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Revision 0

STEADY STATE CORE PHYSICS METHODS FOR BWR DESIGN AND ANALYSIS

Appendix G

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APPENDIX G

ADDITIONAL INFORMATION REQUEST NO. 2

LIST OF TABLES

APPENDIX G

SUMMARY

On January 31, 1991, Gulf States Utilities (GSU) issued Licensing Topical Report EA-CA-91-0001-M, which documented GSU's core analysis methods for performing nuclear fuel reload safety analyses. On December 9, 1991, the U.S. Nuclear Regulatory Commission (NRC) provided 21 questions concerning GSU's core analysis methods. On January 8, 1992, GSU responded to the NRC's questions by providing EA-CA-91-0001-S1, Appendix F to the original topical report. Following the issuance of Appendix F, the NRC asked three additional questions on February 4, 1992, regarding information in GSU topical report EA-CA-91-0001-M. The questions asked the technical reasons for the GSU results for the Loss of Feedwater Heating analysis, the Control Rod Withdrawal Error analysis, and the Standby Liquid Control System cold shutdown margin analysis being nonconservative relative to fuel vendor results. GSU reanalyzed these events for RBS Cycle 3 with similar assumptions to that of the fuel vendor and found the revised results were in close agreement with fuel vendor results. This Appendix describes those assumptions and results of GSU reanalysis.

During the preparation of these responses, an error was discovered in the cycle depletion analyses which defined the core statepoints at which each of the subject analyses was performed. The error, which involved analytical options within SIMULATE-E, resulted in part of the exposure history being analyzed under the Coarse Mesh Diffusion Theory (CMDT) nuclear option rather than the Modified Coarse Mesh Diffusion Theory (MCMDT) stipulated in the methodology description in Chapter 2 of the base report. Since MCMDT and CMDT are permutations of the same nodal coupling theory, the differences were small. This Appendix describes the differences.

This Appendix also contains a reanalysis of the Quad Cities gamma scan local power benchmarks prompted by the discovery of an error in GSU's original analysis. The error was located in the normalization logic of the single-purpose routine used to interpret local power benchmark data. The correction of the normalization logic improved the statistical results and the overall standard deviation for the local power Quad Cities benchmarks. See Section G-4 for a discussion of the correction.

NRC Question:

G-1. Explain the nonconservatism (relative to the fuel vendor) of the GSU Loss of Feedwater Heating (LFWH) analysis for RBS Cycle 3.

GSU Response:

The GSU calculations and the fuel vendor calculations were performed with slightly different assumptions and analytical conditions. While the GSU calculations are formulated differently from the fuel vendor calculations, the analytical results remain conservative relative to best-estimate predictions of plant phenomena. The differences between the two analyses are summarized in Table G-1.1.

Differences in hydraulic modeling and exposure distribution were investigated as potential sources of conservatism in the fuel vendor analysis. Neither of these differences were found to have a significant effect on the Operating Limit MCPR (OLMCPR) calculated for the LFWH transient. Reevaluation of the LFWH transient with MCMDT also resulted in negligible effect on the OLMCPR.

The main difference between the GSU and fuel vendor analyses is in the void and Doppler reactivity, which are included implicitly in the cross sections used by the nodal simulator code. While the GSU coefficients are numerically close to the fuel vendor results, the combination of differences drives a substantial difference in final power level for the LFWH event. Overall accuracy of the Doppler and void feedback mechanisms in the GSU modeling is demonstrated in the benchmark sections of the main report.

To quantify the real difference in analytical results, the GSU methodology was exercised using the fuel vendor assumptions. The results of this reanalysis are shown in Table G-1.2. The comparative results show close agreement between the GSU analysis and the fuel vendor analysis when similar analytical assumptions are employed.

The reanalysis accounted for differences in void and Doppler reactivity feedback coefficients by adjusting the fuel temperature dependence of the fast group absorption cross section in the SIMULATE-E analysis until the final conditions agreed with those in the fuel vendor analysis. While this measure did not duplicate the fuel vendor coefficients exactly, it provided a reasonable approximation of the final effects with a minimum impact on the nuclear modeling.

Conservatism introduced by the use of a high initial power assumption assures final results which are conservative relative to expected plant behavior. The use of reactivity adjustments to raise the final power level provides additional conservatism in the result but is not necessary for the establishment of conservative operating limits for the reactor core.

The fuel vendor results shown in Table G-1.2 are raw analytical output. In the determination of core operating limits, the fuel vendor adds additional conservatism to the calculated ΔCPR before determining the OLMCPR. This adjustment accounts for performing the analysis only at end of cycle conditions. GSU analyses for core operating limits are expected to include a determination of the most conservative exposure point for the LFWH transient during the operating cycle, which would eliminate the need for this allowance.

Table G-1.1 Comparison of GSU and Fuel Vendor Loss of Feedwater Heating Analyses for RBS Cycle 3

Parameter	GSU[1]	Fuel Vendor
Exposure Distribution	Actual	Haling
BOC3 core average exposure, GWd/Te	10.79	10.48
EOC3 core average exposure, GWd/Te	20.22	19.98
Cycle exposure in analysis, GWd/Te	20.22	19.98
Hydraulic Modeling	River Bend BWR Model	Generic BWR/6
Initial Conditions		
Core Power, %NBR	102	102
Core Pressure, psia	1059.1	1058.8
Core Inlet Subcooling, BTU/lb	23.7	23.25
Core Flow/Mlb$_m$/hr	84.5	84.5
ICPR	1.293	1.374
Final Conditions		
Core Power, %NBR	114.9	117.2
Core Pressure, psia	1083.8	1062.6
Core Inlet Subcooling, BTU/lb$_m$	38.9	39.25
Core Flow, Mlb$_m$/hr	84.5	85.9
MCPR	1.217	1.278
Reactivity Coefficients	CASMO analysis	Proprietary methodology
ΔCPR	0.076	0.096
OLMCPR	1.14	1.15

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[1] Results of the original LFWH analysis reported in Section 7.0 of the base report. Except for OLMCPR, these values were taken from Table 7.2.

Table G-1.2 Summary of Loss of Feedwater Heating Analysis with Similar Assumptions for RBS Cycle 3

Parameter	GSU	Fuel Vendor
Initial Conditions		
Core Power, % NBR	102	102
Core Flow, Mlb_m/hr	84.5	84.5
Core Pressure, psia	1058.8	1058.8
Core Inlet Subcooling, BTU/lb_m	23.25	23.25
ICPR	1.315	1.374
Final Conditions		
Core Power, % NBR	117.2	117.2
Core Flow, Mlb_m/hr	85.9	85.9
Core Pressure, psia	1062.6	1062.6
Core Inlet Subcooling, BTU/lb_m	39.25	39.25
MCPR	1.222	1.278
ΔCPR[1]	0.093	0.096
OLMCPR	1.15	1.15

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[1] Calculated value; operating limit is determined by adjusting ΔCPR to allow for uncertainties in core operation.

NRC Question:

G-2. Explain the nonconservatism (relative to the fuel vendor) of the GSU Control Rod Withdrawal Error (CRWE) analysis for RBS Cycle 3.

GSU Response:

The GSU calculations and the fuel vendor calculations were performed with slightly different assumptions and analytical conditions. While the GSU calculations are formulated differently from the fuel vendor calculations, the analytical results remain conservative relative to best-estimate predictions of plant phenomena. The differences between the two analyses are summarized in Table G-2.1.

Differences in hydraulic modeling and exposure distribution were investigated as potential sources of conservatism in the fuel vendor analysis. Neither of these differences were found to have a significant effect on the OLMCPR calculated for the CRWE transient.

When the CRWE transient was reevaluated with MCMDT, the OLMCPR difference between GSU and fuel vendor results was reduced by 0.02, bringing the two methodologies into agreement. The apparent nonconservatism in the CRWE analysis was primarily a result of the selection of nuclear mode in the SIMULATE-E calculation.

The results of the GSU and fuel vendor analyses of the CRWE transient are compared in Table G-2.2.

Table G-2.1 Comparison of GSU and Fuel Vendor Control Rod Withdrawal Error Analyses for RBS Cycle 3

Parameter	GSU	Fuel Vendor
Exposure Distribution	Rodded Depletion	Haling
BOC3 core average exposure, GWd/Te	10.70	10.48
EOC3 core average exposure, GWd/Te	Not used	19.98
Cycle exposure in analysis, GWd/Te	3.00	2.76
Hydraulic Modeling	River Bend FIBWR Model	Generic BWR/6
Strongest Rod Location	32-17	32-17
OLMCPR	1.16	1.18

Table G-2.2 Summary of Control Rod Withdrawal Error Analysis with Similar Assumptions for RBS Cycle 3

Parameter	GSU	Fuel Vendor
Exposure Distribution	Haling	Haling
BOC3 core average exposure, GWd/Te	10.48	10.48
EOC3 core average exposure, GWd/Te	19.98	19.98
Cycle exposure in analysis, GWd/Te	2.76	2.76
Hydraulic Modeling	River Bend FIBWR Model	Generic BWR/6
Strongest Rod Location	32-17	32-17
OLMCPR	1.18	1.18

NRC Question:

G-3. Explain the nonconservatism (relative to the fuel vendor) of the GSU Standby Liquid Control System (SLCS) cold shutdown margin for RBS Cycle 3.

GSU Response:

The GSU calculations and the fuel vendor calculations were performed with slightly different assumptions and analytical conditions. While the GSU calculations are formulated differently from the fuel vendor calculations, the analytical results remain conservative relative to best-estimate predictions of plant phenomena. The differences between the two analyses are summarized in Table G-3.1.

The GSU method calculates the soluble boron worth by adjusting the thermal group absorption cross section consistent with boron worth calculated by CASMO. This calculation is conservatively applied to the SLCS shutdown margin analysis by selecting conservative adjustment factors over the appropriate exposure and void history intervals for each fuel type in the core. Actual boron worth predictions were not made available to GSU by the fuel vendor; however, the fuel vendor method involves approximation of the borated k_∞ for each fuel type by applying a conservatively low boron reactivity worth to a non-borated k_∞ calculation. The fuel vendor estimates this reactivity worth at 70% void history, which is deterministically conservative relative to expected void history in the core.

To quantify the difference between the fuel vendor models and the GSU models, the SLCS cold shutdown margin was reanalyzed using the GSU models and the fuel vendor methods identified above. The results of this reanalysis are shown in Table G-3.2. The comparative results show close agreement between the GSU analysis and the fuel vendor analysis when the analyses are performed on the same basis. SLCS shutdown margins calculated with CMDT are slightly greater than those calculated with MCMDT under the same conditions.

Table G-3.1 Summary of Differences Between GSU and Fuel Vendor Standby Liquid Control System Shutdown Margin Analyses for RBS Cycle 3

Parameter	GSU	Fuel Vendor
Soluble boron concentration in detailed analysis, ppm	660	600[1]
Core average exposure at beginning of cycle 3, GWd/Te	10.69	10.48[2]
Boron worth convention	Conservative	Deterministic

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[1] Fuel vendor analyses contain an arbitrary allowance of 0.01 Δk for the difference between 600 ppm and 660 ppm.

[2] Fuel vendor analysis is based on projected end of previous cycle conditions, while GSU analysis is based on observed end of previous cycle conditions

Table G-3.2 Summary of Standby Liquid Control System Shutdown Margin Analysis with Similar Assumptions for RBS Cycle 3

Parameter	GSU	Fuel Vendor
Critical Eigenvalue	1.00046	1.0002
Borated Eigenvalue[1]	0.97902	0.97890
SLCS Shutdown Margin	0.021	0.021

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[1] Calculated at 600 ppm boron concentration

Benchmark Reanalysis

G-4. Correction of Published Benchmark Analysis: Quad Cities Local Power Gamma Scan Benchmarks

During an independent technical review of the Quad Cities gamma scan benchmark analysis, a logical error was discovered in the computer program used to perform the benchmarks. This error affected only the extraction of CASMO-generated data for bundles containing nonfueled rods; in the benchmark, only assembly GEH002 was affected by the error.

The logical error concerned normalization of the calculated gamma intensity values. The original coding detected the end of local power distribution information by the presence of a zero power value in the data array. The calculated power level for nonfueled rods is zero; hence, the normalization factor for the calculated local power array was truncated at the water rod in the 8x8 bundle evaluations. Resolution of the coding error improved the accuracy of the GEH002 benchmarks to a level consistent with benchmarks performed by others[1].

The corrected results are compared with the original results in Table G-4.1. A revised statistical analysis of the entire benchmark is given in Table G-4.2; the overall standard deviation for the local power benchmarks was calculated to be 3.1% rather than the 3.6% reported in Section 6.3 of the base report.

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[1] A. Dyszel, K.C. Knoll, J.H. Emmett, E.R. Jebsen, C.R. Lehmann, A.J. Roscioli, R.M. Rose, J.P. Spadaro, and W.J. Weadon, "Qualification of Steady State Core Physics Methods for BWR Design and Analysis," **PL-NF-87-001-A**, Pennsylvania Power & Light Company (1987).

Table G-4.1 Quad Cities Gamma Scan Local Power Benchmark Results, RMS Error for Assembly GEH002

Elevation	Reported Value	Revised Value
15.0	0.03031	0.024
21.0	0.04285	0.025
51.0	0.05752	0.027
56.0	0.04895	0.028
87.0	0.03235	0.030
93.0	0.03287	0.031
123.0	0.02655	0.023
129.0	0.02730	0.025

Table G-4.2 Quad Cities Gamma Scan Local Power Benchmark Results, Summary of Overall Benchmark

Assembly	Number of Points	Standard Deviation
GEH002	434	2.676%
CX0672	313	3.295%
GEB159	300	2.900%
GEB161	69	3.169%
CX0214	310	3.561%
Sample	1426	3.090%