ATTACHMENT A

COMMONWEALTH EDISON COMPANY TOPICAL REPORT

BENCHMARK OF BWR NUCLEAR DESIGN METHODS

QUAD CITIES GAMMA SCAN COMPARISONS

(NFSR-0085, SUPPLEMENT 1, REVISION 0)

NFSR-0085
Supplement 1
Revision 0

Nuclear Fuel Services

COMMONWEALTH EDISON COMPANY

TOPICAL REPORT - SUPPLEMENT 1

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Topical Report NFSR-0085 - Supplement 1

Benchmark of BWR Nuclear Design Methods

Quad Cities Gamma Scan Comparisons

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Statement of Disclaimer

Abstract

This supplement to Commonwealth Edison Company (Edison) Topical Report NFSR-0085 summarizes comparisons of Edison nuclear analysis results to gamma scan measurements of fuel assemblies from early cycles of the Quad Cities Unit 1 Nuclear Power Station. The nuclear analysis methods are based on the General Electric neutronic design computer codes TGBLA and PANACEA which have previously been reviewed and approved by the NRC. These methods were benchmarked by Edison for its Boiling Water Reactors in Topical Report NFSR-0085. The results of the Edison gamma scan comparisons further demonstrate that the TGBLA/PANACEA code package can predict the local fuel pin and assembly powers adequately.

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Section 1 - Introduction and Overview

1.1 Introduction

This supplement to Commonwealth Edison Company (Edison) Topical Report NFSR-0085, "Benchmark of BWR Nuclear Design Methods", Reference 1, describes the adequacy of the neutronic code package to predict local and assembly power distributions by comparing results to gamma scan measurements taken during several early cycles at Quad Cities Nuclear Power Station. The design codes TGBLA and PANACEA, which were developed by General Electric (GE), form the methodology basis for these comparisons. This code package was used for the benchmarking of recent reactor cycles for Edison's Boiling Water Reactors (BWRs) in the Edison Topical Report NFSR-0085 (Reference 1). The NRC approved the TGBLA/PANACEA code package for application to BWRs by GE in Reference 2. The bases of these neutronic codes are described more fully in References 3 and 4.

Comparisons to Traversing Incore Probe (TIP) readings were made in the Reference 1 submittal for Edison's BWRs. These comparisons demonstrated the capability of the code package to predict the axial neutron flux shape at the TIP position in the narrow-narrow water gap between fuel assemblies. The total uncertainty in local pin power is conservatively estimated by the TIP predicted-to-measured nodal uncertainty and this value can be confirmed by gamma scan benchmarking. Assembly gamma scan measurements were taken at Quad Cities Unit 1 at the end of Cycles 2, 4, and 5 and comparisons to these provide determination of the adequacy of the code package to predict assembly power distributions. Pin gamma scan measurements were taken at Quad Cities Unit 1 at the end of Cycles 2, 3, and 4 and comparisons to these provide determination of the adequacy of the code package to predict local pin powers.

These gamma scan comparisons were previously made by GE in Reference 3 as part of the original validation of the TGBLA/PANACEA code package. This study has been completed to demonstrate that Edison can adequately calculate individual pin powers and bundle-by-bundle power distributions.

1.2 Overview of NFSR-0085, Supplement 1

The results of the Edison pin and assembly gamma scan comparisons are summarized in Section 2 of this supplement. These demonstrate that Edison can adequately predict the pin-by-pin and bundle-by-bundle power distributions. Section 3 describes the bases of the measurement data and the neutronic validation of the code package in greater detail.

Section 2 - Summary and Conclusions

Assembly gamma scan results were evaluated for three cycles - Quad Cities Unit 1 Cycles 2, 4, and 5. The nodal standard deviations range from approximately 4 to 6% for the three cycles in the database; the bundle integrated standard deviations range from approximately 2 to 4%. The pin gamma scan results were compared to seven assemblies which were measured at the end of Cycles 2, 3, and 4, yielding an overall standard deviation of approximately 3%, with peak power and gadolinia pins being predicted better than the overall database. Detailed results are provided in Section 3.

Based on these results, it is concluded that the TGBLA/PANACEA code package being used at Edison acceptably predicts these local power parameters; namely, the assembly-by-assembly and the pin-by-pin power distributions.

Section 3 - Gamma Scan Comparisons

The results of the comparisons to the Quad Cities gamma scan measurements are presented in this section.

3.1 Purpose of Gamma Scan Comparisons

The Commonwealth Edison Company Topical Report NFSR-0085 demonstrated that the TGBLA/PANACEA code package can adequately predict the Traversing Incore Probe (TIP) readings for the Edison reactors. However, TIP readings are a composite of the power distribution in the bundles surrounding the TIP string, and both bundle-by-bundle and pin-by-pin power distributions cannot be determined from the TIP readings alone. Gamma scans of individual, irradiated, bundles determine the barium-140 content of each bundle by measuring the gamma rays produced by one of its daughter products. These readings can be correlated using barium-140 decay curves to determine the power of individual bundles and fuel pins. Assembly gamma scan results are used to determine the adequacy of the PANACEA predicted bundle-by-bundle power distributions; pin gamma scan results are used to determine the adequacy of the TGBLA predicted pin-by-pin power distributions, which are also known as local peaking factors.

3.2 Basis of Measurements

Gamma scan measurements were taken at the Quad Cities Unit 1 Nuclear Power Station at the end of Cycles 2, 3, 4, and 5. These measurements are documented in References 5 through 8, respectively. Gamma scans are used to measure the relative lanthanum-140 1596 KeV gamma ray intensity. Lanthanum-140 is produced by the decay of the fission product barium-140, which has a half-life of 12.79 days. The concentration of barium-140 is characteristic of the actual power history of the core during the last few months prior to shutdown. The measurements of the gamma rays resulting from the decay of lanthanum-140 are corrected to the same absolute time using the decay constant of lanthanum-140, since the measurements were taken over a period of days. The relative concentration of barium-140 was calculated using the power distribution calculated by PANACEA near the end of each cycle coupled with the barium-140 decay equations.

Two types of gamma scan measurements were performed. Fuel assemblies were measured at the four corners of the assembly to determine the overall bundle power. These are used for the assembly gamma scan comparisons.

The gamma ray intensity of individual, selected, fuel pins was measured at various axial heights and can be compared to local pin power predictions from the lattice physics code TGBLA using the appropriate nodal exposure and void history.

The results reported in this report include the effects of the gamma scan measurement uncertainty, including the uncertainties inherent both in the use of a smeared indication of steady-state power distribution used in determining the predicted barium-140 concentration, and in the correction of the measurements to the same absolute time. The measurement uncertainty can be seen most clearly in the pin gamma scan measurements. It would be expected that fuel pins which are loaded symmetrically to one another across the assembly's diagonal axis would have the same local power peaking. This is not the case, and these small power asymmetries are due mainly to measurement uncertainty.

3.3 Assembly Gamma Scan Comparisons

Assembly gamma scan measurements were taken at the Quad Cities Unit 1 Nuclear Power Station at the end of Cycles 2, 4, and 5. The power distributions from these measurements are compared to the PANACEA calculated power distributions to demonstrate that the bundle-by-bundle power predictions are correct. Table 3.3-1 summarizes the results of the assembly power comparisons for the experimental database. The statistical basis is the same as that described in NFSR-0085, Reference 1, and is described in Appendix A. These results are similar to those reported by GE for a similar database in Reference 3.

The measured and calculated relative barium-140 concentrations for the entire database are shown as a function of axial height in Figures 3.3-1 through 3.3-3 for Quad Cities Unit 1 Cycles 2, 4, and 5, respectively. These figures demonstrate that the axial variation of barium-140, and hence reactor power, has been adequately predicted.

Figures 3.3-4 through 3.3-6 show the percent error in assembly integrated power as a function of core position. Assembly power is being predicted well throughout the core. The peripheral, low power assemblies are predicted slightly better in a relative sense. This is due in large part to the statistical method used, which is the difference between the calculated and measured values, divided by the average measurement value of all assemblies. Since the average measurement value is normalized to unity, an assembly with the same percentage difference would have a greater absolute difference if the bundle power is higher.

Figures 3.3-4 through 3.3-6 contain the comparisons from the quadrant of the core in which the majority of the assemblies in the database were loaded. Some assemblies in the other quadrants were measured and are included in the database statistics. These results are consistent with those shown in Figures 3.3-4 through 3.3-6.

3.4 Pin Gamma Scan Comparisons

Pin gamma scan measurements were performed at Quad Cities Unit 1 at the end of Cycles 2, 3, and 4. Seven assemblies were evaluated in this comparison. Mixed oxide fuel was also measured as part of the Quad Cities gamma scan program, but was not included in this evaluation because Edison has no current plans to load plutonium-fueled assemblies.

A summary of the experimental database used for this comparison is given in Table 3.4-1. These assemblies have an average enrichment of between 2.12 and 2.62 w/o U235, include 7x7 and 8x8 lattice arrays, and exposures between 6.1 and 15.8 GWd/STU. Selected fuel pins within these assemblies were measured at several different axial planes. Other than the mixed oxide data, as discussed above, all available information was used as part of this benchmark.

Table 3.4-2 summarizes the results of the fuel pin power comparisons for the experimental database. The statistical basis is the same as that used in NFSR-0085, Reference 1, and is described in Appendix A. Detailed results of the bundle average local power results from the pin gamma scans are shown in Figures 3.4-1 through Figure 3.4-7.

The pin gamma scan comparison demonstrates excellent overall agreement to the measured data, with the peak power and gadolinia pins predicted better than the overall database.

Table 3.3-1
Results of Assembly Gamma Scans

Cycle	Number of Assemblies	Nodal Standard Deviation, %	Radial Standard Deviation, %
2	84	4.81	2.42
4	116	4.71	3.12
5	111	5.29	4.24

Table 3.4-1
Summary of Experimental Database - Pin Gamma Scans

Assembly ID	Cycle Scanned	Assembly Average Exposure, GWd/St	Assembly Average Enrichment, w/o U235	Lattice Array	Standard Deviation, %
GEH02	EOC2	8.5	2.50	8x8	3.09
CX214	EOC2	15.8	2.12	7x7	3.04
CX672	EOC2	15.8	2.12	7x7	3.85
L2593	EOC3	6.3	2.50	8x8	3.55
L2532	EOC3	6.1	2.50	8x8	2.62
GEH06	EOC3	13.4	2.50	8x8	2.66
L2635	EOC4	15.2	2.62	8x8	3.18

All axial measurements for the above assemblies were used.

Table 3.4-2
Results of Pin Gamma Scan Comparisons

Subset of Database	Number of Data Points	Mean Difference, (P - M) * 100	Standard Deviation, %
All Rods	2791	0.00	3.12
Gadolinia Rods	196	-1.05	2.57
Non-Gadolinia Rods	2595	0.08	3.13
Peak Power Rods	56	1.22	2.60

The mean difference is reported in units of (Predicted - Measured) * 100.

Figure 3.3-1
Relative Average Axial Barium-140 Concentration
Quad Cities Unit 1 Cycle 2

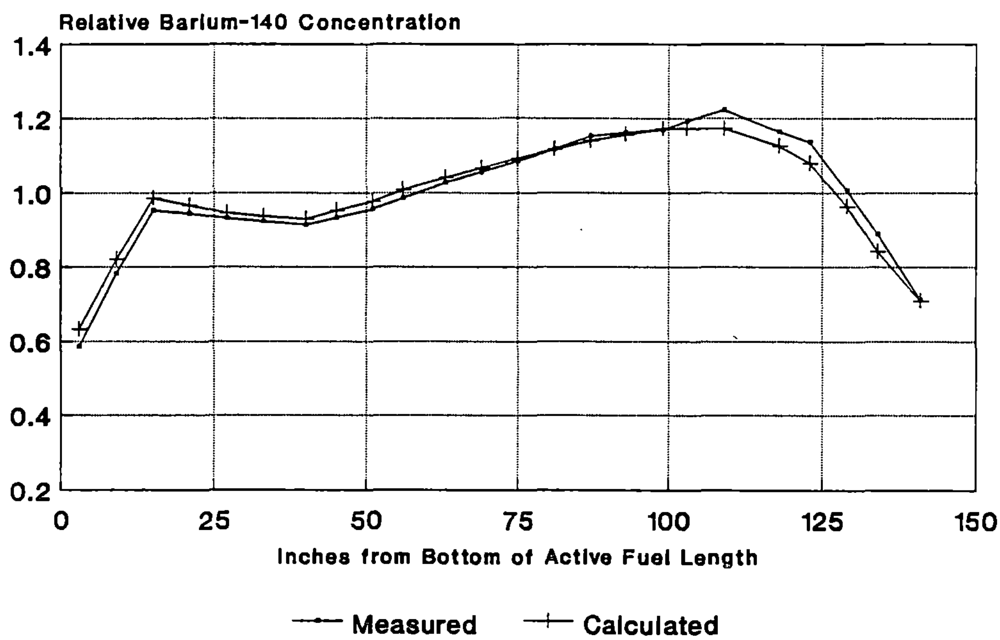

Figure 3.3-2
Relative Average Axial Barium-140 Concentration
Quad Cities Unit 1 Cycle 4

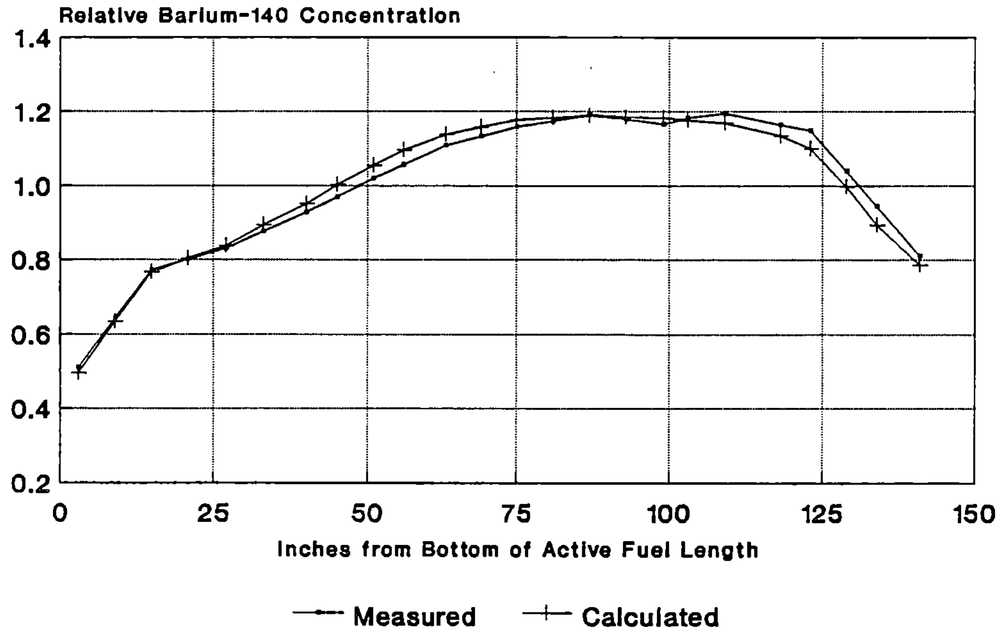

Figure 3.3-3
Relative Average Axial Barium-140 Concentration
Quad Cities Unit 1 Cycle 5

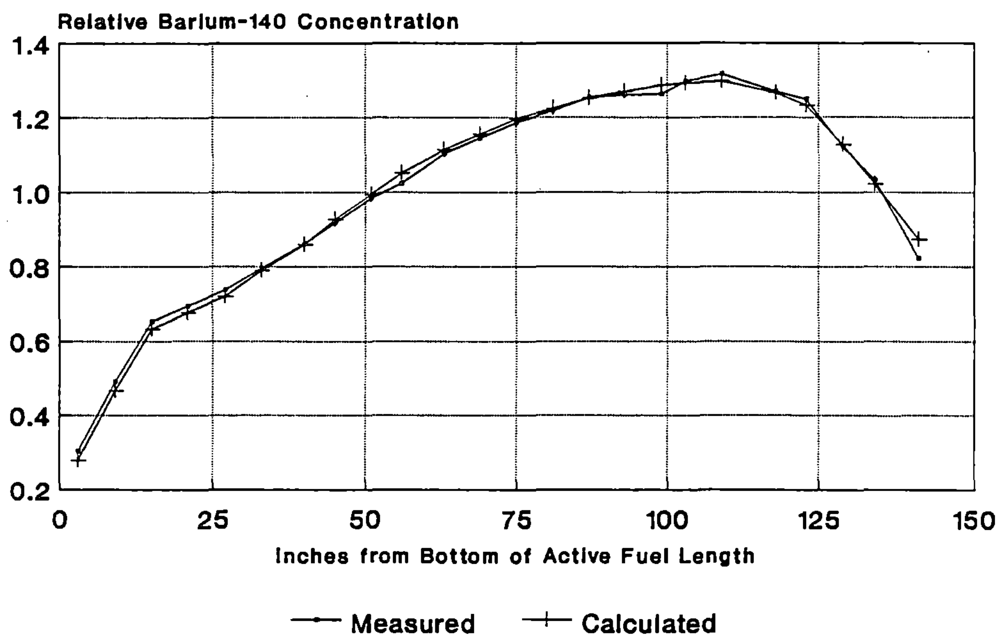

Figure 3.3-4
Assembly Integrated Power Comparisons
Quad Cities Unit 1 Cycle 2

				+1.50										
				+4.16	+2.39									
			+3.72	+3.65		+3.83					+3.21			
		+2.69	+3.15	+3.13		+2.93	+0.98							
		+3.72			+0.97	+3.01		+5.78						
	+1.29		+1.15	+1.97			-0.86	-1.89	-2.89					
-0.33	+2.81		+1.16	+2.20	-2.66	-0.75	+0.94	+0.72		+2.39				
		+0.51		-0.09		+1.14	-2.32		-2.48		-1.84			
	+1.39	+0.29		-0.26	-0.56	+3.09	-1.83	+0.37	-2.36	-2.56		-0.27		
+1.25			+0.02	-0.70		-1.20	-4.49	-2.36			-3.31	-2.70	-3.24	
+1.00	+0.89	+0.75	+2.06	+0.28	-1.46	-0.94	-1.93	-4.24	-3.28	-2.95	-2.99	-3.59	-3.98	

The data is presented in units of:
(Predicted - Measured) * 100.

Figure 3.3-5
Assembly Integrated Power Comparisons
Quad Cities Unit 1 Cycle 4

+1.17	+1.32	+0.93	+1.02	-0.34										
+3.39	+2.85	+2.12	+0.86	+1.34	+0.94									
+2.09	+5.41	+2.74		+4.92	+4.07	+3.83	+1.74	+0.50						
-0.56	+2.75				+3.73		+3.07	+2.72	+0.48					
+0.89		+4.38		+0.59		+4.50		+5.06	+3.32	+1.23				
-0.74	+3.05		+2.34	-1.66	+1.58		+3.85	+1.86	+5.50					
-1.49	-1.56	+1.55	+3.49	-3.20	-0.58	-0.16		+0.89						
-3.53	+2.57		+1.88		+0.24	-0.96	+3.04							
-5.80		+0.26		-0.35		-2.23								
-4.01	+1.76		-0.93	-3.59	-0.89									
-7.48	-0.49	-1.85		+0.34	-1.88			-3.07						
-2.96	+0.07		-1.18											+0.92
-5.34		-2.67												
-8.11	-2.37									+2.68				
	-4.78							-1.22						+1.64

The data is presented in units of:
(Predicted - Measured) * 100.

Figure 3.3-6
Assembly Integrated Power Comparisons
Quad Cities Unit 1 Cycle 5

+0.44	+1.84	+0.97	+1.59	+0.83										
-0.47	+0.74	-0.04	-0.41	+1.81	+0.73									
+1.30	+8.18	+1.12	+6.80	+2.56	+1.58	+3.15	+2.28	+0.53						
-1.29	-0.01	+6.79	+0.60		+2.19	+1.19	+0.82	+1.08	+0.51					
-2.27	+4.53	-0.39	+6.17	-0.39	+5.86	+1.80	+7.22	+2.08	+0.43	+0.76				
-4.51	-1.44	+4.29	-0.65	+5.28	+0.01	+5.61	-0.08	+0.31	+1.31					
-6.11	+3.14	-4.20	+3.09	-1.54	+4.27	-1.47	-1.78	+6.80	+0.98					
-6.44	-3.73	+0.32	-5.78	+0.36	-2.87	-1.17	+3.76							
-4.10	+1.05	-5.26	-0.74	-2.90	+0.12	-3.71	-3.33							
-9.72	-4.46	-0.87	-6.11	-6.96	-6.72									
-9.69	-0.46	-7.75	-1.56	-7.81	-8.16				+5.69					
-5.02	-5.37	-6.28	-3.90											
-3.54	1.64	-2.60	-4.31											
-6.84	-3.93													
	-7.39													

The data is presented in units of:
(Predicted - Measured) * 100.

Figure 3.4-1
Bundle Average Barium-140 Density Distribution

Assembly GEH02

Control Blade

1.0604 1.1279 +6.75	1.0826 1.1198 +3.72	TIE ROD	1.0675 1.0712 +0.37	1.0516 1.0589 +0.72	TIE ROD	1.0901 1.1128 +2.27	1.0859 1.1269 +4.10
1.0807 1.1198 +3.91	1.0174 1.0301 +1.27	1.1049 1.0804 -2.44	1.0528 1.0233 -2.94	1.0328 1.0089 -2.39	1.0450 1.0252 -1.98	1.0965 1.0811 -1.54	1.0141 1.0473 +3.32
TIE ROD	1.0998 1.0805 -1.93	1.0043 0.9709 -3.34	0.9562 0.9194 -3.68	0.9227 0.9075 -1.52	0.9399 0.9206 -1.93	0.9891 0.9726 -1.66	TIE ROD
1.0612 1.0712 +1.00	1.0451 1.0247 -2.04	0.9442 0.9203 -2.39	0.9127 0.8765 -3.62	0.9202 0.8856 -3.46	0.9111 0.8799 -3.11	0.9402 0.9220 -1.81	1.0586 1.0384 -2.02
1.0441 1.0589 +1.47	1.0189 1.0089 -1.00	0.9192 .09062 -1.30	0.9215 0.8856 -3.60	WATER ROD	0.9143 0.8890 -2.53	0.9164 0.9088 -0.76	1.0320 1.0234 -0.86
TIE ROD	1.0430 1.0252 -1.78	0.9404 0.9206 -1.98	0.9007 0.8799 -2.08	0.9117 0.8890 -2.26	0.8876 0.8814 -0.62	0.9227 0.9229 +0.02	TIE ROD
1.0817 1.1128 +3.10	1.0832 1.0811 -0.22	0.9763 0.9726 -0.37	0.9264 0.9220 -0.44	0.9009 0.9088 +0.79	0.9097 0.9229 +1.32	0.9470 0.9735 +2.64	1.0705 1.0954 +2.49
1.0815 1.1267 +4.52	1.0013 1.0473 +4.60	TIE ROD	1.0346 1.0396 +0.50	1.0045 1.0234 +1.89	TIE ROD	1.0520 1.0954 +4.34	0.9703 1.0550 +8.47

MEASURED
PREDICTED
DIFFERENCE

DIFFERENCE =
(PREDICTED - MEASURED) * 100

Figure 3.4-2
Bundle Average Barium-140 Density Distribution

Assembly CX214

Control Blade

1.0866 1.0929 +0.63	1.0119 1.0100 -0.19	TIE ROD	1.0541 1.0229 -3.12	TIE ROD	1.0318 1.0450 +1.32	0.9919 1.0283 +3.63
1.0008 1.0100 +0.92	0.9997 0.9950 -0.47	0.9352 0.9427 +0.75	1.0688 1.0301 -3.88	1.0551 1.0327 -2.24	1.0476 1.0358 -1.17	0.9557 0.9998 +4.42
TIE ROD	0.9373 0.9410 +0.37	1.0129 0.9809 -3.20	0.9749 0.9506 -2.43	0.9648 0.9537 -1.11	0.9924 0.9990 +0.65	TIE ROD
1.0388 1.0229 -1.59	1.0687 1.0301 -3.86	0.9699 0.9506 -1.93	WATER ROD	0.9272 0.9145 -1.26	0.9779 0.9649 -1.30	1.0273 1.0338 +0.65
TIE ROD	1.0521 1.0327 -1.94	0.9652 0.9537 -1.15	0.9374 0.9198 -1.76	0.9279 0.9204 -0.75	0.9519 0.9650 +1.31	TIE ROD
1.0342 1.0480 1.38	1.0363 1.0352 -0.11	0.9706 0.9978 +2.72	0.9842 0.9649 -1.92	0.9498 0.9650 +1.52	0.9801 1.0012 +2.12	1.0440 1.0624 +1.85
0.9966 1.0283 +3.17	0.9659 0.9998 +3.39	TIE ROD	1.0597 1.0338 -2.59	TIE ROD	1.0537 1.0624 +0.87	0.9590 1.0224 +6.34

MEASURED PREDICTED DIFFERENCE

DIFFERENCE =
(PREDICTED - MEASURED) * 100

Figure 3.4-3
Bundle Average Barium-140 Density Distribution

Assembly CX672

Control Blade

1.0409 1.0911 +5.01	0.9842 1.0086 +2.44	TIE ROD	0.9933 1.0222 +2.89	TIE ROD	1.0332 1.0475 +1.43	0.9763 1.0272 +5.09
0.9752 1.0086 +3.35	0.9815 0.9942 +1.27	0.9094 0.9415 +3.22	1.0710 1.0299 -4.11	1.0511 1.0329 -1.82	1.0446 1.0362 -0.84	0.9835 0.9996 +1.60
TIE ROD	0.9346 0.9403 +0.57	1.0321 0.9851 -4.69	0.9787 0.9486 -3.01	0.9764 0.9538 -2.26	1.0248 0.9982 -2.66	TIE ROD
1.0303 1.0199 -1.04	1.0603 1.0299 -3.05	0.9763 0.9501 -2.62	WATER ROD	0.9519 0.9202 -3.17	1.0054 0.9658 -3.96	1.0261 1.0345 +0.84
TIE ROD	1.0767 1.0329 -4.39	0.9560 0.9538 -0.22	0.9503 0.9202 -3.01	0.9017 0.9177 +1.60	0.9955 0.9657 -2.98	TIE ROD
1.0283 1.0475 +1.92	1.0676 1.0362 -3.14	1.0181 0.9982 -1.98	0.9820 0.9658 -1.62	0.9524 0.9630 +1.06	0.9990 1.0020 +0.30	1.0672 1.0632 -0.40
0.9709 1.0300 +5.90	0.9483 0.9996 +5.13	TIE ROD	1.0231 1.0317 +0.86	TIE ROD	1.0247 1.0632 +3.85	0.9972 1.0235 +2.63

MEASURED PREDICTED DIFFERENCE

DIFFERENCE =
(PREDICTED - MEASURED) * 100

Figure 3.4-4
Bundle Average Barium-140 Density Distribution

Assembly L2593

Control Blade

1.0934 1.1451 +5.17	1.1045 1.1382 +3.37	TIE ROD	1.0772 1.0783 +0.11	1.0535 1.0637 +1.02	TIE ROD	1.1114 1.1243 +1.29	1.0918 1.1349 +4.31
1.1198 1.1382 +1.85	1.0352 1.0377 +0.26	1.1224 1.0897 -3.27	1.0423 1.0277 -1.45	1.0168 1.0101 -0.67	1.0357 1.0273 -0.83	1.0863 1.0882 +0.20	1.0278 1.0499 +2.21
TIE ROD	1.1188 1.0897 -2.91	0.9945 0.9690 -2.55	0.9372 0.9139 -2.33	0.9007 0.8997 -0.10	0.9207 0.9142 -0.65	0.9787 0.9684 -1.03	TIE ROD
1.0685 1.0783 +0.98	1.0427 1.0277 -1.49	0.9436 0.9139 -2.97	0.8939 0.8684 -2.56	0.8948 0.8769 -1.79	0.8841 0.8710 -1.31	0.9121 0.9147 +0.26	1.0378 1.0381 +0.03
1.0749 1.0637 -1.12	1.0205 1.0101 -1.04	0.9272 0.8997 -2.75	0.9059 0.8769 -2.90	WATER ROD	0.8914 0.8795 -1.19	0.8987 0.9006 +0.19	1.0147 1.0201 +0.54
TIE ROD	1.0515 1.0273 -2.42	0.9357 0.9142 -2.15	0.8938 0.8710 -2.28	0.8924 0.8795 -1.29	0.8704 0.8715 +0.11	0.9034 0.9146 +1.11	TIE ROD
1.1278 1.1243 -0.35	1.1045 1.0882 -1.63	0.9912 0.9684 -2.28	0.9247 0.9147 -1.00	0.8977 0.9006 +0.29	0.8996 0.9146 +1.50	0.9163 0.9665 +5.02	1.0297 1.0979 +6.82
1.1390 1.1403 +0.13	1.0460 1.0499 +0.39	TIE ROD	1.0583 1.0381 -2.02	1.0242 1.0201 -0.41	TIE ROD	1.0525 11.0979 4.53	0.9621 1.0527 +9.06

MEASURED
PREDICTED
DIFFERENCE

DIFFERENCE = (PREDICTED - MEASURED) * 100

Figure 3.4-5
Bundle Average Barium-140 Density Distribution

Assembly L2532

Control Blade

1.0835 1.1411 +5.76	1.0939 1.1358 +4.19	TIE ROD	1.0586 1.0762 +1.76	1.0473 1.0619 +1.46	TIE ROD	1.1240 1.1235 -0.05	1.1316 1.1393 +0.76
1.0954 1.1358 +4.04	1.0104 1.0354 +2.50	1.0971 1.0886 -0.85	1.0328 1.0268 -0.60	1.0180 1.0095 -0.85	1.0358 1.0271 -0.86	1.1016 1.0888 -1.28	1.0498 1.0491 -0.07
TIE ROD	1.0995 1.0886 -1.09	0.9853 0.9679 -1.74	0.9221 0.9129 -0.93	0.9064 0.8992 -0.72	0.9261 0.9140 -1.22	0.9753 0.9690 -0.62	TIE ROD
1.0780 1.0762 -0.18	1.0313 1.0268 -0.45	0.9221 0.9129 -0.93	0.8725 0.8681 -0.44	0.8866 0.8774 -0.92	0.8853 0.8714 -1.39	0.9190 0.9154 -0.36	1.0683 1.0393 -2.90
1.0520 1.0619 +0.99	1.0131 1.0271 -0.36	0.9016 0.8992 -0.24	0.8950 0.8774 -1.76	WATER ROD	0.8971 0.8808 -1.64	0.9223 0.9019 -2.05	1.0409 1.0217 -1.92
TIE ROD	1.0351 1.0271 -0.80	0.9126 0.9140 +0.13	0.8730 0.8714 -0.16	0.8895 0.8808 -0.87	0.8835 0.8727 -1.08	0.9088 0.9161 +0.73	TIE ROD
1.1116 1.1235 +1.19	1.1016 1.0888 -1.28	0.9819 0.9690 -1.29	0.9198 0.9154 -0.44	0.8954 0.9018 +0.64	0.9096 0.9161 +0.64	0.9393 0.9689 +2.97	1.1076 1.1007 -0.70
1.1081 1.1393 +3.11	1.0221 1.0491 +2.69	TIE ROD	1.0496 1.0393 -1.03	1.0303 1.0217 -0.86	TIE ROD	1.1048 1.1007 -0.41	1.0363 1.0536 +1.74

MEASURED PREDICTED DIFFERENCE

DIFFERENCE =
(PREDICTED - MEASURED) * 100

Figure 3.4-6
Bundle Average Barium-140 Density Distribution

Assembly GEH06

Control Blade

1.0550 1.0970 +4.20	1.0772 1.0810 +0.37	TIE ROD	1.0644 1.0521 -1.23	1.0516 1.0437 -0.79	TIE ROD	1.0564 1.0835 +2.71	1.0437 1.0950 +5.12
1.0616 1.0810 +1.94	1.0217 1.0095 -1.23	1.0989 1.0572 -4.17	1.0350 1.0149 -2.01	1.0169 1.0023 -1.46	1.0329 1.0158 -1.71	1.0720 1.0595 -1.25	0.9839 1.0347 +5.09
TIE ROD	1.1014 1.0572 -4.42	0.9979 0.9698 -2.81	0.9345 0.9288 -0.57	0.9219 0.9169 -0.49	0.9242 0.9301 +0.59	0.9720 0.9719 -0.01	TIE ROD
1.0497 1.0521 +0.24	1.0391 1.0149 -2.43	0.9444 0.9258 -1.56	0.9004 0.8911 -0.93	0.9091 0.9000 -0.92	0.8934 0.8945 +0.12	0.9241 0.9316 +0.75	1.0235 1.0353 +1.18
1.0472 1.0437 -0.35	1.0196 1.0023 -1.73	0.9325 0.9169 -1.56		WATER ROD		0.9032 0.9198 +1.66	1.0122 1.0223 +1.01
TIE ROD	1.0349 1.0158 -1.91	0.9454 0.9301 -1.53		0.9116 0.9034 -0.82	0.9014 0.8960 -0.54	0.9315 0.9326 +0.11	TIE ROD
1.0602 1.0835 +2.32	1.0731 1.0595 -1.37	0.9710 0.9719 +0.09	0.9295 0.9311 +0.16	0.9234 0.9198 -0.36	0.9352 0.9326 -0.27	0.9686 0.9733 +0.47	1.0763 1.0796 +0.34
1.0455 1.0950 +4.95	0.9985 1.0347 +3.62	TIE ROD	1.0385 1.0353 -0.32	1.0299 1.0223 -0.76	TIE ROD	1.0859 1.0796 -0.63	1.0182 1.0492 +3.10

MEASURED PREDICTED DIFFERENCE

DIFFERENCE =
(PREDICTED - MEASURED) * 100

Figure 3.4-7
Bundle Average Barium-140 Density Distribution

Assembly L2635

Control Blade

1.0228 1.0934 +7.06	1.0170 1.0764 +5.93	TIE ROD	1.0319 1.0522 +2.02	1.0342 1.0446 +1.04	TIE ROD	1.0489 1.0812 +3.23	1.0472 1.0917 +4.46
1.0218 1.0764 +5.46	0.9808 1.0086 +2.78	1.0417 1.0618 +2.02	1.0128 1.0218 +0.91	1.0137 1.0097 -0.39	1.0240 1.0226 -0.14	1.0483 1.0641 +1.58	0.9998 1.0357 3.59
TIE ROD	1.0548 1.0618 +0.71	0.9884 0.9779 -1.05	0.9404 0.9383 -0.21	0.9193 0.9264 +0.71	0.9305 0.9394 +0.89	0.9930 0.9796 -1.35	TIE ROD
1.0308 1.0522 +2.14	1.0227 1.0218 -0.08	0.9347 0.9383 +0.37	0.9045 0.9007 -0.38	0.9208 0.9095 -1.13	0.9140 0.9040 -1.00	0.9452 0.9406 -0.45	1.0619 1.0430 -1.89
1.0437 1.0446 +0.09	1.0104 1.0097 -0.07	0.9339 0.9264 -0.75	0.9292 0.9095 -1.97	WATER ROD	0.9202 0.9127 -0.74	0.9310 0.9287 -0.24	1.0519 1.0304 -2.15
TIE ROD	1.0229 1.0226 -0.03	0.9400 0.9394 -0.06	0.9254 0.9040 -2.14	0.9337 0.9127 -2.09	0.9174 0.9052 -1.22	0.9633 0.9413 -2.20	TIE ROD
1.0638 1.0812 +1.74	1.0697 1.0641 -0.56	1.012 0.9726 -3.27	0.9689 0.9406 -2.83	0.9553 0.9287 -2.66	0.9547 0.9413 -1.33	1.0083 0.9806 -2.77	1.0815 1.0852 +0.36
1.0715 1.0917 +2.02	1.0467 1.0357 -1.10	TIE ROD	1.0989 1.0430 -5.59	1.0849 1.0304 -5.45	TIE ROD	1.1082 1.0852 -2.30	1.0468 1.0515 +0.47

MEASURED PREDICTED DIFFERENCE

DIFFERENCE =
(PREDICTED - MEASURED) * 100

Section 4 - References

1. Commonwealth Edison Topical Report NFSR-0085, "Benchmark of BWR Neutronic Methods", November 1990.

2. GE Proprietary Document NEDE-24011-P-A, "General Electric Standard Application for Reactor Fuel", as supplemented.

3. GE Proprietary Document NEDE-30130-P-A, "Steady-State Nuclear Methods", April 1985.

4. GE Proprietary Document NEDE-30002P, "TGBLA Lattice Physics Methods", December 1982.

5. EPRI Document EPRI-NP-214, "Gamma Scan Measurements at Quad Cities Nuclear Power Station Unit 1 Following Cycle 2", July 1976.

6. EPRI Document EPRI-NP-512, "Gamma Scan Measurements at Quad Cities Nuclear Power Station Unit 1 Following Cycle 3", July 1977.

7. GE Document NEDC-25492, "Gamma Scan Measurements at Quad Cities Nuclear Power Station Unit 1 Following Cycle 4", November 1981.

8. GE Proprietary Document NEDM-31138P, "Gamma Scan Measurements at Quad Cities Nuclear Power Station Unit 1 Following Cycle 5", April 1986.

Appendix A
Statistical Basis

Several standard deviations are presented in the text. The bases for these calculations are discussed in this appendix.

Nodal Standard Deviation

The nodal standard deviations are based on the nodal percent differences. The nodal percent differences are calculated as follows:

Nodal Percent Difference = (P - M) / Mbar * 100

where:

P - Predicted
M - Measured
Mbar - Average Measured Value

Since the measured data are normalized such that the assembly average value is one, Mbar will always be equal to one and the above equation simplifies to the difference between the calculated and measured values.

Radial Standard Deviation

The radial standard deviations are based on the radial percent differences, which are the differences between the summations of the predicted bundle power and the measured bundle power. Again, since the measured data are normalized such that the core average value is one, the normalization factor Mbar will always be equal to one.