VIRGINIA ELECTRIC AND POWER COMPANY
RICHMOND, VIRGINIA 23261

November 10, 2003

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

Serial No.	03-313G
NLOS/ETS	R0
Docket Nos.	50-338
	50-339
License Nos.	NPF-4
	NPF-7

VIRGINIA ELECTRIC AND POWER COMPANY (DOMINION)
NORTH ANNA POWER STATION UNITS 1 AND 2
PROPOSED TECHNICAL SPECIFICATIONS CHANGES AND EXEMPTION REQUEST FOR USE OF FRAMATOME ANP ADVANCED MARK-BW FUEL
SUPPLEMENTAL INFORMATION FOR REALISTIC LARGE BREAK LOSS OF COOLANT ACCIDENT (RLBLOCA) ANALYSIS RESULTS

In a May 6, 2003 letter (Serial No. 03-313), Dominion submitted the Realistic Large Break LOCA (RLBLOCA) results for Advanced Mark-BW fuel in North Anna Unit 2 to support the NRC's review of a proposed amendment and exemptions that will permit North Anna Units 1 and 2 to use Framatome ANP Advanced Mark-BW fuel. On August 20, 2003 (Serial No. 03-313A) Dominion provided a response to an August 6, 2003 NRC request for additional information regarding the RLBLOCA results. In an August 28, 2003 meeting to discuss the RLBLOCA analysis results, the NRC staff requested further clarification of Dominion's August 20, 2003 responses. Supplemental information for Questions 1, 5, 9, and 10b was provided on September 5, 2003 (Serial No. 03-313C), Questions 6 and 11a on September 22, 2003 (Serial No. 03-313D), and Questions 2, 3, and 4 on September 26, 2003 (Serial Nos. 03-313E and F). In telephone calls conducted on October 15 and 22, 2003, the Staff requested additional clarification of Dominion's response to Questions 2, 4 and 10a and 10b noted above as well as further discussion concerning containment response modeling.

The attachment to this letter provides the requested clarification for the containment response modeling and Questions 2, 4, 10a and 10b and a commitment to include a peak clad temperature (PCT) penalty in the LOCA analysis associated with the use of the Forslund-Rohsenow heat transfer model. As noted in our August 20, 2003 letter, this information is applicable to both North Anna Units 1 and 2 even though the RAIs received were specific to Unit 2.

A001

To support the use of Framatome Advanced Mark-BW fuel in North Anna Unit 2, Cycle 17, we respectfully request the NRC to complete their review and approval of the license amendment by November 30, 2003. We appreciate your consideration of our technical and schedular requests. If you have any questions or require additional information, please contact us.

Very truly yours,

Leslie N. Hartz
Vice President – Nuclear Engineering

Attachment

Commitments made in this letter:

Add a penalty (currently 64°F) to the peak cladding temperature for both North Anna units, calculated by disabling the Forslund-Rohsenow correlation for rod-to-droplet heat transfer (on the hot rod) when $T_{wall} > T_{min}$. This departure from the methodology in the approved RLBLOCA topical, EMF-2103(P)(A), will be documented in the North Anna UFSAR.

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SN: 03-313G
Docket Nos.: 50-338/339
Subject: RAI - Proposed TS Change/Exemption
Framatome Fuel Transition - RLBLOCA

COMMONWEALTH OF VIRGINIA)
)
COUNTY OF HENRICO)

The foregoing document was acknowledged before me, in and for the County and Commonwealth aforesaid, today by Leslie N. Hartz, who is Vice President - Nuclear Engineering, of Virginia Electric and Power Company. She has affirmed before me that she 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 her knowledge and belief.

Acknowledged before me this 10th day of November, 2003.

My Commission Expires: March 31, 2004.

Maggie McClure
Notary Public

(SEAL)

Dominion Supplemental Responses to NRC Request for Additional Information
North Anna Realistic LBLOCA Analysis
Containment Response Modeling & Questions 2, 4, 10a and 10b of August 20, 2003 letter (Serial No. 03-313A)

In an August 28, 2003 meeting, the NRC staff requested additional information to supplement the responses provided in Dominion's August 20, 2003 letter (Serial No. 03-313A). In letters dated September 5, 2003 (Serial No. 03-313C), September 19, 2003 (Serial No. 03-313D), and September 26, 2003 (Serial Nos. 03-313E and F) the supplemental information was provided to the NRC. Additional clarifying information was requested by the NRC Staff in an October 22, 2003 telephone conference. This response provides the requested information on containment response modeling and Questions 2, 4, 10a and 10b. The responses provided below are applicable to both North Anna Units 1 and 2, even though the RAIs received were specific to Unit 2.

Containment Response Modeling

1. The approach taken to calculate the containment pressure appears to be partly statistical and partly deterministic.

a. For the deterministic portion, please identify those parameters which have a significant effect on the containment pressure and describe how those parameters are determined (including any bias used to add conservatism, i.e. to underestimate the containment pressure). Please include at least the following:

   Initial containment pressure, initial containment temperature, initial containment relative humidity, condensation heat transfer coefficient of structures, heat transfer coefficient between the sump and the containment atmosphere, RWST temperature, assumptions for containment spray including flow and timing, assumptions for the fan coolers including UA & timing, service water temperature for cooling the fan coolers, wall thickness, gap between the liner and concrete, ECCS spillage and condensation, distribution of RCS break flow into droplets water and vapor.

b. Provide a discussion including sensitivity studies if appropriate or necessary to demonstrate that the overall approach to calculate containment pressure is conservative.

   Response:

   Both part a and b of this question are addressed in this response. Consistent with the Code Scaling, Applicability and Uncertainty (CSAU) methodology, containment modeling in the Framatome ANP (FANP) Realistic Large Break Loss of Coolant Accident (RLBLOCA) analysis emphasizes the important physical processes influencing large break LOCA: initial conditions, active heat sinks, and passive heat sinks. The FANP RLBLOCA Phenomena Identification and Ranking Table (PIRT) identifies containment pressure as the only containment-related phenomenon

Attachment 1

Supplemental Responses to Request for Additional Information

Containment Response Modeling & Questions 2, 4, 10a and 10b of August 20, 2003 letter (Serial No. 03-313A)

Realistic Large Break LOCA Analysis Results – North Anna

Framatome Fuel Transition Program
Technical Specification Change

Virginia Electric and Power Company
(Dominion)
North Anna Power Station Units 1 and 2

directly influencing clad temperature response. Accordingly, containment processes directly influencing containment pressure response are the focus of the modeling effort.

The FANP RLBLOCA methodology was approved as a "Best-Estimate" methodology, which conforms to the guidance of Regulatory Guide 1.157. As applied to North Anna Units 1 and 2, the RLBLOCA methodology involves a realistic simulation of containment backpressure. Containment modeling in the RLBLOCA methodology includes both statistical and non-statistical treatment of significant model inputs. The general objective is to obtain containment backpressure results that accommodate expected modeling uncertainties. The most dominant phenomenological influences (ignoring active systems) on containment pressure are: heat transfer to internal structures, break size and effluent modeling, and initial pressure and volume. Consistent with the CSAU methodology, parameters with lesser influence on containment pressure are modeled by assuming nominal or conservatively biased values. The net effect of treating certain parameters with conservatively biased values and others as statistical values is to produce a conservative backpressure result that accommodates expected modeling uncertainties.

Branch Technical Position CSB 6-1 was established to provide guidance to plant licensees and vendors as to how containment systems are to be modeled for Appendix K-based LOCA evaluations. The intent of CSB 6-1 is to provide guidance for the performance of a minimum containment backpressure analysis. The RLBLOCA methodology was approved as a "Best-Estimate" methodology that conforms to Regulatory Guide 1.157. With regard to containment pressure, the Regulatory Guide states (Section 3.12.1):

> *"The containment pressure used for evaluating cooling effectiveness during the post-blowdown phase of a loss-of-coolant accident should be calculated in a best-estimate manner and should include the effects of operation of all pressure-reducing equipment assumed to be available. Best-estimate models will be considered acceptable provided their technical basis is demonstrated with appropriate data and analyses."*

The containment pressure response used in the North Anna RLBLOCA analyses is a realistic calculation applying both best-estimate and conservative modeling assumptions. The CSAU methodology requires that the treatment of important phenomena accommodate anticipated uncertainties. As previously stated, the dominant phenomena influencing containment response are: heat transfer to internal structures, break size and effluent modeling, and initial pressure and volume. A discussion of these dominant influences is presented below. In the North Anna RLBLOCA analyses, other parameters are, with only a few exceptions, modeled by applying CSB 6-1 recommendations. Generally for Framatome ANP RLBLOCA analyses, active systems are assumed to operate at maximum efficiency (as was done for the North Anna analyses and is consistent with CSB 6-1) unless data are available to treat their operation in a best-estimate manner.

Heat Transfer to Internal Structures: *Containment response in the North Anna analyses is simulated using the NRC-approved ICECON containment response model (as incorporated into S-RELAP5) with the exception that the Uchida heat transfer correlation with a multiplier of 1.7 is used to model heat transfer to passive containment structures for the entire simulation. The 1.7 multiplier was derived for a dry containment plant by an analysis performed to equate the heat transfer-to-containment internals as predicted by the basic CSB 6-1 method without the conservative multipliers on Tagami and Uchida to a model described only with the Uchida model. The 1.7 multiplier was validated for the North Anna analyses by demonstrating good (less than one psi tolerance) or bounding agreement between simulations using S-RELAP5 with CSB 6-1 inputs and the existing UFSAR minimum containment response simulation.*

References 1 and 2 present the Uchida model, without augmentation, as best-estimate. The Uchida correlation (without the 1.7 multiplier) was assessed in Reference 1. It was concluded that the Uchida correlation provides a best-estimate result when the bulk gas pressure is one atmosphere and that it progressively under predicts pressure at lower bulk gas pressures. The bulk gas pressure is related to the partial pressure of the gas; hence, it remains essentially constant during LOCA (neglecting temperature effects and accumulator nitrogen). The North Anna units have subatmospheric containments; hence, the Uchida model is conservative for these plants. Furthermore, Uchida with a 1.7 multiplier would be expected to be conservative for typical wet and dry atmospheric containment designs. Uchida's acceptability was also demonstrated via comparisons to GOTHIC predictions. Developmental assessment of GOTHIC has presented the Uchida model (without augmentation) as being a best-estimate model (see Reference 2). It is concluded that the heat transfer coefficient modeling employed in the North Anna RLBLOCA analyses is conservative.

Break Flow: *Break flow has been shown to be the dominant influence on containment pressure. The Framatome ANP RLBLOCA methodology statistically ranges break size over the full spectrum of break sizes defined as large breaks. This includes both double-ended and split breaks. The modeling of critical break flow is treated by applying appropriate uncertainties as described in the RLBLOCA methodology documentation. ECCS injection is modeled in a manner consistent with the realistic LBLOCA evaluation model requirements: all ECCS is injected into the NSSS. The resistance network determines the ECCS that is discharged into the containment through the break. No ECCS is spilled directly to the containment.*

Initial Pressure: *Initial containment pressure (i.e., the partial pressure of air) is indirectly sampled in Framatome ANP RLBLOCA analyses by sampling containment bulk temperature. North Anna employs a dedicated system that is designed to target a desired containment pressure over a narrow range. Real uncertainty associated with containment pressure is small. The Technical Specifications for the North Anna subatmospheric containment establish limits of operation in terms of the allowable air partial pressure. The initial total containment pressure for the RLBLOCA analysis is set to a representative value within this range. Containment temperature has a strong influence on the partial pressure of vapor. Over the sampled temperature range, the partial pressure of vapor ranges from 0.6 to 1.8 psi.*

After adjustment by this range of air partial pressures, the effective sampled initial containment partial pressure range is conservative in comparison with the Technical Specification range. Ranging containment temperature and volume encompasses normal variations in containment pressure.

Containment Volume: *Containment volume is sampled between the nominal volume and the "empty volume." The "empty volume" is defined as simply the volume of the containment dome plus the volume of the containment cylinder, which is significantly larger than the actual volume. This sample range is conservative since the larger containment volume suppresses the containment response following a LOCA, resulting in lower containment pressures. The inherent conservatism resulting from ranging the containment volume serves to accommodate variations in initial containment conditions.*

Other Considerations: *Plant-specific compliance with the Regulatory Guide 1.157 guidance cited above is achieved through the selection of code inputs. Table 1 provides a comparison of key model inputs, as identified in Branch Technical Position CSB 6-1, to the treatment of these items in both the Framatome ANP RLBLOCA guidelines and the model used in the North Anna RLBLOCA analyses. Inspection of the tabulated model parameters illustrates the method, as well as the degree of conservatism for the containment pressure response.*

The Framatome ANP RLBLOCA methodology and the North Anna-specific analyses incorporate these additional conservatisms: 1) mass and energy are treated in equilibrium by S-RELAP5; GOTHIC calculations show that containment response models assuming non-equilibrium break flow produce higher containment pressures; 2) containment spray systems conservatively take no credit for single active failures (i.e., full spray assumed regardless of assumed single failure affecting ECCS); 3) the North Anna passive heat structure surface areas are increased three percent above their nominal values; and 4) paint (a substantial insulator) on all painted heat structures is neglected.

Consistent with the CSAU methodology and Regulatory Guide 1.157, the Framatome ANP RLBLOCA methodology provides for the use of best-estimate containment parameters. If such parameters are not available, bounding values, consistent with CSB 6-1, are recommended. As a final step, the containment model for North Anna was validated against an existing backpressure calculation. The benchmark performed for the North Anna model predicted a transient backpressure response that was within several psi (lower) of the response curve for the Appendix K-based calculation presented in the North Anna UFSAR. This result provides validation of the containment model employed in the North Anna RLBLOCA analyses.

In summary, Framatome ANP's RLBLOCA methodology for the calculation of containment backpressure is qualified as a best-estimate calculation in conformance with the guidance of Regulatory Guide 1.157. For the North Anna application, most of the significant plant-specific containment model inputs (as discussed above) are characterized per CSB 6-1 recommendations. The modeling approach produces a distribution of containment pressure response—the identified PIRT parameter *affecting clad temperature—through ranging of containment volume and temperature. This distribution of containment pressures is sufficiently broad to encompass the effects of model uncertainties and biases. Hence, the overall approach to calculate the North Anna-specific containment pressure is conservative and conforms to Regulatory Guide 1.157.*

Containment Response References:

1. P. F. Peterson, "Theoretical Basis For The Uchida Correlation For Condensation In Reactor Containments," Nuclear Engineering and Design, 162 (1996), pg 301-306.

2. T. L. George, et al., GOTHIC Containment Analysis Package Qualification Report, NAI 8907-09 Revision 5, Richland, Washington, July 1999.

Table 1. Comparison of Model Parameters Recommended by CSB 6-1 to the North Anna RLBLOCA Analyses.

Model Parameter	CSB 6-1	FANP RLBLOCA	North Anna RLBLOCA
Initial Containment Internal Condition			
Containment Gas Temperature[1]	MIN (drywell) MAX (ice)	Sampled	Sampled (84.5 – 121.5 °F)
Containment Pressure	Minimum	Nominal	11.5 psia
Humidity[1]	100%	100%	100%
Initial Outside Containment Ambient Conditions			
Temperature[1]	"reasonably low"	N/A	N/A[2]
Containment Volume	MAX free volume	Sampled (nominal to empty volume)	Sampled (1.825×10^6 to 2.087×10^6 ft^3)
Purge Supply and Exhaust Systems	Open purge lines	N/A	N/A
Active Heat Sinks			
Spray Flow	MAX	Nominal[3] or Bounding (high)	MAX[4]
Spray Temperature	MIN	Nominal[3] or Bounding (low)	Bounding (low) 45 °F/~60 - 80 °F[5]
Fan Cooler Heat Removal	MAX	Nominal[3] or Bounding (high)	N/A[6]
Containment Steam Mixing with Spilled ECCS Water	"should be considered"	Approved Code Model Applied	Approved Code Model Applied
Containment Steam Mixing with Water from Ice Melt	"should be considered"	Approved Code Model Applied	N/A
Passive Heat Sinks	"structures... influence[ing] containment pressure"	Included	Nominal plus 3%[7]
Heat Transfer Coefficients	4 x Tagami (blowdown) and 1.2 x Uchida (refill/reflood)	1.7 x Uchida[8]	1.7 x Uchida

[1] Containment pressure simulations do not show significant sensitivity to this parameter.
[2] The outside air temperature is not used in the S-RELAP5 containment backpressure calculation. The North Anna containment walls are 4.5' concrete, no air gap, and 0.375" steel liner; based on the wall thickness and the short duration (less than 1,000 seconds) of LBLOCA transients, the outside air temperature is irrelevant.
[3] Nominal, if sufficient justification can be developed.
[4] No single active failure credited and minimum spray delay times applied.
[5] The containment sprays at North Anna include one system that draws from the RWST. The other spray system draws from the sump and it is cooled via a heat exchanger. The sump temperature varies over the transient; accordingly, so does the spray temperature. The temperatures specified are for these two systems, respectively.
[6] North Anna does not have fan coolers.
[7] Paint on all painted surfaces is conservatively neglected.
[8] As demonstrated through appropriate validation.

Q2. The sensitivity result presented from disabling the Forslund-Rohsenow model (reported in Letter 03-313F) produced an increase in PCT of 64°F. The NRC staff considers that this change is significant (i.e. greater than 50°F). The licensee is requested to add this PCT penalty to the PCT calculated for the limiting North Anna case and commit to maintaining this penalty as a deviation from the approved RLBLOCA methodology. In addition, please present transient results for PCT and oxidation for this case.

Response:

The reply to Question 2, as originally stated, was among those included in Dominion's Letter 03-313A, dated August 20, 2003 and discussed in a public meeting with NRC staff on August 28, 2003. The original NRC staff request was for Dominion to justify the applicability of the Forslund-Rohsenow model as used in the North Anna application of Framatome ANP's RLBLOCA methodology. The Dominion reply in letter 03-313A cited the Framatome ANP code assessment analyses of numerous FLECHT-SEASET, FLECHT-Skewed and ORNL-THTF reflood tests as the basis for the RLBLOCA heat transfer modeling. A number of these tests resulted in temperatures exceeding 2000°F. The NRC staff's concern was that peak cladding temperatures for the North Anna applications extend above 2000°F. This exceeded the PCT values from certain sensitivities that formed part of the basis for approval of the RLBLOCA topical, EMF-2103(P)(A). The NRC staff's request for this item stated that the S-RELAP5 topical report presented a sensitivity study of the Forslund-Rohsenow model to PCT and quench time to address this concern. The NRC staff indicated that since the analyses for this study were at temperatures lower than those calculated for North Anna, the applicability of the approved RLBLOCA modeling to North Anna may not be justified. It should be noted that the 3-loop sample plant analysis presented in Appendix D of EMF-2103(P)(A) is the analysis which is most comparable to the North Anna Units 1 and 2 RLBLOCA application analysis. The calculated PCT for the 3-loop plant analysis limiting case is 1853°F. The PCT of approximately 1700°F (cited in several of the NRC staff written requests) was obtained from various analysis cases for the 4-loop sample plant, presented in EMF-2103(P)(A).

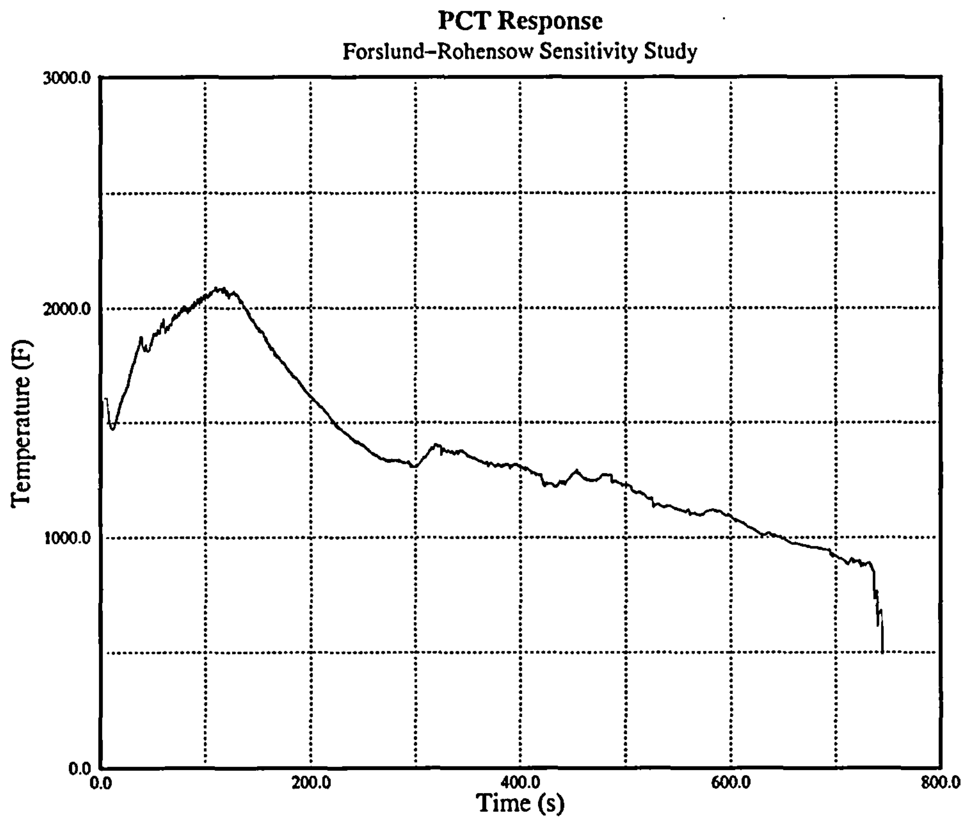
During discussion of this issue at the August 28, 2003 meeting, it was agreed that the Forslund-Rohsenow sensitivity would be repeated for the limiting case from the North Anna RLBLOCA analyses. Results of this analysis were submitted in Dominion letter 03-313F, dated September 26, 2003; the additional request stated above is in response to the material submitted in letter 03-313F.

The approach requested by NRC to deviate from the approved RLBLOCA methodology was discussed in telephone conference calls between Dominion, Framatome ANP, and the NRC staff on October 15 and October 22, 2003. In these discussions, Dominion and Framatome ANP indicated that differences between the modeling used in the FLECHT-SEASET Forslund-Rohsenow sensitivity and the approved RLBLOCA model can explain the observed results. The previous response to Question 2 in letter 03-313F identified that the

RLBLOCA methodology models the hot rod as decoupled, which will not reflect the effects of steam de-superheating that would be expected. The FLECHT-SEASET sensitivity studies modeled coupled rods and associated de-superheating effects, so the reported sensitivities were smaller. This feature of the approved RLBLOCA model results in an unwarranted increase in the plant-specific sensitivity associated with disabling the Forslund-Rohsenow correlation. In the telephone conference call discussions, Dominion noted that the approved RLBLOCA heat transfer models were qualified by demonstrating their ability to predict relevant test data and that the predictive capability of the approved models is unaffected by the North Anna sensitivity. Thus, including the requested plant-specific departure from EMF-2103(P)(A) and the resulting PCT bias is inconsistent with guidance of Regulatory Guide 1.157 regarding the development and qualification of best-estimate models.

Nonetheless, Dominion will add a penalty (currently 64°F) to the peak cladding temperature calculated with the methodology of EMF-2103(P)(A) for both North Anna Units 1 and 2. This PCT penalty was generated by running the limiting Unit 2 case and disabling the Forslund-Rohsenow correlation for rod-to-droplet heat transfer (on the hot rod) when $T_{wall} > T_{min}$. Treatment of this PCT penalty will be documented in the North Anna Units 1 and 2 UFSAR as a plant-specific departure from the methodology in the approved RLBLOCA topical, EMF-2103(P)(A). The transient peak cladding temperature for the sensitivity case is provided in Figure 1. The peak cladding temperature from this case is 2096°F and the peak rod oxidation is 4.0%, as compared with the originally reported results of 2032°F and 3.2%, respectively. The UFSAR description will address both the peak cladding temperature and oxidation effects of this change.

Figure 1



PCT Response
Forslund-Rohensow Sensitivity Study
3000.0
2000.0
1000.0
0.0
Temperature (F)
0.0
200.0
400.0
600.0
800.0
Time (s)

Q4. The convective heat transfer coefficient used in the Framatome ANP RLBLOCA methodology does not extract the effect of radiation heat transfer. Experimental test cases exist for which it can be shown that inclusion of radiation heat transfer in the convective heat transfer coefficient results in non-conservative reflood heat transfer. Confirm that the NA-2 fuel and core configuration will not result in reflood heat transfer that takes undue credit for the inclusion of radiation heat transfer in the convective heat transfer coefficient.

The NRC requests that FANP perform this study by comparing a FLECHT-SEASET test to the North Anna RLBLOCA results. In addition, the NRC requests supplemental calculations using FLECHT-SKEWED tests 13609 and 13914. For all calculations, present results of radiation heat transfer that are appropriate for the hot rod in the bundle.

Response:

The following statement supplements the response to Question 4 of the initial RAI (NRC letter, August 6, 2003), which addresses the neglecting of rod-to-rod radiation in the North Anna Unit 2 analysis.

During a discussion with the NRC concerning the response to this question at the August 28, 2003 meeting, the NRC requested a demonstration of the relative rod-to-rod radiation component related to system and assembly design differences between the FLECHT-SEASET and the Advanced Mark BW fuel assembly scheduled for the North Anna Unit 2 plant. Framatome ANP has performed a rod-to-rod radiation analysis applying the results from the North Anna Unit 2 RLBLOCA analysis. The analysis applies the R2RRAD code, provided by the NRC, for predicting rod-to-rod radiation. This code was modified to: a) examine 6x6 assembly arrays (rather than 5x5), b) account for the larger diameter guide tube rods, and c) calculate an average assembly radiant heat transfer coefficient. The plant hot rod location is taken consistent with FLECHT. A separate code validation study was performed applying results from the FLECHT-SEASET Test 31504. The code results from R2RRAD showed good agreement with results reported in the FLECHT-SEASET data report. The key parameters from the North Anna RLBLOCA analysis modeled in the R2RRAD are given in Table 1.

Table 1. North Anna Unit 2 Key Temperatures

Temperatures	*Degrees F*
Hot Rod	*2,032*
Hot Assembly	*1,838*
Guide Tube	*1,650*
Boundary	*1,650*

For this case, the North Anna Unit 2 PCT result is very similar to the FLECHT-SEASET Test 31504 result at 80 seconds—a suitable comparison point having a relative high radiative heat transfer component. Test 31504 was chosen for its *alignment with the North Anna results (PCT and guide tube temperatures), rather than for radiative heat transfer maximization. Table 2 presents the assembly average rod heat transfer coefficient and the maximum rod heat transfer coefficient from the R2RRAD code for the North Anna and FLECHT-SEASET Test 31504.*

The assembly average rod heat transfer coefficient is consistent with the method of analysis originally performed by Westinghouse in WCAP-9891 and can serve as validation for the R2RRAD code. The maximum rod heat transfer coefficient does not necessarily correspond to the hot rod location; however, it provides the maximum local radiant heat transfer that could be expected and envelopes the radiant heat transfer expected for the hot rod. The North Anna Unit 2 calculation shows that under the conditions calculated in the RLBLOCA analysis, the rod-to-rod radiation component is about 31% higher than the FLECHT-SEASET result for the assembly average rod and over 300% higher for the maximum rod. A key reason why the FLECHT-SEASET results do not show a higher radiant heat transfer is that it was a specific objective during the derivation of the RLBLOCA heat transfer code uncertainties to remove test data that may contribute a bias to the final results. This was necessary to reduce or eliminate scale-effects such as excessive radiant heat transfer from the overall heat transfer model. The FLECHT-SEASET rod data removed from the Framatome ANP heat transfer database includes those rods identified in Figure 6-4 of WCAP-9891 as "cold rods." This approach significantly reduces the potential bias on the model resulting from the cold-wall-effect of the assembly housing on radiant heat transfer.

Table 2. R2RRAD Code Results: Test 31504 versus North Anna.[9]

	Assembly Average HTC (BTU/hr-ft²-R)	*Maximum Rod HTC (BTU/hr-ft²-R)*
North Anna	*2.45*	*9.66*
Test 31504	*1.87*	*2.62*

Tests 13609 and 13914 from the FLECHT-Skewed program were also examined in the same manner as Test 31504. The hot rod and guide tube temperatures were taken at the time of PCT. Due to the limited information in the data report, the hot assembly and boundary temperatures represent averages from the available data channels (rods) in the respective regions at the time of PCT in each data channel. These cases differ significantly in geometry from Test 31504. The rod size is consistent with typical 15x15 fuel array designs. Table 3 provides the results from those studies.

[9] *The results presented in Table 2 are different from those originally transmitted in Dominion letter 03-313F, dated 9/26/03. This change is related to a small correction to the guide tube diameter assumption.*

Table 3. R2RRAD Code Results: Tests 13609 and 13914 versus North Anna

	Assembly Average HTC (BTU/hr-ft^2-R)	Maximum Rod HTC (BTU/hr-ft^2-R)
North Anna	2.45	9.66
Test 13609	2.22	3.55
Test 13914	1.90	3.60

The results from these skewed test cases show higher overall rod-to-rod radiation than in the 17x17 configuration. However, the North Anna results are bounding of the test facility results. Results of this assessment confirm that the treatment of radiant heat transfer incorporated in the approved RLBLOCA model is appropriate for North Anna. No undue credit is obtained from application of the RLBLOCA model to the North Anna Units 1 and 2 analyses.

Q10a Demonstrate that there will be adequate core flow capability for cooling after the safety injection suction switches from the cool RWST water to the warmer sump water. This switch to a warmer, less dense water source could adversely affect both the density head of water in the downcomer and capability for long-term cooling.

Response:

The North Anna Units 1 and 2 long term cooling mode of operation involves the realignment of safety injection suction from the RWST to the containment sump. This realignment is initiated automatically upon the RWST level reaching a specified value. Initiation of sump recirculation can occur as early as 34 minutes after the initiation of a LBLOCA depending on the equipment that is assumed to be operating. An early estimated time for initiation of sump recirculation is conservative for the assessment of the adequacy of core cooling capability upon entering the sump recirculation mode, since this will result in greater core decay heat.

The RLBLOCA analysis demonstrates that the core returns to essentially saturated conditions (peak clad temperature of approximately 250°F) at 460 seconds (Dominion Letter 03-313D, Figure 11-1). This result represents a stabilized core condition where adequate core cooling capability has been demonstrated to exist. Core decay heat at the time of initiation of sump recirculation is substantially less than the core decay heat at the time the core stabilizes. The ratio of the core decay heat at the time of initiation of sump recirculation to the decay heat at the time the core has reached a stable condition ranges from approximately 67% to 69%, depending on the time that sump recirculation is initiated.

At any time during the LBLOCA transient following core stabilization, the heat removal capacity of fluid supplied from the downcomer to the core is a function of (a) core flow, which depends primarily on the relative fluid density between the downcomer and core (essentially at saturated conditions) and (b) the enthalpy condition (degree of subcooling) in the downcomer. The heat removal capability of fluid supplied to the core from the downcomer at the time of initiation of sump recirculation, relative to that supplied at the time of core stabilization, can be assessed by comparing the downcomer and core fluid densities and enthalpy conditions at these two times in the transient.

Dominion has performed an evaluation of the downcomer-to-core fluid density difference (driving head) and enthalpy condition (degree of subcooling) at the time of initiation of sump recirculation relative to the conditions that were demonstrated to exist at the time of core stabilization. Dominion's evaluation demonstrates that the heat removal capacity (i.e., flow multiplied by enthalpy rise) of the fluid supplied to the core from the downcomer just after initiation of sump recirculation has approximately 84% of the heat removal capacity that it had at the time of core stabilization. Because the core has only 67% to 69% of the decay heat load just after initiation of sump recirculation that it had at the time of core stabilization, the relative heat removal capacity of the fluid supplied to the core is greater at the time of initiation of sump recirculation than at the time of core stabilization. There may be an increase in cladding temperature from that which existed just prior to switchover (due to higher core inlet temperature), and there could be some readjustment in core and downcomer conditions while the system hydraulics arrive at a new quasi-equilibrium state. However such perturbations are expected to be minor, while the continued injection of water recirculated from the containment sump ensures that the core temperature will be maintained at an acceptably low value and that decay heat will be removed.

Q10b: The responses provided concerning boron precipitation require elaboration to assess the potential effect of the reduced RWST temperature. Please provide the following results from the calculation performed to determine the switchover time to preclude boron precipitation in the core: temperature of core inlet water vs. time; core boron concentration vs. time; boric acid precipitation concentration vs. time. Also specify how the core temperature is determined and how the mixing of low temperature SI water and water in the lower plenum is treated (e.g., state mixing assumptions and mixing volume).

Response:

The North Anna calculation of time for switchover to hot leg injection employs a conservative methodology developed by Westinghouse and documented in letter CLC-NS-309, submitted to NRC on April 1, 1975. This method was approved as part of the original North Anna Unit 1 and 2 licensing as denoted in Section 6.3.3 of NUREG-0053, including Supplement 1 (Reference 4). The method is a quasi-steady state calculation that does not involve detailed determination of transient *fluid conditions within the reactor vessel. The calculation produces a conservative (i.e., early) calculated time to perform the switchover to hot leg injection that will preclude boron precipitation in the core. In this calculation, the core volume is assumed to include the core region (from bottom to top of active fuel), and volume above the active core, to an elevation equal to the bottom of the vessel nozzles. Analysis assumptions include the following:*

- *The lower plenum volume is ignored. This provides a conservatively small core volume in which boron is assumed to concentrate.*
- *A conservatively high initial sump boron concentration of 1.57 weight %*
- *Decay heat based on an initial reactor power of 102% of rated thermal power and 120% of the 1971 ANS Standard*
- *A constant 116.3 Btu/lbm core inlet enthalpy*
- *ECCS flow delivered to the core is assumed to just match the boiloff rate- the remainder is assumed to spill out the break. This maximizes the rate of concentration of boric acid in the core.*
- *The switchover time is chosen based on the point where calculation of boric acid concentration in the core reaches 23.5 weight %, which is 4.0 weight % below the best estimate precipitation limit at 212°F. A calculated switchover time of 5.26 hours is rounded downward to 5.0 hours to provide additional conservatism.*

Figure 2 provides results from the existing core boron buildup calculation, in terms of the calculated core boric acid concentration as a function of time. The methodology of Westinghouse Letter CLC-NS-309 does not explicitly consider the influence of injection water temperature on the potential for precipitation in the core or lower plenum region of the vessel. Dominion has evaluated this potential effect by assessing postulated mixing during two key phases following the LOCA: Phase 1, which is the timeframe through hot leg switchover; Phase 2, which is the timeframe following hot leg switchover. For Phase 1, this was assessed by postulating mixing between high concentration core water and cooler, low concentration water in the lower plenum (addresses potential precipitation near the core inlet). For Phase 2, mixing was assessed between high concentration core water and cooler, low concentration hot leg injection water (addresses potential precipitation near the core exit). In both cases it was shown that for the limiting case with an assumed core concentration of 23.5 weight %, the potential for boron precipitation exists only if the cooler lower plenum or hot leg injection water temperature is below 85°F. For lower plenum or hot leg injection temperatures above 85°F, and for any mixing fraction, the ratio of mixture boron concentration to mixture temperature is essentially constant, such that achievable mixture concentrations remain below the temperature-

dependent boric acid solubility limit curve. Based on expected sump conditions, stored energy in the reactor coolant system, and mixing of injection flow with steam exiting the core, the temperature of either the lower plenum or hot leg injection water at the time of switchover would be well in excess of 85°F. Thus, this evaluation demonstrates that combinations of boron concentration and temperature will not result in boron precipitation either preceding or following hot leg switchover.

Q10 References:

1. *NUREG-0053, including Supplement 1, "Safety Evaluation Report related to operation of North Anna Power Station Units 1 and 2," USNRC, June 30, 1976.*

Figure 2

North Anna Core Boric Acid Concentration Versus Time Following LOCA