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November 30, 1984

Mr. Harold R. Denton, Director
Office of Nuclear Reactor Regulation
U. S. Nuclear Regulatory Commission
Washington, D. C. 20555

Attention: Ms. E. G. Adensam, Chief
Licensing Branch No. 4

Subject: McGuire Nuclear Station - Docket No. 50-369/370
Catawba Nuclear Station - Docket No. 50-413/414
Response Request for Additional Information Regarding
Topical Report DPC-NF-2010, "Nuclear Physics Metodology
for Reload Design"

In response to your request (Reference Letter, E. G. Adensam to H. B. Tucker, November 5, 1984) for additional information regarding the subject topical report, attached are Duke Power Company's answers to the six questions in the request.

If any additional information or discussion is desired, please feel free to call Scott Gewehr, Duke Power Licensing at (704) 373-7581.

Very truly yours,

H. B. Tucker

Hal B. Tucker

SAG/mjf

Attachment

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Q.1 Please provide additional information regarding the NUC-MARGINS code and its use in the Dropped Rod Analysis. Provide short descriptions of the input, output, calculational models used, benchmark calculations performed and the conservatisms assumed in the analysis.

A.1 Under the terms of the current fuel contract with Westinghouse, Duke Power will provide physics data for the rod drop transient to Westinghouse who will then perform the safety evaluation and/or reanalysis. This relationship will exist until Duke submits its thermal-hydraulic and safety analysis methodology reports to the NRC.

The physics methods described in Section 4.2.2.5, 6.2.2.4, and 9.1.3.3 will be further elaborated herein.

A. Initial conditions for analysis:

1. Control Bank D is inserted to the Rod Insertion Limit.
2. Core Power is 102% Full Power (2% calorimetric error included).
3. A full power xenon distribution is used which would produce a DNB limiting axial power profile.

B. Assumptions for system response upon rod drop:

1. No trip occurs.
2. Control bank D is withdrawn to compensate for the dropped rod.
3. A short duration reactor power overshoot will occur with the turbine-reactor control system eventually leveling out the reactor power to the initial power level.

Search cases are performed as described in Section 4.2.2.5 and 6.2.2.4. EPRI-NODE assembly average powers are converted to $F_{\Delta H}^{N}$ using the method described below. This method is employed for all $F_{\Delta H}^{N}$ evaluations. All physics codes employed are static, therefore, "before" and "after" rod drop power distributions are calculated.

The mathetical formulation of $F_{\Delta H}^{C}$ employs the Section 6.2.1.2 definitions as follows:

$$F_{\Delta H,j}^{C} = [\sum_{i=1}^{K} F_{i,j}^{node} \times RL_{j}^{N} + FR_{j} \times F_{K,j}^{node} \times RL_{j}^{N} + (1-FR_{j}) \times F_{K,J}^{node} \times RL_{j}^{R} + \sum_{i=N+1}^{M} F_{i,j}^{node} \times RL_{j}^{R}] \div M$$

and then:

$$F_{\Delta H}^{C} = \max_{j} (F_{\Delta H,j}^{C})$$

Where:

M = Number of axial nodes.

RL_j^N = Non-rodded radial local factor for assembly j.

$RL^R{}_j$ = Rodded radial local factor for assembly j.

FR_j = Linear fraction of assembly j which does not contain a control rod.

Radial local factors are edited by PDQ-EDIT using fine mesh PDQØ7 mesh average powers. The PDQØ7 cases are two-dimensional simulations with control bank(s) explicitly represented.

The nodal powers, $F_{i,j}^{node}$, are steady state three-dimensional calculations which explicitly model; control bank insertion, boron and xenon conditions, and other reactor state point variables necessary for a best estimate power distribution calculation.

$F_{\Delta H}^{C}$ is then evaluated by the NUC-MARGINS code or by hand calculations using the nodal powers from NODE-P and the RL from PDQ07. The NUC-MARGINS code has been independently verified to yield the correct $F_{\Delta H}^{N}$. $F_{\Delta H}^{T}$ is the ultimate output as defined by equation 6-2 for DNB analysis.

The system transient response and the transient DNB calculations would be performed by Westinghouse if the physics parameters exceeded the bounds of the previous analyses.

Q.2 Identify the nominal and various off-nominal cross-section sets that are generated in order to evaluate the different reactivity coefficients and defects.

A.2 The various fuel cross-section sets that are generated in order to evaluate different reactivity coefficients and defects are identified in Table 2.1. Nominal cross-sections are generated as a function of burnup at an average moderator temperature of 594°F and an average fuel temperature of 1250°F. The off-nominal cross-sections are generated at various burnups with varying moderator and fuel temperatures.

The cross-section representation in PDQØ7 differs between the quarter-core discrete pin and colorset models. The representation employed in the quarter-core model is discussed first and then the colorset discussion follows. All sets, except the baffle, use combined macroscopic and microscopic cross-sections.

Fuel cross-sections in quarter-core PDQØ7 are calculated according to the following relation:

$$\Sigma(T_M, T_F, Bu) = \Sigma_o(Bu) + \frac{\Delta\Sigma}{\Delta T_M} \times (T_M - T_M^{Ref}) + \frac{\Delta\Sigma}{\Delta\sqrt{T_F}} \times (\sqrt{T_F} - \sqrt{T_F}^{Ref})$$

where $\Sigma(T_M, T_F, Bu)$ = the total macroscopic cross-section as a function of moderator temperature, fuel temperature, and burnup.

$\Sigma_o(Bu)$ = the nominal macroscopic cross section as a function of burnup.

$\frac{\Delta\Sigma}{\Delta T_M}$ = the moderator temperature pseudo-microscopic cross-section which relates the change in macroscopic cross-section to change in moderator temperature.

$\frac{\Delta\Sigma}{\Delta\sqrt{T_F}}$ = the fuel temperature pseudo-microscopic cross-section which relates the change in macroscopic cross-section to a change in fuel temperature.

The macroscopic cross-sections given here may be of any type, e.g. transport, absorption, removal, or fission. The pseudo-microscopic cross-sections (or pseudo-micros) account for the change in the macroscopic cross-section as a result of a change from reference conditions. These pseudo-micros are input to PDQØ7 as a function of burnup. The moderator temperature pseudo-micros are determined from the cross-section sets at moderator temperatures of 630°F and 530°F (fuel temperature held constant at 1250°F).

The fuel temperature pseudo-micros are determined from the cross-section sets at fuel temperatures of 1250°F and 594°F (moderator temperature held constant at 594°F).

Most nonfuel cross-sections employed in quarter core calculations are evaluated as shown in Table 2.4, and are consistent with the core average moderator temperature of interest.

The reflector constants are evaluated at T_{inlet} (usually 557°F) and, at Hot Zero Power, are identical to the water gap constants. Baffle constants are evaluated using the method shown in Chapter 4 of EPRI NP-3642-SR (Few-Group Baffle and/or Reflector Constants for Diffusion Calculation Application, EPRI Special Report, August 1984).

Colorset PDQ07 calculations are performed which provide sufficient data to characterize operation from Hot Full Power (HFP) to Cold Zero Power (CZP) conditions. A breakpoint is designated at Hot Zero Power (HZP). Two sets of data (B-Constants) are then used in EPRI-NODE-P calculations:

1. Normal Operation - HFP to HZP

2. Low Temperature - HZP to CZP

B-Constants for the Normal Operation and Low Temperature models are generated following the sequence described in Section 3 of DPC-NF-2010.

Tables 2.1 and 2.4 describe conditions for fuel and non-fuel cross-section sets. The Normal Operation cross-sections input to colorset PDQ07 calculations are shown by the matrices in Table 2.2. Table 2.3 shows matrices of cross section sets for Low Temperature colorset calculations. Nonfuel cross-section sets (Table 2.4) are used which are consistent with the fuel moderator temperature.

Table 2.1

McGuire/Catawba
Fuel Cross-Section Sets

Cross-Section Set Type	T_{mod} (°F)	T_{fuel} (°F)	Power	Burnup Timesteps (GWD/MTU)	Application
P1	594	594	Zero	0.0	HFP → HZP
P2 (Nominal)	594	1250	Full	0.0	"
P3	630	1250	Full	0.0	"
P4	530	1250	Full	0.0	"
P8 (Nominal)	594	1250	Full	0.0, 0.1, 0.5, 1.0, 2.0, 4.0, 6.0, ..., 58.0, 60.0	"
P8B6	594	594	Full	"	"
P8B7	530	1250	Full	"	"
P8B8	630	1250	Full	"	"
P5	200	200	Zero	0.0	HZP → CZP
P9	200	200	Zero	0.0, 0.1, 0.5, 1.0, 2.0, 4.0, 6.0, ..., 58.0, 60.0	"
P6	557	557	Zero	0.0	"
P7	68	68	Zero	0.0	"

Table 2.2

Cross-Section Sets for Normal Operation
PDQØ7 Colorsets

BOL

Effect	P2(Nominal)	P1	P3	P4
	Cross-Section Set Type			
Soluble Boron	X			
K-inf vs. T_{mod}	X		X	X
Migration Area vs. T_{mod}	X		X	X
Doppler	X	X		

Depletion

Reactivity Effect	P8(Nominal)	P8B6	P8B7	P8B8
	Cross-Section Set Type			
Exposure	X			
Soluble Boron	X			
Control Rods	X			
Xenon	X			
Doppler	X	X		
Moderator			X	X

Table 2.3

Cross-Section Sets for Low Temperature
PDQ07 Colorsets

BOL

Effect	Cross-Section Set Type P5	P6	P7
Soluble Boron	X		
K-inf. vs. T_{mod}	X	X	X
Migration Area vs. T_{mod}	X	X	X

DEPLETION

Reactivity Effect	Cross-Section Set Type P9
Exposure	X
Soluble Boron	X
Control Rods	X

Table 2.4

McGuire/Catawba
Non-fuel Cross-Section Sets

Material	Moderator Temperatures (°F)
Water Cap/Reflector	630, 594, 557, 530, 200, 68
Guide Tube/Inst. Tube	630, 594, 557, 530, 200, 68
Control Rod	594, 557, 200, 68
Burnable Poison Rod	594, 557, 200, 68
Baffle	EPRI NP-3642-SR

Q.3 Provide a short description of the PDQ-EDIT code and describe the verification program that was undertaken to test data generated with PDQ-EDIT for use in SNA-CORE.

A.3 PDQ-EDIT is a utility code written by Duke Power Company that is capable of reading Internal File Management (IFM) files written by PDQ07. This code is primarily used to develop theoretical factors for SNA-CORE, and to edit and process data contained on pointwise flux, power and concentration IFM files. PDQ-EDIT, like all Nuclear Design software used in safety related analysis, is quality assured as required by Duke Power Company's Administrative Policy Manual for Nuclear Stations.

SNA-CORE theoretical factors are generated from PDQ-EDIT in what is commonly known as theoretical factor sets. Each theoretical factor set is valid over a user defined burnup range. Theoretical factor sets consist of assembly average powers, assembly peak pin powers, and detector mesh average two-group fluxes.

Verification of theoretical factor sets is accomplished by the utility code SNAVER. SNAVER compares the symmetric assembly average and peak pin powers on either a 1/4-core or 1/8-core basis, and then calculates a percent difference for each power at a given location with respect to the average at that location. Percent differences greater than 0.1% are flagged by the program. The cognizant engineer must then verify whether these errors are justified. SNAVER also checks for consistancy between detector fluxes at symmetric locations, and for correct data format.

The formal benchmarking of theoretical factors developed from PDQ-EDIT was accomplished by comparing measured powers from Westinghouse's INCORE code, to those calculated from SNA-CORE for Sequoyah Unit 1 Cycle 1. All measured powers were inferred from plant supplied flux traces. Results from these comparisons are shown in Figures 1 thru 7. Good agreement between the two codes was observed. A summary of the average absolute relative error, and the standard deviation associated with these errors are presented in Table 1.

In conclusion, comparisons between measured data from Westinghouse's INCORE code and Duke's SNA-CORE code demonstrate the accuracy of the PDQ07, PDQ-EDIT, SNA-CORE code package. Also, in addition to the software quality assurance program employed at Duke, SNAVER provides an independent means of verifying the correctness of theoretical factor sets before they are used in a production environment.

Table 1

Statistical Summary of INCORE versus SNA-CORE
Measured Powers for Sequoyah 1 Cycle 1

CASE	Burnup EFPD	Average Absolute Relative Frror (%)	Standard Derration %
1	71.82	1.34	1.84
2	101.62	1.06	1.43
3	133.30	1.14	1.48
4	166.04	1.28	1.64
5	231.70	1.21	1.48
6	292.04	1.20	1.51
7	378.92	1.05	1.34

Average Absolute Relative Error $(\overline{D}) \equiv \left|[(\text{SNA-CORE} - \text{INCORE})/\text{INCORE}]\right| * 100$

$$\overline{D} \equiv \sum_{i=1}^{N} D_i/N$$

FIGURE 1

SEQUOYAH 1 CYCLE 1 SNA-CORE VS. INCORE MEASURED POWERS
71.82 EFPD 100(%)FP CONTROL BANK D AT 200 STEPS WITHDRAWN

	H	G	F	E	D	C	B	A	
	1.12	1.05	1.17	1.11	1.15	1.05	1.01	.71	
8	1.17	1.08	1.17	1.14	1.18	1.07	1.01	.71	
		1.16	1.11	1.19	1.16	1.13	1.01	.77	
9		1.17	1.13	1.19	1.17	1.13	1.03	.77	
			1.18	1.12	1.18	1.09	.98	.66	
10			1.17	1.14	1.18	1.11	.97	.65	
				1.18	1.13	1.08	.92	.56	
11				1.19	1.16	1.08	.92	.55	
					1.09	.99	.86		
12					1.12	.99	.83		
						1.02	.51	SNA-CORE	
13						.99	.49	INCORE	

FIGURE 2

SEQUOYAH 1 CYCLE 1 SNA-CORE VS. INCORE MEASURED POWERS
101.62 EFPD 100(%)FP CONTROL BANK D AT 218 STEPS WITHDRAWN

		H	G	F	E	D	C	B	A
	SNA-CORE	1.14	1.06	1.16	1.13	1.17	1.06	1.00	.71
8	INCORE	1.16	1.09	1.17	1.15	1.17	1.08	1.00	.71
	SNA-CORE		1.16	1.12	1.18	1.16	1.12	1.01	.76
9	INCORE		1.17	1.14	1.18	1.18	1.13	1.03	.76
	SNA-CORE			1.18	1.13	1.17	1.09	.97	.65
10	INCORE			1.17	1.15	1.17	1.11	.96	.65
	SNA-CORE				1.17	1.13	1.08	.91	.55
11	INCORE				1.18	1.16	1.08	.92	.55
	SNA-CORE					1.11	1.00	.85	
12	INCORE					1.11	1.00	.83	
	SNA-CORE						1.02	.51	
13	INCORE						.99	.50	

FIGURE 3

SEQUOYAH 1 CYCLE 1 SNA-CORE VS. INCORE MEASURED POWERS
133.30 EFPD 100(%)FP CONTROL BANK D AT 216 STEPS WITHDRAWN

		H	G	F	E	D	C	B	A
8	SNA-CORE	1.14	1.08	1.17	1.14	1.16	1.07	.99	.70
	INCORE	1.16	1.11	1.17	1.17	1.17	1.09	.99	.71
9	SNA-CORE		1.17	1.14	1.19	1.17	1.12	1.01	.76
	INCORE		1.17	1.16	1.18	1.19	1.12	1.03	.76
10	SNA-CORE			1.18	1.14	1.17	1.09	.96	.65
	INCORE			1.17	1.16	1.16	1.11	.95	.65
11	SNA-CORE				1.16	1.13	1.06	.91	.55
	INCORE				1.17	1.16	1.06	.92	.55
12	SNA-CORE					1.09	1.00	.84	
	INCORE					1.10	1.00	.82	
13	SNA-CORE						1.01	.51	
	INCORE						.98	.50	

FIGURE 4

SEQUOYAH 1 CYCLE 1 SNA-CORE VS. INCORE MEASURED POWERS
166.04 EFPD 100(%)FP CONTROL BANK D AT 210 STEPS WITHDRAWN

		H	G	F	E	D	C	B	A
		1.13	1.09	1.17	1.15	1.14	1.08	.99	.71
8		1.16	1.11	1.17	1.10	1.15	1.10	.99	.71
			1.16	1.15	1.19	1.17	1.11	1.01	.76
9			1.17	1.18	1.18	1.19	1.11	1.03	.76
				1.18	1.15	1.16	1.09	.96	.66
10				1.17	1.18	1.15	1.11	.95	.65
					1.16	1.13	1.06	.91	.55
11					1.17	1.17	1.06	.92	.55
						1.08	1.00	.84	
12						1.09	1.00	.82	
	SNA-CORE						1.00	.51	
13	INCORE						.97	.50	

FIGURE 5

SEQUOYAH 1 CYCLE 1 SNA-CORE VS. INCORE MEASURED POWERS
231.70 EFPD 100(%)FP CONTROL BANK D AT 216 STEPS WITHDRAWN

		H	G	F	E	D	C	B	A
8	SNA-CORE	1.10	1.08	1.14	1.16	1.13	1.09	.99	.72
	INCORE	1.12	1.10	1.14	1.19	1.13	1.12	.99	.73
9	SNA-CORE		1.13	1.16	1.16	1.17	1.09	1.02	.76
	INCORE		1.14	1.18	1.15	1.19	1.09	1.04	.77
10	SNA-CORE			1.16	1.16	1.14	1.10	.96	.67
	INCORE			1.15	1.18	1.13	1.12	.95	.68
11	SNA-CORE				1.14	1.14	1.05	.92	.56
	INCORE				1.14	1.17	1.05	.93	.56
12	SNA-CORE					1.07	1.02	.84	
	INCORE					1.08	1.02	.82	
13	SNA-CORE						1.00	.53	
	INCORE						.98	.52	

FIGURE 6

SEQUOYAH 1 CYCLE 1 SNA-CORE VS. INCORE MEASURED POWERS
292.04 EFPD 100(%)FP CONTROL BANK D AT 216 STEPS WITHDRAWN

	H	G	F	E	D	C	B	A	
	1.07	1.07	1.12	1.15	1.11	1.10	.99	.74	
8	1.09	1.09	1.12	1.18	1.12	1.13	.99	.75	
		1.11	1.15	1.14	1.16	1.08	1.03	.78	
9		1.11	1.18	1.13	1.18	1.08	1.05	.78	
			1.14	1.16	1.12	1.11	.97	.69	
10			1.13	1.18	1.11	1.13	.96	.69	
				1.12	1.13	1.05	.93	.58	
11				1.12	1.16	1.05	.94	.57	
					1.06	1.04	.85		
12					1.07	1.04	.83		
						1.00	.55		SNA-CORE
13						.98	.54		INCORE

FIGURE 7

SEQUOYAH 1 CYCLE 1 SNA-CORE VS. INCORE MEASURED POWERS
378.92 EFPD 100(%)FP CONTROL BANK D AT 222 STEPS WITHDRAWN

		H	G	F	E	D	C	B	A
8	SNA-CORE	1.02	1.04	1.08	1.14	1.09	1.10	1.00	.77
	INCORE	1.06	1.06	1.08	1.15	1.09	1.13	1.01	.79
9	SNA-CORE		1.07	1.13	1.10	1.14	1.07	1.05	.80
	INCORE		1.08	1.15	1.10	1.15	1.07	1.07	.81
10	SNA-CORE			1.10	1.14	1.09	1.11	.98	.73
	INCORE			1.09	1.15	1.09	1.13	.97	.74
11	SNA-CORE				1.09	1.13	1.05	.96	.60
	INCORE				1.10	1.15	1.05	.97	.60
12	SNA-CORE					1.06	1.06	.87	
	INCORE					1.07	1.06	.85	
13	SNA-CORE						1.02	.58	
	INCORE						1.00	.57	

Q.4. Comment on the reasons for the 3.1% non-conservative bias in the calculated peak axial powers (Section 11.5.4). Describe the model refinements, if any, that have been undertaken to reduce this bias.

A.4. The reason there is a -0.031 bias on the calculated peak axial powers (Section 11.5.4) is that the models used by Duke at the time of this report underpredicted the peak axial power. This -0.031 bias is the mean difference ($\overline{D}$) and is defined by equation 11-2. This value is a difference and not a percentage difference. The mean percent difference for all cases considered was -2.195% (Table 11-10). Again, it should be pointed out, that this number applies to all peak C, M pairs $\geq$ 1.0.

Although Dukes' models underpredict the peak axial power on an average of -2.195%, the Observed Nuclear Reliability Factor (ONRF) directly reflects this non-conservative prediction. This can be seen by examining equation 11-11. Because $\overline{D}$ is subtracted from $\overline{M}$, this equation is conservative for all cases of $\overline{D}$. (That is, $\overline{D}$ being positive, negative, or 0)

Consider the ONRF calculation of the peak axial power on Table 11-6. In this example if $\overline{D}$ were 0 the ONRF would be 1.035. With a $\overline{D}$ of -0.031 the ONRF is 1.058. This is a 2.2% increase in ONRF. The $\overline{D}$ of -0.031 represents a 2.195% underprediction of measured peak axial power. (Table 11-10). Therefore, it can be seen from this example, that there is a 1% increase in ONRF for each 1% that the model underpredicts the measured peak axial power.

In summary, even though the models used by Duke underpredict the peak axial power, the ONRF reflects this underprediction. As shown in the above example, there is a 1 to 1 correspondence in the percentage of the underprediction to the percentage increase in the ONRF.

The model refinements undertaken to reduce this underprediction are discussed in the answer to question 6 parts one and two. The refinements are; 1) normalization of EPRI-NODE-P to include unrodded M^2 adjustments, and 2) an increase in the number of axial nodes. Attached are the results of some maps compared to predictions using 12 levels and 18 levels of EPRI-NODE-P. Attached are the Difference Means and Standard Deviations for Assembly Peak Axial Powers (C, M $\geq$ 1.0), and Assembly Radial Powers. Also attached are Percent Difference Means (C, M $\geq$ 1.0) for Assembly Peak Axial Powers and Assembly Radial Powers.

Table 4-1

Difference Means and Standard Deviations for Assembly Radial Powers
(C, M $\geq$ 1.0)

Unit/Cycle	EPRI-NODE-P Model	N	$\overline{D}$	$S(\overline{D})$	$\overline{ABS(D)}$	S(ABS(D))
M1/C2	12 Level	144	-0.002	0.017	0.014	0.010
M1/C2	18 Level	144	-0.002	0.015	0.012	0.010

Difference Means and Standard Deviations for Assembly Peak Axial Powers
(C, M $\geq$ 1.0)

Unit/Cycle	EPRI-NODE-P Model	N	$\overline{D}$	$S(\overline{D})$	$\overline{ABS(D)}$	S(ABS(D))
M1/C2	12 Level	232	-0.004	0.031	0.025	0.018
M1/C2	18 Level	246	0.030	0.035	0.036	0.029

Percent Difference Means for Assembly Radial Powers
(C, M $\geq$ 1.0)

Unit/Cycle	EPRI-NODE-P Model	Mean % Difference	Mean Absolute % Difference
M1/C2	12 Level	-0.170	1.35
M1/C2	18 Level	-0.142	1.17

Percent Difference Means for Assembly Peak Axial Powers
(C, M $\geq$ 1.0)

Unit/Cycle	EPRI-NODE-P Model	Mean % Difference	Mean Absolute % Difference
M1/C2	12 Level	-0.407	2.039
M1/C2	18 Level	2.382	2.890

FIGURE 4.1

MCGUIRE-1 CYCLE-2 ASSEMBLY PEAK AXIAL POWERS - CALC (12 LEVEL) VS. MEAS

18 EFPD 100%FP CONTROL BANK D AT 207 STEPS WITHDRAWN

	H	G	F	E	D	C	B	A
	.95	1.08	1.24	.97	.93	.80	1.09	1.28
8	.93	1.06	1.27	.98	1.00	.85	1.19	1.27
	1.10	1.27	1.25	1.03	.98	.93	1.50	1.30
9	1.09	1.27	1.25	1.03	1.02	.95	1.53	1.28
	1.24	1.25	1.25	1.28	1.00	.96	1.13	1.19
10	1.28	1.27	1.27	1.32	1.03	1.00	1.19	1.16
	.98	1.04	1.28	1.25	1.27	1.14	1.52	.92
11	1.00	1.04	1.32	1.28	1.29	1.15	1.48	.91
	.94	.99	1.01	1.27	1.43	1.43	1.29	
12	1.02	1.04	1.02	1.30	1.40	1.41	1.26	
	.81	.93	.97	1.14	1.43	.99	.79	
13	.88	.98	1.05	1.17	1.44	.98	.77	
	1.10	1.51	1.14	1.52	1.30	.80		
14	1.12	1.46	1.14	1.44	1.26	.79		
	1.28	1.31	1.19	.93	CALC			
15	1.27	1.26	1.15	.90	MEAS			

FIGURE 4.2

MCGUIRE-1 CYCLE-2 ASSEMBLY PEAK AXIAL POWERS - CALC (12 LEVEL) VS. MEAS

30 EFPD 100%FP CONTROL BANK D AT 194 STEPS WITHDRAWN

	H	G	F	E	D	C	B	A	
	.90	1.04	1.21	.95	.92	.82	1.12	1.30	
8	.92	1.06	1.26	.98	1.02	.89	1.20	1.30	
	1.05	1.24	1.22	1.00	.98	.95	1.53	1.33	
9	1.08	1.26	1.25	1.03	1.04	1.00	1.53	1.29	
	1.22	1.23	1.24	1.30	1.01	.98	1.16	1.21	
10	1.27	1.26	1.26	1.32	1.04	1.04	1.21	1.19	
	.95	1.01	1.30	1.26	1.28	1.15	1.54	.94	
11	1.00	1.04	1.33	1.29	1.31	1.17	1.52	.94	
	.92	.98	1.02	1.28	1.43	1.43	1.31		
12	1.03	1.05	1.04	1.31	1.42	1.44	1.29		
	.83	.96	.98	1.16	1.44	1.00	.80		
13	.90	1.01	1.08	1.19	1.46	1.01	.79		
	1.12	1.54	1.16	1.55	1.31	.81			
14	1.15	1.50	1.16	1.45	1.28	.81			
	1.31	1.33	1.21	.94	CALC				
15	1.30	1.30	1.16	.90	MEAS				

FIGURE 4.3

MCGUIRE-1 CYCLE-2 ASSEMBLY PEAK AXIAL POWERS - CALC (12 LEVEL) VS. MEAS

48 EFPD 100%FP CONTROL BANK D AT 228 STEPS WITHDRAWN

	H	G	F	E	D	C	B	A
	.94	1.08	1.22	.98	.95	.81	1.07	1.24
8	.92	1.04	1.23	.97	1.00	.86	1.16	1.25
	1.10	1.25	1.23	1.04	1.00	.92	1.46	1.27
9	1.07	1.24	1.22	1.01	1.01	.97	1.48	1.24
	1.23	1.24	1.24	1.26	1.01	.94	1.11	1.15
10	1.25	1.23	1.22	1.27	1.00	1.01	1.17	1.14
	.99	1.04	1.26	1.22	1.22	1.10	1.47	.90
11	.99	1.03	1.26	1.22	1.25	1.12	1.45	.90
	.96	1.01	1.01	1.22	1.35	1.36	1.24	
12	1.00	1.02	1.00	1.25	1.34	1.37	1.23	
	.82	.92	.94	1.10	1.36	.95	.77	
13	.87	.97	1.04	1.14	1.39	.96	.76	
	1.08	1.47	1.11	1.47	1.24	.78		
14	1.11	1.45	1.12	1.39	1.23	.78		
	1.24	1.27	1.16	.90	CALC			
15	1.26	1.25	1.12	.87	MEAS			

FIGURE 4.4

MCGUIRE-1 CYCLE-2 ASSEMBLY PEAK AXIAL POWERS - CALC (12 LEVEL) VS. MEAS

61 EFPD 100%FP CONTROL BANK D AT 220 STEPS WITHDRAWN

	H	G	F	E	D	C	B	A
	.92	1.05	1.19	.97	.94	.81	1.08	1.25
8	.91	1.03	1.23	.96	1.00	.86	1.15	1.24
	1.07	1.22	1.20	1.02	.99	.93	1.47	1.27
9	1.06	1.23	1.21	1.00	1.00	.96	1.47	1.24
	1.20	1.21	1.21	1.24	1.00	.95	1.12	1.16
10	1.24	1.22	1.21	1.26	1.00	1.01	1.17	1.14
	.97	1.02	1.24	1.20	1.22	1.11	1.47	.91
11	.99	1.03	1.26	1.22	1.24	1.12	1.45	.90
	.95	1.00	1.00	1.22	1.35	1.36	1.24	
12	1.01	1.02	1.00	1.24	1.33	1.35	1.22	
	.82	.93	.95	1.11	1.36	.95	.77	
13	.88	.98	1.04	1.14	1.38	.96	.75	
	1.09	1.48	1.12	1.48	1.24	.78		
14	1.10	1.44	1.12	1.38	1.22	.77		
	1.25	1.27	1.16	.91	CALC			
15	1.24	1.23	1.11	.87	MEAS			

FIGURE 4.5

MCGUIRE-1 CYCLE-2 ASSEMBLY PEAK AXIAL POWERS - CALC (12 LEVEL) VS. MEAS

101 EFPD 100%FP CONTROL BANK D AT 223 STEPS WITHDRAWN

	H	G	F	E	D	C	B	A
	.91	1.03	1.16	.96	.95	.83	1.08	1.22
8	.90	1.03	1.23	.97	1.01	.88	1.14	1.21
	1.04	1.19	1.17	1.00	.99	.94	1.46	1.25
9	1.04	1.21	1.19	1.00	1.01	.97	1.45	1.21
	1.17	1.17	1.17	1.23	.99	.96	1.11	1.14
10	1.22	1.20	1.19	1.25	1.00	1.01	1.15	1.13
	.96	1.01	1.23	1.19	1.20	1.09	1.45	.90
11	.99	1.02	1.25	1.21	1.23	1.10	1.41	.90
	.95	1.00	.99	1.20	1.31	1.32	1.21	
12	1.01	1.02	1.00	1.23	1.30	1.32	1.20	
	.84	.94	.96	1.09	1.32	.94	.77	
13	.89	.98	1.03	1.12	1.34	.95	.76	
	1.09	1.46	1.11	1.45	1.21	.77		
14	1.10	1.43	1.11	1.37	1.20	.77		
	1.22	1.25	1.14	.90	CALC			
15	1.21	1.20	1.10	.87	MEAS			

FIGURE 4.6

MCGUIRE-1 CYCLE-2 ASSEMBLY PEAK AXIAL POWERS - CALC (12 LEVEL) VS. MEAS

130 EFPD 100%FP CONTROL BANK D AT 216 STEPS WITHDRAWN

		H	G	F	E	D	C	B	A
8	CALC	.90	1.02	1.18	.95	.95	.85	1.09	1.21
	MEAS	.93	1.04	1.23	.98	1.01	.89	1.14	1.20
9	CALC	1.04	1.20	1.18	1.00	.99	.96	1.46	1.24
	MEAS	1.07	1.23	1.20	1.01	1.02	.98	1.45	1.20
10	CALC	1.18	1.18	1.18	1.24	1.00	.97	1.12	1.14
	MEAS	1.23	1.22	1.20	1.26	1.01	1.02	1.14	1.11
11	CALC	.95	1.00	1.24	1.19	1.20	1.10	1.44	.90
	MEAS	.99	1.03	1.26	1.22	1.24	1.11	1.41	.90
12	CALC	.95	1.00	1.00	1.20	1.30	1.31	1.20	
	MEAS	1.03	1.04	1.02	1.24	1.31	1.32	1.19	
13	CALC	.85	.96	.97	1.10	1.31	.95	.77	
	MEAS	.90	1.00	1.05	1.13	1.34	.95	.76	
14	CALC	1.09	1.46	1.12	1.44	1.20	.78		
	MEAS	1.10	1.43	1.11	1.37	1.19	.77		
15	CALC	1.21	1.24	1.14	.90				
	MEAS	1.19	1.20	1.10	.87				

FIGURE 4.7

MCGUIRE-1 CYCLE-2 ASSEMBLY PEAK AXIAL POWERS - CALC (18 LEVEL) VS. MEAS

18 EFPD 100%FP CONTROL BANK D AT 207 STEPS WITHDRAWN

		H	G	F	E	D	C	B	A
8	CALC	.96	1.11	1.27	1.00	.96	.82	1.13	1.32
	MEAS	.93	1.06	1.27	.98	1.00	.85	1.19	1.27
9	CALC	1.13	1.30	1.28	1.06	1.01	.95	1.55	1.35
	MEAS	1.09	1.27	1.25	1.03	1.02	.95	1.53	1.28
10	CALC	1.27	1.28	1.29	1.32	1.03	.99	1.17	1.23
	MEAS	1.28	1.27	1.27	1.32	1.03	1.00	1.19	1.16
11	CALC	1.00	1.06	1.32	1.29	1.31	1.17	1.57	.95
	MEAS	1.00	1.04	1.32	1.28	1.29	1.15	1.48	.91
12	CALC	.97	1.02	1.03	1.31	1.47	1.47	1.33	
	MEAS	1.02	1.04	1.02	1.30	1.40	1.41	1.26	
13	CALC	.83	.96	.99	1.17	1.47	1.01	.82	
	MEAS	.88	.98	1.05	1.17	1.44	.98	.77	
14	CALC	1.13	1.56	1.17	1.57	1.34	.82		
	MEAS	1.12	1.46	1.14	1.44	1.26	.79		
15	CALC	1.33	1.35	1.23	.96				
	MEAS	1.27	1.26	1.15	.90				

MCGUIRE-1 CYCLE-2 ASSEMBLY PEAK AXIAL POWERS - CALC (18 LEVEL) VS. MEAS

30 EFPD 100%FP CONTROL BANK D AT 194 STEPS WITHDRAWN

Row		H	G	F	E	D	C	B	A
8	CALC	.92	1.06	1.24	.97	.94	.84	1.15	1.34
	MEAS	.92	1.06	1.26	.98	1.02	.89	1.20	1.30
9	CALC	1.08	1.27	1.26	1.03	1.01	.98	1.58	1.37
	MEAS	1.08	1.26	1.25	1.03	1.04	1.00	1.53	1.29
10	CALC	1.25	1.26	1.27	1.34	1.04	1.01	1.19	1.25
	MEAS	1.27	1.26	1.26	1.32	1.04	1.04	1.21	1.19
11	CALC	.98	1.04	1.34	1.30	1.32	1.19	1.59	.97
	MEAS	1.00	1.04	1.33	1.29	1.31	1.17	1.52	.94
12	CALC	.95	1.01	1.04	1.32	1.47	1.48	1.35	
	MEAS	1.03	1.05	1.04	1.31	1.42	1.44	1.29	
13	CALC	.85	.98	1.01	1.19	1.48	1.03	.83	
	MEAS	.90	1.01	1.08	1.19	1.46	1.01	.79	
14	CALC	1.16	1.59	1.20	1.59	1.35	.84		
	MEAS	1.15	1.50	1.16	1.45	1.28	.81		
15	CALC	1.35	1.38	1.25	.97				
	MEAS	1.30	1.30	1.16	.90				

FIGURE 4.9

MCGUIRE-1 CYCLE-2 ASSEMBLY PEAK AXIAL POWERS - CALC (18 LEVEL) VS. MEAS

48 EFPD 100%FP CONTROL BANK D AT 228 STEPS WITHDRAWN

		H	G	F	E	D	C	B	A
8	C	.96	1.10	1.25	1.00	.98	.84	1.11	1.28
	M	.92	1.04	1.23	.97	1.00	.86	1.16	1.25
9	C	1.12	1.28	1.26	1.06	1.03	.95	1.51	1.31
	M	1.07	1.24	1.22	1.01	1.01	.97	1.48	1.24
10	C	1.26	1.27	1.27	1.30	1.04	.97	1.14	1.19
	M	1.25	1.23	1.22	1.27	1.00	1.01	1.17	1.14
11	C	1.01	1.07	1.30	1.26	1.26	1.14	1.52	.93
	M	.99	1.03	1.26	1.22	1.25	1.12	1.45	.90
12	C	.98	1.03	1.04	1.26	1.39	1.40	1.28	
	M	1.00	1.02	1.00	1.25	1.34	1.37	1.23	
13	C	.84	.95	.97	1.14	1.40	.98	.79	
	M	.87	.97	1.04	1.14	1.39	.96	.76	
14	C	1.11	1.52	1.15	1.52	1.28	.80		
	M	1.11	1.45	1.12	1.39	1.23	.78		
15	C	1.29	1.31	1.20	.93	CALC			
	M	1.26	1.25	1.12	.87	MEAS			

FIGURE 4.10

MCGUIRE-1 CYCLE-2 ASSEMBLY PEAK AXIAL POWERS - CALC (18 LEVEL) VS. MEAS

61 EFPD 100%FP CONTROL BANK D AT 220 STEPS WITHDRAWN

	H	G	F	E	D	C	B	A
	.95	1.08	1.23	.99	.97	.84	1.12	1.29
8	.91	1.03	1.23	.96	1.00	.86	1.15	1.24
	1.10	1.25	1.24	1.05	1.02	.96	1.52	1.31
9	1.06	1.23	1.21	1.00	1.00	.96	1.47	1.24
	1.23	1.24	1.25	1.28	1.03	.98	1.15	1.20
10	1.24	1.22	1.21	1.26	1.00	1.01	1.17	1.14
	1.00	1.05	1.28	1.24	1.26	1.14	1.52	.93
11	.99	1.03	1.26	1.22	1.24	1.12	1.45	.90
	.98	1.02	1.03	1.26	1.39	1.40	1.28	
12	1.01	1.02	1.00	1.24	1.33	1.35	1.22	
	.85	.96	.98	1.14	1.40	.98	.80	
13	.88	.98	1.04	1.14	1.38	.96	.75	
	1.12	1.53	1.16	1.52	1.28	.80		
14	1.10	1.44	1.12	1.38	1.22	.77		
	1.29	1.31	1.20	.94	CALC			
15	1.24	1.23	1.11	.87	MEAS			

FIGURE 4.11

MCGUIRE-1 CYCLE-2 ASSEMBLY PEAK AXIAL POWERS - CALC (18 LEVEL) VS. MEAS

101 EFPD 100%FP CONTROL BANK D AT 223 STEPS WITHDRAWN

		H	G	F	E	D	C	B	A
8	CALC	.93	1.05	1.20	.98	.97	.85	1.12	1.26
	MEAS	.90	1.03	1.23	.97	1.01	.88	1.14	1.21
9	CALC	1.07	1.23	1.21	1.03	1.02	.97	1.51	1.29
	MEAS	1.04	1.21	1.19	1.00	1.01	.97	1.45	1.21
10	CALC	1.21	1.21	1.21	1.27	1.02	.99	1.15	1.18
	MEAS	1.22	1.20	1.19	1.25	1.00	1.01	1.15	1.13
11	CALC	.98	1.03	1.27	1.23	1.24	1.13	1.49	.93
	MEAS	.99	1.02	1.25	1.21	1.23	1.10	1.41	.90
12	CALC	.98	1.02	1.02	1.24	1.35	1.36	1.25	
	MEAS	1.01	1.02	1.00	1.23	1.30	1.32	1.20	
13	CALC	.86	.98	.99	1.13	1.36	.97	.79	
	MEAS	.89	.98	1.03	1.12	1.34	.95	.76	
14	CALC	1.12	1.51	1.15	1.49	1.25	.80		
	MEAS	1.10	1.43	1.11	1.37	1.20	.77		
15	CALC	1.26	1.29	1.18	.93				
	MEAS	1.21	1.20	1.10	.87				

FIGURE 4.12

MCGUIRE-1 CYCLE-2 ASSEMBLY PEAK AXIAL POWERS - CALC (18 LEVEL) VS. MEAS

130 EFPD 100%FP CONTROL BANK D AT 216 STEPS WITHDRAWN

		H	G	F	E	D	C	B	A
8	CALC	.93	1.05	1.21	.98	.97	.88	1.13	1.25
	MEAS	.93	1.04	1.23	.98	1.01	.89	1.14	1.20
9	CALC	1.07	1.24	1.22	1.03	1.02	.99	1.50	1.27
	MEAS	1.07	1.23	1.20	1.01	1.02	.98	1.45	1.20
10	CALC	1.22	1.22	1.22	1.27	1.03	1.00	1.15	1.17
	MEAS	1.23	1.22	1.20	1.26	1.01	1.02	1.14	1.11
11	CALC	.98	1.03	1.27	1.23	1.24	1.13	1.48	.93
	MEAS	.99	1.03	1.26	1.22	1.24	1.11	1.41	.90
12	CALC	.98	1.03	1.03	1.24	1.34	1.35	1.24	
	MEAS	1.03	1.04	1.02	1.24	1.31	1.32	1.19	
13	CALC	.88	.99	1.00	1.13	1.35	.98	.80	
	MEAS	.90	1.00	1.05	1.13	1.34	.95	.76	
14	CALC	1.13	1.50	1.15	1.48	1.24	.80		
	MEAS	1.10	1.43	1.11	1.37	1.19	.77		
15	CALC	1.25	1.27	1.17	.93				
	MEAS	1.19	1.20	1.10	.87				

Q.5 Duke Power Company's contention that no uncertainty in calculated pin powers needs to be accounted for has not been adequately established. One of a set of standard problems, recently developed at Brookhaven National Laboratory for a licensee to assess its ability to calculate typical PWR fuel assemblies, is attached. The licensee's solution using PDQ07 will be an important means of determining the uncertainty in the calculated pin peaking factors.

A.5 Both NFS-1001A and Section 8 of DPC-NF-2010 presented justification the the PDQØ7 model using two group MND cross sections overpredicts the maximum rod powers when compared to both measured criticals and more advanced transport theory calculations. These comparisons covered different assembly designs, different enrichments, different burnable absorbers, different fuel and moderator temperatures, and different soluble boron concentrations.

Duke Power as prime contractor to DOE has recently performed additional cold criticals at B&W. Results from two of the criticals, compared to EPRI-CELL/PDQØ7 calculations are attached (Report DOE/ET/34212-41, April, 1984). Core 1 represents a no burnable absorber B&W fuel assembly and Core 5 a gadolinium poisoned B&W fuel assembly.

Figure A-3 (Figure 5.1, Answer 5) and A-4 (Figure 5.2) show comparisons of measured to calculated powers for these cores. The maximum rod powers were overpredicted by EPRI-CELL/PDQØ7 by 1.2% and 1.4% respectively. An analysis of the eitht highest measured pins for each critical assembly shows that the average pin power difference was + 0.0061 (Core 1) and + 0.0104 (Core 5) with PDQØ7 overpredicting relative to measured.

Page A-4 of DOE/ET/34212-41 attributes the overprediction of pin powers near the water holes to use of MND thermal cross sections.

Duke Power has performed the requested calculations on the BNL benchmark assembly problem using EPRI-CELL/PDQØ7. The results of those calculations are attached. Figures 5.3 through 5.16 present PDQØ7 calculated rod powers for the non-rodded and 16 BP cases. Table 5.1 presents rod power summary data for these analyses. Table 5.2 presents summary reactivity information as requested in section II of the benchmark problem. In accordance with the Duke-NRC telephone agreement, data for items I.2 through I.5 of the problem will not be presented.

From the information presented in NFS-1001A, DPC-NF-2010, DOE/ET/34212-41, and the benchmark assembly calculations, sufficient analyses have been performed to show that no additional pin peak uncertainty is necessary.

Table 5.1

Benchmark Problem

EPRI-CELL/PDQØ7 Analysis

Maximum Rod Power Summary

Exposure (MWD/MT)	Non-BP Assembly	16-BP Assembly
0	1.060	1.107
500	1.059	1.104
5000	1.054	1.073
10000	1.046	1.041
20000	1.028	1.021
30000	1.014	1.016
40000	1.008	1.010

Table 5.2

Benchmark Problem

Reactivity Defect Calculations

No BP's

Case	Description	0 MWD/MTU K-Infinity	0 MWD/MTU % Δρ	30000 MWD/MTU K-Infinity	30000 MWD/MTU % Δρ
0	Base	1.183699	--	0.896243	-
1	Doppler	1.194852	-0.789	0.907013	-1.325
2	MTC	1.186067	-0.169	0.897301	-0.132
3	68°F	1.211947	-1.969	0.898143	-0.236
4	300°F	1.204695	-1.472	0.904724	-1.046
5	SOLB	1.241994	-3.965	0.937659	-4.928
6	Xe	1.223867	-2.773	0.921068	-3.007
7	Rods	0.789700	42.149	0.605476	53.583

16 BP's

Case	Description	0 MWD/MTU K-Infinity	0 MWD/MTU % Δρ	30000 MWD/MTU K-Infinity	30000 MWD/MTU % Δρ
0	Base	1.020581	--	0.901031	--
1	Doppler	1.030387	-0.932	0.912429	-1.386
2	MTC	1.025619	-0.481	0.903525	-0.306
3	68°F	1.069628	-4.493	0.912266	-1.367
4	300°F	1.053687	-3.079	0.916026	-1.817
5	SOLB	1.060567	-3.694	0.938213	-4.398
6	Xe	1.049333	-2.685	0.926059	-3.000

Table 5.2
(Continued)

Additional Xenon Defect Data

No BP's

	0 MWD/MTU	30,000 MWD/MTU
Xenon Defect (% $\Delta\rho$)	-2.773	-3.007
Xenon Concentration (Atoms/cm^3)[1]	2.1337×10^{15}	1.8623×10^{15}
Xenon Defect (% $\Delta\rho$/atoms/cm^3)[2]	-1.300×10^{-15}	-1.615×10^{-15}

16 BP's

	0 MWD/MTU	30,000 MWD/MTU
Xenon Defect (%	-2.685	-3.000
Xenon Concentration (atoms/cm^3)[1]	2.1334×10^{15}	2.0056×10^{15}
Xenon Defect (% /atoms/cm^3)[2]	-1.259×10^{-15}	1.496×10^{-15}

1. Value averaged over <u>entire</u> assembly volume.
   Fuel to Assembly volume ratio = .90459.

2. Defect per unit volume evaluated over entire assembly.

Table 5.3

1. Name of Codes - PDQØ7; EPRI-CELL[1]
   Code Sources EPRI; EPRI[1]
   Version 2; RAM112[1]

2. Reference for Calculational Method - DPC-NF-2010

3. Assembly Solution Method - Two Group Diffusion Theory

4. Pin-Cell Solution Method - Transport Theory [1]

5. Spatial Mesh Assy/Pin-Cell

   Assembly - One mesh interval per pin

   Pin-Cell[1] - Four Mesh intervals in fuel pin
   One mesh interval in clad
   Five mesh intervals in moderator
   Two mesh intervals in extra region

6. Neutron Cross Section Library - ENDF/B4[1]

7. Number of Fast/Thermal Groups

	No. Fast Groups	No. Thermal Groups
Assembly	1	1
Pin Cell[1]	62	35

8. Depletion Steps -

   Assembly (hrs) - 0, 150, 500, 1000, 2000, 3000, 4000, 5000, 6000, 8000, 10000, 12000, 14000, 16000, 18000, 20000, 22000, 24000, 26000, 28000, 30000, 32000, 34000, 36000, 38000, 40000

   Pin/Cell(MWD/MTU)[1] 0, 0.001, 100, 500, 1000, 2000, 4000, 6000, 8000, 10000, 12000, 14000, 16000, 18000, 20000, 22000, 24000, 26000, 28000, 30000, 32000, 34000, 36000, 38000, 40000

1 _ All cross-section sets for benchmark problem except CRA and BP were calculated with EPRI-CELL.

Table 5.3 (Continued)

1. Name of Codes - CASMO2E[2]
   Code Sources STUDSVIK
   Version 5

2. Reference for Calculational Method - DPC-NF-2010

3. Assembly Solution Method - Two Group Diffusion Theory

4. Pin-Cell Solution Method - Transport Theory[2]

5. Spatial Mesh Assy/Pin-Cell

   Assembly - One mesh interval per pin[1]

   Pin-Cell - One mesh interval per pin[2]

6. Neutron Cross Section Library - ENDF/B3[2]

7. Number of Fast/Thermal Groups

	No. Fast Groups	No. Thermal Groups
Assembly	4	3
Pin-Cell	9	16

8. Depletion Steps

   Assembly - See Table 5.3 page 1

   Pin-Cell (MWD/MTU)[2] - 0, 150, 500, 1000, 2000, 3000, 5000, 7500, 10000, 12500, 15000, 20000, 25000, 30000, 35000, 40000

[2] - Refers to Burnable Poison and Control Rod Data

Figure A-3. Comparisons of Measured and Predicted Normalized Relative Power Densities for Core 1

INCORE DETECTOR	1.018 1.038 .020	1.011 .997 -.014	.987 .979 -.008	.981 .975 -.006	.997 .978 -.019	.966 .958 -.008	.945 .936 -.009
	1.019 1.035 .016	1.067 1.069 .002	1.012 1.015 .003	1.009 1.012 .003	1.058 1.054 -.004	.999 .988 -.011	.945 .941 -.004
		WATER	1.081 1.087 .006	1.090 1.089 -.001	WATER	1.032 1.045 .013	.953 .947 -.006
			1.054 1.070 .016	1.104* 1.117* .013	1.086 1.100 .014	.989 .994 .005	.945 .939 -.006
				WATER	1.059 1.062 .003	.965 .957 -.008	.934 .928 -.006
					.988 .986 -.002	.938 .937 -.001	.923 .919 -.004
					Measured RPD Calculated RPD ΔRPD	.925 .921 -.004	.914 .911 -.003
							.903 .903 .000

RMS(ΔRPD) = 0.008

Max (ABS(ΔRPD)) = 0.020

*Maximum power fuel rod predicted or measured.

FIGURE 5.1

Figure A-4. Comparisons of Measured and Predicted Normalized Relative Power Densities for Core 5

INCORE DETECTOR	1.005 1.026 .021	.913 .886 -.027	.170 .196 .026	.932 .903 -.029	1.036 1.045 .009	1.063 1.077 .014	1.072 1.090 .018
	.999 1.021 .022	1.017 1.012 -.005	.931 .901 -.030	1.007 .997 -.010	1.125 1.135 .010	1.094 1.112 .018	1.089 1.096 .007
		WATER	.988 .962 -.026	1.087 1.073 -.014	WATER	1.158* 1.174* .016	1.100 1.102 .002
			.181 .203 .022	1.050 1.035 -.015	1.131 1.158 .027	1.088 1.105 .017	1.086 1.090 .004
				WATER	1.048 1.018 -.030	1.035 1.018 -.017	1.070 1.070 .000
					.187 .211 .024	.963 .939 -.024	1.054 1.058 .004
				Measured RPD Calculated RPD ΔRPD		1.018 1.009 -.009	1.060 1.069 .009
							1.070 1.083 .013

UO_2-Gd_2O_3

RMS(ΔRPD) = 0.018

Max (ABS(ΔRPD)) = 0.030

*Maximum power fuel rod predicted or measured.

FIGURE 5.2

PDQØ7 CALCULATED
ROD POWERS

	PDQ-7
PPMB	400
NUMBER BA	0
K-INFINITY	1.18377
BURNUP	0
*MAX. ROD POWER	1.060

0.								
1.035	1.013							
1.038	1.013	1.015						
0.	1.029	1.032	0.					
1.037	1.014	1.018	1.044	1.051				
1.035	1.011	1.015	1.043	1.060 *	0.	PDQØ7		
0.	1.019	1.023	0.	1.042	1.014	0.975		
1.012	0.991	0.993	1.006	0.989	0.961	0.942	0.932	
0.975	0.971	0.970	0.972	0.964	0.951	0.942	0.939	0.949

FIGURE 5.3

PDQØ7 CALCULATED
ROD POWERS

	PDQ-7
PPMB	400
NUMBER BA	0
K-INFINITY	1.17560
BURNUP	500
*MAX. ROD POWER	1.059

PDQØ7

0.								
1.035	1.013							
1.037	1.013	1.014						
0.	1.028	1.032	0.					
1.037	1.013	1.017	1.043	1.051				
1.034	1.011	1.015	1.043	1.059 *	0.			
0.	1.018	1.022	0.	1.041	1.014	.975		
1.012	.992	.993	1.006	.989	.962	.943	.933	
.976	.971	.971	.972	.964	.952	.942	.940	.950

FIGURE 5.4

PDQØ7 CALCULATED
ROD POWERS

	PDQ-7
PPMB	400
NUMBER BA	0
K-INFINITY	1.12604
BURNUP	5000
*MAX. ROD POWER	1.054

0.								
1.032	1.012							
1.034	1.012	1.014						
0.	1.026	1.029	0.					
1.034	1.013	1.016	1.040	1.047				
1.031	1.010	1.014	1.039	1.054 *	0.	PDQØ7		
0.	1.017	1.021	0.	1.038	1.013	.977		
1.011	.992	.993	1.006	.990	.965	.947	.938	
.978	.974	.973	.974	.967	.955	.947	.944	.954

FIGURE 5.5

PDQØ7 CALCULATED
ROD POWERS

	PDQ-7
PPMB	400
NUMBER BA	0
K-INFINITY	1.06962
BURNUP	10,000
*MAX. ROD POWER	1.046

0.								
1.028	1.012							
1.030	1.012	1.013						
0.	1.023	1.026	0.					
1.029	1.012	1.015	1.034	1.040				
1.027	1.010	1.013	1.034	1.046 *	0.	PDQØ7		
0.	1.015	1.018	0.	1.032	1.010	.980		
1.009	.994	.995	1.005	.991	.969	.954	.945	
.981	.978	.977	.978	.971	.961	.953	.950	.958

FIGURE 5.6

PDQØ7 CALCULATED
ROD POWERS

	PDQ-7
PPMB	400
NUMBER BA	0
K-INFINITY	0.97482
BURNUP	20,000
*MAX. ROD POWER	1.028

0.								
1.019	1.010							
1.019	1.010	1.011						
0.	1.016	1.018	0.					
1.019	1.010	1.012	1.023	1.026				
1.017	1.008	1.010	1.022	1.028 *	0.	PDQØ7		
0.	1.010	1.012	0.	1.019	1.006	.986		
1.005	.997	.997	1.002	.994	.980	.969	.962	
.988	.986	.986	.986	.981	.973	.967	.965	.969

FIGURE 5.7

PDQØ7 CALCULATED
ROD POWERS

	PDQ-7
PPMB	400
NUMBER BA	0
K-INFINITY	0.89624
BURNUP	30,000
*MAX. ROD POWER	1.014

0.								
1.010	1.007							
1.011	1.007	1.007						
0.	1.009	1.010	0.					
1.011	1.007	1.008	1.013	1.014				
1.010	1.006	1.007	1.012	1.014 *	0.	PDQØ7		
0.	1.005	1.006	0.	1.009	1.002	.992		
1.002	.999	.999	1.001	.997	.989	.982	.978	
.994	.993	.993	992	.989	.985	.981	.979	.981

FIGURE 5.8

PDQØ7 CALCULATED
ROD POWERS

	PDQ-7
PPMB	400
NUMBER BA	0
K-INFINITY	0.83305
BURNUP	40.000
*MAX. ROD POWER	1.008

0.								
1.005	1.003							
1.005	1.003	1.004						
0.	1.005	1.005	0.					
1.005	1.004	1.004	1.007	1.008 *				
1.005	1.003	1.004	1.006	1.008 *	0.	PDQ-7		
0.	1.003	1.003	0.	1.005	1.001	.996		
1.001	.999	.999	1.000	.998	.994	.991	.988	
.997	.996	.996	.996	.995	.992	.990	.988	.989

FIGURE 5.9

PDQØ7 CALCULATED
ROD POWERS

	PDQ-7
PPMB	400
NUMBER BA	16
K-INFINITY	1.02062
BURNUP	0
*MAX. ROD POWER	1.107

0.								
1.054	1.027							
0.954	0.986	1.029						
0.	0.964	1.046	0.					
0.957	0.986	1.021	1.022	0.959				
1.064	1.030	0.975	0.925	0.883	0.			
0.	1.060	0.957	0.	0.882	0.906	0.954		
1.107 *	1.062	0.989	0.942	0.950	0.980	1.008	1.038	
1.083	1.066	1.035	1.013	1.013	1.027	1.046	1.067	1.092

PDQØ7

FIGURE 5.10

PDQØ7 CALCULATED
ROD POWERS

	PDQ-7
PPMB	400
NUMBER BA	16
K-INFINITY	1.01969
BURNUP	500
*MAX. ROD POWER	1.104

0.								
1.053	1.027							
0.957	0.987	1.028						
0.	0.966	1.046	0.					
0.959	0.987	1.021	1.023	0.962				
1.063	1.030	0.976	0.929	0.888	0.	PDQØ7		
0.	1.059	0.959	0.	0.887	0.910	0.955		
1.104 *	1.059	0.989	0.944	0.952	0.980	1.006	1.034	
1.080	1.063	1.033	1.012	1.012	1.025	1.042	1.062	1.087

FIGURE 5.11

PDQØ7 CALCULATED
ROD POWERS

	PDQ-7
PPMB	400
NUMBER BA	16
K-INFINITY	1.02749
BURNUP	5,000
*MAX. ROD POWER	1.073

0.								
1.046	1.023							
0.983	0.997	1.024						
0.	0.987	1.040	0.					
0.984	0.996	1.019	1.027	0.987				
1.052	1.024	0.989	0.963	0.938	0.	PDQØ7		
0.	1.045	0.979	0.	0.933	0.941	0.961		
1.073 *	1.038	0.991	0.964	0.964	0.975	0.988	1.005	
1.047	1.035	1.014	1.000	0.998	1.003	1.012	1.025	1.044

FIGURE 5.12

PDQØ7 CALCULATED
ROD POWERS

	PDQ-7
PPMB	400
NUMBER BA	16
K-INFINITY	1.02278
BURNUP	10,000
*MAX. ROD POWER	1.041

0.								
1.036	1.018							
1.007	1.005	1.018						
0.	1.006	1.031	0.					
1.007	1.004	1.016	1.027	1.008				
1.038	1.016	1.000	0.995	0.986	0.	PDQØ7		
0.	1.029	0.998	0.	0.978	0.972	0.970		
1.041 *	1.017	0.994	0.984	0.977	0.973	0.974	0.979	
1.017	1.009	0.998	0.990	0.986	0.984	0.986	0.992	1.006

FIGURE 5.13

PDQØ7 CALCULATED
ROD POWERS

	PDQ-7
PPMB	400
NUMBER BA	16
K-INFINITY	0.97150
BURNUP	20,000
***MAX. ROD POWER**	1.021

0.								
1.020	1.010							
1.018	1.009	1.010						
0.	1.015	0.017	**0.**					
1.018	1.008	1.010	1.020	1.020				
1.019	1.008	1.007	1.017	1.021 *	**0.**	PDQØ7		
0.	1.012	1.010	**0.**	1.012	1.000	0.984		
1.010	1.000	0.997	1.000	0.991	0.978	0.971	0.968	
0.994	0.991	0.988	0.987	0.982	0.976	0.973	0.973	0.979

FIGURE 5.14

PDQØ7 CALCULATED
ROD POWERS

	PDQ-7
PPMB	400
NUMBER BA	16
K-INFINITY	0.90103
BURNUP	30,000
*MAX. ROD POWER	1.016

0.								
1.011	1.006							
1.013	1.007	1.006						
0.	1.011	1.010	0.					
1.012	1.007	1.007	1.012	1.014				
1.010	1.005	1.006	1.013	1.016 *	0.	PDQØ7		
0.	1.005	1.007	0.	1.010	1.002	0.991		
1.003	1.000	1.000	1.001	1.000	0.987	0.981	0.978	
0.995	0.993	0.992	0.991	0.988	0.984	0.981	0.980	0.983

FIGURE 5.15

PDQØ7 CALCULATED
ROD POWERS

	PDQ-7
PPMB	400
NUMBER BA	16
K-INFINITY	0.84163
BURNUP	40,000
*MAX. ROD POWER	1.010

0.								
1.005	1.003							
1.007	1.004	1.004						
0.	1.006	1.005	0.					
1.007	1.004	1.004	1.007	1.008				
1.005	1.003	1.004	1.008	1.010 *	0.	PDQØ7		
0.	1.003	1.004	0.	1.007	1.002	0.995		
1.001	0.999	0.999	1.001	0.998	0.993	0.989	0.987	
0.996	0.996	0.995	0.995	0.993	0.990	0.988	0.988	0.989

FIGURE 5.16

Q.6 Please provide the updates to DPC-NF-2010, if any, that will make it consistent with the methodologies being used by Duke Power.

A.6 The following sections address updates to the methods described in DPC-NF-2010.

1. EPRI-NODE-P Normalization:

In addition to adjusting radial albedoes, small M^2 adjustments are made for various fuel types (usually only fresh fuel) to attain better agreement with PDQØ7 radial power calculations. Fugures 6.1 and 6.2 show the improvement for assembly radial powers with respect to measurement. Figures 6.3 and 6.4 address assembly peak power improvements. The data in figures 6.1 through 6.4 represent McGuire Unit 1 Cycle 2.

2. Axial Nodal Modeling:

Section 11 of DPC-NF-2010 presents a benchmark analysis which employed twelve axial nodes per assembly. Core-specific axial modeling would conform to the physics requirements of the core. Answer 4 addressed the calculated-to-measured improvement shown by employing eighteen axial nodes per assembly. Should future fuel assemblies become non-uniform, i.e., axial blankets or part length burnable absorbers, the Duke Power version of EPRI-NODE-P can adequately model the core.

Since the upgrades described in parts 1 and 2 have significantly improved calculated-to-measured agreement, the ONRF values for F_Q and $F_{\Delta H}^N$ in DPC-NF-2010 are considered conservative. Therefore, even though the upgraded methods have demonstrated improved agreement, Duke Power will still employ previously derived ONRFs.

3. EPRI-NODE-P Enhancements:

EPRI-NODE-P has received several major enhancements which are discussed below. This enhanced version was used throughout the analyses shown in DPC-NF-2010. These enhancements are:

a. Partial reactivity formulations due to xenon, moderator temperature, and doppler temperature have been revised to include third order burnup dependent multipliers.

b. Fuel assemblies can be axially modeled as containing up to three different fuel types.

c. Rodded M^2 is linearly adjusted according to the fraction of node length occupied by a control rod.

d. The full power volumetric average fuel temperature has been revised to a burnup dependent fourth order polynomial.

f. The nodal source convergence routine has been modified to use the Gauss-Seidel iterative method with the inclusion of an optional acceleration parameter.

g. Minor enhancements have also been made which allow more user-friendly input and output features.

Likewise, Duke Power's fitting code EPRI-SUPERLINK has been modified to provide compatibility with EPRI-NODE-P. All codes are rigorously tested and certified before production usage in conformance with Duke Power's Q/A procedures.

MCGUIRE-1 CYCLE-2 ASSEMBLY RADIAL POWERS - CALC (NO MSQUARE ADJ) VS. MEAS

48 EFPD 100%FP CONTROL BANK D AT 228 STEPS WITHDRAWN

	H	G	F	E	D	C	B	A	
	.84	.97	1.15	.88	.88	.73	.91	1.03	
8	.83	.94	1.11	.87	.90	.77	.98	1.06	
	.99	1.18	1.16	.93	.90	.83	1.25	1.04	
9	.97	1.12	1.10	.91	.91	.85	1.26	1.05	
	1.16	1.16	1.16	1.20	.92	.86	.93	.96	
10	1.13	1.11	1.11	1.16	.91	.89	.99	.97	
	.88	.94	1.20	1.16	1.15	.97	1.23	.76	
11	.89	.93	1.16	1.11	1.12	.98	1.23	.77	
	.89	.91	.92	1.15	1.23	1.16	1.05		
12	.91	.92	.91	1.13	1.19	1.19	1.06		
	.74	.84	.86	.97	1.16	.79	.65		
13	.79	.87	.91	.99	1.20	.83	.66		
	.91	1.25	.93	1.24	1.05	.65			
14	.98	1.26	.97	1.20	1.05	.67			
	1.03	1.05	.96	.76	CALC				
15	1.06	1.05	.95	.75	MEAS				

FIGURE 6.1

MCGUIRE-1 CYCLE-2 ASSEMBLY RADIAL POWERS - CALCULATED VS. MEASURED

48 EFPD 100%FP CONTROL BANK D AT 228 STEPS WITHDRAWN

		H	G	F	E	D	C	B	A
8	CALCULATED	.83	.96	1.10	.88	.86	.75	.95	1.03
	MEASURED	.83	.94	1.11	.87	.90	.77	.98	1.06
9	CALCULATED	.98	1.13	1.12	.93	.91	.85	1.24	1.04
	MEASURED	.97	1.12	1.10	.91	.91	.85	1.26	1.05
10	CALCULATED	1.11	1.12	1.13	1.16	.93	.88	.97	.96
	MEASURED	1.13	1.11	1.11	1.16	.91	.89	.99	.97
11	CALCULATED	.88	.94	1.16	1.13	1.13	1.00	1.23	.75
	MEASURED	.89	.93	1.16	1.11	1.12	.98	1.23	.77
12	CALCULATED	.86	.91	.93	1.13	1.22	1.19	1.04	
	MEASURED	.91	.92	.91	1.13	1.19	1.19	1.06	
13	CALCULATED	.76	.86	.88	1.00	1.19	.85	.66	
	MEASURED	.79	.87	.91	.99	1.20	.83	.66	
14	CALCULATED	.96	1.24	.98	1.23	1.05	.66		
	MEASURED	.98	1.26	.97	1.20	1.05	.67		
15	CALCULATED	1.03	1.05	.96	.75				
	MEASURED	1.06	1.05	.95	.75				

FIGURE 6.2

MCGUIRE-1 CYCLE-2 ASSEMBLY PEAK AXIAL POWERS - CALC (NO MSQUARE ADJ) VS. MEAS

48 EFPD 100%FP CONTROL BANK D AT 228 STEPS WITHDRAWN

	H	G	F	E	D	C	B	A
	.97	1.11	1.29	1.00	1.00	.81	1.06	1.30
8	.92	1.04	1.23	.97	1.00	.86	1.16	1.25
	1.13	1.32	1.30	1.06	1.02	.93	1.54	1.32
9	1.07	1.24	1.22	1.01	1.01	.97	1.48	1.24
	1.30	1.31	1.31	1.33	1.03	.95	1.09	1.20
10	1.25	1.23	1.22	1.27	1.00	1.01	1.17	1.14
	1.01	1.07	1.33	1.28	1.28	1.10	1.53	.94
11	.99	1.03	1.26	1.22	1.25	1.12	1.45	.90
	1.01	1.02	1.03	1.28	1.41	1.37	1.30	
12	1.00	1.02	1.00	1.25	1.34	1.37	1.23	
	.82	.93	.95	1.10	1.37	.92	.78	
13	.87	.97	1.04	1.14	1.39	.96	.76	
	1.06	1.55	1.10	1.54	1.30	.79		
14	1.11	1.45	1.12	1.39	1.23	.78		
	1.30	1.32	1.21	.95	CALCULATED			
15	1.26	1.25	1.12	.87	MEASURED			

FIGURE 6.3

MCGUIRE-1 CYCLE-2 ASSEMBLY PEAK AXIAL POWERS - CALC (18 LEVEL) VS. MEAS

48 EFPD 100%FP CONTROL BANK D AT 228 STEPS WITHDRAWN

		H	G	F	E	D	C	B	A
8	CALC	.96	1.10	1.25	1.00	.98	.84	1.11	1.28
	MEAS	.92	1.04	1.23	.97	1.00	.86	1.16	1.25
9	CALC	1.12	1.28	1.26	1.06	1.03	.95	1.51	1.31
	MEAS	1.07	1.24	1.22	1.01	1.01	.97	1.48	1.24
10	CALC	1.26	1.27	1.27	1.30	1.04	.97	1.14	1.19
	MEAS	1.25	1.23	1.22	1.27	1.00	1.01	1.17	1.14
11	CALC	1.01	1.07	1.30	1.26	1.26	1.14	1.52	.93
	MEAS	.99	1.03	1.26	1.22	1.25	1.12	1.45	.90
12	CALC	.98	1.03	1.04	1.26	1.39	1.40	1.28	
	MEAS	1.00	1.02	1.00	1.25	1.34	1.37	1.23	
13	CALC	.84	.95	.97	1.14	1.40	.98	.79	
	MEAS	.87	.97	1.04	1.14	1.39	.96	.76	
14	CALC	1.11	1.52	1.15	1.52	1.28	.80		
	MEAS	1.11	1.45	1.12	1.39	1.23	.78		
15	CALC	1.29	1.31	1.20	.93				
	MEAS	1.26	1.25	1.12	.87				

FIGURE 6.4