Level: The plant is assumed to be operating in steady state at 2,951 MWt (102% of the current licensed power, 2,893 MWt).

2. Total System Flow: The initial RCS flow is 289,100 gpm.

3. Fuel Parameters: Initial fuel pin parameters are taken from TACO3 (Reference 7-7) computer runs.

4. Pumped ECCS flows are based on the limiting assumption of either a single active failure (minimum ECCS) or no failure (maximum ECCS). ECCS injection is initiated 27 seconds after receipt of safety injection signal (SIS). The accumulator tank injected water volume is 993 ft^3 per tank.

5. Total Peaking Factor, F_q: The maximum total peaking factor assumed is 2.19.

6. The moderator density reactivity coefficient is based on BOL conditions to minimize negative reactivity.

7. The clad rupture model developed for Framatome ANP's M5™ cladding material is used for LBLOCA predictions. This NRC-approved model is implemented as described in Reference 7-8.

8. Tube plugging is uniformly set at 7 percent per steam generator (SG). An additional 5 percent is used to account for SG tube deformation under combined LOCA and seismic loading during the reflood transient.

7.2.1 RELAP5 Modeling

The RELAP5 computer code is used to analyze RCS thermal-hydraulic behavior and core thermal response during blowdown. RELAP5 permits a user to construct a nuclear steam-supply system (NSSS) representation resulting in a plant model appropriate to the fluid system being analyzed. The control volume (CV) and junction representation is shown in Figures 7.2-1 and 7.2-2. The baffle-barrel simulation shown in Figure 7.2-2 is representative of Unit 1, an upflow plant. Unit 1 will be the basis of discussion in the remainder of this section. Unit 2 is a downflow plant, and its baffle-barrel region representation is shown and discussed later. The plant model was developed in accordance with the RSG LBLOCA EM (Reference 7-1, Volume I).

RELAP5 inputs consist of volume geometry (area and height), flow-related parameters (resistance, hydraulic diameter, surface roughness, etc.), primary metal data, and initial conditions (pressure, temperature and flow). The non-equilibrium, non-homogenous option is used throughout the model, except for the core region, where the equilibrium, homogeneous option is selected. A time-dependent volume is used to provide containment boundary conditions. All major components within the reactor vessel, loops and steam generators are considered as stored energy in heat structure inputs. Within a specific region, primary metals are grouped together based on similar thickness and geometry. The exterior surfaces of the primary and secondary system pressure boundaries are assumed insulated to maximize stored energy in metal slabs.

7.2.2 REFLOD3B Modeling

REFLOD3B (Reference 7-3) simulates the thermal-hydraulic behavior of the primary system during the core refill and reflood phases of LOCA. The noding arrangement, shown in Figure 7.2-3, is consistent with the RSG LOCA EM (Reference 7-1). The reactor vessel (RV) is represented by a model consisting of four fixed nodes. Nodes 1R and 2R are volumes above and below the steam-water interface in the inner vessel region, respectively, and nodes 3R and 4R represent liquid and steam volumes, respectively, in the downcomer region including the lower plenum. The primary system piping is represented by two loops similar to the RELAP5 blowdown model with a reduced number of volumes. Values for volume geometry and flow path hydraulic parameters are developed from the RELAP5 blowdown model.

RELAP5 end-of-blowdown (EOB) results define the starting point for the REFLOD3B calculation. The core and system initial conditions for REFLOD3B are derived from those of the associated RELAP5 run at EOB, taking into account the differing nodalization. Initial liquid inventory for REFLOD3B is equivalent to the liquid remaining in the reactor vessel below the upper plenum support plate at EOB added to the accumulator liquid bypassed to containment following the end of bypass in RELAP5. The initial liquid inventory is placed in the lower plenum of the REFLOD3B model. The initial flow rates, gas volumes, liquid inventories, and pressures of the accumulator tanks are taken directly from RELAP5. The reactor vessel steam volumes (1R and 4R) are initialized with saturated steam corresponding to containment pressure. The loops are initialized with superheated steam corresponding to the containment pressure and fluid temperature of the secondary sides. The minimum containment backpressure as a function of time is used as a boundary condition in the REFLOD3B calculation.

All REFLOD3B computations used a modified version of the code that incorporates a NAPS-specific carryout rate fraction (CRF) option within the CRFCKN option. The new option is discussed and its use justified in Reference 7-18.

7.2.3 CONTEMPT Modeling

The RSG EM (Reference 7-1) specifies that the minimum containment backpressure, generally reported in the FSAR, is assumed in the LBLOCA analysis. The backpressure time histories reported in the North Anna UFSAR were of insufficient duration (and unsuitable for conservative extrapolation) for use in the LOCA calculations. Therefore, Framatome ANP performed a NAPS-specific minimum containment backpressure analysis using the CONTEMPT code (Reference 7-5). CONTEMPT and associated methods for determining minimum backpressure were approved for application to B&W-designed, dry containment plants (Reference 7-6). A converged backpressure is obtained through iteration between CONTEMPT, and RELAP5 and REFLOD3B. Containment modeling follows the requirements set forth in Standard Review Plan 6.2.1.5 and Branch Technical Position, CSB 6-1. The performance of a minimum containment backpressure analysis within the RSG EM is discussed and justified in Reference 7-19. This application is NAPS-specific.

7.2.4 BEACH Modeling

The BEACH code is used to determine fuel rod cladding temperature response during the refill and reflooding phase of a LOCA. The BEACH model, shown in Figure 7.2-4, consists of separate hot and average fuel assemblies and respective flow channels. Time-dependent inlet and outlet volumes permit inputs of boundary data from the REFLOD3B calculation. No crossflow is permitted between the hot and average channels of the BEACH model. Otherwise, BEACH model subdivision is equivalent to the RELAP5 core model described in Section 7.2.1. The nodalization is consistent with that specified in the RSG LOCA EM (Reference 7-1).

In accordance with the RSG LOCA EM (Reference 7-1), the BEACH run is restarted from RELAP5 at EOB. Fuel assembly thermal parameters are transferred directly between the codes. The initial temperature of the steam surrounding the fuel assemblies is set equal to the adjacent cladding surface temperature at the EOB. Inlet and outlet pressures, flooding rate, inlet water temperature, and core decay heat boundary data are input from the REFLOD3B calculation. The NAPS calculations rely upon the application of BEACH to reduced flooding rates, in accordance with Appendix I of the augmentation to Reference 7-4.

Detailed descriptions of the RELAP5, REFLOD3B, and BEACH models (control volumes and junctions) have been presented in previous submittals, most recently in Reference 7-14, and will not be repeated herein.

Figure 7.2-1: RELAP5 LBLOCA Loop Noding Diagram

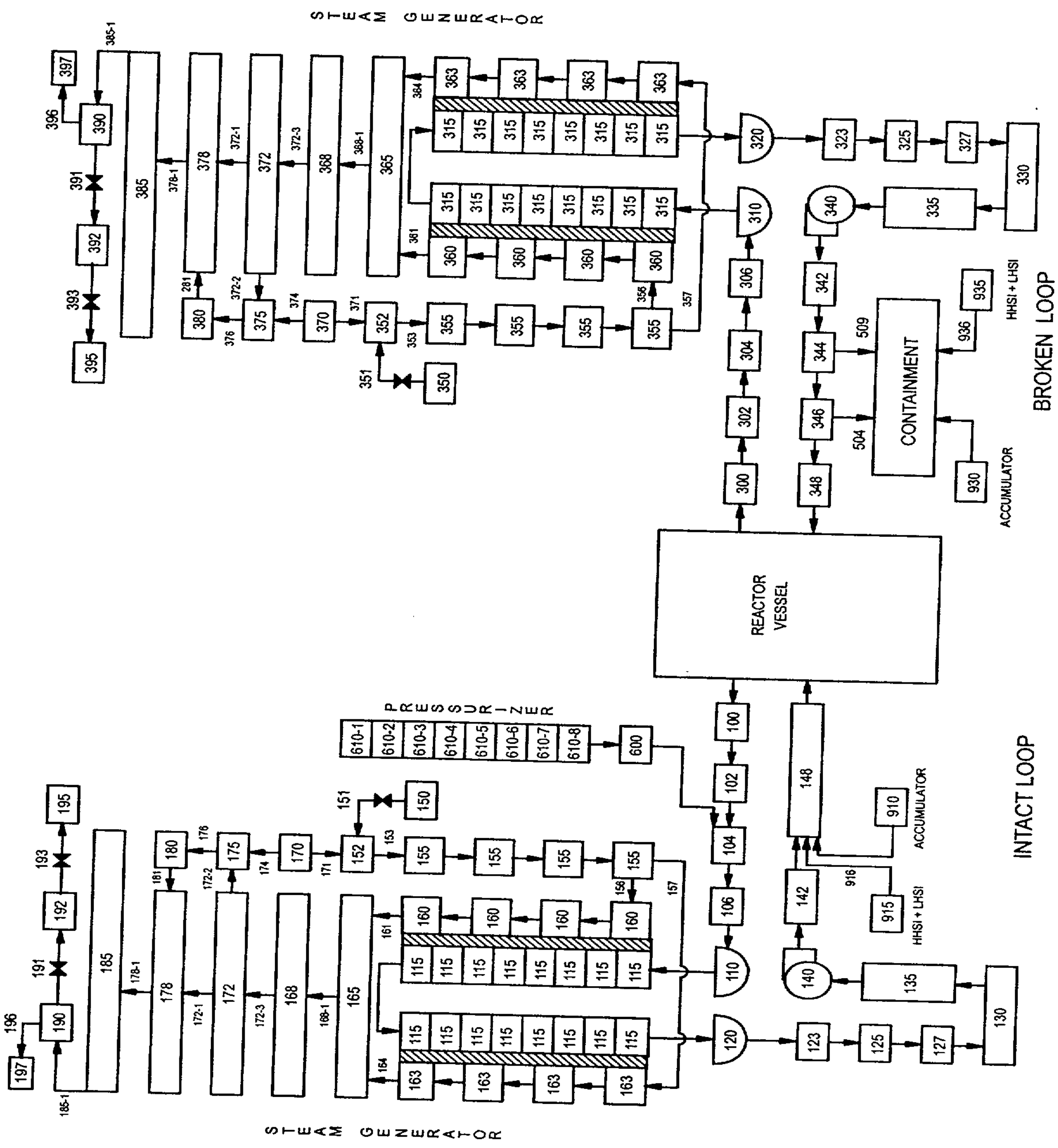


Figure 7.2-2: RELAP5 LBLOCA RV Noding Diagram—Unit 1

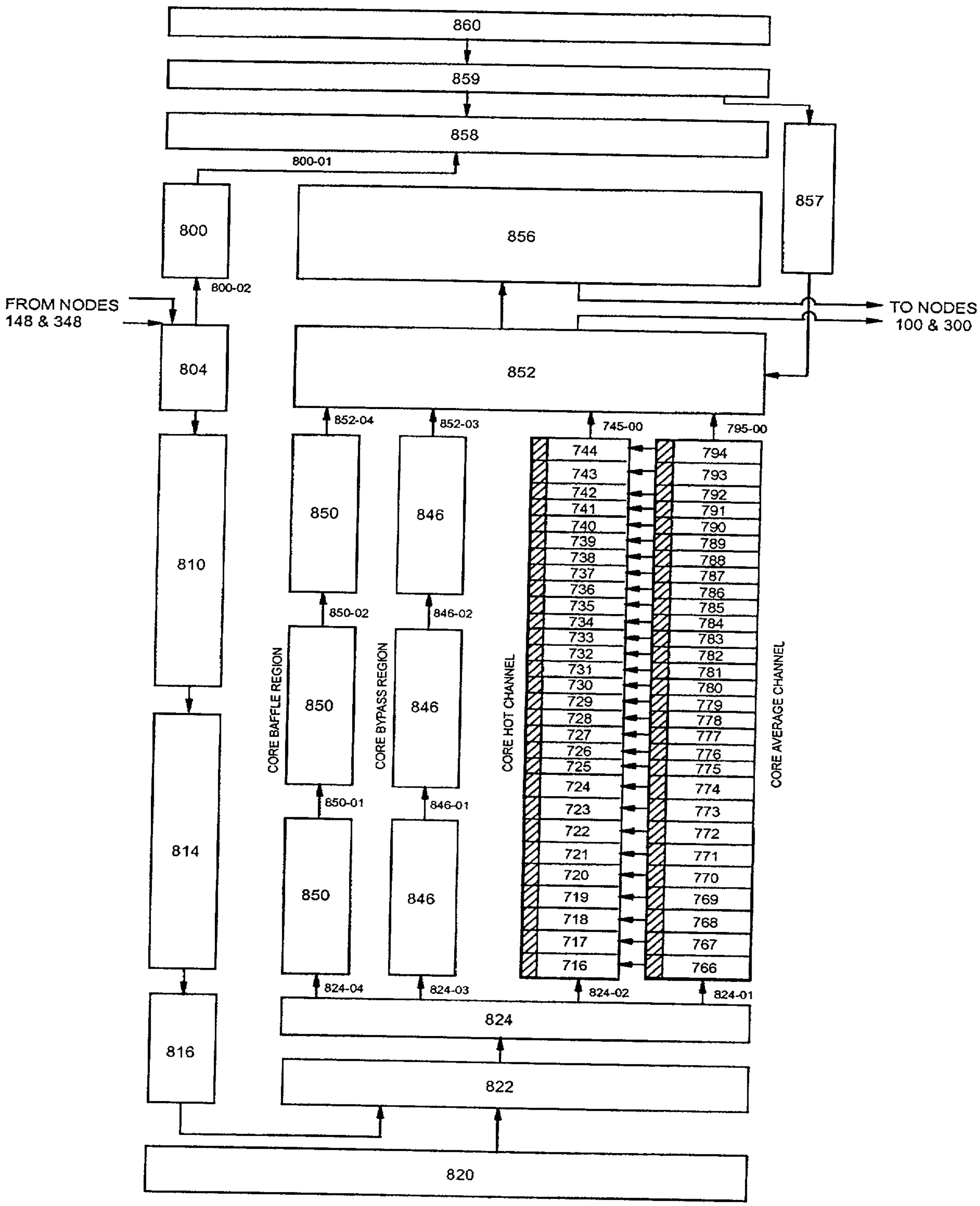


Figure 7.2-3: REFLOD3B Noding Diagram

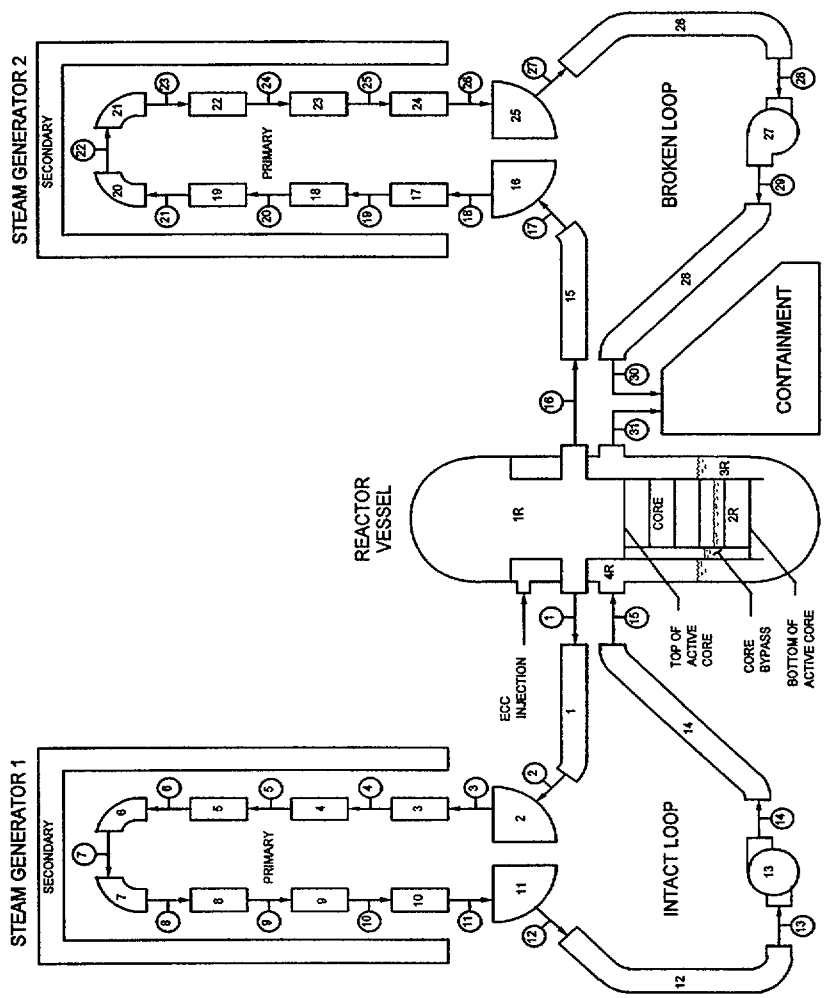
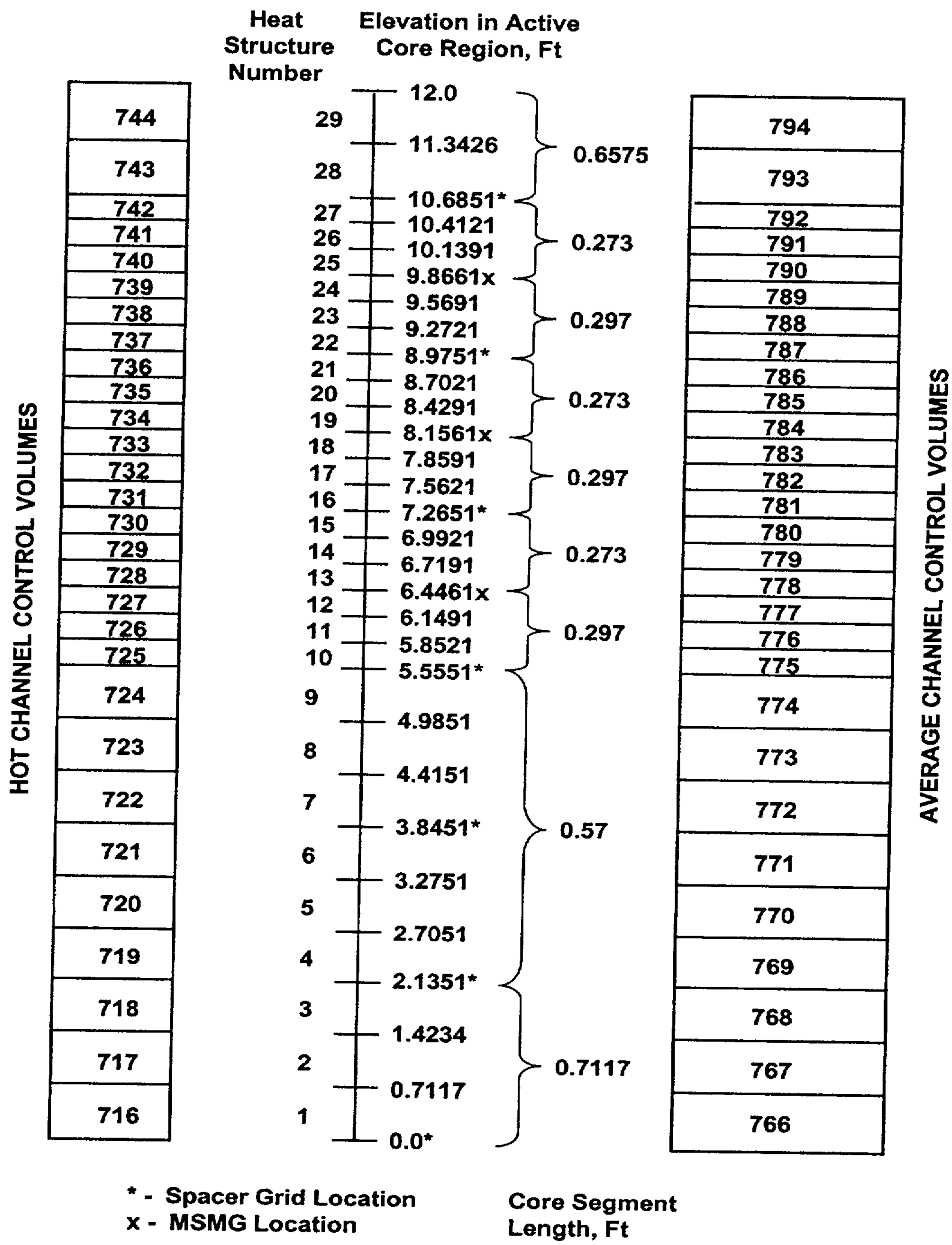


Figure 7.2-4: BEACH Core Noding Diagram



7.3 Sensitivity Studies

LOCA evaluations require that a number of sensitivity studies be performed with the EM to assure model convergence and conservatism. Studies such as the break spectrum study are considered plant-specific and are discussed later. Many of the large break EM studies, such as those demonstrating solution convergence, are generic. The studies are documented and discussed in Volume I of Reference 7-1, notably Appendixes A, C, D, and E. Continued validity through EM revisions is likewise discussed and established in these appendixes. Section 7.3.1 below identifies the generic EM sensitivity studies that are applicable to NAPS. Section 7.3.2 discusses the plant-specific sensitivity studies.

7.3.1 Evaluation Model Generic Studies

Many of the sensitivity studies presented in the EM topical report (Reference 7-1) are generic studies that apply to all RSG plants. The studies considered generic demonstrate results that are characteristic of the EM (the codes and the code interfaces) and are not plant-dependent. This demonstration need not be repeated for plant-specific applications provided the modeling techniques used adhere to the EM guidelines. Validation of the generic sensitivity studies is not required for this application.

The generic studies performed and documented in Reference 7-1, Volume I, Appendix A, include RELAP5 time step, loop nodalization, break noding arrangement, pressurizer location (intact loop versus broken loop), core crossflow, and core nodalization. For REFLOD3B, the RC pump rotor resistance study in Section A.2.4 of Reference 7-1, Volume I confirms the locked rotor configuration is limiting with respect to PCT.

Besides generically applicable sensitivity studies, several EM sensitivity studies are considered confirmable. Confirmable studies remain valid under most but not all circumstances. Originally addressed in the base RSG LOCA EM (Reference 7-1, Volume I), the validity of the confirmable studies was verified as applicable to subsequent LBLOCA EM revisions. The studies include RELAP5 RC pump degradation and RC pump operating status (tripped versus running) blowdown studies. The REFLOD3B loop noding study verifies the sufficiency of the noding detail used in the REFLOD3B model. An additional confirmable study performed is a time-in-life study. They are documented in Appendix A of Reference 7-1, Volume I. Several of the confirmable studies were redone herein, and the study results are reported in Section 7.3.2.

Large break LOCA analyses consider three break locations: (1) hot leg, (2) cold leg pump suction, and (3) cold leg pump discharge. Both hot leg and pump suction breaks produce PCT results below those predicted for pump discharge breaks. This is mainly attributed to the effects of break location upon core flooding rate. The pump discharge location produces combined effects of reduced downcomer pressure and complete loss of the broken loop ECCS, resulting in lower flooding rate. This is consistent with the results of various prior analyses. The conclusion of pump discharge breaks being limiting is also solidly supported based simply on technical reasoning (as set forth in Volume I, Section C.4 of Reference 7-1). Therefore, it is concluded generically that the pump discharge is the limiting break location. The break location portion of the spectrum study is confirmed as applicable to the NAPS units. For this application, all LBLOCA spectrum cases will be located at the pump discharge.

7.3.2 Plant-Specific Studies and Spectrum Analysis

Most LBLOCA analysis inputs and assumptions are set by the EM (Reference 7-1, Volume I) and its sensitivity studies. However, certain parameters depend on plant-specific inputs and are established by individual plant studies. These studies, including the spectrum analysis, are performed to identify the limiting break case and plant model configuration for use in computing LOCA limits. Figure 7.3-1 shows the order in which the plant-specific studies were performed. This section presents the results of the plant-specific studies leading to the final modeling configuration used in computing the LOCA limits.

7.3.2.1 Base Case

The first step in performing a series of sensitivity studies is to establish a base case. For the studies presented in this section the base case is a double-ended, cold leg, guillotine break (DECLG) at the pump discharge with a discharge coefficient (C_d) of 0.6. The C_d of 0.6 derives from the limiting value determined in the NAPS lead test assembly (LTA) LBLOCA analysis (Reference 7-12). Pumped ECCS injection is set at "MAX ECCS" (no active failure). All cases use the same, mid-core-peaked (CV 14 in Figure 7.2-4), axial power profile in both the hot pin and the hot bundle. Core peaking is modeled with a F_q of 2.19. The RCPs are tripped at transient initiation. Loss-of-offsite power is also assumed coincident with transient initiation. The calculated PCT is 1938°F.

7.3.2.2 RCP Degradation Study

The pump degradation study establishes the RCP two-phase degradation-modeling basis. The base case uses the curve from the RELAP5 report NUREG/CR-4312 (Reference 7-10). This blowdown sensitivity study was previously run for a typical Westinghouse 4-loop plant. The original study (Reference 7-1, Volume I, Section A.3.3) compared results using degradation multiplier curves (termed M1 and M3 modified) from a prior Framatome ANP LOCA EM and the curve given in the RELAP5 report NUREG/CR-4312. This study, using the same three degradation curves, is repeated herein for the first Westinghouse 3-loop plant application. Minimal end-of-blowdown (EOB) differences are noted between the three cases. Based on these results use of the RELAP5 degradation curve (NUREG/CR-4312) is confirmed for Westinghouse 3-loop plants. The RELAP5 degradation curve provides the best representation at higher void fractions. The base plant model is unchanged relative to the RCP, two-phase, degradation, multiplier curve.

7.3.2.3 *RCP Status Study*

The RCP status study is a blowdown study that establishes pumps powered or pumps tripped as the limiting configuration. The study is repeated herein for the first application of the LOCA EM to a Westinghouse 3-loop plant. The base case trips the pumps at transient initiation. Minimal EOB differences are noted between the two cases. The trending denotes a minor blowdown core cooling benefit associated with the pumps being powered. A clear PCT benefit would accrue to the pumps powered case in reflood since steam-binding effects would be reduced. Pumps tripped is the limiting configuration and the base case will not be changed regarding RCP status.

7.3.2.4 *RELAP5 Pressurizer Location Study*

The RSG EM does not require this study to be redone. However, because the NAPS analysis is the first application to a Westinghouse 3-loop plant, the study was repeated. The pressurizer (PRZ) location study (Section A.3.2 of Reference 7-1, Volume I) shows there is little difference in results when the PRZ is moved from the intact loop to the broken loop. That was reconfirmed herein, with the intact loop placement demonstrating slightly more limiting results. On that basis, the base case configuration was not changed with respect to PRZ location.

7.3.2.5 *Minimum versus Maximum ECCS Study*

A study was conducted to determine which condition for the ECCS pumped injection is limiting, with or without a single failure. Under a single failure assumption, only one train of pumped ECCS injection is available. This is termed "MIN ECCS" injection. It assumes flow from one high head pump and one low head pump. With no failure, two ECCS trains are available. This is termed "MAX ECCS" injection. It assumes flow from two high head pumps and two low head pumps.

In the analysis, the extra injection capacity spills directly to the containment. There it acts to reduce both the containment pressure and accordingly the core-flooding rate. Hence, the assumption of no single failure can result in worse PCT consequences than assuming a single failure. A calculation was made assuming an active single failure, "MIN ECCS." The base case assumes no failure, "MAX ECCS." The study confirmed that assuming no single active failure produces limiting results and the base case remains unchanged.

7.3.2.6 *Core Baffle-Barrel Study*

The NAPS units are essentially identical plants. The only potentially significant difference between the two plants is the core baffle-barrel region. NAPS Unit 1 (and the base RELAP5 plant model) is configured as an upflow plant. The terminology "upflow" refers to the relationship between the downcomer and baffle-barrel regions. The RV noding for Unit 1 is shown in Figure 7.2-2; note that in normal operation the downcomer and the baffle-barrel region flow in opposite directions. NAPS Unit 2 is a downflow plant; the baffle-barrel region is directly linked to the downcomer and it flows in the same direction as the downcomer. Figure 7.3-2 shows the RV noding for Unit 2. In Unit 2, the baffle-barrel region is fed through a connection from the bottom of CV 804 to the top of PIPE component 850. The flow direction in PIPE component 850 is now vertically downward. PIPE component 850 is no longer connected to upper plenum CV 852. Excepting the above-discussed differences, the RV noding for Units 1 and 2 is the same.

The purpose of this study was to determine the limiting core baffle-barrel region configuration (i.e., upflow or downflow). The results showed little difference between the baffle-barrel configuration, and the PCTs were virtually identical. On that basis, the upflow configuration of the base case was not revised.

7.3.2.7 Time-in-Life Study

The time-in-life (TIL) sensitivity study defines the limiting fuel pin initial conditions for LOCA analysis within a given fuel cycle based on PCT response in the hot channel. Fuel initialization comprises burnup-dependent factors such as volume-averaged fuel temperature, gap size, gas composition, and pin pressure. TACO3 (Reference 7-7) runs were made to predict the behavior of these parameters to end of life (EOL), which is 60 GWd/mtU for Advanced Mark-BW fuel. Adherence to the fuel pin limiting conditions is ensured through the specification of a constraint, K_{BU}, upon the allowable local linear heat rate.

Prior work concluded that the time of maximum stored energy is the limiting TIL provided blowdown ruptures are precluded. A fuel pin constraint (K_{BU}) is defined as a multiplier to the total peaking, F_q. This factor acts to reduce the total allowable peaking and assures, in the absence of blowdown ruptures, BOL as the limiting TIL. This factor, K_{BU}, is shown in Figure 7.3-3. K_{BU} is equal to 1.0 between 0 and 44.6 GWd/mtU and then linearly decreases to 0.6781 at 60 GWd/mtU.

The study performed for this application verified the above conclusions for the NAPS units with Advanced Mark-BW fuel. LBLOCA cases were run for BOL, 10 GWd/mtU, 30 GWd/mtU, 44.6 GWd/mtU, and EOL. The results validated conclusions from prior work to be applicable to Westinghouse 3-loop plants. BOL was the limiting configuration and the base case will not be changed relative to TIL.

7.3.2.8 Discharge Coefficient Study

A break spectrum analysis is performed to determine the limiting break configuration. (Break location was discussed in Section 7.3.1.) The study is generic, applicable to NAPS, and concludes that pump discharge breaks are limiting. Hence, the break spectrum analysis comprises a C_d study and a break type study. The discharge coefficient (or break size) study is considered first, followed by the break type study in Section 7.3.2.9.

A C_d of 0.6 is used in the base case. Cases were also run for C_d values of 1.0, 0.8, and 0.4. The results of the study verified that a C_d of 0.6 is the limiting value, and the base case was not changed relative to discharge coefficient. The PCT for the limiting case changed from 1,938°F in the TIL study (Section 7.3.2.7), to 1,931°F. This small PCT change is due to the use of a reduced BEACH time-step. The TIL study recommended the use of a smaller BEACH time-step in all subsequent LBLOCA calculations.

7.3.2.9 Break Type Study

The break type study completes the set of spectrum analysis cases. The study predicts the limiting break type, guillotine or split. The base case models a guillotine break. A 2A (A = break area) split break at the pump discharge with C_d = 0.6 was run. In an absolute PCT sense, the split break was the limiting case. However, after examining the split transient, it was evident that the result was due to non-physical behavior by REFLOD3B.

Core temperatures for the split break case was substantially lower than those in the corresponding guillotine case at EOB and remained lower during the initial portion of the reflood transient. In REFLOD3B, the rapid quenching of the first core slab for the split break case caused a substantial non-physical core carryout that was well above that predicted by the data-based CRFCKN carryout rate fraction (CRF) correlation. Due to the equilibrium fluid modeling in REFLOD3B, the excessive liquid carryout is instantaneously converted to vapor, causing a pressure spike sufficient to force all core liquid out of the core. This effectively inserts a delay in the reflood transient, which resumes at a higher clad temperature. The issue was conservatively addressed by imposing a 20°F adder (1°F higher than the PCT difference between the limiting guillotine and split cases) on the guillotine case. The guillotine case is considered the limiting case and it was used to perform the LOCA limit calculations.

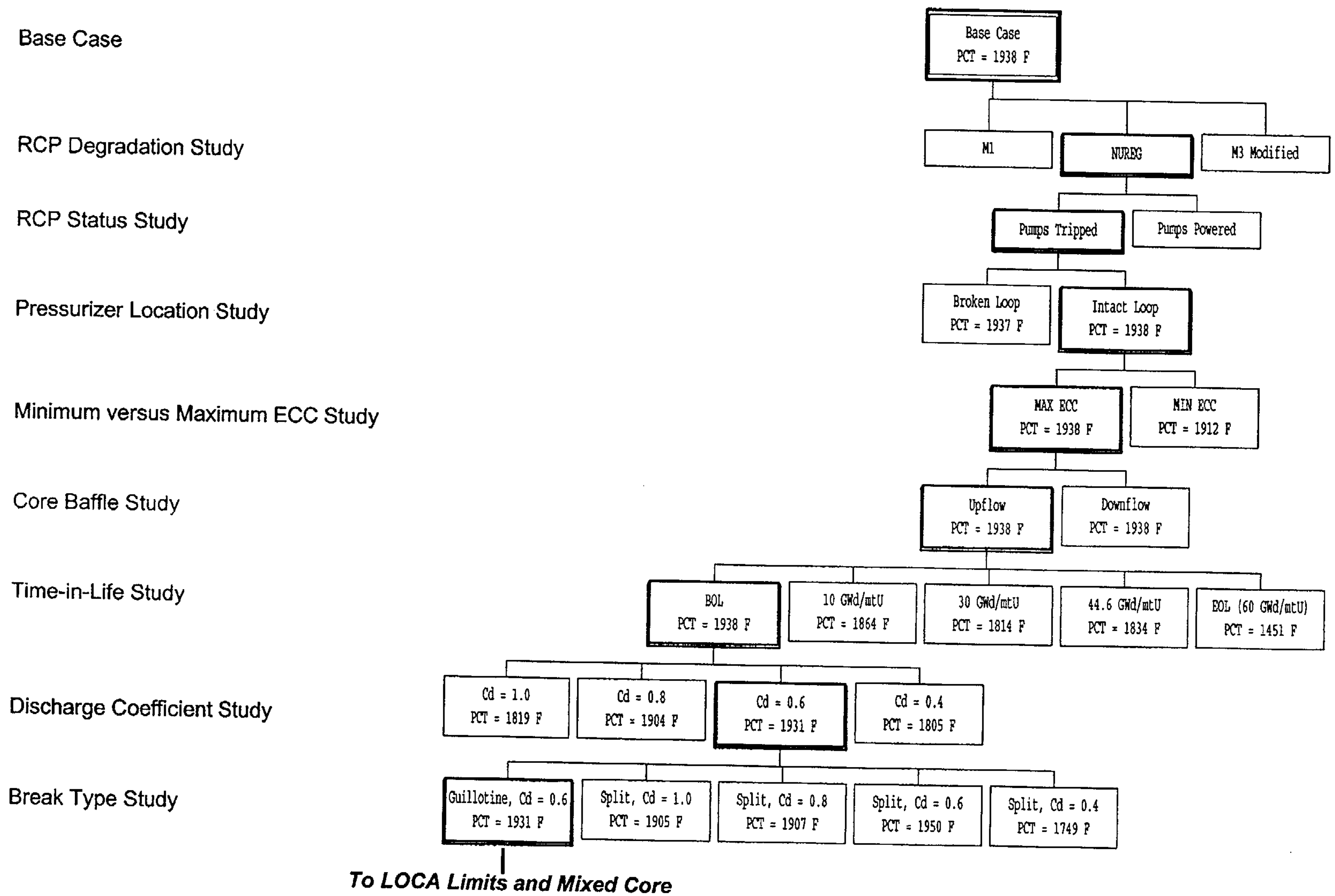


Figure 7.3-1: Plant Specific Sensitivity Study Diagram

Figure 7.3-2: RELAP5 LBLOCA RV Noding Diagram – Unit 2

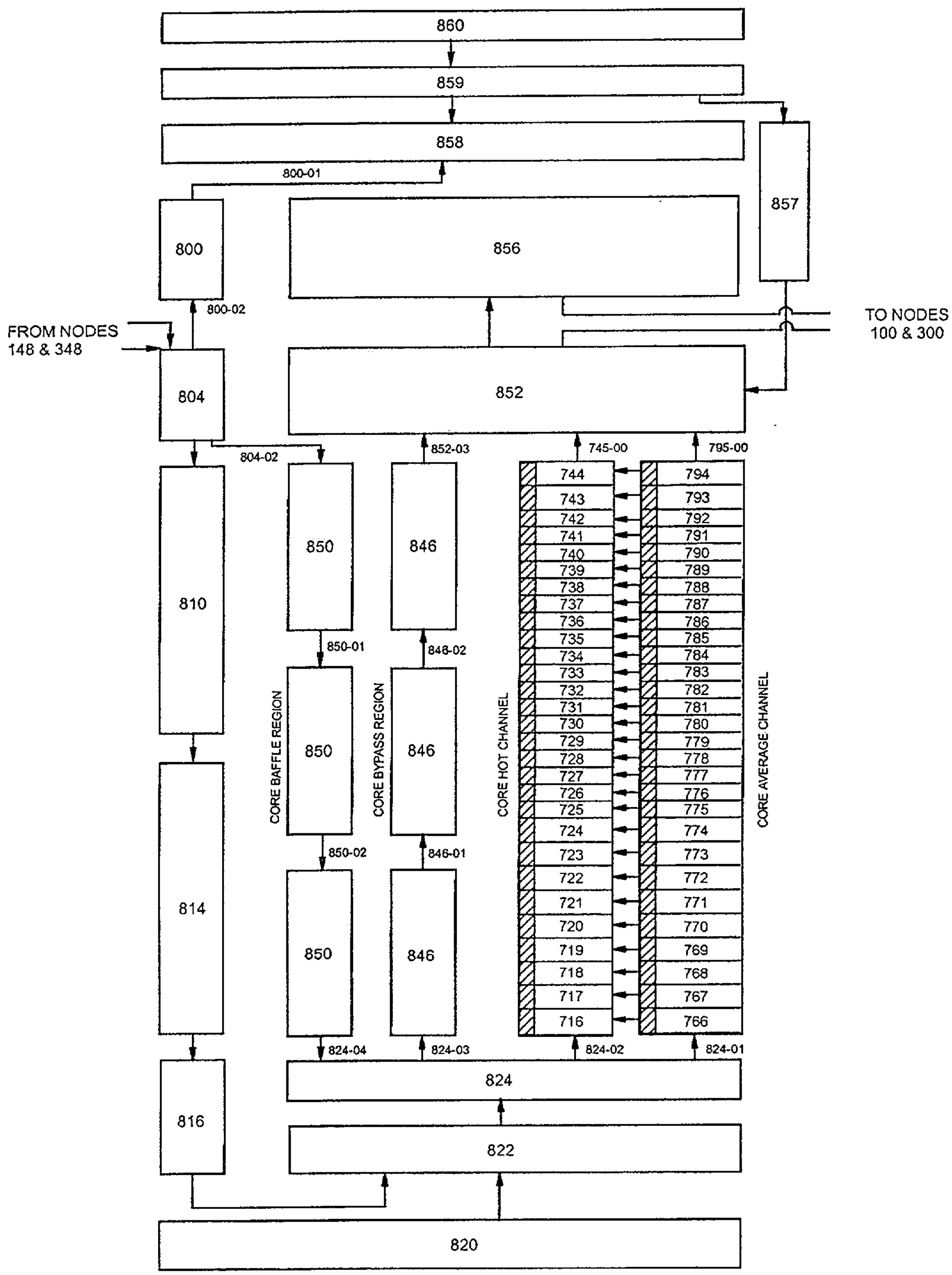
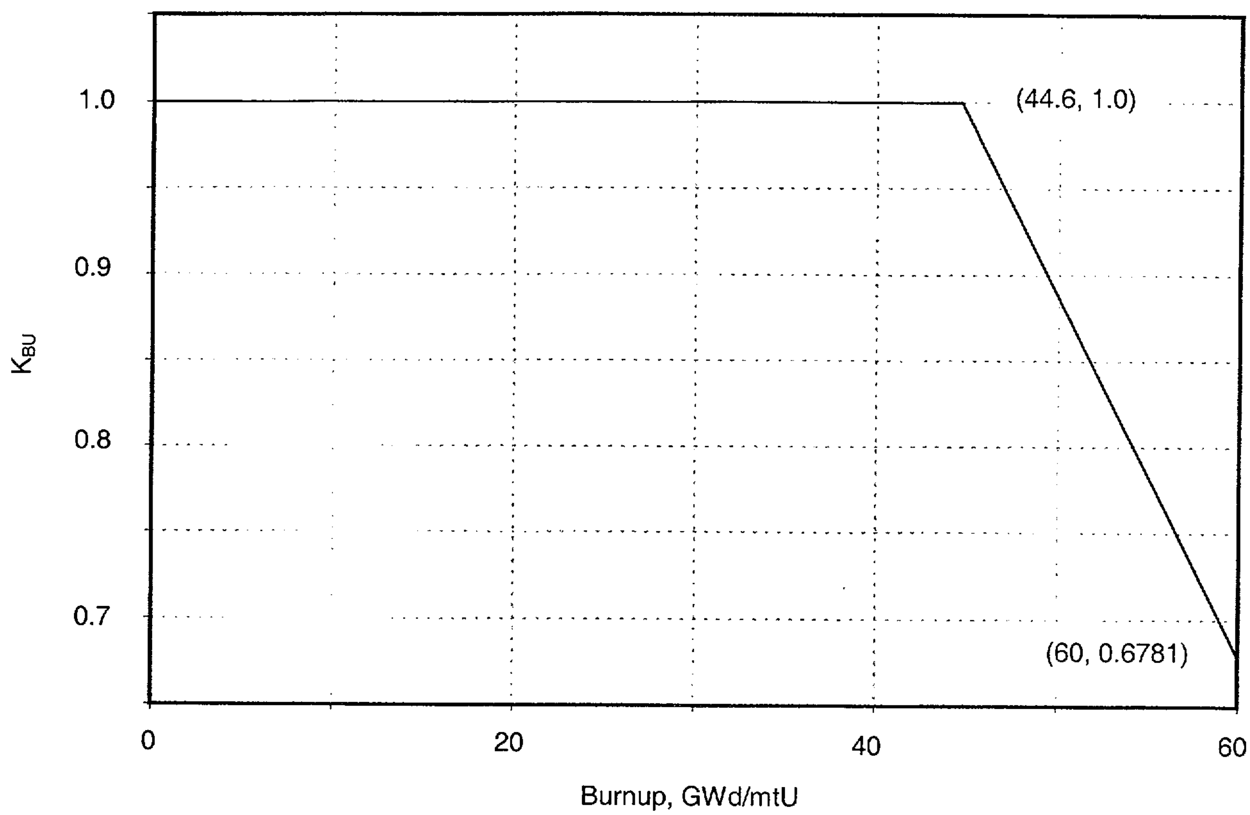


Figure 7.3-3: LOCA Limits: Burnup Adjustment Factor, K_{BU}, Curve



7.4 LOCA Limits

The LBLOCA evaluation is concluded with an analysis set showing compliance with 10CFR50.46 for the core limits of operation. The term limit is used because these cases are run at the limit of allowable local core power generation and are the bases for the core power distribution limits. The LOCA limit calculations comprise the set of cases used to demonstrate compliance of the reload fuel cycles and peaking limits to the criteria of 10CFR50.46. Cases are run at five axial elevations such that a curve of allowable peak linear heat rate as a function of core elevation can be constructed or confirmed. This limit curve is contained in the Core Operating Limits Report (COLR), which is referenced in the North Anna Technical Specifications. Plant operation is controlled so as not to exceed local peaking and allowable power values.

7.4.1 LOCA Limit Dependencies

Absolute LOCA limits to power and peaking for a given core elevation can be determined through repeated calculations with successively higher local power levels until one or more of the applicable acceptance criteria are approached. The approach adopted in the NAPS analysis validates the existing COLR peaking limits, which were predetermined to be acceptable for fuel cycle design and plant operations purposes. The set of LOCA limit cases simply confirms compliance with the applicable criteria.

Figure 7.4-1 shows the hot channel axial power profiles selected for the NAPS LOCA limit analysis. Cases are run with full cores of Advanced Mark-BW fuel. Transition cores are considered in Section 7.8. Figure 7.4-2 shows the hot channel K_Z curve; the curve is normalized to a total peaking factor, F_q, of 2.19. Calculations are performed using the limiting plant model configuration established in Section 7.3. Both the hot pin and hot bundle are initialized at a radial peaking factor of 1.55 ($F_{\Delta h}$). Figure 7.3-3 shows the LOCA limit burnup adjustment factor, K_{BU}. The burnup curve is established to assure BOL as the limiting TIL, as verified by the time-in-life study in Section 7.3.2.7. For the NAPS units, the allowable hot pin power as a function of core elevation and burnup is the product of 2.19, K_Z, and K_{BU}. Having set the desired hot channel axial and radial peaking, LBLOCA calculations can be performed with the core power peaked at various core elevations.

7.4.2 LOCA Limit Results

To validate Figure 7.4-2, five separate LBLOCA calculations were performed. The five cases have power peaks centered at the middle of the second, third, fifth, seventh and ninth grid spans. The minimum containment, backpressure response is shown in Figure 7.4-3.

The results of the calculations are given in Table 7.4-1. Figures 7.4-4 through 7.4-9 show for the limiting 10.3-ft peak power case: (1) Blowdown system pressure, (2) Blowdown hot channel mass flow at the peak power location, (3) Flooding rate, (4) Hot channel quench front and collapsed liquid level, (5) Hot channel PCT and clad temperature at the rupture location, and (6) Hot pin local cladding oxidation. The oxidation figure includes the amount of oxide assumed prior to the start of the accident. Local accumulated oxidation at the end of the REFLOD3B transient is used in the whole-core oxidation calculation. The LOCA limit calculations follow the method set forth in the Dominion May 13, 2002 and June 19, 2002 letters to the NRC (References 7-21 and 7-22). The calculated results presented in this section are based on ending the transient at approximately 400 seconds. The basis for this is presented in Section 7.9.

7.4.2.1 3.0-ft Peak Power Case

In this case, the axial power shape is peaked well below the core mid-plane. The predicted PCT is 1,986°F. The high PCT value is attributable to the type of REFLOD3B behavior previously found and discussed in the Break Type Study, Section 7.3.2.9. The highest local oxidation, 4.6 percent, occurs at the PCT location. The whole-core oxidation is 0.69 percent.

7.4.2.2 4.7-ft Peak Power Case

With the power peaked at 4.7 feet, this case resembles the 3.0-ft case. The PCT is 1,896°F. The highest local oxidation, 2.5 percent, occurs at the PCT location. The whole-core oxidation is 0.69 percent.

7.4.2.3 6.9-ft Peak Power Case

The axial power shape is peaked slightly above the core mid-plane. The PCT is 1,926°F. The highest local oxidation, 3.6 percent, occurs at the PCT location. The whole-core oxidation is 0.69 percent.

7.4.2.4 8.6-ft Peak Power Case

In accordance with the K_Z limit shown in Figure 7.4-2, this case is run at a lower peaking than the three prior cases. The PCT is 1,987°F. The highest local oxidation is 4.3 percent at the PCT location. The whole-core oxidation is 0.72 percent.

7.4.2.5 10.3-ft Peak Power Case

Like the 8.6-ft case, this case is also run at reduced peaking defined by the curve in Figure 7.4-2. The PCT is 1,998°F. The highest local oxidation is 4.6 percent at the ruptured location. The whole-core oxidation is 0.75 percent. This is the limiting LOCA limit case.

7.4.3 Compliance with 10CFR50.46

The LOCA limit calculations directly demonstrate compliance with PCT and local metal-water reaction criteria of 10CFR50.46. In all cases, PCT and local metal-water oxidation are below criteria limits of 2,200°F and 17 percent, respectively. These cases also serve as the basis for demonstrating compliance with whole-core oxidation and coolable geometry criteria, as presented in Sections 7.5 and 7.6, respectively. Section 7.7 addresses compliance with the long-term cooling criterion.

Table 7.4-1: LOCA Limit Results

Parameter	Peak Power Elevation, ft				
	3.0	4.7	6.9	8.6	10.3
EOB, s	19.2	19.3	19.4	19.3	18.6
RV Liquid at EOB, ft^3	60.9	64.3	72.5	71.8	42.0
Bottom-of-Core Recovery, s	28.29	28.28	28.24	28.26	28.57
Hot Pin					
PCT, °F	1,914.1	1,896.4	1,926.4	1,986.5	1,998.3
PCT Time, s	94.9	146.7	190.9	234.8	207.0
PCT Node	8	12	18	24	23
Oxide at PCT Node, %	3.0	2.5	3.61	4.25	4.24
Rupture Node PCT, °F	1,766.0	1,680.2	1,686.4	1,712.2	1,917.9
Rupture Time, s	61.7	57.6	65.9	68.3	76.4
Rupture PCT Time, s	73.3	61.8	143.8	130.4	207.1
Rupture Node	5	8	15	18	24
Oxide at Rupture Node, %	1.87	2.13	2.64	3.18	4.57
Hot Bundle					
PCT, °F	1,901.7	1,889.7	1,919.6	1,981.8	1,991.6
PCT Time, s	122.7	146.7	190.9	235.8	207.0
PCT Node	9	12	18	24	23
Oxide at PCT Node, %	2.79	2.46	3.57	4.20	4.20
Rupture Node PCT, °F	1,985.7	1,657.4	1,682.9	1,707.3	1,918.0
Rupture Time, s	63.8	59.2	67.0	76.1	76.7
Rupture PCT Time, s	75.3	61.8	143.8	83.9	207.1
Rupture Node	8	8	15	18	24
Oxide at Rupture Node, %	4.64	1.95	2.58	3.14	4.50
Whole-Core Oxide, %	0.69	0.69	0.69	0.72	0.75

Figure 7.4-1: LOCA Limits: Hot Channel Axial Power Profiles

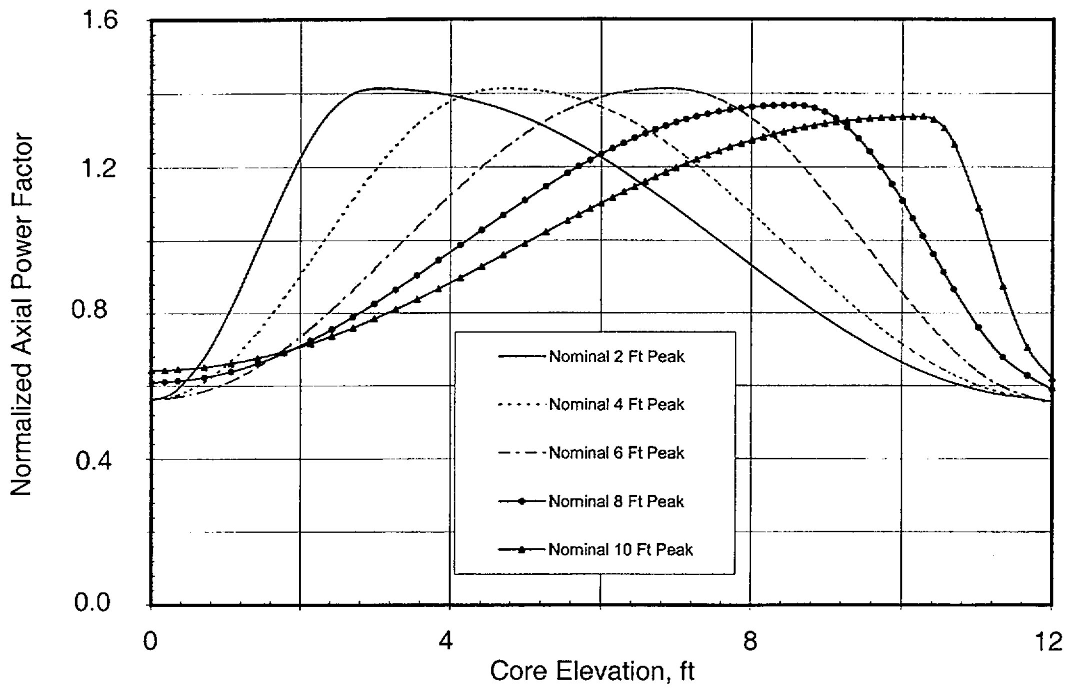


Figure 7.4-2: LOCA Limits: Hot Channel K_Z Curve for Advanced Mark-BW Fuel

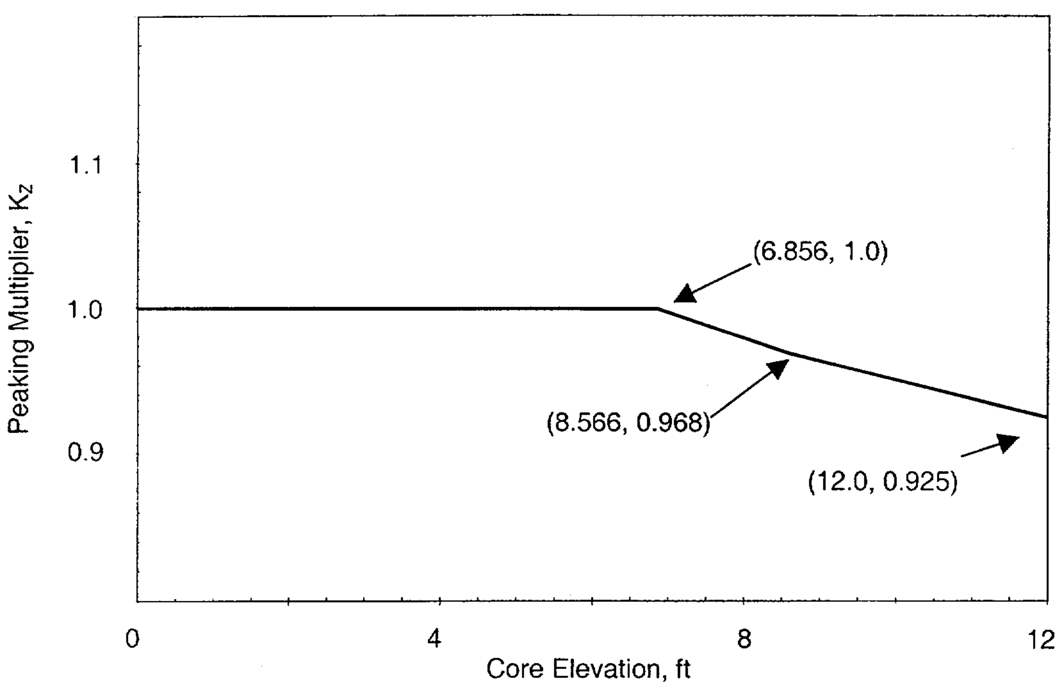


Figure 7.4-3: LOCA Limits: Minimum Containment Backpressure

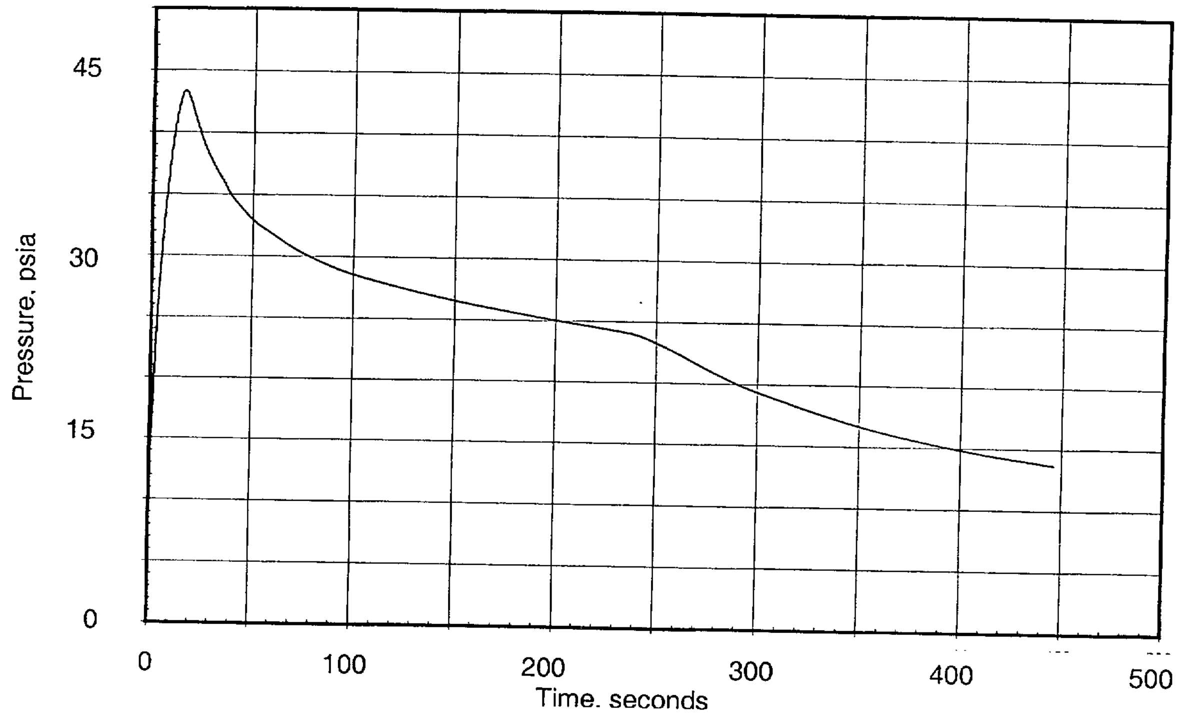


Figure 7.4-4: LOCA Limits: Blowdown System Pressure, 10.3-ft Case

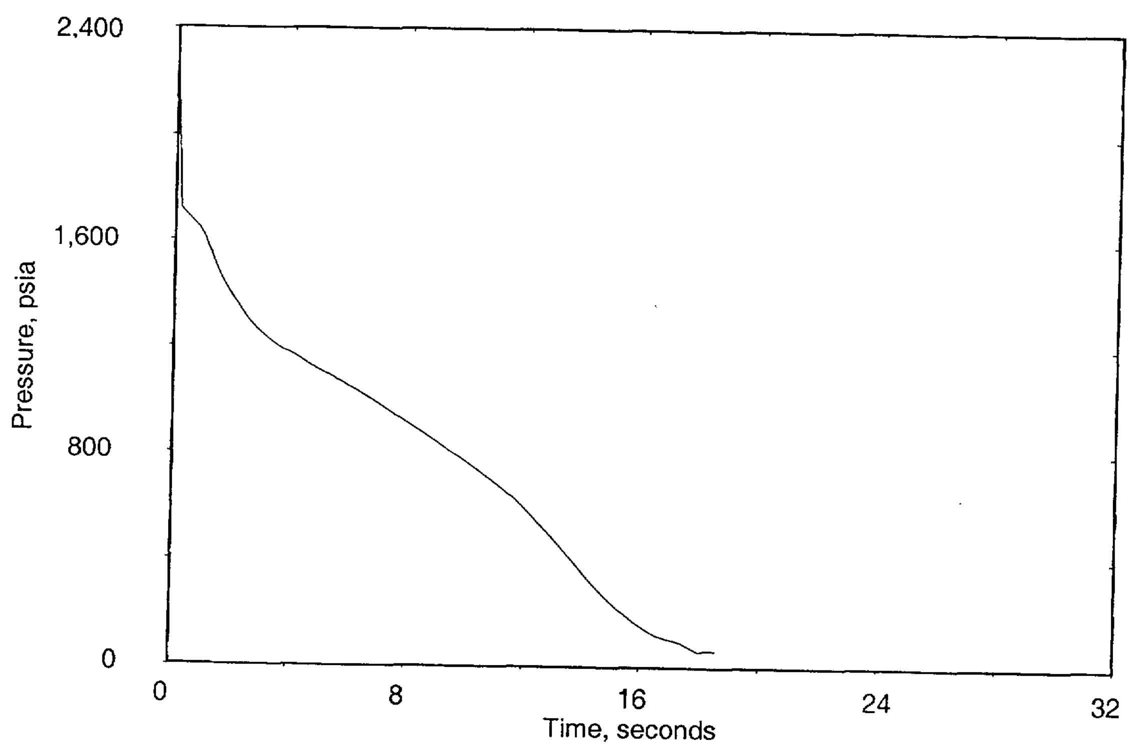


Figure 7.4-5: LOCA Limits: Blowdown Hot Channel Mass Flow at Peak Power Location, 10.3-ft Case

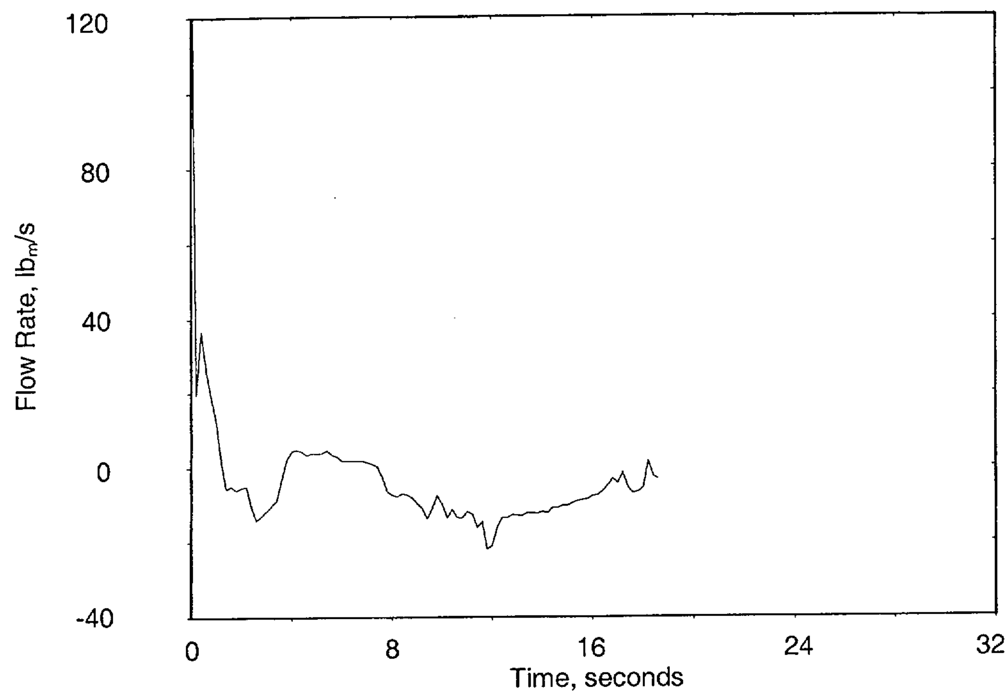


Figure 7.4-6: LOCA Limits: Flooding Rate, 10.3-ft Case

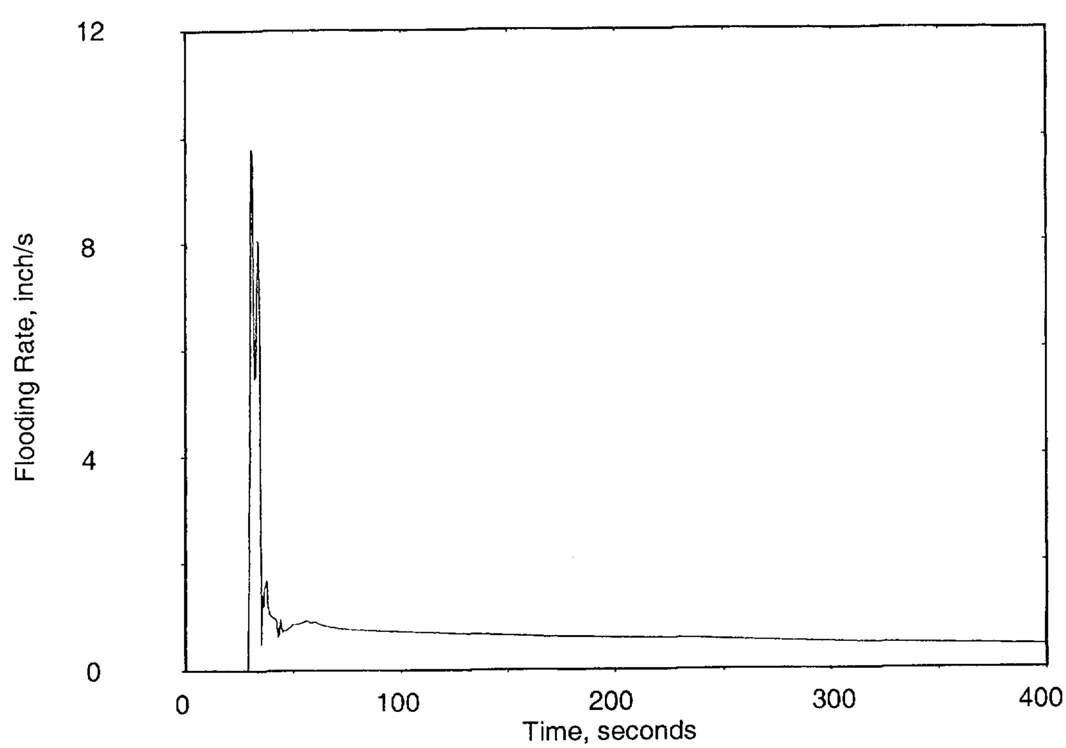


Figure 7.4-7: LOCA Limits: Hot Channel Quench Front and Collapsed Liquid Level, 10.3-ft Case

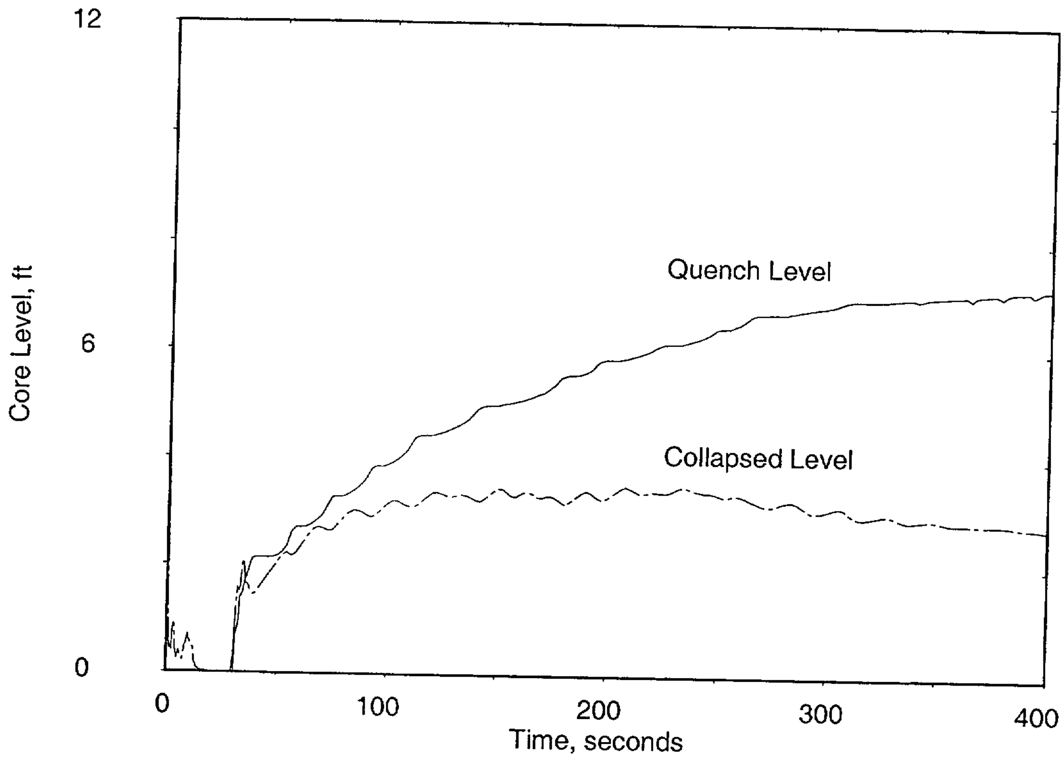


Figure 7.4-8: LOCA Limits: Hot Pin PCT and Clad Temperature at Rupture Location, 10.3-ft Case

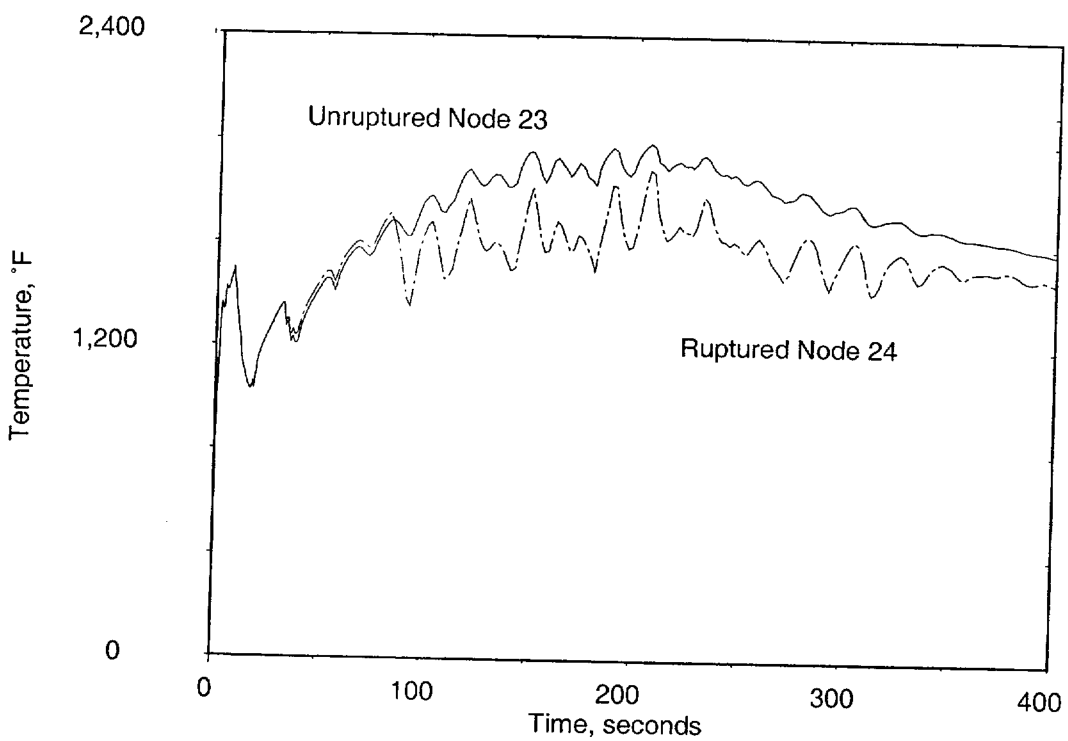
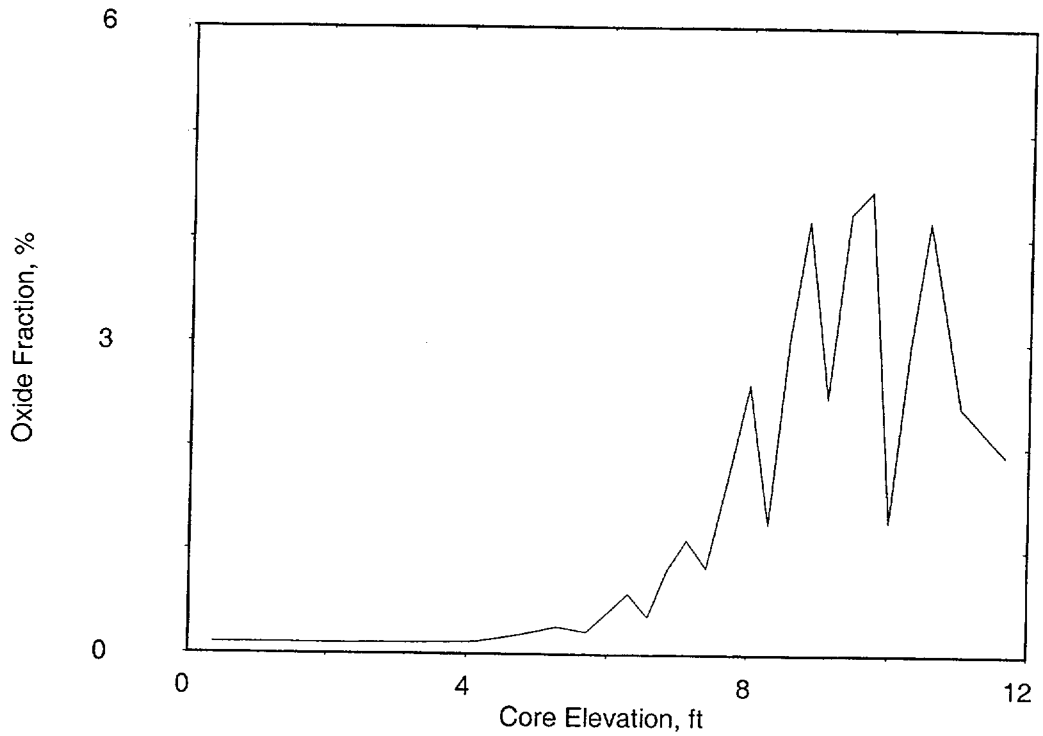


Figure 7.4-9: LOCA Limits: Hot Pin Local Cladding Oxidation, 10.3-ft Case



7.5 Whole-Core Oxidation and Hydrogen Generation

The third criterion of 10CFR50.46 states that:

> "The calculated total amount of hydrogen generated from the chemical reaction of the cladding with water or steam shall not exceed 0.01 times the hypothetical amount that would be generated if all of the metal in the cladding cylinders surrounding the fuel, excluding the cladding surrounding the plenum volume, were to react."

The method provided in the Framatome ANP EM (Reference 7-1) is applied to determine core-wide oxidation for each of the five LOCA limit cases. A description of the calculation is presented in Volume III of Reference 7-1, beginning on page LA-229.

Local cladding oxidation is generally continued until the cladding temperature falls below 1,000°F, and REFLOD3B predicts quench at the given core elevation. However, for this NAPS-specific application, calculations are based on a transient end time of about 400 seconds. This is discussed and justified in Section 7.9. The local oxidation is summed over the core to predict the core-wide oxidation. The distribution of fuel assembly powers used in this calculation was selected to conservatively bound expected core operations. Figure 7.4-9 illustrates the local hot pin oxidation, including the initial oxidation layer, as a function of the active core elevation for the limiting LOCA limit case (10.3-ft case). The difference between this distribution and the one used for the whole-core calculation is the subtraction of the initial oxide layer before integrating. This establishes a proper measure of the hydrogen produced from the LBLOCA transient, relative to the criterion. The calculation results for each of the five LOCA limit cases are given in the following table.

LOCA Limit Case	Whole-Core Oxide Percentage
3.0-ft	0.69
4.7-ft	0.69
6.9-ft	0.69
8.6-ft	0.72
10.3-ft	0.75

The maximum whole-core oxidation for the NAPS units is 0.75. Thus, the third criterion of 10CFR50.46, which limits the whole-core reaction to less than or equal to 1 percent, is met.

7.6 Core Geometry

The fourth acceptance criterion of 10CFR50.46 states that:

> "Calculated changes in core geometry shall be such that the core remains amenable to cooling."

The calculations in Section 7.4 directly assess the alterations in core geometry (i.e. clad rupture) resulting from LOCA at the limiting core elevations. The calculations demonstrate that the fuel pin is successfully cooled. Clad swelling and flow blockage modeling due to rupture are discussed in Reference 7-8 for Framatome ANP's advanced clad material, M5™. For all the LOCA limit cases, the hot assembly flow area reductions at rupture are less than 60 percent. This is within the NRC-accepted upper limit of possible channel blockage for the M5™ swelling and rupture model given in Reference 7-8. Neither the M5™ blockage value nor the 60 percent blockage constitutes total sub-channel obstruction.

The effect of fuel rod bowing on whole-core blockage is considered in the fuel assembly and fuel rod designs that minimize the potential for rod bowing. The minor adjustments of fuel pin pitch due to rod bowing do not alter the fuel assembly flow area substantially and the average sub-channel flow areas are preserved. Therefore, due to the axial distribution of blockage caused by rupture, no coplanar blockage of the fuel assembly occurs, and the core remains amenable to cooling.

NAPS-specific calculations indicate that deformation of the fuel pin lattice in some core periphery fuel assemblies occurs from the combined mechanical LOCA and seismic loads (Reference 7-15, Section 3.3.3). The predicted deformations have a maximum impact of reducing the subchannel flow area of one row of pins by 32 percent. (If the deformation is evenly spread over three rows of fuel pins the blockage per subchannel reduces to 11 percent.) The assembly flow area is reduced by less than two percent. Thus, total blockage at any elevation along the fuel assembly will not exceed the M5™ blockage limit.

A conservative evaluation of the impact of this amount of flow area reduction was conducted with the following results: (1) The coolant flow within these assemblies is not substantially altered, and (2) The maximum cladding temperature during LOCA is less than 1,800°F, below the temperature at which significant metal-water reaction occurs. Hence, these grid deformations do not lead to conditions that interfere with core coolability.

The consequences of thermal and mechanical deformation of the fuel assemblies in the core were assessed. The resultant deformed geometry maintains a coolable configuration. The conclusions rely on basic phenomena encountered during LOCA and are equally applicable to the Advanced Mark-BW fuel and the current resident Westinghouse fuel. Therefore, the coolable geometry requirements of 10CFR50.46 are met, and the core remains amenable to cooling.

7.7 Long-Term Cooling

The fifth acceptance criterion of 10CFR50.46 states that:

> "...the calculated core temperature shall be maintained at an acceptably low value and decay heat shall be removed for the extended period of time required by the long-lived radioactivity remaining in the core."

Successful initial operation of the ECCS is shown by demonstrating that the core is quenched and the cladding temperature is returned to near saturation. Thereafter, long-term cooling is achieved by the pumped injection systems. These systems are redundant and provide a continuous flow of cooling water to the core fuel assemblies so long as the coolant channels in the core remain open. For a cold leg break, the concentration of boric acid within the core can induce a crystalline precipitation that may prevent coolant flow from reaching portions of the core. This section evaluates the initial operation of the ECCS, considers the long-term supply of water to the core, and discusses the procedures to prevent the build-up of boric acid in the core.

7.7.1 Initial Cladding Cooldown

The LOCA EM heat transfer models used to predict clad temperature following the start of clad cooldown are conservatively biased. They are not directly used to predict clad quench, rather they indicate that the core temperatures are declining toward quench and that quench is imminent. After quenching, core heat transfer is generally through pool nucleate boiling or forced convection to liquid, depending on the break location (cold leg breaks are in pool nucleate boiling and hot leg breaks are in forced convection to liquid). Either heat transfer mechanism is fully capable of maintaining the core within a few degrees of the coolant saturation temperature. Thus, within ten to fifteen minutes following a large break LOCA, the core is returned to an acceptably low temperature.

7.7.2 Extended Coolant Supply

Once the core is cooled to low temperature, maintaining that condition relies upon the systems that are designed to provide a continuous supply of coolant to the core. Detailed descriptions of the plant systems and functions are provided in the NAPS UFSAR. Long-term core cooling with the ECCS is independent of the fuel design. Thus, the current licensing basis remains valid for Advanced Mark-BW fuel assemblies.

7.7.3 Boric Acid Concentration

The long-term cooling mechanism for a hot leg break is forced convection to liquid. Once cooling is established a positive core flow is assured, boron precipitation is rendered a non-issue, and no further consideration is necessary. For cold leg breaks, there is no forced flow through the core. The liquid head balance between the core and the downcomer prevents ECCS water from entering the core at a rate faster than core boil-off. Extra injection simply flows out the break and spills to the containment floor. With no core flow, core boiling acts to concentrate boric acid adding to the potential for precipitation and core blockage. To eliminate boron precipitation and any accompanying core blockage, operator action is required to establish hot leg recirculation (positive core flow).

In this mode, the ECCS is aligned to inject into the hot legs. In doing so, the hot leg injection provides a positive core flow capable of controlling the concentration of boric acid. The timing and effectiveness of the hot leg injection is established by demonstrating that the in-vessel concentration of boric acid is below solubility limits. There is no dependency on the fuel element design since concentrations depend on ECCS injection rate, RCS geometry, and core power level. Since the Framatome ANP fuel does not alter these factors, the current evaluation remains valid and is equally applicable to Advanced Mark-BW fuel. Emergency operating procedures exists that provide guidance to address the boric acid precipitation issue and ensure that long-term cooling is maintained.

7.7.4 Adherence to Long-Term Cooling Criterion

Compliance with this criterion is demonstrated in the NAPS UFSAR. It is independent of fuel design. The initial phase of core cooling results in low clad and fuel temperatures. A pumped injection system, capable of recirculation, is available and operated by the plants to provide extended coolant injection. The concentration of dissolved solids is limited to acceptable levels through the timely implementation of hot leg injection. Hence, long-term cooling is established and compliance to 10CFR50.46 demonstrated.

7.8 Evaluation of Transition Cores

The previous discussion addressed LOCA analyses that were performed for full cores of Advanced Mark-BW fuel. This section addresses the LOCA aspects of a mixed or transition core configuration. The Framatome ANP base analysis, which modeled a full core of Advanced Mark-BW fuel, is assessed for impact due to co-residence with Westinghouse fuel. Basic assembly design parameters for the two fuel types are compared in Table 1.0-1 of Reference 7-15. Both assemblies are quite similar. For two cycles of operation, Westinghouse and Framatome ANP fuel will reside side-by-side in the core. After completion of the second transition cycle at each unit, the cores will be fueled with essentially all Advanced Mark-BW fuel.

Because the external fuel pin dimensions will be the same between co-resident fuel designs, there will be no effect on LOCA thermal-hydraulic predictions. Fuel in the LOCA models is treated as being physically uniform; it is unaffected by the small differences in pellet length. There is no difference in pellet OD; hence, fuel-stored energy and flooding rate predictions are not affected. Guide and instrument tube differences do not affect a large portion of the fuel assembly and do not affect the LOCA evaluation. The internal flow area of the guide and instrument tubes is larger for the Advanced Mark-BW fuel than it is for NAIF. The shift in flow area from inside the guide and instrument tubes to the heated channels is small and inconsequential.

A difference in fuel assembly pressure drops is the one issue that could produce a discernable change in LOCA results. Therefore, LOCA transient response was examined for transition cores composed of co-resident Advanced Mark-BW fuel and NAIF assemblies. The primary difference between the two fuel designs is the use of three MSMGs in the upper half of the Advanced Mark-BW fuel. These mid-span grids promote added turbulence and flow mixing mid-way between structural grids. Due to the MSMGs, the Advanced Mark-BW fuel has a larger pressure drop than does the NAIF. The competing effects of flow diversion, resulting from the added pressure drop associated with the presence of the MSMGs, and flow mixing, resulting directly from the design (the mixing vanes) of the MSMGs, were evaluated. The evaluation purpose was to determine if a PCT penalty is appropriate for either NAIF or the Advanced Mark-BW fuel during core transition cycles.

The first mixed core of Advanced Mark-BW fuel and NAIF will consist of approximately 40 percent Framatome ANP fuel and 60 percent Westinghouse fuel. About one-third of the Westinghouse fuel will be low-powered assemblies residing on the core periphery. The remaining NAIF assemblies will be located in the center of the core and evenly interspersed with the Framatome ANP fuel in a "checker board" type pattern. The centrally located NAIF assemblies (at least once burned) will be somewhat lower in power than the Framatome ANP fuel. Some flow diversion from the Framatome ANP fuel to NAIF assemblies occurs due to the locally higher pressure drop of the Advanced Mark-BW fuel and the power imbalance (NAIF would be the lower powered assembly) between assemblies.

The effect of flow diversion is mitigated by the fuel assembly loading pattern, a NAIF assembly surrounded by Framatome ANP assemblies (and vice versa). The flow coming into the Westinghouse assemblies through each of its four faces reduces inflow from the other faces. In essence, the four inflows provide resistance to each other and tend to limit the amount of flow diversion from a given Framatome ANP assembly. Flow diversion that does occur is counterbalanced in two ways. First, the local depressurization downstream of a MSMGs will promote flow back into the Framatome ANP assemblies, i.e. flow recovery is prompt in both a spatial and temporal sense. Secondly, the MSMGs provide a mixing mechanism by adding fluid turbulence, resulting in improved heat transfer. Since the assemblies are evenly spaced in the center of the core, the tendency is to homogenize the fluid among the Framatome ANP and Westinghouse fuel assemblies. Overall, flow diversion is counterbalanced by the mixing induced by the MSMGs within the central portion of the core. Therefore, no penalty is required for the first transition core cycle.

The second mixed core cycle will consist of approximately 80 percent Advanced Mark-BW fuel and 20 percent NAIF with the low powered Westinghouse fuel residing on the core periphery. The Advanced Mark-BW fuel will reside in the center of the core; in essence, it will act much like a full core of Advanced Mark-BW fuel with a PCT consistent with that configuration. Therefore, no penalty is required for the second transition core cycle.

The full core LOCA analysis results of the respective fuel assemblies are applicable for licensing during mixed core operation. The LOCA analysis in the current NAPS UFSAR provides the licensing basis for the use of NAIF (Vantage 5H variant) and the Technical Specifications limitations applied to those assemblies are based on those analyses. The analysis presented in Section 7.4, as amended in Section 7.9, provides the licensing basis for the Advanced Mark-BW during mixed core operation. The Technical

Specifications applied to the Advanced Mark-BW fuel are based on the assumptions of this analysis.

7.9 LBLOCA Post-Analysis of Record Evaluations

In addition to the LBLOCA analyses presented in this report, various subsequent evaluations and re-analyses may be performed, as needed, to address errors, emergent issues, or to support plant changes. The issues or changes are evaluated and the PCT impact on calculated results is quantified. The resultant increase or decrease is applied to the analysis of record (AOR), forming the LBLOCA licensing base for the NAPS units. The results of all evaluations, including penalties and benefits, are summarized in Table 7.9-1.

7.9.1 Break Type Study

This study, discussed in Section 7.3.2.9, predicted that the PCT for the split break was higher than that for the corresponding guillotine break case. An examination of the split break transient revealed that the high PCT value was due to non-physical behavior by REFLOD3B.

The examination noted that the split case was substantially colder than the corresponding guillotine case at EOB and remained so during the initial portion of the reflood transient. In reflood, the rapid quenching of the first core slab caused a substantial non-physical core carryout which was well above that predicted by the data-based CRFCKN carryout rate fraction (CRF) correlation. Due to REFLOD3B being an equilibrium code, the excessive liquid carryout is instantaneously converted to vapor, causing a pressure spike sufficient to force all core liquid out of the core. This effectively restarts the reflood transient, but it now starts at a higher clad temperature. The issue was conservatively addressed by imposing a PCT adder of +20°F to the guillotine case. The guillotine break type was used to perform the LOCA limit calculations. The 20°F PCT addition is recorded in Table 7.9-1.

7.9.2 Downcomer Boiling and Transient Termination

The Framatome ANP RSG LOCA EM simulates the course of a LOCA through the blowdown, refill, and reflooding phases until saturated fluid is predicted to exist in the downcomer during the reflooding period. Since this model cannot simulate two-phase fluid behavior in the downcomer region of the reactor vessel in the reflooding calculation, the NRC has expressed a concern about the effect that boiling in the downcomer might have on the calculation of the peak cladding temperature. Because of this concern, it was further suggested either that the model be refined to simulate the effects of boiling or that an adjustment be made to the peak cladding temperature to account for this phenomenon. The following discussion presents the results of following the latter suggestion, in which a conservative estimate is made of the possible effects of downcomer boiling.

The calculations presented in Section 7.4 to demonstrate compliance with 10CFR50.46 show that saturation is reached in the downcomer at about 400 seconds. This is during the later stages of reflood and well past the time that PCT is calculated to occur. Boiling could occur at this time because energy stored in the reactor vessel wall would continue to heat the fluid in the downcomer. Continued boiling will cause the liquid level to drop and the void fraction in the downcomer to increase. These effects will reduce the static head in the downcomer, which in turn will reduce the reflood rate in the core. Under some circumstances, the core flow could become sufficiently reduced such that the cladding temperature peaks a second time and that this peak, occurring late in the reflood phase, could be higher than the initial peak.

An estimate of the downcomer boiling effect was made using Framatome ANP's realistic evaluation model (Reference 7-23). This model, which is based on the S-RELAP5 computer code, has the capability to simulate downcomer boiling. The estimate was obtained by running the realistic model in two modes. First, the model was run as indicated in Reference 7-23, with its inherent capability to predict the boiling phenomenon. Second, the model was run with downcomer boiling suppressed. Based upon these analyses, adjustments were developed for application to the deterministic results. By applying these adjustments to the deterministic results, the complete cooldown and quenching of the core is accounted for. The adjustments capture the transient effects that occur beyond 400 seconds, thereby making the extension of the deterministic calculations beyond 400 seconds unnecessary.

7.9.2.1 Downcomer Modeling and the Boiling Phenomenon

The Framatome ANP realistic large break LOCA evaluation model (RLBLOCA), which is based on the S-RELAP5 computer code, provides for an accurate, spatially representative calculation of the fluid conditions and the heat transfer in the downcomer region. The fluid volumes in this model are capable of calculating steam production, steam-water slip, and coolant void fraction. The downcomer is divided axially into six levels and azimuthally into four regions. The lower plenum is axially divided into two levels. Primary metal is represented by separate thick- and thin-walled heat structures attached to each fluid control volume. This realistic model is demonstrated to properly evaluate the potential for and consequences of downcomer boiling during late reflood in the sensitivity study and the benchmarks discussed in the following text.

7.9.2.2 Downcomer Boiling Sensitivity Study

The RLBLOCA model was set up to represent the North Anna Power Station and was run through a complete set of realistic cases, as defined in Reference 7-23. The results, which are shown in Figure 7.9-1, are for the 95/95 case from that set. The upper trace, with a peak cladding temperature of 1,932°F at 220 seconds, is from the calculation in which boiling was permitted. The second trace, with a peak temperature of 1,831°F at 150 seconds, is identical to the first run but with boiling suppressed, as previously described.

The behavior of the two realistic calculations is similar until about 120 seconds. At this time in the boiling case, cladding temperature starts to turn around. This turnaround also occurs for the non-boiling case at about the same cladding temperature but somewhat later, at about 150 seconds. In addition, at around 140 seconds in the boiling case, the boiling in the downcomer has penetrated downward, significantly reducing the downcomer driving head and slowing the core flooding rate. These effects reduce the core cooling and cause a rise in the cladding temperature. In the non-boiling case, however, none of these effects occurs, and heat removal in the core continues to increase, steadily cooling the cladding. At approximately 220 seconds in the boiling case, a relative equilibrium is achieved in which the downcomer head has stabilized and the cladding temperature begins to decrease because the decay heat is being removed. Subsequently, both cases predict decreasing cladding temperatures.

The peak cladding temperatures in the two cases occur at different times, at approximately 150 seconds for the non-boiling case and at 220 seconds for the boiling case. The difference in the two cases, at the time of the eventual peak of the boiling case is about 250°F. Were the difference in cladding temperatures to be evaluated at 300 seconds, the difference would be around 600°F. However, the difference between the two PCTs is only 101°F. Thus, the effect of downcomer boiling on cladding temperatures can be large, but the largest effects occur after the cladding temperature has peaked.

7.9.2.3 Benchmarks

Experimental indications of downcomer boiling are limited. The literature contains references to the CCTF program, the UPTF program, and selected Semiscale experiments. The fundamental processes that lead to downcomer boiling, however, are basic to any current and well-formulated system code. To adequately simulate boiling, it is necessary to determine the condition of the fluid within the downcomer, the heat transfer from the reactor vessel wall, and the relative flow of steam against water. All of these processes have been widely studied and a larger number of code benchmark experiments are available. For S-RELAP5, the system code used in the realistic LOCA evaluation model, these benchmarks are presented in the code verification and validation report, Reference 7-24. These benchmarks establish the overall ability of S-RELAP5 to compute system behavior under a variety of circumstances, including downcomer boiling.

Beyond the overall applicability of S-RELAP5, a benchmark that demonstrates the ability of the code to predict boiling in the downcomer is useful to confirm the capability of the code for this application. The Semiscale Tests S-04-5, S-04-6, and S-06-3 achieve significant depletion of the downcomer inventory (Reference 7-25) and are by far the most relevant of the available experiments. S-RELAP5 was benchmarked to Test S-06-3, and the results are provided below.

7.9.2.3.1 *Semiscale* Test S-06-3

Semiscale Test S-06-3 was designed to simulate a double-ended guillotine LOCA, and conditions were selected so that it could serve as the counterpart for the LOFT L2-3 test. Because of the reduced scale of this facility (designed as 1/1500 volume scaled), metal mass is exaggerated relative to what might be expected in a commercial plant. For this reason, it presents a good example of the potential impact of downcomer boiling.

A benchmark for Test S-06-3 has been reported in the RLBLOCA methodology document and the S-RELAP5 Verification and Validation Report (References 7-23 and 7-24). After that benchmark, further information about the downcomer behavior during the test has been obtained, and the benchmark discussed herein includes this new information. The primary effect of this improved understanding of downcomer behavior is in the modeling of the space in the downcomer between the vessel and a filler structure that was placed in the downcomer to maintain the correct hydraulic volume scale. Earlier benchmarks assumed that this space was voided. It has subsequently been determined, however, that this space actually filled with water shortly after the experiment began. The presence of water significantly increases the transfer of heat from the downcomer metal structures. Other minor modifications were made to improve the S-RELAP5 blowdown prediction: (1) an increase in the discharge coefficients for the vessel-side break, (2) a decrease in the discharge coefficients for the pump-side break, (3) turning off the choking model on the vessel-side break at 22 seconds, and (4) use of a data-based, pressure boundary condition in the pressurizer. These changes were implemented to improve blowdown and refill dynamics and have no significant influence on the downcomer boiling phenomenon during reflood.

The important parameter used to track downcomer boiling in test S-06-3 is downcomer differential pressure. Downcomer differential pressure is well correlated to liquid level. Figure 7.9-3 shows the differential pressure between the lower head and downcomer at the cold leg nozzle for both the calculation and the experimental data. The S-RELAP5 prediction, while it "leads" the data in timing, satisfactorily replicates the downcomer boiling effect on liquid level. Downcomer boiling was observed in the test beginning around 100 seconds, which is indicated by the sharp decrease in differential pressure at that time. This same effect was predicted by S-RELAP5 to occur at about 75 seconds. The differential pressure is reduced by approximately 50 percent and remains at that level for about 100 seconds before recovering prior to the end of the transient at 300 seconds.

It is concluded from this benchmark that S-RELAP5 is capable of predicting the significant phenomena associated with downcomer boiling. This capability is demonstrated by comparison of the differential pressures in Figure 7.9-3. This benchmark along with the broad range of benchmarks provided in the Verification and Validation Report (Reference 7-24) qualifies S-RELAP5 to provide meaningful quantification of the downcomer boiling effect for application to North Anna.

7.9.2.4 Adjustment Determination

The Framatome ANP realistic evaluation model has been used to demonstrate the conservatism in the deterministic model and to develop a conservative estimate of the effect of downcomer boiling. In Section 7.9.2.2, two cases were analyzed using the RLBLOCA EM: one with downcomer boiling and one without. The cladding temperature transient results from these two cases are shown in Figure 7.9-1.

The differences between these two calculations were used to determine adjustments that can be applied to the deterministic results to conservatively estimate the effects of downcomer boiling in the context of an Appendix K evaluation model. From Figure 7.9-1, the difference in peak cladding temperature is 101°F. The predicted local oxidation for the two cases is 2.02 percent and 3.67 percent, which is a difference of 1.65 percent. The predicted whole-core oxidation for the two cases is 0.10 percent and 0.19 percent, which is a difference of 0.09 percent. Table 7.9-1 summarizes the deterministic results, the adjustments derived from the realistic calculations, and the final results, which show compliance with the criteria of 10CFR50.46.

7.9.2.5 Summary

The Framatome ANP RSG LOCA EM does not include features that can address downcomer boiling and the protracted cladding cooldown and quench period that result therefrom. Therefore, to address the potential effect for downcomer boiling, adjustments were developed for application to NAPS predictions based on the RSG LOCA EM.

A conservative assessment has been made based on results using the Framatome ANP realistic ECCS evaluation model. This model is based on the S-RELAP5 code, which has the ability to accurately calculate the effects of boiling in the reactor vessel downcomer. The model has been benchmarked against pertinent experimental data, including Semiscale Test S-06-3, with satisfactory results. Thus, the approach to the determination of the adjustment factors is well founded.

Table 7.9-1 summarizes the deterministic results, the adjustments derived from the realistic calculations, and the results. All of the adjusted values meet the criteria of 10CFR50.46 with considerable margins.

Table 7.9-1

LBLOCA Licensing Basis

Item	PCT, °F	Local Oxidation, %	Whole-Core Oxidation, %
AOR (Calculated Result)*	**1,998**	**4.57**	**0.75**
Break Type Study, Section 7.3.2.9	20	N/A	N/A
Downcomer Boiling and Transient Termination, Section 7.9.2	101	1.65	0.09
Licensing Basis	**2,119**	**6.22**	**0.84**

* 10.3-foot LOCA limit case (limiting case) from Section 7.4.2.5

Figure 7.9-1

North Anna Realistic LOCA Prediction—PCT Independent of Location

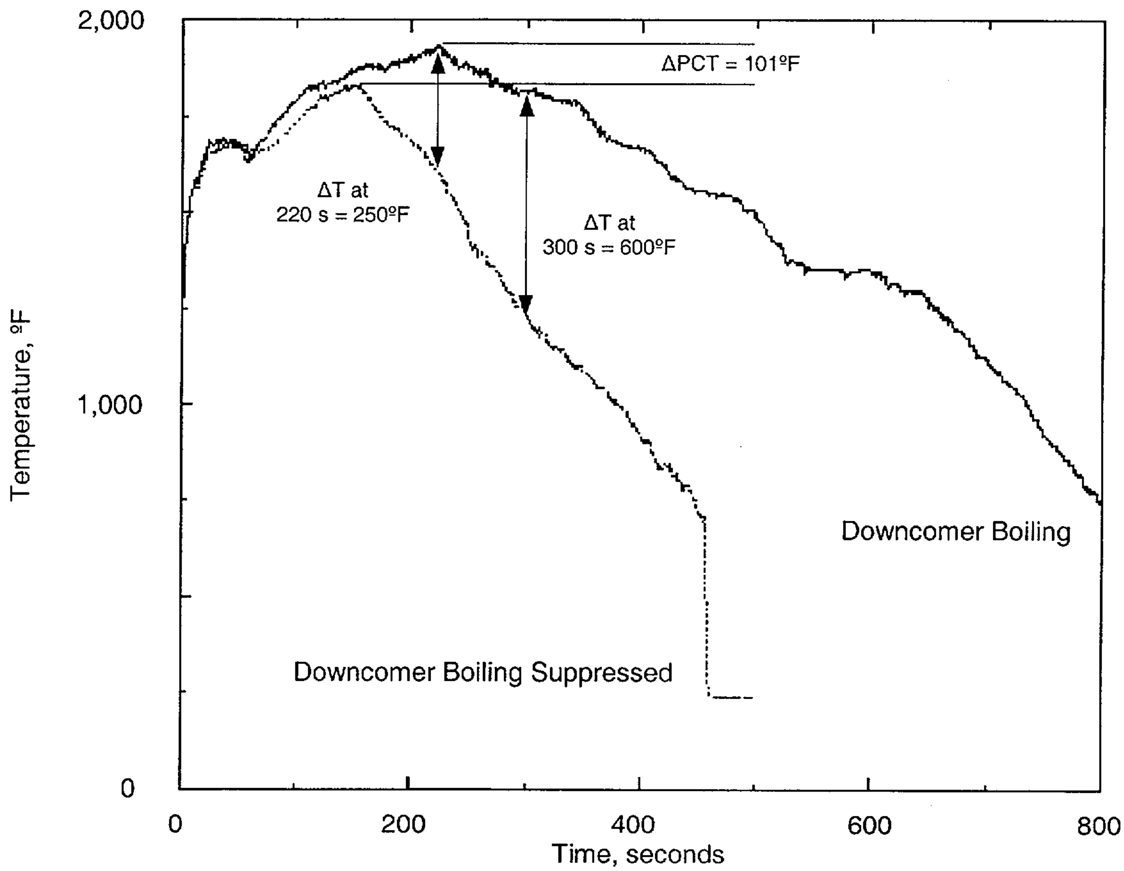


Figure 7.9-2

North Anna Realistic LOCA Prediction—Downcomer Liquid Level Comparison

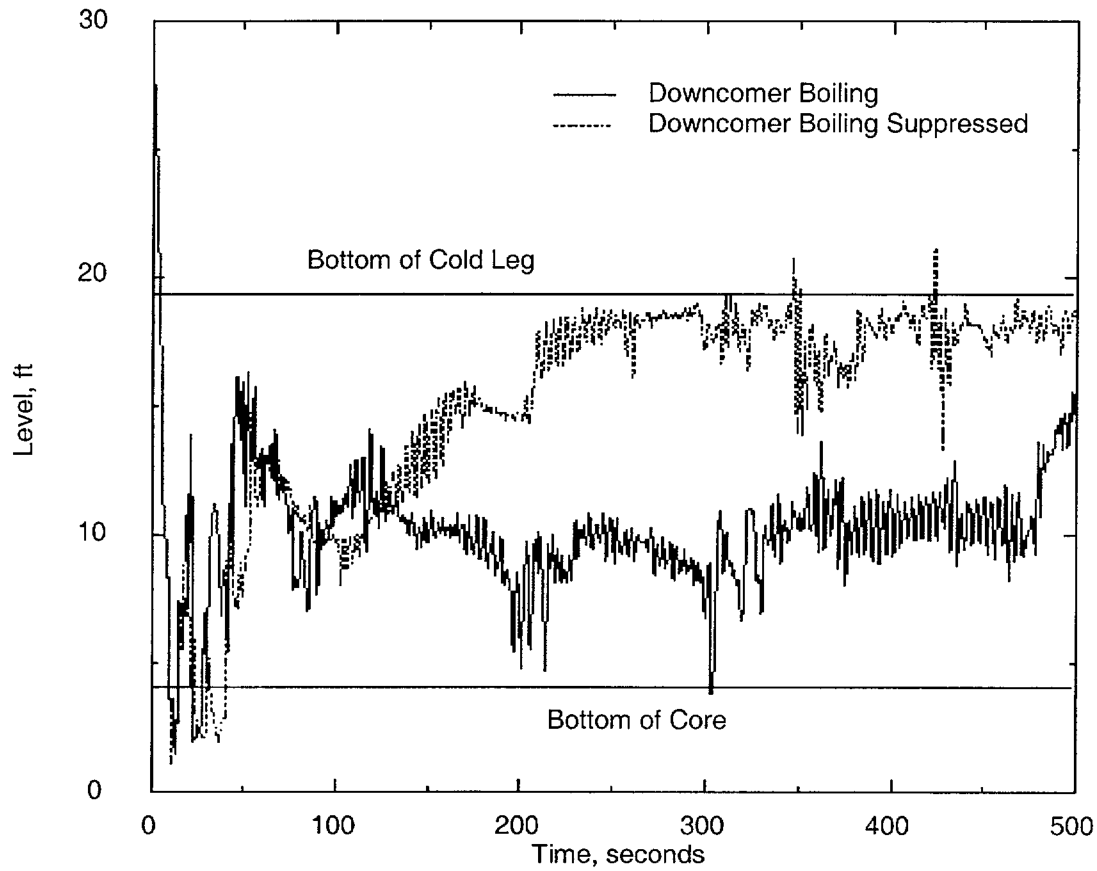
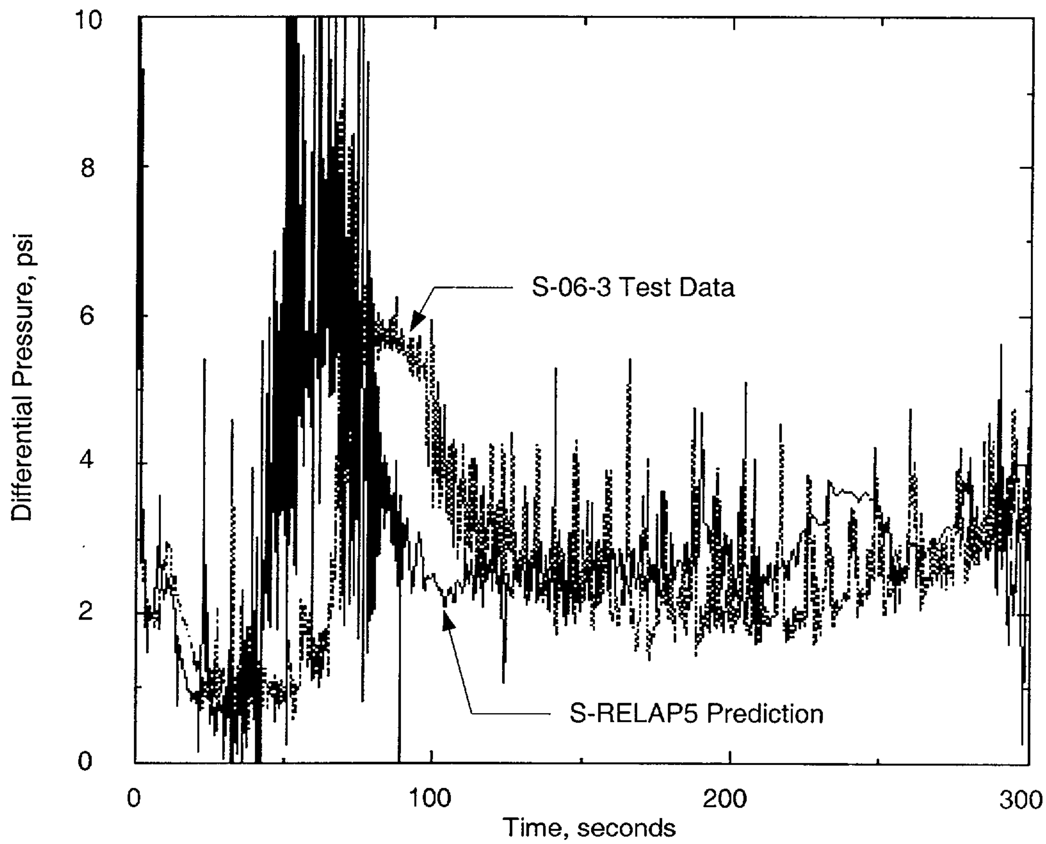


Figure 7.9-3

S-RELAP5 Benchmark of Semiscale Test S-06-3—Downcomer Pressure Drop



7.10 SBLOCA Evaluation

The North Anna evaluation for SBLOCA followed a course employed (and approved by the NRC) in two prior transitions to Framatome ANP fuel for plants with recirculating steam generators (References 7-11, 7-13 and 7-16). The approach involves demonstrating that the current Westinghouse SBLOCA licensing basis is equally applicable to Framatome ANP Advanced Mark-BW reload fuel. This approached is detailed and justified in Reference 7-20.

7.11 Conclusions

10CFR50.46 specifies that the ECCS for a commercial nuclear power plant must meet five criteria. The calculations and evaluations documented in this chapter demonstrate that the two NAPS units meet the required licensing criteria when operated with Advanced Mark-BW fuel. LOCA calculations performed in concurrence with an approved evaluation model (Reference 7-1) demonstrate compliance for a full core of Advanced Mark-BW fuel for postulated breaks up to and including the double-ended severance of the largest primary coolant pipe. The co-residence of Advanced Mark-BW fuel and NAIF assemblies in the same fuel cycle is concluded to be of minimal consequence and does not cause the calculated clad temperature of either assembly to approach the limits of 10CFR50.46.

Specifically, this report concludes that when the North Anna units are operated with Advanced Mark-BW fuel:

1. The calculated PCT for the limiting case is less than <u>2,200°F</u> (Section 7.4).
2. The maximum calculated local clad oxidation is less than <u>17 percent</u> (Section 7.4).
3. The maximum amount of core-wide oxidation does not exceed <u>1 percent of the fuel cladding</u> (Section 7.5).
4. The cladding remains <u>amenable to cooling</u> (Section 7.6).
5. <u>Long-term cooling is established and maintained</u> after the LOCA (Section 7.7).

Large break studies performed using the Framatome ANP RSG LOCA evaluation model show that the double-ended guillotine break at the pump discharge with a discharge coefficient of 0.6 and maximum ECCS is the limiting case. Table 7.4-1 shows the results of this accident for the Advanced Mark-BW fuel design when the assumed axial location of peak power is varied along the length of the fuel pin. The local power for the Advanced Mark-BW fuel is controlled to the peaking limit curves, Figures 7.3-3 and 7.4-2. The results of Sections 7.4, 7.5, 7.6 and 7.7 demonstrate compliance with the five criteria of 10CFR50.46. The transition core was evaluated and no significant impact, requiring a PCT penalty, on either NAIF or Advanced Mark-BW fuel was noted. Post-analysis of record evaluations are discussed in Section 7.9. Table 7.9-1 gives the licensing base PCT and oxidation values for the 10.3-foot LOCA limit case, the limiting LOCA case. Finally, the small break LOCA evaluation in Section 7.10 concluded that the current North Anna UFSAR analysis (a 10CFR50.46-compliant analysis for NAIF) is equally applicable to Framatome ANP supplied Advanced Mark-BW fuel.

7.12 References

7-1 RSG LOCA - BWNT Loss-of-Coolant Accident Evaluation Model for Recirculating Steam Generator Plants, BAW-10168P-A, Revision 3, December 1996.

7-2 RELAP5/MOD2-B&W - An Advanced Computer Program for Light Water Reactor LOCA and Non-LOCA Transient Analysis, BAW-10164P-A, Revision 3, July 1996. Augmented by NRC Staff SER transmitted via letter from Leslie W. Barnett, NRC, to James F. Mallay, Framatome ANP, April 9, 2002.

7-3 REFLOD3B - Model for Multinode Core Reflooding Analysis, BAW-10171P-A, Revision 3, December 1995.

7-4 BEACH - A Computer Program for Reflood Heat Transfer during LOCA, BAW-10166P-A, Revision 4, February 1996. Augmented by Framatome ANP letter from James F. Mallay, Framatome ANP, to Document Control Desk, NRC, NRC:01:050, December 10, 2001.

7-5 CONTEMPT – Computer Program for Predicting Containment Pressure-Temperature Response to LOCA, BAW-10095A, Revision 1, April 1978.

7-6 BWNT LOCA - BWNT Loss-of-Coolant Accident Evaluation Model for Once-Through Steam Generator Plants, BAW-10192P-A, June 1998.

7-7 TACO3 - Fuel Pin Thermal Analysis Code, BAW-10162P-A, January 1990.

7-8 Evaluation of Advanced Cladding and Structural Material (M5) in PWR Reactor Fuel, BAW-10227P-A, February 2000.

7-9 Not used.

7-10 V. H. Ransom et al., RELAP5/MOD2 Code Manual, Volumes 1 and 2, NUREG/CR-4312, EGG-2396, August 1985.

7-11 Mark-BW Reload LOCA Analysis for the Catawba and McGuire Units, BAW-10174A, Revision 1, September 1992.

7-12 Mark-BW17 Lead Test Assemblies for North Anna Power Station, BAW-2272P, July 1996.

7-13 Mark-BW Reload LOCA Analysis for the Trojan Plant, BAW-10177, October 1990.

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7-15 Letter: L. N. Hartz (Virginia Electric and Power Company) to Document Control Desk (NRC), "North Anna Power Station Units 1 and 2, Proposed Technical Specifications Changes and Exemption Request Use Framatome ANP Advanced Mark-BW Fuel," Serial No. 02-167, March 28, 2002.

7-16 Letter: Roby Bevan (NRC) to James E. Cross (Portland General Electric Company), "NRC Staff Evaluation of Topical Report BAW-10177 (TAC No. 80468)," September 24, 1991.

7-17 NAPS UFSAR, Revision 37.

7-18 Letter: L. N. Hartz (Virginia Electric and Power Company) to Document Control Desk (NRC), "North Anna Power Station Units 1 and 2, REFLOD3B Code Update in Support of Proposed Technical Specifications Changes and Exemption Request to Use Framatome ANP Advanced Mark-BW Fuel," Serial No. 02-167B, July 25, 2002.

7-19 Letter: L. N. Hartz (Virginia Electric and Power Company) to Document Control Desk (NRC), "North Anna Power Station Units 1 and 2, Minimum Containment Pressure Analysis to Support Proposed Technical Specifications Changes and Exemption Request Use Framatome ANP Advanced Mark-BW Fuel," Serial No. 02-167A, July 9, 2002.

7-20 Letter: L. N. Hartz (Virginia Electric and Power Company) to Document Control Desk (NRC), "North Anna Power Station Units 1 and 2, SBLOCA Evaluation to Support Proposed Technical Specifications Changes and Exemption Request for Use of Framatome ANP Advanced Mark-BW Fuel," Serial No. 02-167C, August 2, 2002.

7-21 Letter: L. N. Hartz (Virginia Electric and Power Company) to Document Control Desk (NRC), "North Anna Power Station Units 1 and 2, Proposed LOCA Modeling Approach for Transition to Framatome ANP Advanced Mark-BW Fuel," Serial No. 02-305, May 13, 2002.

7-22 Letter: L. N. Hartz (Virginia Electric and Power Company) to Document Control Desk (NRC), "North Anna Power Station Units 1 and 2, Updated LOCA Modeling Approach for Transition to Framatome ANP Advanced Mark-BW Fuel," Serial No. 02-305A, June 19, 2002.

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7-24 S-RELAP5: Code Verification and Validation, EMF-2102(P), Revision 0, August 2001.

7-25 Summary of the Semiscale Program (1965-1986), NUREG/CR-4945, July 1987.