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

Subject: Catawba Nuclear Station, Unit 2
Docket No. 50-414
Catawba Unit 2 Cycle 8 Startup Physics Test
Rod Swap Review Criterion Failure Report

The attached report is provided in accordance with the requirements specified within the NRC Safety Evaluation Report (SER) for Duke Power Company's "Rod Swap Methodology Report for Startup Physics Testing", dated May 22, 1987. The Catawba 2 Cycle 8 bank worth measurements using the rod swap methodology was completed on November 29, 1995. The measured worth of the Reference Bank (Shutdown Bank B) deviated from the predicted worth by 11%. This deviation exceeded the review criterion of 10% for the Reference Bank measurement. The acceptance criterion of 15% was met. As specified within the May 22, 1987 NRC SER, a report is to be submitted to the NRC within 75 days of the test.

The attached report provides the Catawba 2 Cycle 8 startup physics test results and summarizes an investigation made by Duke Power Company to explain the larger than expected Reference Bank worth deviation.

The review and acceptance criteria for all other bank measurements were met, including the total rod worth criterion. No other anomalies were observed during the startup physics testing for Catawba Unit 2 Cycle 8.

Please contact Scott Gewehr at (704) 382-7531 or Scott Thomas at (704) 382-3868 if there are any questions regarding this submittal.

Very truly yours,

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1.0 Introduction

Rod worth measurements at Catawba Nuclear Station are performed using the Rod Swap methodology described in Reference 1. The testing methodology employs two sets of criteria for evaluating test results. These criteria are:

1) Review Criteria, which has no safety significance, and

2) Acceptance Criteria, which is based on meeting safety analysis input assumptions

Attachment 1 contains an excerpt from the NRC Safety Evaluation Report (SER) for Reference 1. This excerpt details the review and acceptance criteria for rod worth measurements performed using the rod swap methodology.

During the Catawba Unit 2 Cycle 8 rod swap test performed on November 29, 1995, the worth of the Reference Bank (Shutdown Bank B) was measured 11% higher than its predicted value. This deviation exceeded the 10% review criterion for the Reference Bank measurement. The acceptance and review criteria for all other bank measurements were met, including the criterion for total rod worth.

Exceeding a review criterion does not a have a safety significance. Safety significant deviations are defined by acceptance criterion, which are based on exceeding uncertainties assumed in the safety analysis. Review criterion are established to define deviations which are larger than expected and are based on historical data and accuracies of both measured and predicted data. In the case of the Reference Bank worth measurement, the review criterion is also based on the fact that the Reference Bank worth influences the inferred worth of all other banks. In general, a deviation beyond the review criteria warrants a review of the measured and predicted data in an effort to explain the larger than expected error.

Core predictions for Catawba 2 Cycle 8 are made by Duke Power Company using the NRC approved CASMO/SIMULATE methodology described in Reference 2. For completeness, a review of the safety analysis input parameters which are sensitive to changes in rod worth was performed to confirm the acceptability of the FSAR Chapter 15 accident analyses. All input parameters and Chapter 15 accident analyses for Catawba 2 Cycle 8 were found to be acceptable.

This report summarizes the investigation of the larger than expected Reference Bank worth deviation. The following areas were investigated and are discussed in this report:

- analytical models and calculations
- plant procedures and measured data
- correlation of flux map measurements to rod worth
- fuel and burnable poison manufacturing data

2.0 Catawba 2 Cycle 8 Zero Power Test Results

The startup physics test program for Catawba 2 Cycle 8 was performed according to the NRC approved test program for Catawba and McGuire described in Reference 3. Results from the Catawba 2 Cycle 8 startup physics testing at zero power are shown in Table 1. The results show excellent agreement for the Isothermal Temperature Coefficient (ITC), with a difference of only -0.33 pcm/°F. The boron endpoint comparisons are also very good. The measured worth of the Reference Bank deviated from the predicted worth by 11%.

The other rod worth results in Table 1 show the inherent bias associated with mispredicting the Reference Bank worth in the rod swap methodology.. The inferred bank worths of the remaining banks are calculated based on the critical height of the Reference Bank (with the test bank fully inserted) and the measured integral rod worth curve of the Reference Bank. Thus, deviations in the Reference bank integral worth curve affect the determination of the test bank worths.

The predicted and measured integral worth curves for the Reference Bank are shown in Figure 1. The trend of increased differences between the two curves from full-out (0 pcm deviation) to full-in conditions (100 pcm deviation) is expected to produce larger errors in higher worth test banks. In general, the rod worth results shown in Table 1 show this behavior. The highest worth test banks (CB and CC) have errors of -12.6% and -7.3%, respectively, while the lower worth banks tend to have smaller errors.

The difference in critical boron between ARO and Reference Bank-in can be used to calculate an "equivalent" Reference Bank worth. Table 1 shows that the measured Reference Bank worth is reduced to 955 pcm using the measured boron difference and a predicted boron worth of -6.92 pcm/ppmB. This form of the measured Reference Bank worth agrees better with the predicted worth, and is within -6.1%.

Detector reaction rate errors from full core flux maps taken at 30% and 60% full power are shown in Figures 2 and 3, respectively. The error distributions shown in these maps are well within the acceptance criteria of 10% error at specific locations and 5% core average RMS. A trend of slightly underpredicting the reaction rates in reinserted assemblies is shown in the figures. Overall, Figures 2 and 3 show good agreement between predicted and measured reaction rates considering the off nominal core conditions of the maps.

Results from the first flux map at 100% full power, equilibrium conditions are shown in Figure 4. The error distribution between measured and predicted assembly power is very good, with a maximum error adjacent to Shutdown B locations of less than 1%. This map also shows a trend of slightly underpredicted powers in reinserted assemblies. For example, assembly powers near the Reference Bank location (C-9) are underpredicted by approximately 1%. The slight trend of underpredicted assembly powers of reinserted assemblies in Figures 2-4 may explain part of the underprediction of the Reference Bank worth since the Catawba 2 Cycle 8 core design only allows control rods to be inserted in these locations.

2.0 Catawba 2 Cycle 8 Zero Power Test Results (cont.)

Overall, the startup physics test results are in very good agreement with predictions. It is obvious that no gross error exists in either the core loading or in the core model. The critical boron and ITC results demonstrate that the core model accurately predicted core reactivity. The flux map results show a slight trend of underpredicting power of reinsert assemblies, but this observation does not explain the full magnitude of the Reference Bank worth deviation.

Table 1

Catawba 2 Cycle 8
Zero Power Physics Test Results

Boron End Points

	Measured	Predicted	Diff. (P-M)
ARO Boron (ppmB)	1869	1876	7
Reference Bank in Boron (ppmB)	1731	1746	15

Isothermal Temperature Coefficient

	Measured	Predicted	Diff. (P-M)
Isothermal Coefficient (pcm/°F)	-3.14	-3.47	-0.33

Rod Worths

Bank ID	Measured Worth (pcm)	Predicted Worth (pcm)	Difference (P-M)	%Difference (1-M/P)*100
SA	283	269	-14	-5.2
SB	1000	900	-100	-11.1
SC	470	437	-33	-7.6
SD	470	436	-34	-7.8
SE	570	516	-54	-10.5
CA	374	360	-14	-3.9
CB	803	713	-90	-12.6
CC	809	754	-55	-7.3
CD	594	584	-10	-1.7
Total	5373	4969	-404	-8.1

Boron Equivalent Reference Bank Worth

	Measured	Predicted	Difference (P-M)	%Difference (1-M/P)*100
Boron Difference, ARO-SB in (ppmB)	138	130	-8	-6.2
Boron Equivalent Worth (pcm)	955	900	-55	-6.1
Differential Boron Worth (pcm/ppmB)	-7.24	-6.92	0.32	-4.6

Figure 1

Catawba 2 Cycle 8
Measured and Predicted Integral and Differential Worth
of Shutdown Bank B (Reference Bank)

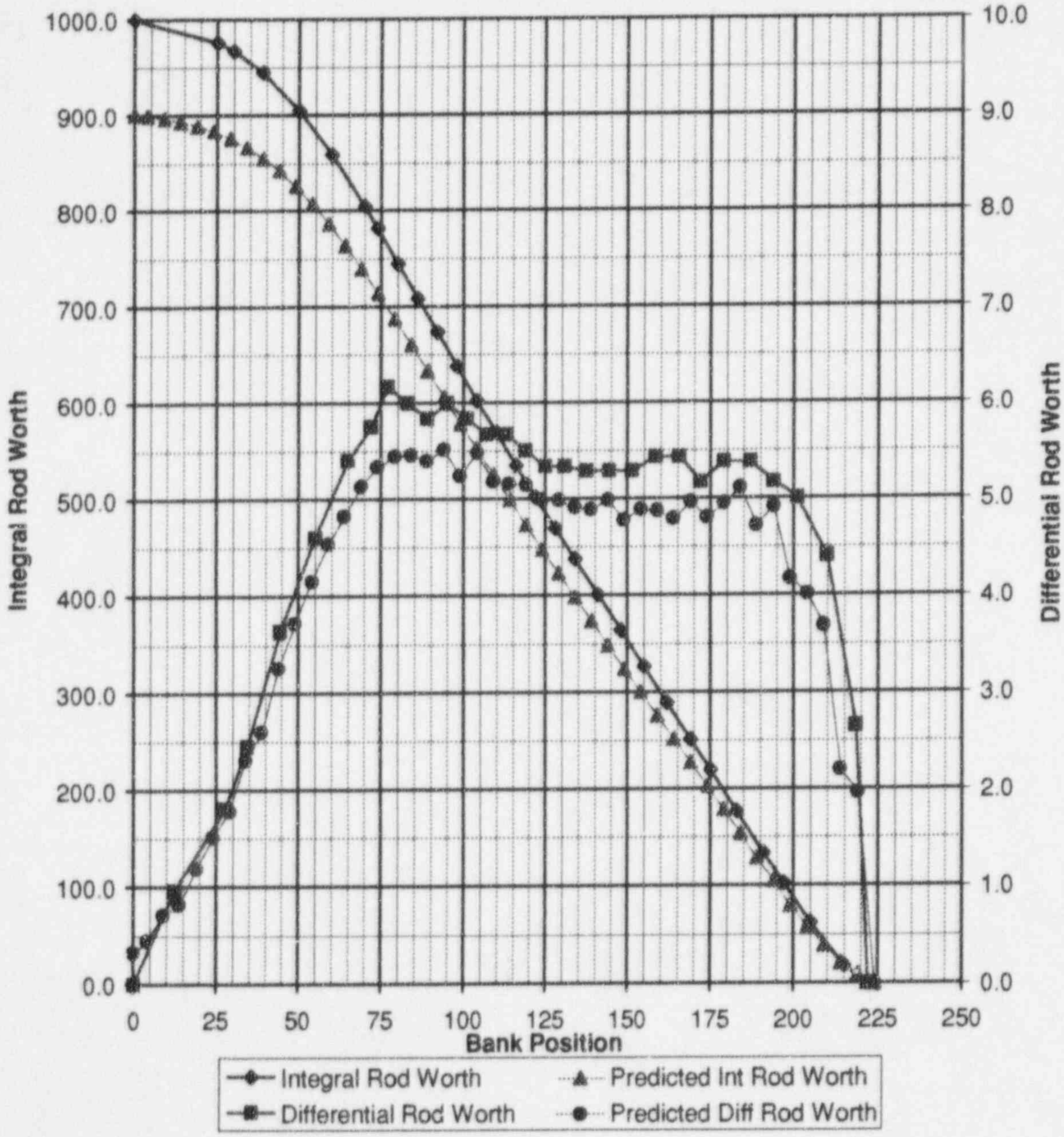

Figure 2

Catawba 2 Cycle 8
Measured to Predicted Reaction Rate Errors
30% FP, BOC, CD at 216 swd, No Xe

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
A									-1.20		-1.20				
B						-3.30		0.00					2.90		
C					0.00		-1.40	0.90							
D			3.40					-0.50		0.00		-0.70		2.10	
E					0.50				-1.20		0.20				
F	0.00		1.40				5.00	2.40						-2.50	
G					-0.10				5.10			-0.30			
H		1.50	0.50	0.70		0.90					-2.00		-0.90		-1.40
J	2.00						3.70	5.80		4.10				-1.60	
K		-3.10				0.50						-1.70			
L					-1.00			-2.40		0.30			-3.70		
M							-0.40								
N		2.50		0.30		-1.20		-0.70					-1.10		
P				-0.70					-0.70						
R		XX				-1.20		2.10			-2.00				

RMS=2.1%

Shutdown B Locations

%Diff = 100*((Calc-Meas)/Calc)

Figure 3

Catawba 2 Cycle 8
Measured to Predicted Reaction Rate Errors
60% FP, BOC, CD at 216 swd, No Xe

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
A									2.60		0.40				
B						-2.90		-0.70					5.70		
C					-1.80		0.10	0.40							
D			1.60					0.30		-0.70		-1.00		2.50	
E					-1.40				0.00		-0.30				
F	0.00		-0.50				3.70	4.60						-1.70	
G					0.00				3.50			0.00			
H		1.20	0.00	1.30		1.40					-2.00		-1.70		1.90
J	3.10						2.90	4.10		3.50				-2.90	
K		-4.00				0.00						0.30			
L					-1.70			-3.20		-0.20			-3.20		
M							0.60								
N		6.20		-1.00		-1.70		-0.60					0.60		
P				1.10					-1.40						
R						-0.40		3.80			1.10				

RMS=2.3%

Shutdown B Locations

%Diff = 100*((Calc-Meas)/Calc)

Figure 4

Catawba 2 Cycle 8
HFP Radial Power Distribution Comparison
SIMULATE versus Measured
5 EFPD, Eq Xe, Eq Sm

	H	G	F	E	D	C	B	A
8	0.8840 0.8620 2.55	1.1150 1.0930 2.01	1.1320 1.1360 -0.35	1.2440 1.2630 -1.50	1.2020 1.2200 -1.48	1.1930 1.1870 0.51	0.9320 0.9360 -0.43	0.4300 0.4280 0.47
9	1.1150 1.0980 1.55	1.1070 1.0910 1.47	1.1740 1.1670 0.60	1.1680 1.1760 -0.68	1.2230 1.2290 -0.49	1.1400 1.1460 -0.52	1.1060 1.1090 -0.27	0.5480 0.5480 0.00
10	1.1320 1.1350 -0.26	1.1790 1.1690 0.86	1.0620 1.0580 0.38	1.2010 1.1980 0.25	1.1900 1.1870 0.25	1.2060 1.2080 -0.17	1.0960 1.1120 -1.44	0.7760 0.7840 -1.02
11	1.2440 1.2610 -1.35	1.1710 1.1780 -0.59	1.2060 1.2040 0.17	1.1950 1.1920 0.25	1.2170 1.2090 0.66	1.1490 1.1480 0.09	1.0940 1.1030 -0.82	0.4170 0.4210 -0.95
12	1.2020 1.2120 -0.83	1.2230 1.2250 -0.16	1.1890 1.1920 -0.25	1.2170 1.2140 0.25	1.1630 1.1540 0.78	1.1400 1.1290 0.97	0.6270 0.6280 -0.16	
13	1.1930 1.1870 0.51	1.1410 1.1410 0.00	1.2060 1.2140 -0.66	1.1490 1.1520 -0.26	1.1410 1.1230 1.60	0.7050 0.6930 1.73	0.2950 0.2890 2.08	
14	0.9320 0.9330 -0.11	1.1060 1.1090 -0.27	1.0960 1.1140 -1.62	1.0940 1.1000 -0.55	0.6270 0.6180 1.46	0.2950 0.2880 2.43	SIMULATE Measured % Error	
15	0.4300 0.4310 -0.23	0.5470 0.5500 -0.55	0.7760 0.7840 -1.02	0.4170 0.4210 -0.95				

3.0 Core Model Evaluation

Core predictions for Catawba 2 Cycle 8 are made by Duke Power Company using the NRC approved CASMO/SIMULATE methodology described in Reference 2. A review of the computer models used in the generation of control rod worth data and the rod swap test data was performed. Areas investigated included the following:

- cycle 7 operating history
- cross section generation
- model setup
- rod swap calculations
- as built enrichment and burnable poison loadings

A review of the Cycle 7 operating history showed no anomalies which might impact the Cycle 8 results. For completeness, the differences in predicted and measured assembly burnups were evaluated using a modified core model in which the nodal burnup distribution was adjusted to match measured burnups. As expected, the modified core model produced rod worths within 1 pcm of the original core model. Therefore, the operating histories of reinserted assemblies were modeled sufficiently to produce accurate bank worth predictions.

The review found no errors in the cross section generation, core model development, or in the calculation of rod swap data.

A review of the as built enrichments and burnable poison loadings showed no deviations and no preferential core loading that would contribute to the Reference Bank worth deviation.

As an independent check of the Reference Bank worth prediction, Framatome Cogema Fuels (FCF), formally B&W, was contracted to calculate rod worth data for Catawba 2 Cycle 8. The FCF calculations were made using the NRC approved CASMO/NEMO methodology described in Reference 4. The Reference Bank worth predicted by NEMO was 939 pcm, 6.5% lower than measured, and 4.3% higher than SIMULATE. A comparison of NEMO and SIMULATE predictions of the hot zero power (HZP) radial power distribution showed excellent agreement. The comparison showed a slight trend of SIMULATE underpredicting the power in reinserted assemblies relative to NEMO. While small, this may explain some of the difference between SIMULATE and NEMO Reference Bank worth predictions.

A comparison of the kinetic parameters calculated by SIMULATE and NEMO for Catawba 2 Cycle 8 was also made. These parameters do not affect predicted rod worths since the analyses are based on solving the steady state neutron diffusion equation. However, the kinetic parameters are important to the measured reactivity since they are used in the reactivity computer to solve the inverse point kinetics equations. The agreement between SIMULATE and NEMO was excellent. The difference between total delayed neutron fraction is only 0.1%. Although both methodologies use CASMO, this comparison confirms that the importance weighting of nodal kinetics parameters is being performed consistently.

3.0 Core Model Evaluation (cont.)

Overall, the review of the SIMULATE core model for Catawba 2 Cycle 8 revealed no significant errors which would explain the Reference Bank worth misprediction.

4.0 Measured Data Evaluation

A review of plant procedures and reactivity trace data from the strip recorder for the Reference Bank worth measurement showed no anomalies. An independent determination of the Reference Bank worth was performed using an alternate strip chart reactivity trace. The independent evaluation of the trace data was within 5 pcm of the official analysis. Therefore, the analysis of the boron exchange reactivity data is considered accurate and correct.

The reactivity computer checkout procedure involved a reactivity insertion of approximately 20 pcm. The checkout showed less than 0.5% error between theoretical reactivity based on the measured period (in-hour equation), and the solution of the inverse point kinetics equation by the reactivity computer. Therefore, the reactivity computer was demonstrated to be functioning correctly.

The maximum boron dilution rate during the measurement was 436 pcm/hr, which is below the maximum dilution rate of 500 pcm/hr specified in the NRC SER for Reference 1.

The only potential anomaly in the measured data involved the application of leakage current compensation to the power range signal. The Catawba 2 Cycle 8 startup testing used the power range excore detector signal as input to the reactivity computer. Since the power range detectors are uncompensated ion chambers, there is a potential that a measurable amount of the total signal is composed of gamma interactions and normal electronic leakage. Neither of these contributions to the signal are proportional to the neutron flux level at the low core flux levels typical of startup physics testing, and constitute a background leakage current. In general, measured reactivity is low if the leakage current is not removed. The magnitude of the effect is dependent on the flux level. At the low end of the flux test band the effect is greater since the leakage current constitutes a larger portion of the total signal.

The method used at Catawba and other Westinghouse plants to compensate the power range detector for leakage current involves the application of a bucking current. The bucking current is equal to the leakage current signal, but opposite in sign. The summation of the bucking current and the power range current signal effectively produces a compensated signal for use in the reactivity computer. Bucking current values for previous Catawba startups were established prior to any bank withdrawal, but after dilution to the critical boron concentration. A typical bucking current had been approximately 0.5×10^{-8} amps.

For the Catawba 2 Cycle 8, a change in the startup program required a change in the core configuration typically used to establish the bucking current. The bucking current was set with shutdown banks withdrawn and the system at the refueling boron concentration. The bucking current for Catawba 2 Cycle 8 was established at 1.0×10^{-8} amps, approximately double the previous applications.

4.0 Measured Data Evaluation (cont.)

There are few possible reasons for the increase in bucking current:

1) The core reactivity is essentially the same between a fully rodded core at the critical boron concentration and a core at the refueling boron concentration and the shutdown banks withdrawn. However, the withdrawal of all shutdown banks may cause a spatial redistribution of the flux signal toward the periphery. (Note that SD, SE, and SA are located near the power range detector.) The flux redistribution may result in less shadowing of the detector and produce more detector current from core multiplication.

2) During the Catawba 2 Cycle 8 testing, a bad connection in the cable supplying the power range current signal was discovered after achieving criticality. This bad connection may have existed during the establishment of the bucking current, causing a misapplication of the detector compensation.

3) Some amount of cycle to cycle variation in the gamma portion of the bucking current is expected due to loading pattern changes.

4) The electronic leakage in the circuit can change due to age, radiation damage, etc.

The cause of the increased bucking current for Catawba 2 Cycle 8 is unknown. If the increase is due to items 3) and 4), then the bucking current was applied correctly and the reactivity measurements are considered accurate. However, if the increase is due to items 1) or 2), the bucking current may have overcompensated the signal.

A simple study was performed to quantify the possible effect of overcompensation on measured reactivity. The results showed that overcompensation can produce higher measured rod worths. The magnitude of the possible measured reactivity increase was shown to be comparable (but opposite direction) to low measured reactivity caused by an uncompensated signal.

5.0 Conclusions

With the exception of the Reference Bank worth measurement, the overall startup physics test results for Catawba 2 Cycle 8 were very good. Measured core reactivity and power distributions showed excellent agreement with predictions.

The review of the analytical core model, cross-section generation, and rod swap data generation showed no errors. The review of the cycle 7 operating history effects showed negligible effects on calculated rod worths. A review of the manufacturing data for assembly enrichments and burnable poison loadings showed no variations beyond contract specifications and no preferential loading was detected which would explain the misprediction of the Reference Bank worth. The boron equivalent worth calculated using the difference in critical boron between ARO and Reference Bank-in showed an inferred worth 4.5% lower than the corresponding worth determined by the reactivity computer.

The review of the measured data concluded that the analysis of the Reference Bank reactivity data was correct. In addition, all limits and precautions associated with this test were met. The only anomaly evident in the measured data was the higher than expected bucking current used to compensate the power range detector, which may have led to a higher measured Reference Bank worth.

Based on this review, the most likely explanation of the 11% deviation of the Reference Bank worth is a combination of two effects that were both in the same direction. First, from the comparison of the predicted power distribution to measured and NEMO, a slight trend of underpredicted assembly powers in reinserted assemblies was noted. Since the Catawba 2 Cycle 8 core loading pattern only allows control rods in reinserted assemblies, this may explain a portion of the rod worth underprediction. Second, the application of bucking current to compensate the power range detectors is suspect. The bucking current applied for Catawba 2 Cycle 8 was twice the value experienced previously. This possible overcompensation of the detector signal may have resulted in a higher measured Reference Bank worth.

From this review it can be concluded that no gross errors exist in either the core model or in the core loading. The acceptance and review criteria for all bank measurements except the Reference Bank review criterion were met, including the criterion for total rod worth. A review of the safety analysis input parameters confirmed that the FSAR Chapter 15 accident analysis for Catawba 2 Cycle 8 is acceptable and there are no safety concerns associated with the larger than expected deviation in Reference Bank worth.

6.0 References

1. "Rod Swap Methodology Report for Startup Physics Testing", Approved Topical Report DPC-NE-1003-A, Duke Power Company, December, 1986

2. "Nuclear Design Methodology Using CASMO-3/SIMULATE-3P", Approved Topical Report DPC-NE-1004A, Duke Power Company, November, 1992

3. "Reload Startup Physics Test Program for The McGuire and Catawba Nuclear Stations", NRC SER , May 18, 1988

4. "NEMO -- Nodal Expansion Method Optimized", Approved Topical Report BAW-10180-A, B&W Fuel Company, Lynchburg, Virginia, May, 1992

Attachment 1

Excerpt From Rod Swap Methodology SER
Topical Report DPC-NE-1003-A

Attachment 1

Excerpt From Rod Swap Methodology SER
Topical Report DPC-NE-1003-A

Based on our review of the material submitted, we find the rod swap methodology as proposed by Duke Power Company to be acceptable subject to the following conditions, to which Duke Power Company has agreed:

1) The boron dilution rate for measurement of the reference bank shall not exceed 500 pcm.

2) All banks, both control and shutdown banks, must be measured.

3) The review criteria are:

   A. The absolute value of the percent difference between measured and predicted integral worth for the reference bank is ≤ 10 percent.

   B. For all banks other than the reference bank, either (whichever is greater);

      1) the absolute value of the percent difference between inferred and predicted integral worths is ≤ 15 percent or
      2) the absolute value of the reactivity differences between inferred and predicted integral worths is ≤ 100 pcm. *

   C. The sum of the measured/inferred worth of all the rods must be ≤ 110 percent of the predicted worth.

4) The acceptance criteria are:

   (1) The sum of the measured/inferred worth of all the rods must be > 90 percent of the predicted worth.

   (2) For all banks other than the reference bank, either (whichever is greater)

      a) the absolute value of the percent difference between inferred and predicted integral worth is < 30 percent or
      b) the absolute value of the reactivity difference between inferred and predicted integral worths is < 200 pcm.

   (3) The absolute value of the percent difference between measured and predicted integral worth for the reference bank is < 15 percent.

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*A pcm is equal to 10^{-5} $\Delta k/k$.

Attachment 1 (continued)

Excerpt From Rod Swap Methodology SER
Topical Report DPC-NE-1003-A

5) Additional testing is required if the reference bank boron concentrations and reactivity computer worth do not agree. Remedial action for failure of an acceptance or review criterion requires investigation and solution within 30 days (for acceptance criterion) or 60 days (for review criterion). The licensee must then submit a report of the findings to the NRC within 45 days of the test (for acceptance criterion) or within 75 days of the test (for review criterion).