ATTACHMENT II

SAFETY EVALUATION REPORT

H. B. ROBINSON, UNIT 2, CYCLE 10

RELOAD ANALYSIS - LOCA ANALYSES

1.0 INTRODUCTION

During Cycle 9, H. B. Robinson Unit 2 (HBR-2) operated at reduced power and system temperature in order to improve operating conditions for the steam generators. For Cycle 10, the licensee, Carolina Power and Light (CP&L), has replaced the steam generators in order to allow a return to full power operation at 2300 MWT. In addition, for Cycle 10, the licensee has implemented a low radial leakage fuel management scheme in order to reduce vessel fluence. Peak assembly discharges are also being increased for HBR-2 to 44,000 MWD/MTU. As a result of the latter two changes, the total nuclear enthalpy rise factor ($F_{\Delta H}^{T}$) has been increased to 1.65.

To support these changes for Cycle 10 operation at HBR-2, the licensee has provided revised LOCA analyses in References 1 through 3. This SER presents our evaluation of these submittals. We first address the compliance of the ECCS evaluation model, utilized for these analyses, to the requirements of Appendix K to 10 CFR 50. We then evaluate the adequacy of the LOCA analyses performed to demonstrate compliance with 10 CFR 50.46.

2.0 Evaluation Model

The ECCS evaluation model utilized to perform the LOCA analysis for HBR-2 is the revised Exxon Nuclear Company (ENC) evaluation model. This model is called EXEM/PWR and is documented in references 4, 5 and 6. This model is currently under staff review and a more detailed SER on EXEM/PWR will be issued separately. This section documents our review of EXEM/PWR, as utilized for the

HBR-2 Cycle 10 LOCA analysis, and evaluates its conformance to the required features of Appendix K to 10 CFR 50.

EXEM/PWR contains several models updates to the currently approved ENC-WREM IIA PWR ECCS evaluation model, reference 7. The model updates for EXEM/PWR are shown in Table 1. Each of these changes is discussed separately below.

2.1 Fuel Rod Model-RODEX2 Code

The RODEX2 Code is documented in reference 8. The RODEX2 code is based upon the previously approved GAPEX code, reference 9. As part of the EXEM/PWR model, ENC uses the RODEX2 code to provide the initial fuel stored energy and fuel rod internal pressures utilized as inputs to various portions of the evaluation model.

The staff has previously reviewed and approved the RODEX2 code for LOCA applications. Our evaluation of this code is contained in reference 10. Specifically, we found that the RODEX2 code satisfies the requirements of Appendix K, section I.A.I.

2.2 Clad Swelling and Rupture Model

In reference 11, ENC proposed a revised clad swelling and rupture model. This model, which includes the data base of NUREG-0630, reference 12, is used in the RELAP4 and TOODEE2 codes.

The staff has previously reviewed this model for compliance with section I.B of Appendix K. As documented in reference 13, we found this model meets those requirements.

2.3 Revised Fuel Rod Model - RELAP4-EM Code

The RELAP4-EM code, used as part of the EXEM/PWR ECCS evaluation model, has been updated to make its fuel models consistent with the approved RODEX2 fuel performance code. These updates include gap conductance, internal rod pressure, fuel conductivity and radial power distribution and are described in reference 5.

We have reviewed the modifications to the RELAP4-EM fuel model updates and find them acceptable.

2.4 Split Break Model

Currently the REFLEX code only simulates a guillotine break configuration with a discharge coefficient of 1.0. This assumption is conservative for split breaks and guillotine breaks with discharge coefficients less than 1.0. As part of EXEM/PWR, the REFLEX code has been modified to allow modeling of split breaks and guillotine breaks with smaller discharge coefficients.

For modeling of split breaks, the REFLEX code has been modified to allow the fluid streams from the downcomer and steam generators to mix before leaving the break. A junction is then used to simulate the break path to containment.

Double-ended guillotine breaks with smaller discharge coefficients are simulated with the current REFLEX noding scheme. However, to account for the smaller discharge coefficient, an equivalent K-factor is used to simulate the increased break resistance.

We have reviewed these model changes and find them acceptable.

2.5 REFLEX Core Outlet Enthalpy Model

The currently approved REFLEX model uses a constant value for the core exit enthalpy. The core exit enthalpy used is determined at the upper plenum pressure and the fluid temperature corresponding to the steam generator secondary side saturation temperature. The core exit enthalpy model has been upgraded such that fluid enthalpy is calculated based upon an energy balance performed for the core.

The revised core outlet enthalpy model accounts for energy added to the fluid below the quench front, stored energy release as the quench front progresses, and energy added to the fluid above the quench front. To demonstrate the appropriateness of the model, ENC performed benchmarks of FLECHT tests 34711, 34610, and 31922, reference 14. These benchmarks showed good agreement to the data.

Based upon the benchmarks performed, and a detailed review of the equations utilized, we have concluded that this model is acceptable.

2.6 Steam Cooling Model

Section I.D.5 of Appendix K to 10 CFR 50 requires that a steam cooling model be utilized to predict heat transfer coefficients when flooding rates fall below one inch per second. In addition, the steam cooling model must take into account the effect of flow blockage relative to both local steam flow and heat transfer. EXXON developed, as part of their currently approved ENC WREM-IIA PWR ECCS evaluation model, a steam cooling model which fully complied with these requirements. However, recent experimental data in references 15 and 16 have shown that the currently approved Exxon steam cooling model is overly conservative. As a result, Exxon develop, and submitted as part of EXEM/PWR, a revised steam cooling model.

The revised steam cooling model calculates an equivalent steam flow for use in the TOODEE-2 (reference 17) energy solution which assures that superheated steam exits the core. This flow rate includes the effect of blockage based upon the currently approved flow divergence model of the ENC WREM-IIA PWR ECCS evaluation model.

The rod surface heat transfer coefficients are calculated by the following method. First, local unblocked heat transfer coefficients are calculated using an appropriate reflood heat transfer correlation for the fuel modeled. The local heat transfer coefficients are then modified to account for the effect of blockage on mass flux and hydraulic diameter. In addition, the heat transfer coefficients are adjusted to account for the effects of increased turbulence and breakup of entrained liquid droplets downstream of the blockage. The net effect of these modifications is a decrease in heat transfer downsteam of the flow blockage relative to that which would be obtained in an unblocked core. Calculations performed by Exxon with the revised steam cooling model indicate that peak cladding temperatures are approximately 15°F higher relative to that which would be obtained using the unblocked ENC-2 FLECHT coefficients.

The staff has reviewed the revised steam cooling model and finds it acceptable. Recent experimental data in reference 15 and 16, obtained with flooding rates below one inch per second, indicate that the effect of blockage is to enhance heat transfer, relative to an unblocked fuel assembly, downsteam of the blockage plane. Since the revised Exxon steam cooling model predicts decreased heat transfer, we find that the effect of flow blockage on local steam flow and heat transfer has been treated conservatively. Thus, the revised steam cooling model fully meets the requirements of section I.D.5 of Appendix K to 10 CFR 50.

2.7 FLECHT Heat Transfer Coefficients

As part of the EXEM/PWR ECCS evaluation model, revised FLECHT-based reflood heat transfer coefficients were proposed. These heat transfer coefficients were not used in the LOCA analyses performed for HBR-2 Cycle 10 operation. Rather, the currently approved WREM-IIA reflood heat transfer coefficient were utilized. We find this approach acceptable.

In performing the analyses, documented in reference 3, to verify the allowable linear heat generation rates versus axial location proposed for Cycle 10, the WREM-IIA reflood heat transfer coefficients were modified to account for axial power distribution effects. To account for the effects of axial power distribution, adjustments are made to both the REFLEX and TOODEE2 codes. These adjustments are made based upon conserving the integral power between the fuel rod and the FLECHT rod. The specific methodology employed is detailed in reference 6.

To demonstrate the appropriateness of their model, ENC benchmarked data for the FLECHT skewed profile low flooding rate heat transfer tests 11428, 14331 and 16110. These data were obtained from reference 21. The benchmarks showed that the method for adjusting for axial power distribution yielded higher cladding temperatures, and hence lower heat transfer coefficients, than observed in the FLECHT experiments. Thus, the method is conservative.

In addition to evaluating the information provided by ENC, we have reviewed some of the FLECHT data to assure that the ENC methodology is conservative. Comparisons were made between the FLECHT cosine tests 02114 and 03113 and the skewed power shape tests 15305 and 11003 using the proposed ENC method. These comparisons further showed that the ENC method is conservative. Thus, we find the adjustment to the FLECHT heat transfer coefficients to be acceptable.

2.8 Summary of EXEM/PWR Model Compliance

Based on the foregoing, we find that the EXEM/PWR evaluation model, as utilized to support Cycle 10 operation for HBR-2, is wholly in conformance with Appendix K to 10 CFR 50.

3.0 LOCA Analyses

To support Cycle 10 operation of HBR-2, the licensee submitted several LOCA analyses. In reference 1, the limiting break, based on previous HBR-2 LOCA analyses, was analyzed to demonstrate conformance to 10 CFR 50.46 for a peak rod burnup range up to 49,000 MWD/MTU. Since a new ECCS evaluation model, EXEM/PWR, was utilized for the analyses, the licensee provided, via reference 2, a break spectrum analysis to confirm that the limiting break remained the same. Finally, reference 3 provides verification that the allowable linear heat generation rates as a function of axial elevation satisfies the requirements of 10 CFR 50.46. Our evaluation of these submittals follow.

3.1 Limiting Break Analysis

An analysis of the limiting break, a double-ended guillotine cold leg break with a discharge coefficient of 0.8, was performed using the EXEM/PWR ECCS evaluation model. The analysis was performed using the following assumptions:

- 102% of the rated power level of 2300 MWT,
- Steam generator tube plugging of 6%,
- Peak linear heat generation rate of 14.16 KW/FT,
- Total peaking factor, F_Q^T, of 2.36,
- Enthalpy rise factor, $F_{\Delta H}^T$ of 1.65,
- Peak assembly discharge exposure of 44,000 MWD/MTU,
- Peak rod exposure of 49,000 MWD/MTU,
- Single failure assumption of loss of one HPSI and one LPSI pump.

The results of the limiting break analysis are summarized in Table 2. As shown, the peak cladding temperature is 2042°F, local zirconium metal-water reaction is 4.65%, and whole core metal-water reaction is less than 1% for the worst case analyzed. Thus, the analysis demonstrates conformance with the requirements of 10 CFR 50.46.

We have reviewed the assumptions utilized within the licensee's analyses. The use of 102% of the rated power level satisfies the requirement of Appendix K, section I.A. The peaking factors utilized are consistent with HBR-2 Technical Specification 3.10.2.1. The single failure assumption utilized satisfies Appendix K, section D.1. To assure that the LOCA analysis covers fuel conditions for a burnup range up to 49,000 MWD/MTU peak rod exposure, a burnup sensitivity study was performed. Values analyzed were 2,000 MWD/MTU (highest stored energy), an EOL burnup of 49,000 MWD/MTU (highest internal rod pressure), and an intermediate burnup of 9,000 MWD/MTU. We find the burnups analyzed are sufficient to demonstrate conformance to 10 CFR 50.46 for rod exposure up to 49,000 MWD/MTU in HBR-2.

Based on the foregoing, we find that the limiting break for HBR-2 complies with the requirements of 10 CFR 50.46

3.2 Break Spectrum Analysis

The LOCA analyses performed for Cycle 10 operation of HBR-2 utilized the EXEM/PWR ECCS evaluation model. As this was the first application of EXEM/PWR ECCS evaluation model for HBR-2, the licensee provided, in reference 2, a break spectrum analysis to confirm that the limiting break had not been changed. The analysis was performed using the same assumptions employed in the limiting break analysis described above except that only the worst case burnup, 2,000 MWD/MTU, was analyzed. The results of the analysis are summarized on Table 3 and demonstrates comformance to 10 CFR 50.46. As shown, the analysis demonstrated that the limiting break remained the double-ended guillotine cold leg break with a discharge coefficient of 0.8.

We find that the break spectrum analysis performed for Cycle 10 operation of HBR-2 satisfies Appendix K, Section C.1. Thus, conformance to 10 CFR 50.46 has been demonstrated for the entire break specture.

3.3 K(z) Curve

To define allowable linear heat generation rates as a function of core elevation, HBR-2 utilizes the K(z) curve. This curve, which is given in Figure 3.10-3 of the HBR-2 Technical Specifications, defines the normalized peaking factor, relative to the total peaking factor, F_Q^T of 2.32, as a function of elevation. To confirm that the linear heat generation rates allowed by the K(z) curve satisfies the requirements of 10 CFR 50.46, the licensee submitted additional LOCA analyses in reference 3.

The K(z) curve analyses were as performed for the limiting break and utilized the same input assumptions and model described above except for two areas. First, in order to examine linear generation rates in the upper portion of the core, the axial power shape was modified from a chopped cosine to a shape which peaked at 9 feet. The peaking factors utilized at and above the 9 foot were chosen to give the same peaking factor as that allowed by the K(z) curve. Secondly, the model utilized included the EXEM/PWR methodology, documented in reference 6, which adjusts the reflood heat transfer coefficients for axial power distribution effects.

A summary of the analyses provided in reference 3 is given on Table 4. Since the proposed K(z) curve is burnup dependent, two evaluations were performed using the axial power shape peaked at 9 feet in order to cover the different burnup ranges. The inputs utilized for each of the burnup ranges were chosen to maximize peak cladding temperature. As shown in the table, both cases yielded peak cladding temperatures less than the 2200°F criteria of 10 CFR 50.46. In addition both the local zirconium metal-water reaction and whole core metal water reaction are less than the criteria specified by 10 CFR 50.46.

We have reviewed the licensee's analysis and have concluded that the K(z) curve limits the allowed linear heat generation rates such that the requirements of 10 CFR 50.46 are met.

4.0 SUMMARY

Based upon the analyses provided by the licensee in references 1 through 3, we have concluded that the LOCA analyses performed for Cycle 10 of HBR-2 satisfies the requirements of 10 CFR 50.46 and that the evaluation model utilized satisfies the requirements of Appendix K to 10 CFR 50.

TABLE 1

ECCS Model Updates of EXEM/PWR

- Fuel Rod Model - RODEX 2
  - Stored Energy
  - Fission Gas Release

- Blowdown Model - RELAP4-EM Code
  - NUREG-0630 Clad Rupture Blockage Model
  - Modified Fuel Rod Model

- Reflood Model - REFLEX Code
  - Leakage Flow From Upper Plenum to Downcomer*
  - Split Break Model
  - Core Outlet Enthalpy Model
  - Revised Carryout Rate Fraction Correlation*

- Heatup Model - TOODEE2 Code
  - 17 x 17 FLECHT Heat Transfer Correlation*
  - Revised Steam Cooling Model
  - NUREG-0630 Clad Rupture Blockage Model
  - Adjustments to FLECHT Heat Transfer Coefficient

*Not used in HBR-2 Cycle 10 LOCA Analysis

Table 2

HBR-2 Limiting Case LOCA Analyses

(Double-Ended Guillotine Cold Leg Break, Discharge Coefficient = 0.8)

Analysis Results	2 MWD/MTU Peak Rod Exposure	9 MWD/MTU Peak Rod Exposure	49 MWD/MTU Peak Rod Exposure
Peak Clad Temperature (PCT), °F	2042	1815	1785
Peak Clad Temperature Reached, sec	60	139	139
Peak Clad Temperature Elevation, ft	6	8.5	8.5
Local Zr/H_2O Reaction (max.), %	4.65	1.93	1.72
Total H_2 Generation, % of Total Zr Reacted	<1	<1	<1

TABLE 3

H. B. Robinson Unit 2

Large Break Spectrum Results

Calculational Basis	
License Core Power, MWt	2300
Power Used for Analysis, MWt	2346
Peak Linear Power for Analysis, kW/ft	14.16
Total Peaking Factor, F_Q^T	2.32
Enthalpy Rise, Nuclear $F_{\Delta H}^T$	1.65
Steam Generator Tube Plugging (%)	6.00

	*(CD = 1.0) ** DECLG	(CD = 0.8) DECLG	(CD = 0.6) DECLG
Peak Cladding Temperature °F	1885	2042	1808
Peak Temperature Location, ft	6.0	6.0	8.5
Local Zr/H_2O Reaction (Max.), %	2.70	4.65	2.18
Local Zr/H_2O Location, ft	6.0	6.0	6.0
Local Zr/H_2O	<1%	<1%	<1%
Hot Rod Burst Time, sec	39.66	39.9	46.40
Hot Rod Burst Location, ft	6.0	6.0	6.0

*CD = Discharge Coefficient
**DECLG = Double-Ended Cold Leg Guillotine

Table 4

H. B. Robinson Unit 2 K(Z) Determination Results

<u>Calculational Basis</u>

License Core Power, MWt	2300
Power Used for Analysis, MWt	2346
Break Size, DECLG	0.8
Enthalpy Rise, Nuclear, $F^{T}H$	1.65
Steam Generator Tube Plugging, %	6.00

	Peaked at 6 feet	Peaked at 9 feet	Peaked at 9 feet
Hot Rod Exposure Range, MWD/kgU	0 - EOL	0 - 9	9 - EOL
Peak Linear Heat Generation Rate (LHGR)	14.16	12.39	12.57
Total Peaking Factor, $F_Q T$	2.32	2.03	2.06
Peak Cladding Temperature, °F	2042	2197	2183
Peak Temperature Location, ft	6.0	10.75	10.75
Local Zr/H_2O Location, ft	6.0	10.75	10.75
Local Zr/H_2O Reaction (Max.), %	4.65	6.19	5.89
Total Zr/H_2O	<1%	<1%	<1%
Hot Rod Burst Time, sec	39.9	49.37	51.57
Hot Rod Burst Location, ft	6.0	9.0	9.0

REFERENCES

(1) "H.B. Robinson Unit 2 Large Break LOCA-ECCS Analysis With Increased Enthalpy Rise Factor," XN-NF-84-72, July 1984.

(2) "H.B. Robinson Unit 2 Large Break LOCA-ECCS Analysis With Increased Enthalpy Rise Factor: Break Spectrum," XN-NF-84-72 Supplement 1, August 1984.

(3) "H.B. Robinson Unit 2 Large Break LOCA-ECCS Analysis With Increased Enthalpy Rise Factor: K(z) Curve," XN-NF-84-72 Supplement 2, August 1984.

(4) "Exxon Nuclear Company Evaluation Model EXEM/PWR ECCS Model Updates," XN-NF-82-20(P), Rev. 1, August 1984.

(5) "Exxon Nuclear Company Evaluation Model EXEM/PWR ECCS Model Updates, XN-NF-82-20(P), Rev. 1, Supplement 2, June 1984.

(6) "Exxon Nuclear Company Evaluation Model EXEM/PWR ECCS Model Updates: Adjustments to FLECHT Based Heat Transfer Coefficients," XN-NF-82-20(P), Rev. 1, Supplement 4, July 1984.

(7) XN-NF-78-30(A), "Exxon Nuclear Company WREM-Based Generic PWR ECCS Evaluation Model Update ENC WREM-IIA," Exxon Nuclear Company, Inc., Richland, WA 99352, May 1979.

(8) XN-NF-81-58(P), Rev. 2, "RODEX2: Fuel Rod Thermal-Mechanical Response Evaluation Model," Exxon Nuclear Company, Inc., Richland, WA 99352, February 1983.

(9) XN-73-25, "GAPEX: A Computer Program for Predicting Pellet-to-Cladding Heat Transfer Coefficients," Exxon Nuclear Company, Inc., Richland, WA, August 13, 1973.

(10) Letter, C.O. Thomas (NRC) to J.C. Chandler (ENC), Subject: "Acceptance for Referencing of Licensing Report XN-NF-81-58(P)," November 16, 1983.

(11) XN-NF-82-07(A), Rev. 1, "Exxon Nuclear Company ECCS Cladding Swelling and Rupture Model, "Exxon Nuclear Company, Inc., Richland, WA 99352, March 1982.

(12) D.A. Power and R.O. Meyer, "Cladding Swelling and Rupture Models for LOCA Analysis," NRC Report NUREG-0630, April 1980.

(13) Letter, C.O. Thomas (NRC) to G.F. Owsley (ENC), Subject: "Acceptance for Referencing of Topical Report XN-NF-82-07(P), Revision 1," October 14, 1982.

(14) "PWR FLECHT SEASET Unblocked Bundle, Forced and Gravity Reflood Task Data Report," EPRI NP-1459, September 1981.

(15) M.J. Loftus, et al, "PWR FLECHT SEASET 21-Rod Bundle Flow Blockage Task Data and Analysis Report," EPRI Report NP-2014, September 1982.

(16) M.J. Loftus, et al, "PWR FLECHT SEASET 163-Rod Bundle Flow Blockage," NRC Report NUREG/CR-3314, October 1983.

(17) G.N. Lauben, NRC Report NUREG-75/057, "TOODEE2: A Two-Dimensional Time Dependent Fuel Element Thermal Analysis Program," May 1975.

(18) G.P. Lilly, et.al., "PWR FLECHT Skewed Profile Low Flooding Rate Test Series Evaluation Report," WCAP-9183, November 1977.