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SUBJECT: Forwards "Comparison of Two Dimensional & Three Dimensional Analyses of Core w/Part Length Burnable Position Rods," detailing info re power distribution monitoring in Cycle 8 during initial startup.

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December 1, 1983
AEP:NRC:0745J

Donald C. Cook Nuclear Plant Unit No. 1
Docket No. 50-315
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POWER DISTRIBUTION MONITORING

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

Dear Mr. Denton:

The attachment to this letter is the information regarding power distribution monitoring in Donald C. Cook Nuclear Plant Unit 1, Cycle 8 during initial startup, and confirms conversations which we had with members of your staff during the week of October 31, 1983. Due to the introduction of part length burnable poison rods in Cycle 8, American Electric Power Service Corporation determined that the use of three-dimensional theoretical factors was necessary for providing a better estimate of measured hot channel factors. During startup and prior to entering data in the flux map, AEPSC detected errors in the Westinghouse generated three-dimensional theoretical factors. Accordingly, the 90% RTP flux map was analyzed with the conventional Westinghouse generated two-dimensional theoretical factors. Added restrictions on heat flux hot channel factor, F_Q, were imposed by AEPSC as recommended by Westinghouse in conjunction with the use of two-dimensional theoretical factors. Based on the results from the flux map, the reactor power was raised to 95% RTP. The flux maps taken at 90% RTP and 95% RTP were rerun with the corrected three-dimensional factors which supported increasing power level to 100% RTP. The purpose of the attached report is to review the added restrictions imposed on F_Q during the short period in which Unit 1 operation was based on results from the 90% flux map analyzed with two-dimensional theoretical factors.

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This document has been prepared following corporate procedures which incorporate a reasonable set of controls to insure its accuracy and completeness prior to signature by the undersigned.

Very truly yours,

Milton P. Alexich
Vice President

MPA:bjs

cc: John E. Dolan
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G. Charnoff
E.R. Swanson, NRC Resident Inspector - Bridgman

ATTACHMENT TO AEP:NRC:0745J

COMPARISON OF TWO DIMENSIONAL

AND THREE DIMENSIONAL ANALYSES

OF A CORE WITH PART LENGTH BURNABLE POISON RODS

1. INTRODUCTION

The reactor core of the Donald C. Cook Nuclear Plant Unit 1, Cycle 8 consists of 193 fuel assemblies arranged as shown in Figure 1. Of these assemblies, 113 are Exxon manufactured assemblies from previous cycles and 80 are Westinghouse manufactured assemblies for the Cycle 8 feed region. Each fuel assembly consists of a 15 X 15 array of 204 fuel rods, 20 RCC guide thimbles and one instrumentation thimble. Part Length Burnable Poison rods (PLBP) are incorporated in some of the fresh fuel assemblies and is shown in Figure 1. In these PLBP assemblies the lower foot and the top nine inches are unpoisoned.

By utilizing the DETECTOR code (part of the CORE package), best estimates for the power distribution are obtained by combining measured in-core detector responses with calculated values for the detector responses and for the power distribution. These calculated values are termed theoretical factors.

Conventionally theoretical factors have been obtained from XY two dimensional (2D) predictive analysis computer methods performed by the fuel vendor. However, Westinghouse (W) now has the capability to produce 3D theoretical factors by combining coarse mesh (48 axial mesh points and 4 XY mesh points per assembly) with detailed XY (pin by pin) 2D calculational results.

American Electric Power Service Corporation (AEPSC) requested these 3D theoretical factors for use in Cycle 8. The 3D theoretical factors are available for three axial configurations which consist of axial average values for the bottom 12 inches, middle 123 inches, and top 9 inches.

For purposes of ex-core/in-core detector calibration, and for analysis of any other maps in which the control rods are significantly inserted, W also provided 2D theoretical factors. These are available for two axial configurations: all-rods-out (ARO) and D-Bank fully inserted (DBI). These theoretical factors are to be used for analyzing quarter core flux maps for the sole purpose of obtaining axial offsets.

During Cycle 8 power ascension in the week of October 31, 1983 AEPSC discovered discrepancies in the full power 3D theoretical factors. As a result, the 90% (of full power) map was analyzed utilizing the 2D theoretical factors. For this map the following additional penalties in the technical specification for the heat flux peaking factor, F_Q, were applied as recommended by W:

(1) 15% reduction in the F_Q limit for the top and bottom ten percent of the core,

(2) 2% reduction for the next 10%, and

(3) 1% reduction for the center sixty percent of the core.

With these added restrictions, and utilizing 2D theoretical factors, the DETECTOR results for the 90% power map showed that the estimate for the allowable power was 96.5%. This estimate is conservative since no further flattening of power is assumed.

The power level was then raised to 95% and another map taken. Due to additional power flattening at this power level, the estimate for the allowable power was 98%. The flux map was analyzed with 2D theoretical factors.

Unit 1 was held at the 95% power level throughout the remainder of the week of October 31, 1983. By Friday, November 4, 1983 W had determined the mistake in the data processing of the 3D theoretical factors, had transmitted a tape of new 3D theoretical factors to AEPSC, and had performed a QA verification of the values.

On Friday, November 4, 1983 the 95% power map was reanalyzed by AEPSC, results were checked, and no discrepancies found. Consistent with the margin gained with the 3D factors, Unit 1 was subsequently taken to full power on Monday, November 7, 1983.

The purpose of this report is to review the adequacy of the technical specification penalties during the short period in which the 2D theoretical factors were used.

2. POWER AND FLUX CHARACTERISTICS IN A CORE WITH PART LENGTH BURNABLE POISON RODS

The radial power distribution in a core with part length burnable poison rods (PLBP) is significantly different at axial locations with no PLBP's compared to axial locations with PLBP's.

This is illustrated in Figure 2 which lists assembly powers from the AEPSC-3D-XTG calculation for hot full power conditions. Results are presented for axial planes 2 and 24 (out of 48 axial nodes and numbering from the top downward) and for the axially integrated assembly powers. All three power distributions are separately normalized to give an average assembly power of unity in that plane.

Significant differences in the power sharing are observed for assemblies with PLBP's; eg H-13, G-12, F-11; and AEPSC's request for 3D theoretical factors was a result of this type of analysis. For example, if power at the top of assembly F-11 is extrapolated from detector readings in assembly F-12 using 2-D theoretical factors, then there is a potential for underestimating power in F-11 as much as 20%.

These calculational differences are further illustrated in Table 1 for three sample assemblies. The assembly at L-10 contains fresh fuel of 3.3% enrichment and

has 16 PLBP's. Assemblies L-11 and L-13 have no PLBP's and both had an initial enrichment of 2.9%. However, L-11 has been irradiated to 21820 MWD/MT while L-13 has a burnup of 9536 MWD/MT.

Again in Table 1 the assembly powers are all normalized to an average of unity for each axial configuration (or axial node for the XTG results). Relative values for the calculated detector responses are also listed in Table 1. These values have been normalized to give power to response ratios of unity for the dominant axial configuration for Assembly L-10.

For the 3D values axial configuration 3 is at the top of the core and corresponds to XTG nodes 1 through 3. Axial configuration 1 is at the bottom and corresponds to XTG nodes 45 through 48.

The change in the relative power for different axial configurations of Asm. L-10 is clear from both the XTG data and the 3D theoretical factors.

The effect of utilizing 2D theoretical factors will be addressed in the next section.

LOCATIONS OF SOURCES AND BURNABLE ABSORBERS

	R	P	N	M	L	K	J	H	G	F	E	D	C	B	A
1					8	10B SS*	10B 4	10B	10B 4	10B	8				
2			8	9	10B 12	9	10A 12	8	10A 12	9	10B 12	9	8		
3		8	9	10B 12	9	10A 16	8	10A 16	8	10A 16	9	10B 12	9	8	
4		9	10B 12	9	9	9	10A 16	9	10A 16	9	9	9	10B 12	9	
5	8	10B 12	9	9	8	10A 16	8	9	8	10A 16	8	9	9	10B 12	8
6	10B	9	10A 16	9	10A 16	8	10A 12	8	10A 12	8	10A 16	9	10A 16	9	10B
7	10B 4	10A 12	8	10A 16	8	10A 12	9	9 SS	9	10A 12	8	10A 16	8	10A 12	10B 4
8	10B	8	10A 16	9	9	8	9	8	9	8	9	9	10A 16	8	10B
9	10B 4	10A 12	8	10A 16	8	10A 12	9	9	9	10A 12	8	10A 16	8	10A 12	10B 4
10	10B	9	10A 16	9	10A 16	8	10A 12	8	10A 12	8	10A 16	9	10A 16	9	10B
11	8	10B 12	9	9	8	10A 16	8	9 SS	8	10A 16	8	9	9	10B 12	8
12		9	10B 12	9	9	9	10A 16	9	10A 16	9	9	9	10B 12	9	
13		8	9	10B 12	9	10A 16	8	10A 16	8	10A 16	9	10B 12	9	8	
14			8	9	10B 12	9	10A 12	8	10A 12	9	10B 12	9	8		
15					8	10B	10B 4	10B	10B 4	10B SS*	8				

X - Region Number
YY - Number of Wet Annular Burnable Absorbers, or
- Source Rods (unirradiated source, SS; irradiated source, SS*)

Figure 1

	H	G	F	E	D	C	B	A
8	0.882 0.874 0.935							
9	1.111 1.108 1.104	1.145 1.137 1.156						
10	0.926 0.913 0.994	1.204 1.183 1.329	0.933 0.910 1.043					
11	1.073 1.062 1.088	0.932 0.912 1.019	1.111 1.079 1.303	0.918 0.906 0.973				
12	1.104 1.086 1.144	1.145 1.112 1.325	1.072 1.057 1.112	1.188 1.193 1.114	1.110 1.114 1.057			
13	1.137 1.112 1.278	0.934 0.920 0.996	1.209 1.192 1.315	1.122 1.125 1.072	1.114 1.114 1.126	0.684 0.688 0.660		
14	0.984 0.992 0.940	1.267 1.277 1.220	1.175 1.194 1.041	1.050 1.056 1.031	0.565 0.567 0.554	0.256 0.256 0.259		
15	1.195 1.250 0.891	1.138 1.183 0.901	1.034 1.080 0.786	0.385 0.392 0.358				

Donald C. Cook Nuclear Plant
Unit No. 1
Cycle No. 8

HFP
XTG-3D

KEY

0.256	2-D Power, Axially Avg.
0.256	Rel. Power in Axial Plane No. 24
0.259	Rel. Power in Axial Plane No. 2

FIGURE 2

TABLE 1

SAMPLE DATA

DATA SOURCE	AXIAL CONFIGURATION OR AXIAL LOCATION	POWER THEORETICAL FACTORS (P)			DETECTOR RESPONSE THEORETICAL FACTORS (R)			RATIO OF POWER TO DETECTOR RESPONSE		
		L-10	L-11	L-13	L-10	L-11	L-13	L-10	L-11	L-13
W3D	3	1.2728	1.0749	1.0934	1.1970	1.1612	1.0909	1.0633	0.9257	1.0023
TF'S	2	1.1118	0.9691	1.1546	1.1118*	1.1731	1.2139	1.0*	0.8261	0.9511
	1	1.2492	0.9751	1.1136	1.1785	1.0902	1.1292	1.0600	0.8944	0.9862
W2D	DBI	1.3600	1.1529	1.1427	1.3582	1.3922	1.2784	1.0013	0.8281	0.8939
TF'S	ARO	1.1280	0.9747	1.1500	1.1280*	1.1744	1.2805	1.0	0.8300	0.8981
	1	1.299	0.993	1.076						
	2	1.303	0.973	1.072						
	3	1.283	0.961	1.076						
	4	1.157	0.988	1.124						
AEP	24	1.079	0.906	1.125						
XTG	44	1.130	0.918	1.124						
	45	1.258	0.886	1.075						
	46	1.283	0.894	1.070						
	47	1.285	0.913	1.074						
	48	1.276	0.935	1.081						

*Normalized to give unity ratio of power to response.

3. POWER CALCULATION IN THE DETECTOR CODE

For a simplified example where only a single detector is used, the fundamental equation for power calculation is:

$$P_k^{M,n} = \frac{P_k^{C,n}}{R_i^{C,n}} R_i^M \qquad (1)$$

where,

$P_k^{M,n}$ is the best estimate for power at horizontal location k, based on n dimensional theoretical factors,

$P_k^{C,n}$ is the calculated power (theoretical factor)

$R_i^{C,n}$ is the calculated detector response (TF), and

R_i^M is the measured detector response at horizontal location i.

If we define the relative difference between 2D and 3D best estimates of the powers as

$$r = \frac{P_k^{M,2}}{P_k^{M,3}} - 1 \qquad (2)$$

then combination of (1) and (2) gives

$$r = \frac{P_k^{C,2} \; R_i^{C,3}}{P_k^{C,3} \; R_i^{C,2}} - 1 \qquad (3)$$

Sample values for the relative differences are listed in Table 2 using the data of Table 1. Values are listed for both the instrumented case (where the single detector within the fuel assembly is utilized) and for extrapolation from one location to another. For the purpose of comparison, in the case of the 2D theoretical factors we use the DBI factors for axial configuration 3 and the ARO factors for axial configurations 1 and 2.

For the selected sample, data differences as large as 10% are observed for power calculations in instrumented assemblies and differences as large as 20% for power calculations by extrapolation from detector responses in other assemblies. This clearly indicates the desirability of 3-D theoretical factors for cycle 8 flux maps.

The simplified power calculation of Table 2 is only valid for use of a single detector with no axial flux synthesis. Actual DETECTOR results involve more complicated combinations of detectors and theoretical factors. Examples from the computer results are presented in the next section.

Table 2

Sample Relative Differences Between 2D and 3D Best Estimate Powers, %

	Instrumented Results			Extrapolated Results		
AC	L-10	L-11	L-13	L10/L11	L10/L13	L11/L13
3	-5.8	-10.5	-10.8	-10.9	- 8.8	- 8.5
2	0.0*	0.5	- 5.6	1.3	- 3.8	- 4.7
1	-5.7	- 7.2	- 8.9	-16.2	-20.4	-11.9

* Normalized to zero

4. COMPARISON OF COMPUTER RESULTS FOR 2D VERSUS 3D THEORETICAL FACTORS

The results of this section are taken from the 90% power map. This map (as well as that for 95% power) displayed excellent symmetry characteristics. Therefore in the DETECTOR analysis the symmetry power calculational option was utilized. For locations with no symmetry detectors the nearest detectors to any symmetrical location were utilized. Moreover, multiple detector responses (eg all symmetry detectors) were averaged and an axial flux synthesis technique was employed.

Selected results from DETECTOR runs with 2D theoretical factors are compared to results with 3D theoretical factors in Table 3.

The results for Asm. L-10 can be compared to the hand estimates given in Column 2 of Table 2.

Fuel pin H15FD is the limiting pin for the F_Q technical specification (at axial location 25) for both the 2D and the 3D analyses of the 90% power map. (Location G-14 is limiting in the 95% map in agreement with the calculated XTG results presented in Figure 3). The same pin is limiting for F_Q surveillance requirements which incorporate a transient V(Z) parameter. Axial location 28 is limiting for the F_Q surveillance.

TABLE 3

2D AND 3D "MEASURED" POWER

RESULTS FROM DETECTOR

HOR. LOC. BP POWER OPT. FUEL POWER	H-15 NO BP INS H15FD			L-10 BP INS ASM			E-14 BP NEAREST-SYM E14AA		
AL	2D	3D	r(%)	2D	3D	r(%)	2D	3D	r(%)
61	2.303	2.341	-1.6						
60	2.954	3.002	-1.6						
59	3.860	3.924	-1.6	4.7925	5.0220	-4.6	4.719	4.432	6.5
58	4.662	4.737	-1.6						
57	5.311	5.334	-0.4						
56	5.541	5.528	0.2						
28	10.135	9.911	2.3	7.6011	7.5713	0.4	9.648	9.568	0.8
25	10.169	9.944	2.3						
7	8.298	8.122	2.2						
6	7.760	7.601	2.1						
5	7.016	6.876	2.0						
4	6.051	5.929	2.1						
3	4.854	4.757	2.0	4.1704	4.3600	-4.3	4.719	5.073	-7.0
2	3.317	3.250	2.1						
1	1.660	1.625	2.2						

Fuel pin E14AA is limiting for the $F_{\Delta H}$ technical specification, based on the 3D analysis. The E-14 location is uninstrumented and has no detectors in symmetric locations.

The difference in limiting F_Q is 1.6648/1.6279 - 1 or 2.3% which, of course, is consistent with Table 3. The difference in limiting $F_{\Delta H}$ is 1.3943/1.3626 - 1 or again 2.3%. However, for limiting $F_{\Delta H}$ the 2D analysis predicts a different fuel pin than that of the 3D analysis.

5. UNCERTAINTY ANALYSIS IN THE DETECTOR CODE

While the difference between 2D and 3D power predictions are of interest, of greater interest are the uncertainties of results of both analyses relative to true values for power.

The DETECTOR code estimates uncertainties in the predictions for F_Q and for $F_{\Delta H}$ for each flux map and for each power calculational option. This analysis is described in detail in the CORE documentation, SNA-1624, however a summary is given below.

There are four principle steps in the uncertainty analysis:

(1) determining the variance in using a detector at horizontal location i to predict detector response at horizontal location k,

(2) determining the variance in predicting the local (within assembly) ratio of pin power to predicted (or measured) detector response in that assembly,

(3) establishment of 95% confidence limits for the standard deviations (square-root of the variance), and

(4) multiplying the results of (3) by the one-sided 95% probability factor (1.6449).

Results of the uncertainty analysis are listed in Table 4 for the symmetry power calculational option, which was utilized in the DETECTOR analyses of the 90% power map.

The differences between the best estimate and the conservative uncertainties result from the local uncertainty factor (Step 2). The algorithm for internal calculation of the local uncertainty factor was introduced in the February, 1983 Version of DETECTOR. Prior to that time AEPSC utilized an input data value of 1.35% for the standard deviation in the local factor, based upon analysis of critical experiment results by Exxon Nuclear Company. The conservative estimates of the uncertainties in Table 4 utilize this value. The best estimates for the standard deviations in the local factor for the 90% power map are as follows:

T.F Set	Standard Deviation, %	
	$F_{\Delta H}$	F_Q
3D	0.65	0.67
2D	0.83	1.00

It is seen from Table 4 that even the 2D theoretical factors yield 95%/95% uncertainties that are lower than the technical specification value of 5% for F_Q and 4% for $F_{\Delta H}$. It should be noted that uncertainty estimates apply specifically to the 90% map and is not generic.

Table 4

Estimated Uncertainties in F_Q and $F_{\Delta H}$ Predictions, %

Theoretical Factors		Standard Deviations % $F_{\Delta H}$	F_Q	95/95 Uncertainties $F_{\Delta H}$	F_Q
3D	Best Est	1.06	1.33	2.02	2.52
	Conserv.	1.59	1.77	3.03	3.36
2D	Best Est	1.23	2.38	2.34	4.53
	Conserv.	1.63	2.55	3.10	4.85

6. UNCERTAINTIES AS A FUNCTION OF AXIAL LOCATION

While the DETECTOR code does not perform an uncertainty analysis for each axial location, it is possible to derive rational estimates for these values.

The principal component in the uncertainty analysis is the ratio of calculated to measured detector response. If we call the standard deviation in this ratio, σ_r, then the variance in predicting detector responses, σ^2, is

$$\sigma = 2\sigma_r^2 - 2\sigma_{ik} \qquad (4)$$

where σ_{ik} is the covariance related to predicting detector response at horizontal location k from the measured response at horizontal location i. The covariance goes to zero for random combinations of detector locations and goes to σ_r^2 for perfect correlation.

The bounds of the variance in predicting detector response are, therefore;

$$0 \leq \sigma^2 \leq 2\sigma_r^2 \qquad (5)$$

As part of the axial flux synthesis, values for σ_r are available from the DETECTOR code as a function of axial location. Selected values for these residuals are listed in Table 5.

We then obtain a rough estimate for the uncertainty as a function of axial location by assuming that the ratio of σ_{ik} to σ_r^2 is constant as is the ratio of the variance in the local peaking factor to σ^2.

Specifically, the uncertainty estimates of Table 5 are obtained by multipling σ_r by the ratio 3.36/3.93 = 0.855, where the numerator is the (conservative) estimate for the 95%/95% uncertainty in F_Q for the 3D analysis, and the denominator is the value of σ_r for the limiting axial location 28.

Likewise for the 2D analysis the ratio is 4.85/4.39 = 1.105.

Finally, the differences of the residuals and of the rough estimates for the 95%/95% uncertainties are listed in Table 6. The third column of Table 6 lists the differences between the rough estimates for the 2D 95%/95% uncertainties and the 5% uncertainty incorporated in the F_Q technical specification.

It is concluded that the use of 2D theoretical factors for the 90% and 95% power maps was justified. In particular, the last two columns of Table 6 indicate that the added F_Q penalties were reasonable for the center 80% of the core and

quite conservative for the top and bottom 10%. The large errors at axial locations 1 and 61 are typical and not due to the 2D factors. These points are strongly affected by errors in precise detector location and physical irregularities in the core axial boundaries due to fuel pin slippage.

Certainly the combination of the 2D penalties and maintaining a power level of 95% while using the 2D factors was quite conservative.

Table 5

Rough Estimates for Uncertainty

as a Function of Axial Location

Axial	Residuals, σ_r, %		Est. 95/95 Uncert.	
Location	2D	3D	2D	3D
61	28.56	30.16	31.6	25.8
60	8.61	11.83	9.5	10.1
59	7.04	9.03	7.8	7.7
58	5.07	5.00	5.6	4.3
57	3.60	2.94	4.0	2.5
56	3.87	3.32	4.3	2.8
28	4.39	3.93	4.8	3.4
7	5.14	3.57	5.7	3.1
6	6.59	3.57	7.3	3.1
5	8.60	4.28	9.5	3.7
4	10.28	5.82	11.4	5.0
3	12.78	8.80	14.1	7.5
2	12.89	9.01	14.2	7.7
1	33.42	31.52	36.9	26.9

Table 6
Comparison of 2D Uncertainties with 3D Uncertainties as a Function of Axial Location

Axial Location	Residual Differences 2D - 3D, %	95/95 Uncertainty Differences 2D - 3D, %	2D 95/95 Uncertainty -5%
61	-1.6	5.8	26.6
60	-3.2	-0.6	4.5
59	-2.0	0.1	2.8
58	0.1	1.3	0.6
57	0.7	1.5	-1.0
56	0.6	1.5	-0.7
-			
-			
-			
28	0.5	1.4	-0.2
-			
-			
-			
7	1.6	2.6	0.7
6	3.0	4.2	2.3
5	4.3	5.8	4.5
4	4.5	6.4	6.4
3	4.0	6.6	9.1
2	3.9	6.5	9.2
1	1.9	10.0	31.9