DUKE POWER COMPANY

CATAWBA AND McGUIRE NUCLEAR STATIONS

DYNAMIC ROD WORTH MEASUREMENT USING CASMO/SIMULATE

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Abstract

This report documents the results of an extensive benchmark using CASMO/SIMULATE to calculate cycle specific analytical factors to support Dynamic Rod Worth Measurements (DRWM) at the Catawba and McGuire Nuclear Stations. A comparison of results from six separate startups at Catawba and McGuire is presented to quantify differences between Duke and Westinghouse processed DRWM measured data. This report evaluates the benchmark results and concludes that the Duke DRWM analytical factors calculated using CASMO/SIMULATE produce measured bank worths consistent with the corresponding Westinghouse computations.

This report also addresses the set of five criteria which were approved by the NRC in the Westinghouse DRWM topical report. These criteria are used to assess the ability of a utility to perform independent DRWM computations. The five criteria are specifically addressed in this report to demonstrate, from both a technical and programmatic perspective, that Duke Power's methodology for DRWM computations is acceptable.

The benchmark comparisons documented in this report are more comprehensive than usual, recognizing the differences in physics code methodologies between Duke and Westinghouse. Duke gathered additional DRWM benchmark data for Catawba and McGuire to qualify the reactor physics calculations and the technology transfer of the DRWM technique. As expected, this report shows that the independent physics code methodologies used by Duke and Westinghouse produce different analytical factors and measured bank worths. However, the results contained in this report demonstrate that the differences are acceptably small and the CASMO/SIMULATE codes are suitable replacements for the Westinghouse physics codes in the DRWM methodology.

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1. INTRODUCTION

Duke Power purchased the Dynamic Rod Worth Measurement (DRWM) technology and equipment from Westinghouse in September 1997. Westinghouse has been responsible for performing the DRWM computations for the last six Catawba and McGuire cycles. These startups include Catawba Unit 1 Cycles 11 & 12, Catawba Unit 2 Cycle 10, McGuire Unit 1 Cycle 13, and McGuire 2 Cycles 12 & 13. For future DRWM tests, Duke Power intends to perform the analytical computations necessary to support DRWM. Through the information provided in this report, Duke Power intends to demonstrate that the analytical computations necessary to support DRWM for future cycles of both Catawba and McGuire can be performed by Duke Power.

Appendix A contains the approved NRC criteria from Reference 1 that must be addressed in order to perform computations to support DRWM. NRC approved these criteria with the intent that successfully meeting these criteria constitutes inherent NRC approval to perform computations to support DRWM in the Low Power Physics Testing (LPPT). This report demonstrates that the intent of these criteria has been met for the Duke DRWM computations at Catawba and McGuire.

The Catawba and McGuire data for DRWM are presented in Section 2.

Section 3 of this report evaluates the results of an extensive benchmark using CASMO/SIMULATE to calculate cycle specific analytical factors to support Dynamic Rod Worth Measurements (DRWM) at Catawba and McGuire. A comparison of results from six separate startups at Catawba and McGuire is presented to quantify differences between Duke and Westinghouse processed DRWM measured data.

The benchmark comparisons documented in this report are more comprehensive than usual, recognizing the differences in physics code methodologies between Duke and Westinghouse. Duke gathered additional DRWM benchmark data for Catawba and McGuire to qualify the reactor physics calculations and the technology transfer of the DRWM technique. All four units at Catawba and McGuire are sister units, having the same basic core design, cycle lengths and control bank layout. Therefore, the benchmark data can be treated as a collective set of data in which the conclusions are equally applicable to all four units. The control bank layouts for all four units at Catawba and McGuire are shown on Figure 1.

Section 4 of this report addresses the set of five criteria which were approved by the NRC in Reference 1. These criteria are used to assess the ability of a utility to perform independent DRWM computations. The five criteria are specifically addressed to demonstrate, from both a technical and programmatic perspective, that Duke Power's methodology for performing DRWM computations is acceptable.

Station personnel received initial training on DRWM procedures, the use of the Advanced Digital Reactivity Computer (ADRC), and application of the ADRC to performing LPPT using DRWM prior to DRWM testing at both Catawba and McGuire. Additional training was also received during each of the six applications of DRWM at Duke. Personnel performing computations to support DRWM were initially trained by Westinghouse in these computations in March 1998 and received procedures on how to perform these computations at that time. This training included the ability to set up input, understand and interpret output results, understand applications and limitations, and to perform analyses in compliance with the procedures provided by Westinghouse.

Duke's DRWM computations make use of the Westinghouse DRWM technique of Reference 1. The steady-state physics calculations to support the Duke DRWM computations are made using the NRC approved CASMO-3/SIMULATE-3P methodology described in Reference 2. To improve DRWM bank worth comparisons, Duke has adopted the Tuttle delayed neutron data from Reference 5 for reactivity measurements.

The dynamic calculations to support Duke DRWM computations are made using the SIMULATE-3 Kinetics (S3K) program. S3K is a three-dimensional transient neutronic version of the NRC-approved SIMULATE-3P code and utilizes the same neutron cross section library. It employs a fully implicit time integration of neutron flux and delayed neutron precursors. The NRC has approved S3K for use in the UFSAR Chapter 15 Rod Ejection Analyses (REA) for Catawba and McGuire (Reference 3). The Duke REA benchmark results and results for industry benchmark problems discussed in Section 6.6 of Reference 3 demonstrate that S3K adequately performs transient neutronic calculations with thermal hydraulic feedback. In comparison, the DRWM calculations are simpler since they are isothermal calculations which do not involve thermal hydraulic feedback. For application to DRWM, the extensive benchmark results contained in this report demonstrate that S3K is suitable to generate analytical constants necessary for DRWM.

Application of these codes and procedures, and the Westinghouse DRWM procedure, is controlled by the Duke Power quality assurance program described in Reference 4. This quality assurance program meets the requirements of 10 CFR 50, Appendix B.

Figure 1

Catawba and McGuire
Control and Shutdown Bank Locations

	R	P	N	M	L	K	J	H	G	F	E	D	C	B	A
1															
2				SA		CB		CC		CB		SA			
3					SD		SB		SB		SC				
4		SA		CD				SE				CD		SA	
5			SC										SD		
6		CB				CC		CA		CC				CB	
7			SB										SB		
8		CC		SE		CA		CD		CA		SE		CC	
9			SB										SB		
10		CB				CC		CA		CC				CB	
11			SD										SC		
12		SA		CD				SE				CD		SA	
13					SC		SB		SB		SD				
14				SA		CB		CC		CB		SA			
15															
	R	P	N	M	L	K	J	H	G	F	E	D	C	B	A

XX Bank

Control Bank	Number of Rods	Shutdown Bank	Number of Rods
CA	4	SA	8
CB	8	SB	8
CC	8	SC	4
CD	5	SD	4
		SE	4
Total	25	Total	28

2. COMPARISON OF RESULTS

Table 4 provides the DRWM measured and predicted rod worths based on Westinghouse computations for the Catawba 1 Cycle 11, McGuire 2 Cycle 12, McGuire 1 Cycle 13, and Catawba 2 Cycle 10, Catawba 1 Cycle 12, and McGuire 2 Cycle 13 LPPT programs, respectively. Table 5 provides the DRWM measured and predicted rod worths based on Duke Power computations for the same cycles.

Table 6 compares the predicted rod worths for each of the six cycles based on Westinghouse and Duke Power data. Table 7 compares the rod worths measured by the DRWM technique for each of the six cycles using Westinghouse and Duke Power analytical data.

3. DISCUSSION OF RESULTS

The DRWM benchmark results documented in this report are evaluated in Section 3.1 below using the criteria contained in the Westinghouse DRWM Topical Report (Reference 1). These criteria were approved by the NRC to assess whether a utility is qualified to perform DRWM calculations independent of Westinghouse. The approved criteria are focused on quantifying differences due to code users and code methodologies. An additional evaluation is performed in Section 3.2 using the bank worth review and acceptance criteria from Low Power Physics Testing (LPPT). These criteria were also approved by the NRC in Reference 1, but focus on the differences between measured and predicted bank worths.

3.1 Code Methodology Evaluation

The numerical criteria approved by the NRC to assess utilities which intend to independently calculate DRWM analytical factors are shown below. These criteria are contained in Reference 1.

DRWM Acceptable Deviations for NRC Notification Letter

Parameter	Acceptable Deviation
Calculated Bank Worth	± 2% or ± 25 pcm (whichever is greater)
Calculated Total Worth of All Banks	± 2%
Measured Bank Worth	± 2% or ± 25 pcm (whichever is greater).
Measured Total Worth of All Banks	± 2%

The individual bank acceptable deviation criterion is setup consistent with criteria used for bank worth measurements during LPPT. The intent is to compare to the larger of the two deviation limits, % or absolute, whichever is greater. For example, if a bank worth of 1000 pcm is measured, the absolute error criterion is 25 pcm (as stated above), and the 2% criterion is 0.02*1000 = 20 pcm. In this example, the absolute difference criterion of 25 pcm would be used since it is larger than the 2% criterion. Bank worth acceptance criteria such as these are designed to account for the differences in bank worths, which range from 200 pcm to over 1000 pcm. For lower worth banks, differences are compared to the absolute difference criterion, and for higher worth banks the % difference criterion is used. For a ± 2% or ± 25 pcm criterion, all bank worths less than 1250 pcm (=25/0.02) are compared to the 25 pcm criteria. Therefore, since this report contains no banks worth more than 1250 pcm, only the ± 25 pcm criterion is applicable.

Table 1 provides a summary of the comparison between Duke and Westinghouse DRWM results for the six benchmark cycles. The maximum bank worth differences in Table 1 were chosen based on the maximum absolute difference between Duke and Westinghouse.

Table 1
Benchmark Summary of Westinghouse and Duke DRWM Results

	Maximum Predicted Bank Worth Difference		Predicted Total Bank Worth Difference	Maximum Measured Bank Worth Difference		Measured Total Bank Worth Difference
Cycle	Bank	(D-W) pcm	%(D-W)/W	Bank	(D-W) pcm	%(D-W)/W
C1C11	SA	-23.2	-1.7	SC	-8.6	-1.0
M2C12	SA	-13.8	-1.0	CB	-7.0	-0.6
M1C13	SB	20.8	-0.1	CB	-9.3	-0.7
C2C10	SA	-18.7	-1.6	CB	-5.0	-0.5
C1C12	SA	-30.7	-1.9	CB	-4.3	-0.3
M2C13	SA	-39.2	-1.1	CB	-10.6	-0.6

D = Duke
W = Westinghouse

The complete set of results provided in Table 6 and Table 7 show that the ± 2% or ± 25 pcm criterion are met in 108 of the 114 comparisons (54 predicted bank worths, 54 measured bank worths, and 6 total bank worths). The 6 comparisons that do not meet the criteria are comprised of the following comparisons:

- 4 *predicted bank worths* from M2C13 (Banks CC, CD, SA and SC)
- 2 *predicted bank worths* from C1C12 (Banks CB and SA),

Overall, the DRWM benchmark results can be summarized as follows:

1) The differences between Duke and Westinghouse *predicted bank worth* meet either the ± 2% or ± 25 pcm criterion in 48 of the 54 cases. A total of 6 predicted bank worths in M2C13 and C1C12 exceed the 25 pcm criterion. The trend in the predicted bank worth deviations is consistent with the observed differences in the predicted radial Hot Zero Power (HZP) power distribution between Duke and Westinghouse. Relative to Westinghouse, Duke typically under predicts the relative power of assemblies located near the core periphery (assemblies containing banks SA, CD, SD, and SC), and over predicts the powers of assemblies

near the core interior (assemblies containing banks CC, CA, and SB). Duke typically predicts lower worths for banks SA, CD, SD, and SC than Westinghouse due to differences in the radial power distribution. However, the *measured bank worths* for these six banks generally fall between the Duke and Westinghouse *predicted bank worths,* indicating that this is only a bias between *predicted bank worths.*

The M2C13 and C1C12 *predicted bank worths* differences are larger than the previous cycle comparisons. Although the magnitude of the differences is small and acceptable, both Duke and Westinghouse performed a thorough investigation of the M2C13 predictions, and Duke performed an investigation of the C1C12 predictions. To understand the cause, the model setup, cross-section generation, core shuffling, core depletion, and design information were examined. No deficiencies were identified in either the Duke or Westinghouse nuclear models that explain the larger than expected power distribution and bank worth differences. The reviews concluded that the differences are the result of code and methodology differences between SIMULATE and ANC, and are not attributable to model or calculational errors. Although the investigations did not uncover the exact cause of the larger differences, slightly higher differences in the power distribution comparison were noted for assemblies that operated near the periphery for more than one cycle. Both M2C13 and C1C12 contained more assemblies of these types, located at or near control rod locations, than previous cycles. It is possible that the different spectral history treatments between ANC and SIMULATE are partially responsible for the larger differences in the predicted power distributions.

2) The differences between the Duke and Westinghouse *predicted total bank worths* meet the $\pm$ 2% criterion for all six cores analyzed. The Duke *predicted total bank* worths are consistently lower than Westinghouse *predicted total bank worths* (from -0.1% to –1.9%). As discussed above, the Duke predicted HZP radial power distribution is typically lower in assemblies located near the periphery. Figure 1 shows that more of the control banks are located near the periphery, which tends to over emphasize the contribution of the peripheral assemblies to the calculation of

the total bank worth. The trend of Duke's *predicted total bank worth* being slightly lower than Westinghouse is consistent with the HZP radial power distribution differences.

3) The difference between the *measured bank worths* calculated by Duke and Westinghouse methods meet the $\pm$ 2% or $\pm$ 25 pcm criterion for all banks. The maximum difference is –10.6 pcm for Bank CB in McGuire 2 Cycle 13. This comparison shows excellent agreement between the Duke and Westinghouse data.

4) The *measured total bank worth* differences between Westinghouse and Duke for the 6 cores range from –1.0 to –0.3%. The measured values from Duke calculations are consistently lower than the values from Westinghouse calculations. Since the extent of this under prediction is small, this deviation is acceptable.

The overall comparison between Westinghouse and Duke results is excellent. The differences shown in Table 1 are well within the expected range for a comparison between two independent core simulator methodologies. The fundamental methodology differences between Duke and Westinghouse are expected to produce differences such as these for predicted bank worths. Other than using the same loading patterns, plant parameters, depletion step information, and the same methodology to calculate the DRWM analytical factors, the Westinghouse and Duke data were produced independently. Westinghouse used the ALPHA/PHOENIX/ANC (APA) and SPNOVA codes, while Duke used the CASMO/SIMULATE/S3K codes. The comparison shows that Duke and Westinghouse produce very consistent results and that the Duke methodology is a suitable substitute for the Westinghouse DRWM methodology. The results also demonstrate that Duke has implemented the DRWM analytical factor methodology consistent with the approved Westinghouse methodology.

3.2 Measured to Predicted Evaluation

The previous section focused on evaluating the differences in bank worth due to code methodology differences between Duke and Westinghouse. This section performs an evaluation of the predicted bank worths relative to measured bank worths. This section uses the data contained in Table 4 and Table 5 to summarize measured to predicted results for each of the six benchmark cycles. For this evaluation, the appropriate review and acceptance criteria are those used in LPPT to assess the accuracy of the measured results. The review and acceptance criteria from Reference 1 are:

DRWM *Review* Criteria for Low Power Physics Testing (LPPT)

Parameter	Criteria
Individual Bank Worths	Measured worths ± 15% or ± 100 pcm of their predicted worths, whichever is greater
Total Worth of All Banks	Sum of measured worths ±8% of the sum of predicted worths

DRWM *Acceptance* Criteria for Low Power Physics Testing (LPPT)

Parameter	Criteria
Total Worth of All Banks	Sum of measured worths ≥90% of the sum of predicted worths

For the ± 15% or ± 100 pcm criterion, all bank worths less than 667 pcm (=100/0.15) are compared to the 100 pcm criterion, and banks with predicted worths greater than 667 ppm are compared to the 15% criterion.

Table 2 presents the Westinghouse DRWM results for each of the benchmark cycles. The maximum bank worth differences shown in Table 2 were chosen by comparing each bank worth difference to the appropriate limit; low worth banks (< 667 pcm) were compared to 100 pcm, and high worth banks were compared to 0.15*(predicted bank worth). The banks with the minimum margin to the criterion were selected for inclusion in Table 2.

Table 2
Westinghouse Measured to Predicted DRWM Results

Cycle	Bank	Westinghouse Maximum Bank Worth Difference			Total Bank Worth Difference
		Predicted Worth (pcm)	(M-P) pcm	%(M-P)/P	%(M-P)/P
C1C11	CD	631	63.8	10.1	1.7
M2C12	CA	337	-42.9	-12.7	0.2
M1C13	CB	645	25.1	3.9	0.3
C2C10	SB	916	88.3	9.6	2.8
C1C12	CB	697	22.7	3.3	1.1
M2C13	CB	643	47.1	7.3	2.9

M = Measured (using Westinghouse analytical factors)
P = Predicted

Table 3 presents the Duke DRWM results for each of the benchmark cycles. The maximum bank worth differences were chosen similar to Table 2.

Table 3
Duke Measured to Predicted DRWM Results

Cycle	Bank	Duke Maximum Bank Worth Difference			Total Bank Worth Difference
		Predicted Worth (pcm)	(M-P) pcm	%(M-P)/P	%(M-P)/P
C1C11	CD	612.9	74.8	12.2	2.5
M2C12	CA	323.8	-30.9	-9.5	0.6
M1C13	CC	740.8	-32.2	-4.3	-0.3
C2C10	CB	543.7	52.4	9.6	4.0
C1C12	CB	667.7	47.6	7.1	2.8
M2C13	CB	630.0	49.8	7.9	3.4

M = Measured (using Duke analytical factors)
P = Predicted

The results in Table 2 and Table 3 show that both Westinghouse and Duke meet the $\pm$ 15% or $\pm$ 100 pcm LPPT review criterion for individual banks, and the $\pm$8% total bank worth review criterion. In addition, the acceptance criterion of $\geq$ 90% of the sum of the predicted worths is met for all cycles.

Overall, the Duke measured to predicted comparison is very consistent with the Westinghouse results.

4. COMPLIANCE WITH FIVE DRWM CRITERIA

Appendix A contains the five criteria that have been approved by the NRC in Reference 1 to assess the ability of a utility to perform DRWM computations. This section specifically addresses each criterion.

4.1 Criterion 1: Eligibility of Codes for DRWM Computations

Only lattice physics codes and methods which have received prior NRC review and approval are eligible to be used in determining the physics constants to be used in DRWM. For the Duke application of DRWM, both the CASMO lattice physics code and the SIMULATE three dimensional core simulator code have been approved by the NRC for use by Duke in Reference 2.

The SIMULATE-Kinetics (S3K) code for the dynamic modeling of the DRWM process is a three-dimensional transient neutronic version of SIMULATE-3, and utilizes the same neutron cross section library. As part of the NRC approval of DPC-NE-2009, S3K has been approved for Rod Ejection Accident analysis (NRC letter of September 22, 1999 to G.R. Peterson of Catawba Nuclear Station). As discussed in Section 1, the S3K code is also necessary for the Duke DRWM calculations. The extensive benchmarking of the Duke DRWM calculations, making use of the S3K code, with the measured data and with the Westinghouse calculations show excellent agreement. Therefore, S3K is seen to be suitable for the Duke DRWM calculations. As part of the Duke request for NRC approval of the Duke DRWM methodology, S3K approval for DRWM applications for McGuire and Catawba is also being requested.

4.2 Criterion 2: Application of Procedures to DRWM Computations

This criterion states that "In a manner consistent with the procedures obtained from Westinghouse, the utility analyses shall be performed in conformance with in-house application procedures which ensure that the use of the methods is consistent with the Westinghouse approved application of the DRWM methodology". Duke has incorporated the Westinghouse provided DRWM computational procedures into an internal procedure to ensure consistency with the NRC approved methodology. Future Duke DRWM analyses will be performed according to the Duke DRWM procedure. The Duke QA program described in Reference 4 will be used to perform all DRWM computations. Therefore, Criterion 2 has been met.

4.3 Criterion 3: Training and Qualification of Utility Personnel

This criterion states that the first application of DRWM will be performed by Westinghouse, which will ensure that DRWM is applicable to the specific plant, provide utility personnel with training in the DRWM technique and be used to meet Criterion 4. Duke has exceeded these expectations by having Westinghouse perform computations for the first six DRWM applications at Catawba and McGuire. Duke station personnel received training and procedures on the use of the Advanced Digital Reactivity Computer (ADRC), and application of the ADRC to performing LPPT using DRWM prior to testing at Catawba and McGuire. Additional training was received during each of the six applications of DRWM.

Duke personnel performing computations to support DRWM have been initially trained by Westinghouse in these computations. Duke has received calculational procedures from Westinghouse on how to perform the DRWM computations. The Westinghouse training included the ability to set up input, understand and interpret output results, understand applications and limitations, and to perform analyses consistent with the procedures provided by Westinghouse. Duke has an established training and qualification program that is used to ensure that only qualified personal perform reload design calculations. The same training program will be used to ensure that future users of the DRWM methodology have a good working knowledge of the codes and methods. Therefore, Criterion 3 has been met.

4.4 Criterion 4: Comparison Calculations for the DRWM Technique

Section 3 provides an evaluation of the results from the six DRWM demonstration cycles. The comparisons show that the individual bank worth criteria of $\pm 2\%$ or $\pm$ 25 pcm were met for all of the *measured bank worths* and most of the *predicted bank worth* comparisons. A total of *six predicted bank worths*, four banks in McGuire 2 Cycle 13, and two banks in Catawba 1 Cycle 12, exceeded the 25 pcm criterion. As discussed in Section 3.0, the magnitude of the predicted bank worth deviations is acceptably small since the comparison involves two independent physics methodologies. Overall, the comparisons of *predicted bank worths* between Westinghouse and Duke are considered excellent. The differences between Westinghouse and Duke predicted bank worths are consistent with differences in the predicted HZP radial power distribution.

The comparisons in Section 3 show that the *total bank worth* criterion of $\pm 2\%$ was met for both predicted and measured bank worths in all six benchmark cycles.

In conclusion, considering the entire benchmark database, all of the criteria have been met with the exception of six individual bank worths in two cycles. The cause of the larger *predicted bank worth* differences in the six banks of McGuire 2 Cycle 13 and Catawba 1 Cycle 12 has been identified as being due to differences in the predicted radial power distribution. The magnitude of the deviations for predicted bank worths are small and are considered acceptable. Overall the comparison between Westinghouse and Duke predictions are considered good for comparisons of two independent physics methodologies. The comparisons that exceeded the $\pm$25 pcm criterion have been investigated and the reason for the larger deviations is understood and the magnitudes are not unexpected. Finally, all of the review and acceptance criteria for measured to predicted bank worth comparisons were easily satisfied. Therefore, it is concluded that the intent of Criterion 4 has been met in this evaluation.

4.5 Criterion 5: Quality Assurance and Change Control

The calculations for DRWM will be conducted using engineering calculation procedures which ensure conformance with the Duke QA program described in Reference 4. The Duke procedures have provisions for implementing changes to the methods and procedures being used for DRWM. Processes are available which provide a means by which Duke can directly inform Westinghouse and track any problems or errors discovered while performing the DRWM calculations or procedures. Westinghouse also has a requirement to inform utilities that have taken a technology transfer on DRWM of changes to the process as part of their QA procedures regarding technology transfer. Therefore, Criterion 5 has been met.

5. CONCLUSIONS

Based on the results in Section 2 and the discussions of the results in Section 3, it is concluded that the intent of the review criteria in Appendix A has been met. Section 4 showed that Duke has acceptably addressed the five criteria that have been establish to assess a utilities' ability to perform DRWM computations. Therefore, Duke has demonstrated through an extensive benchmark evaluation, that future Catawba and McGuire DRWM applications can be performed using Duke methods. The first application of Duke Power analytical computations to support DRWM in LPPT is scheduled to occur with the startup of McGuire 1 Cycle 14 which will occur on or about October 31, 1999.

6. REFERENCES

1. "Westinghouse Dynamic Rod Worth Measurement Technique", WCAP-13360-P-A, Revision 1, October 1998.

2. "Nuclear Design Methodology Using CASMO-3/SIMULATE-3P", DPC-NE-1004PA, Revision 1, December 1997.

3. "Duke Power Company Westinghouse Fuel Transition Report", DPC-NE-2009P, (NRC letter of September 22, 1999 to G.R. Peterson of Catawba Nuclear Station).

4. "Topical Report Quality Assurance Program", Duke Energy Corporation, DUKE-1-A, Amendment 25, May 31, 1999.

5. "Delayed-Neutron Yields in Nuclear Fission", R. J. Tuttle, Proceedings of the Consultants' Meeting on Delayed Neutron Properties, International Nuclear Data Committee INDC(NDS)-107/G+Special, March 26-30, 1979.

Table 4

Measured and Predicted Rod Worths
Based on
Westinghouse Predictions

Catawba 1 Cycle 11

BANK	WORTH (pcm)		DIFFERENCE	
	Measured	Predicted	% (M-P)/P	pcm
CA	374.6	397.4	-5.7	-22.8
CB	634.7	610.3	4.0	24.4
CC	889.5	888.0	0.2	1.5
CD	695.0	631.2	10.1	63.8
SA	235.6	232.6	1.3	3.0
SB	889.7	890.0	0.0	-0.3
SC	468.3	443.0	5.7	25.3
SD	462.9	440.1	5.2	22.8
SE	460.8	494.2	-6.8	-33.4
TOTAL	5111.1	5026.8	1.7	84.3

McGuire 2 Cycle 12

BANK	WORTH (pcm)		DIFFERENCE	
	Measured	Predicted	% (M-P)/P	pcm
CA	293.9	336.8	-12.7	-42.9
CB	667.3	644.2	3.6	23.1
CC	763.0	811.7	-6.0	-48.7
CD	624.0	613.5	1.7	10.5
SA	305.5	288.2	6.0	17.3
SB	1067.4	1040.1	2.6	27.3
SC	511.1	489.8	4.3	21.3
SD	513.1	490.8	4.5	22.3
SE	489.0	506.4	-3.4	-17.4
TOTAL	5234.3	5221.5	0.2	12.8

McGuire 1 Cycle 13

BANK	WORTH (pcm)		DIFFERENCE	
	Measured	Predicted	% (M-P)/P	pcm
CA	290.4	304.6	-4.7	-14.2
CB	670.4	645.3	3.9	25.1
CC	709.3	725.4	-2.2	-16.1
CD	569.0	569.9	-0.2	-0.9
SA	262.9	268.4	-2.0	-5.5
SB	994.7	978.1	1.7	16.6
SC	464.1	455.8	1.8	8.3
SD	455.7	455.4	0.1	0.3
SE	513.3	513.2	0.0	0.1
TOTAL	4929.8	4916.1	0.3	13.7

Table 4 (continued)

Measured and Predicted Rod Worths
Based on
Westinghouse Predictions

Catawba 2 Cycle 10

BANK	WORTH (pcm)		DIFFERENCE	
	Measured	Predicted	% (M-P)/P	pcm
CA	377.8	422.1	-10.5	-44.3
CB	601.1	552.9	8.7	48.2
CC	885.9	851.9	4.0	34.0
CD	558.9	563.3	-0.8	-4.4
SA	236.4	240.1	-1.5	-3.7
SB	1004.5	916.2	9.6	88.3
SC	402.5	393.5	2.3	9.0
SD	403.5	393.7	2.5	9.8
SE	477.1	477.1	0.0	0.0
TOTAL	4947.7	4810.8	2.8	136.9

Catawba 1 Cycle 12

BANK	WORTH (pcm)		DIFFERENCE	
	Measured	Predicted	% (M-P)/P	pcm
CA	275.3	288.2	-4.5	-12.9
CB	719.6	696.9	3.3	22.7
CC	780.6	766.1	1.9	14.5
CD	467.2	478.2	-2.3	-11.0
SA	317.0	326.5	-2.9	-9.5
SB	814.6	782.1	4.2	32.5
SC	449.1	457.5	-1.8	-8.4
SD	474.3	461.6	2.8	12.7
SE	511.2	498.3	2.6	12.9
TOTAL	4808.9	4755.4	1.1	53.5

McGuire 2 Cycle 13

BANK	WORTH (pcm)		DIFFERENCE	
	Measured	Predicted	% (M-P)/P	pcm
CA	340.6	352.8	-3.5	-12.2
CB	690.4	643.3	7.3	47.1
CC	815.0	780.9	4.4	34.1
CD	598.9	609.2	-1.7	-10.3
SA	277.6	295.7	-6.1	-18.1
SB	984.6	908.7	8.4	75.9
SC	466.4	463.2	0.7	3.2
SD	478.6	469.2	2.0	9.4
SE	502.9	487.4	3.2	15.5
TOTAL	5155.0	5010.4	2.9	144.6

Table 5

Measured and Predicted Rod Worths
Based on
Duke Predictions

Catawba 1 Cycle 11

BANK	WORTH (pcm)		DIFFERENCE	
	Measured	Predicted	% (M-P)/P	pcm
CA	369.8	396.9	-6.8	-27.1
CB	627.0	587.4	6.7	39.6
CC	886.9	892.5	-0.6	-5.6
CD	687.7	612.9	12.2	74.8
SA	234.5	209.4	12.0	25.1
SB	883.2	888.0	-0.5	-4.8
SC	459.7	428.0	7.4	31.7
SD	458.2	424.3	8.0	33.9
SE	455.5	500.1	-8.9	-44.6
TOTAL	5062.5	4939.5	2.5	123.0

McGuire 2 Cycle 12

BANK	WORTH (pcm)		DIFFERENCE	
	Measured	Predicted	% (M-P)/P	pcm
CA	292.9	323.8	-9.5	-30.9
CB	660.3	645.6	2.3	14.7
CC	761.3	808.3	-5.8	-47.0
CD	620.2	606.5	2.3	13.7
SA	303.1	274.4	10.5	28.7
SB	1067.1	1045.1	2.1	22.0
SC	505.3	483.2	4.6	22.1
SD	508.1	484.2	4.9	23.9
SE	485.3	500.7	-3.1	-15.4
TOTAL	5203.6	5171.8	0.6	31.8

McGuire 1 Cycle 13

BANK	WORTH (pcm)		DIFFERENCE	
	Measured	Predicted	% (M-P)/P	pcm
CA	289.5	302.9	-4.4	-13.4
CB	661.1	646.8	2.2	14.3
CC	708.6	740.8	-4.3	-32.2
CD	564.4	557.1	1.3	7.3
SA	260.5	256.6	1.5	3.9
SB	993.2	998.9	-0.6	-5.7
SC	459.0	443.8	3.4	15.2
SD	450.3	443.4	1.6	6.9
SE	510.1	521.7	-2.2	-11.6
TOTAL	4896.7	4912.0	-0.3	-15.3

Table 5 (continued)

Measured and Predicted Rod Worths Based on Duke Predictions

Catawba 2 Cycle 10

BANK	WORTH (pcm)		DIFFERENCE	
	Measured	Predicted	% (M-P)/P	pcm
CA	374.2	412.9	-9.4	-38.7
CB	596.1	543.7	9.6	52.4
CC	885.9	857.9	3.3	28.0
CD	556.4	552.8	0.7	3.6
SA	237.1	221.4	7.1	15.7
SB	1001.3	913.5	9.6	87.8
SC	399.6	382.3	4.5	17.3
SD	400.3	382.0	4.8	18.3
SE	472.2	465.5	1.4	6.7
TOTAL	4923.1	4732.0	4.0	191.1

Catawba 1 Cycle 12

BANK	WORTH (pcm)		DIFFERENCE	
	Measured	Predicted	% (M-P)/P	pcm
CA	274.9	296.4	-7.3	-21.5
CB	715.3	667.7	7.1	47.6
CC	783.3	771.4	1.5	11.9
CD	464.2	469.5	-1.1	-5.3
SA	317.7	295.8	7.4	21.9
SB	814.1	776.9	4.8	37.2
SC	445.8	437.5	1.9	8.3
SD	470.5	442.9	6.2	27.6
SE	510.1	506.4	0.7	3.7
TOTAL	4795.9	4664.5	2.8	131.4

McGuire 2 Cycle 13

BANK	WORTH (pcm)		DIFFERENCE	
	Measured	Predicted	% (M-P)/P	pcm
CA	338.6	363.0	-6.7	-24.4
CB	679.8	630.0	7.9	49.8
CC	816.3	814.2	0.3	2.1
CD	594.6	570.3	4.3	24.3
SA	278.1	256.5	8.4	21.6
SB	979.2	929.5	5.3	49.7
SC	461.4	436.9	5.6	24.5
SD	473.3	444.3	6.5	29.0
SE	500.7	509.3	-1.7	-8.6
TOTAL	5122.0	4954.0	3.4	168.0

Table 6

Comparison of Predicted Rod Worths Based on Westinghouse and Duke Data

Catawba 1 Cycle 11

BANK	Predicted ROD WORTH (pcm)		DIFFERENCE	
	Westinghouse	Duke	% (D-W)/W	pcm
CA	397.4	396.9	-0.1	-0.5
CB	610.3	587.4	-3.8	-22.9
CC	888.0	892.5	0.5	4.5
CD	631.2	612.9	-2.9	-18.3
SA	232.6	209.4	-10.0	-23.2
SB	890.0	888.0	-0.2	-2.0
SC	443.0	428.0	-3.4	-15.0
SD	440.1	424.3	-3.6	-15.8
SE	494.2	500.1	1.2	5.9
TOTAL	5026.8	4939.5	-1.7	-87.3

McGuire 2 Cycle 12

BANK	Predicted ROD WORTH (pcm)		DIFFERENCE	
	Westinghouse	Duke	% (D-W)/W	pcm
CA	336.8	323.8	-3.9	-13.0
CB	644.2	645.6	0.2	1.4
CC	811.7	808.3	-0.4	-3.4
CD	613.5	606.5	-1.1	-7.0
SA	288.2	274.4	-4.8	-13.8
SB	1040.1	1045.1	0.5	5.0
SC	489.8	483.2	-1.3	-6.6
SD	490.8	484.2	-1.3	-6.6
SE	506.4	500.7	-1.1	-5.7
TOTAL	5221.5	5171.8	-1.0	-49.7

McGuire 1 Cycle 13

BANK	Predicted ROD WORTH (pcm)		DIFFERENCE	
	Westinghouse	Duke	% (D-W)/W	pcm
CA	304.6	302.9	-0.6	-1.7
CB	645.3	646.8	0.2	1.5
CC	725.4	740.8	2.1	15.4
CD	569.9	557.1	-2.2	-12.8
SA	268.4	256.6	-4.4	-11.8
SB	978.1	998.9	2.1	20.8
SC	455.8	443.8	-2.6	-12.0
SD	455.4	443.4	-2.6	-12.0
SE	513.2	521.7	1.7	8.5
TOTAL	4916.1	4912.0	-0.1	-4.1

Table 6 (continued)

Comparison of Predicted Rod Worths Based on Westinghouse and Duke Data

Catawba 2 Cycle 10

BANK	Predicted ROD WORTH (pcm)		DIFFERENCE	
	Westinghouse	Duke	% (D-W)/W	pcm
CA	422.1	412.9	-2.2	-9.2
CB	552.9	543.7	-1.7	-9.2
CC	851.9	857.9	0.7	6.0
CD	563.3	552.8	-1.9	-10.5
SA	240.1	221.4	-7.8	-18.7
SB	916.2	913.5	-0.3	-2.7
SC	393.5	382.3	-2.8	-11.2
SD	393.7	382.0	-3.0	-11.7
SE	477.1	465.5	-2.4	-11.6
TOTAL	4810.8	4732.0	-1.6	-78.8

Catawba 1 Cycle 12

BANK	Predicted ROD WORTH (pcm)		DIFFERENCE	
	Westinghouse	Duke	% (D-W)/W	pcm
CA	288.2	296.4	2.8	8.2
CB	696.9	667.7	-4.2	-29.2
CC	766.1	771.4	0.7	5.3
CD	478.2	469.5	-1.8	-8.7
SA	326.5	295.8	-9.4	-30.7
SB	782.1	776.9	-0.7	-5.2
SC	457.5	437.5	-4.4	-20.0
SD	461.6	442.9	-4.1	-18.7
SE	498.3	506.4	1.6	8.1
TOTAL	4755.4	4664.5	-1.9	-90.9

McGuire 2 Cycle 13

BANK	Predicted ROD WORTH (pcm)		DIFFERENCE	
	Westinghouse	Duke	% (D-W)/W	pcm
CA	352.8	363.0	2.9	10.2
CB	643.3	630.0	-2.1	-13.3
CC	780.9	814.2	4.3	33.3
CD	609.2	570.3	-6.4	-38.9
SA	295.7	256.5	-13.3	-39.2
SB	908.7	929.5	2.3	20.8
SC	463.2	436.9	-5.7	-26.3
SD	469.2	444.3	-5.3	-24.9
SE	487.4	509.3	4.5	21.9
TOTAL	5010.4	4954.0	-1.1	-56.4

Table 7

Comparison of Measured Rod Worths Based on Westinghouse and Duke Data

Catawba 1 Cycle 11

BANK	Measured ROD WORTH (pcm)		DIFFERENCE	
	Westinghouse	Duke	% (D-W)/W	pcm
CA	374.6	369.8	-1.3	-4.8
CB	634.7	627.0	-1.2	-7.7
CC	889.5	886.9	-0.3	-2.6
CD	695.0	687.7	-1.1	-7.3
SA	235.6	234.5	-0.5	-1.1
SB	889.7	883.2	-0.7	-6.5
SC	468.3	459.7	-1.8	-8.6
SD	462.9	458.2	-1.0	-4.7
SE	460.8	455.5	-1.2	-5.3
TOTAL	5111.1	5062.5	-1.0	-48.6

McGuire 2 Cycle 12

BANK	Measured ROD WORTH (pcm)		DIFFERENCE	
	Westinghouse	Duke	% (D-W)/W	pcm
CA	293.9	292.9	-0.3	-1.0
CB	667.3	660.3	-1.0	-7.0
CC	763.0	761.3	-0.2	-1.7
CD	624.0	620.2	-0.6	-3.8
SA	305.5	303.1	-0.8	-2.4
SB	1067.4	1067.1	0.0	-0.3
SC	511.1	505.3	-1.1	-5.8
SD	513.1	508.1	-1.0	-5.0
SE	489.0	485.3	-0.8	-3.7
TOTAL	5234.3	5203.6	-0.6	-30.7

McGuire 1 Cycle 13

BANK	Measured ROD WORTH (pcm)		DIFFERENCE	
	Westinghouse	Duke	% (D-W)/W	pcm
CA	290.4	289.5	-0.3	-0.9
CB	670.4	661.1	-1.4	-9.3
CC	709.3	708.6	-0.1	-0.7
CD	569.0	564.4	-0.8	-4.6
SA	262.9	260.5	-0.9	-2.4
SB	994.7	993.2	-0.2	-1.5
SC	464.1	459.0	-1.1	-5.1
SD	455.7	450.3	-1.2	-5.4
SE	513.3	510.1	-0.6	-3.2
TOTAL	4929.8	4896.7	-0.7	-33.1

Table 7 (continued)

**Comparison of Measured Rod Worths
Based on
Westinghouse and Duke Data**

Catawba 2 Cycle 10

BANK	Measured ROD WORTH (pcm)		DIFFERENCE	
	Westinghouse	Duke	% (D-W)/W	pcm
CA	377.8	374.2	-1.0	-3.6
CB	601.1	596.1	-0.8	-5.0
CC	885.9	885.9	0.0	0.0
CD	558.9	556.4	-0.4	-2.5
SA	236.4	237.1	0.3	0.7
SB	1004.5	1001.3	-0.3	-3.2
SC	402.5	399.6	-0.7	-2.9
SD	403.5	400.3	-0.8	-3.2
SE	477.1	472.2	-1.0	-4.9
TOTAL	4947.7	4923.1	-0.5	-24.6

Catawba 1 Cycle 12

BANK	Measured ROD WORTH (pcm)		DIFFERENCE	
	Westinghouse	Duke	% (D-W)/W	pcm
CA	275.3	274.9	-0.1	-0.4
CB	719.6	715.3	-0.6	-4.3
CC	780.6	783.3	0.3	2.7
CD	467.2	464.2	-0.6	-3.0
SA	317.0	317.7	0.2	0.7
SB	814.6	814.1	-0.1	-0.5
SC	449.1	445.8	-0.7	-3.3
SD	474.3	470.5	-0.8	-3.8
SE	511.2	510.1	-0.2	-1.1
TOTAL	4808.9	4795.9	-0.3	-13.0

McGuire 2 Cycle 13

BANK	Measured ROD WORTH (pcm)		DIFFERENCE	
	Westinghouse	Duke	% (D-W)/W	pcm
CA	340.6	338.6	-0.6	-2.0
CB	690.4	679.8	-1.5	-10.6
CC	815.0	816.3	0.2	1.3
CD	598.9	594.6	-0.7	-4.3
SA	277.6	278.1	0.2	0.5
SB	984.6	979.2	-0.5	-5.4
SC	466.4	461.4	-1.1	-5.0
SD	478.6	473.3	-1.1	-5.3
SE	502.9	500.7	-0.4	-2.2
TOTAL	5155.0	5122.0	-0.6	-33.0

APPENDIX A

In order for a utility to perform their own physics calculations to support the use of the Dynamic Rod Worth Measurement (DRWM) technique during the Low Power Physics Testing (LPPT), the following five criteria must be met. Compliance with the following five criteria demonstrates a utility's qualification and constitutes inherent NRC approval to use DRWM in their LPPT. To document its qualification, the utility must send the NRC a notification of compliance with the criteria and the date of the intended first application of the codes to determine the DRWM physics constants for LPPT. Any voluntary limitations or restrictions of the utility's use of the DRWM methodology must also be addressed in the notification. The NRC would then, at their option, audit the application of the utility's DRWM program to ensure compliance.

1) <u>Criterion 1: Eligibility of Codes for DRWM Computations</u>

Only lattice physics codes and methods which have received prior NRC review and approval are eligible to be used in determining the physics constants to be used in DRWM. The NRC review ensures that the codes being used for the DRWM computations were developed under a qualified QA program and were properly benchmarked and verified.

2) <u>Criterion 2: Application of Procedures to DRWM Computations</u>

In a manner consistent with the procedures obtained from Westinghouse, the utility analyses shall be performed in conformance with in-house application procedures which ensure that the use of the methods is consistent with the Westinghouse approved application of the DRWM methodology.

3) <u>Criterion 3: Training and Qualification of Utility Personnel</u>

The first application of DRWM for LPPT will be performed by Westinghouse. This will ensure that DRWM is applicable to the specific plant, provide utility personnel with training in the DRWM technique and be used to meet Criterion 4 - Comparison Calculations for the DRWM Technique. The first application of DRWM for LPPT by Westinghouse will be applicable for all of the same plant type at the plant site of application. If the fuel vendor should change subsequent to the first application, a second application by Westinghouse is not required.

Utilities shall establish and implement a training program to ensure that each qualified user of the DRWM methodology has a good working knowledge of the codes and methods used for DRWM. This training shall include the ability to set up input decks, understand and interpret output results, understand applications and limitations, and to perform analyses in compliance with the procedures provided by Westinghouse.

4) Criterion 4: Comparison Calculations for the DRWM Technique

Prior to the first application by a utility using their own methods to perform physics calculations in support of DRWM for LPPT, the utility will demonstrate its ability to use the methods supplied by Westinghouse by comparing its calculated results with the analyses and results obtained by Westinghouse during the first, or subsequent, application(s) of DRWM at the utility's plant. These comparisons must be documented in a report which is part of the utility's QA records. Any significant differences between the calculations and the comparison data must be discussed in the report. As a minimum, the following parameters should be compared to the supplier of the DRWM methodology calculations, and should agree within the given acceptable deviation:

Parameter	Acceptable Deviation
Calculated Bank Worth	±2% or ±25 pcm
Calculated Total Worth of All Banks	±2%
Measured Bank Worth Obtained for First Application	±2% or ±25 pcm
Measured Total Worth Obtained for First Application	±2%

5) Criterion 5: Quality Assurance and Change Control

All calculations for DRWM by a utility using the Westinghouse methodology which has been approved by the NRC shall be conducted under the control of a quality assurance program which meets the requirements of 10 CFR 50, Appendix. The utility QA program will also include the following:

a) A provision for implementing changes in the methods and procedures being used for DRWM.

b) A provision for informing Westinghouse of any problems or errors discovered while using the DRWM[1] methods or procedures.

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1 Westinghouse has a requirement to inform utilities that have taken a Technology Transfer on DRWM of changes to the process as part of the their QA procedures regarding Technology Transfer.