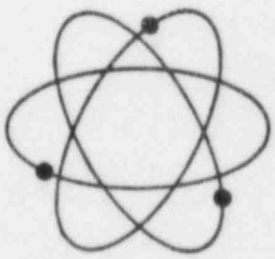
VEP-NOS-8

Vepco

A STUDY OF THE EFFECTS OF A REDUCED NUMBER OF THIMBLES ON THE RESULTS OF INCORE FLUX MAP ANALYSIS



NUCLEAR OPERATIONS DEPARTMENT
VIRGINIA ELECTRIC AND POWER COMPANY

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A STUDY OF THE EFFECTS OF A REDUCED NUMBER OF THIMBLES ON THE RESULTS OF INCORE FLUX MAP ANALYSIS

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ABSTRACT

The purpose of this study is to examine the effects of reducing the number of monitored thimbles on incore map analysis results produced by the INCORE code. The present Technical Specifications for the Surry and North Anna power stations require a minimum of thirty-eight monitored thimbles for a full core map. This study was performed to derive incremental conservative factors which can be used to produce conservative results when applied to the power distribution parameters for incore maps which have less than the presently required minimum number of monitored thimbles and, thereby, allow such maps to be acceptable for incore analysis.

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SECTION 1 - INTRODUCTION

The Technical Specifications for the Surry and North Anna Power Stations require that any valid full-core flux map be taken with a minimum of thirty-eight monitored thimbles. In the event of a malfunction in the flux mapping system hardware, it might be desirable to take valid full-core flux maps with a lesser number of monitored thimbles. This study shows the behavior of the results of flux map analyses using less thimbles. From those results, appropriate incremental conservative factors have been determined for important incore power distribution parameters based upon the number of monitored thimbles that provided data for the analysis. These factors, when applied to the appropriate power distribution parameters, yield results that are equivalent to or conservative with respect to the results of a map utilizing the present minimum number of required thimbles.

In order to perform this study, the INCORE code was modified to reduce the program output and to provide an automatic random selection of thimbles. The program output for this study consisted of a core map of the chosen thimbles, the average axial offset, the maximum F-delta-H, the maximum Fq, the Fq*P minimum margin, the average quadrant power tilt, the Fxy at the core midplane for Surry maps, and the maximum Fxy and the minimum Fxy margin for North Anna maps.

A total of eight flux maps from Surry and North Anna were used as the reference data base for this study. For each of those flux maps, three major analysis cases were considered. The major analysis cases utilized data obtained from thirty-eight, thirty-two, and twenty-six monitored thimbles. For each of the major analysis cases, a minimum of one hundred

individual analyses were performed. (The flux maps and the number of major analysis cases that were performed for each map are described in Appendix 1). Following this, a statistical study was performed on the data that was generated. Each map analysis result was checked for uniqueness and only analyses with at least four thimbles per quadrant were used.

The applicability of this report is limited to incore flux map analysis results developed by the Vepco staff for the Surry and North Anna Power Stations.

SECTION 2 - DESCRIPTION OF THE INCORE CODE MODIFICATIONS

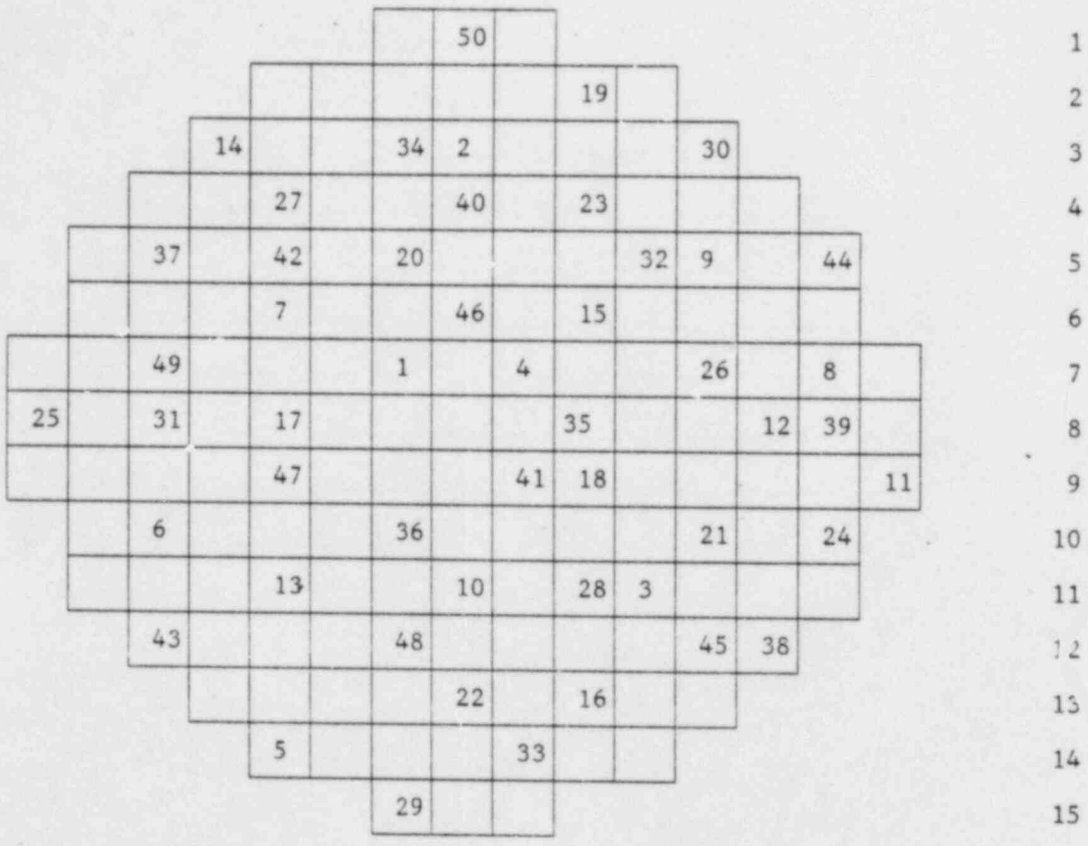
The current Vepco version of the INCORE code[1] was modified in order to reduce the program output to a minimum and to allow the automatic selection of randomly chosen thimbles. The calculational basis of the code was not changed in any manner. Output statements were deleted from the program until the output consisted only of the values for the parameters of interest to this study.

The fifty possible monitored thimble locations in the core were represented by a one-dimensional array of fifty columns, the location of each column in the array corresponding to a particular thimble location. The INCORE code assigned a value to each of the fifty columns depending on whether the thimble location corresponding to that particular column was monitored or not. A value of one was assigned if the location was monitored, and a value of zero if it was not. This provided an efficient method for checking on the uniqueness of a randomly selected map. A map of the possible monitored core locations is given as Figure 2-1.

After the program output had been reduced to a minimum, the code was used to analyze the same flux map several times during one execution. This step was performed in order to verify that the modified code would correctly analyze a sequence of flux maps.

FIGURE 2-1

CORE MAP OF MONITORED LOCATIONS



SECTION 3 - DESCRIPTION OF THE RANDOM THIMBLE SELECTION PROCESS

A single dimensional array of size fifty was initalized before beginning the analysis of a map. This array contained the numeric identification of all the valid thimbles for the map (see Figure 2-1). The first element of the array contained the identication number of the calibration thimble. This was typically a "1" which stands for the J-7 core location which is the calibration thimble for the North Anna 1 and 2 and Surry 2 maps. For the Surry 1 maps, the first element of the array contained a "4" which is the identification number of the G-7 core location which is the calibration thimble for that unit. The remaining elements of the array contained the identification of the other valid thimbles.

A shuffle of the data was accomplished by randomly choosing two numbers, m and n, between two and i inclusive, where i is the maximum number of valid thimbles (the number measured in the original case) and m is not equal to n. Elements m and n of the array were interchanged. After the shuffle had been performed a random number of times (from 200 to 300), the first j elements of the array contained the thimbles used for the map analysis. For this study, j was twenty-six, thirty-two, or thirty-eight. After the map was analyzed using this list of thimbles, the array was shuffled again in the same manner and the analysis continued.

SECTION 4 - DESCRIPTION OF CODE OUTPUT

The output of the modified INCORE code was stored in a data set for further use. The first line of the data set is a title line which contains the station, unit, cycle, and map identification, the number of thimbles used, and the numerical representation of the valid thimbles. As seen in the examples below, the list of valid thimbles given on the title line is composed of ones and zeroes. A one represents a thimble that was monitored in the original map and a zero represents a thimble that was not. This convention was also used in the numerical representation of the flux map case described below. For a North Anna reduced thimble case, each flux map is described by three lines of information. The first line contains the numerical representation of the map of monitored locations and the number of thimbles per quadrant. The second line contains the assemblywise power distribution standard deviation, the average absolute percent difference to prediction, the average axial offset, the maximum F-delta-H, the maximum Fq, the minimum Fq*P margin and its nodal location, and the average quadrant power tilt. The third line contains the nodal location of the maximum Fxy, the maximum Fxy, and the minimum Fxy margin for the rodded and unrodded core regions respectively. Zero entries for the parameters on this line indicate that no rodded Fxy and minimum Fxy margin values existed. The following is an example of the output associated with the first two reduced thimble cases from a North Anna map:

```
N1-2-01   26 THIMBLES   11111111111111111111111111111111111111111011111011111
11101101110111010110100110000110101001011000010100   4.5   6.5   5.5   9.5
  3.97681  6.13923 47.67577  1.67375  3.27350 11.04805 10  1.07207
 0   0.0       0.0     40   1.84261   2.19095
10101010010111011000111000100111011001010101011100   8.0   6.0   6.0   6.0
```

```
 4.10122  6.23767 48.53163  1.58809  2.99493 18.61774 10  1.08003
0   0.0       0.0      40   1.84034   2.31153
```

For a Surry case study, the first line of the data set is a title line and is identical with the North Anna case. Each reduced thimble flux map consists of two lines of information. The first line contains the numerical representation of the map of monitored locations and the number of thimbles per quadrant. The second line contains the assembly wise power distribution standard deviation, the average absolute percent difference to prediction, the average axial offset, the maximum F-delta-H, the maximum Fq, the minimum Fq*P margin and its nodal location, Fxy at the core midplane, and the average quadrant power tilt. The following is an example of the output associated with the first two reduced thimble cases from a Surry map:

```
S2-6-12 32 THIMBLES 11110111111111111111111111111100110011101111111110
11110111011111110111111101010110011000010010000011110  6.0  8.5  6.0 11.5
 0.75552  1.14992 -2.38548  1.33039  1.59392 21.03532 33 1.33541 1.00413
10110111110101101110001111111000100111001110111010  8.5  8.0  6.5  9.0
 1.04885  1.30237 -2.30167  1.35082  1.63676 18.91289 34 1.36192 1.00458
```

SECTION 5 - STATISTICAL ANALYSIS METHODOLOGY AND INCREMENTAL CONSERVATIVE FACTOR DEVELOPMENT

The current Technical Specifications for Surry and North Anna require that full core flux maps be taken with at least thirty-eight thimbles. In order to justify using less thimbles for a full core flux map for Technical Specifications surveillance compliance, it is necessary to show that the results obtained using data from less than thirty-eight thimbles are equivalent to or conservative with respect to the results obtained using data from thirty-eight or more thimbles. In order to evaluate this, the results for the twenty-six thimble and thirty-two thimble case studies were compared with the results of the thirty-eight thimble case studies. The results for the thirty-eight thimble case studies were defined to be the bounding values for each parameter obtained in accordance with the current Technical Specifications.

For the parameters F-delta-H, Fq, and Fxy, it is necessary that the results for the twenty-six and thirty-two thimble case studies be greater than the minimum result associated with the thirty-eight thimble case studies for these parameters. The mean minus three times the standard deviation of the case studies was used to estimate the lower bound on the expected range of values for these parameters. The percent difference between the result of the thirty-eight thimble case and the reduced number of thimbles case was then calculated as shown below:

$$\% \text{ penalty}_i = \left(1 - \frac{(M-3\sigma)_i^j}{(M-3\sigma)_i^{38}}\right) * 100$$

where M is mean value for the parameter

σ is the standard deviation

i is the flux map I.D.

j is the case study I.D.; i.e., 26 or 32 thimbles

For a few of the cases, the minimum value for a parameter was less than M-3σ. For those cases, the minimum value was used to calculate the % penalty.

For the parameters minimum Fq*P margin and the minimum Fxy margin, it is necessary that the results for the twenty-six and thirty-two thimble case studies be less than the maximum result associated with the thirty-eight thimble case study. For these parameters, the maximum value for each case study was used as an estimate of the upper bound on the expected range of values for these parameters. The difference between the result of the thirty-eight thimble case and the reduced number of thimbles case was then calculated as shown below:

$$\% \text{ penalty}_i = MV_i^j - MV_i^{38}$$

where MV is the maximum value of the parameter being considered

i is the flux map I.D.

j is the case study I.D., i.e., 26 or 32 thimbles

Finally, incremental conservative factors were derived for each parameter using the percent penalty values. For the parameters F-delta-H, Fq, and Fxy, this was done by first taking the most conservative percent penalty value for each and rounding the values up to the next highest integer. These values were then used to calculate the incremental conservative factors as shown below:

$$ICF_i = 1 + \%\ penalty_i^{MAX}/100$$

where ICF_i is the incremental conservative factor

i designates the parameter of interest; i.e., F-delta-H, Fq, or Fxy

$\%penalty^{MAX}$ is the maximum value for the percent penalty rounded up to the next highest integer.

For the parameters minimum Fq*P margin and the minimum Fxy margin, the ICF_i values were developed by taking the highest percent penalty value for each and rounding them up to the next highest integer.

SECTION 6 - RESULTS

A summary of the results for all of the case studies for the maximum F-delta-H, the maximum Fq, the minimum Fq*P margin, the maximum Fxy, and the minimum Fxy margin is presented in Tables 6-1 through 6-5, respectively. The columns labeled "measured" are the values that were obtained from the analysis for the eight incore flux maps used as the basis for the study utilizing all of the available data. The mean, minimum and maximum values, and the standard deviation are the results associated with the analysis of each case studied. As can be seen from the information listed on these tables, the results associated with the twenty-six and thirty-two thimble case studies are quite similar to the results associated with the thirty-eight thimble case study for each flux map. The percent penalty values on Tables 6-1 through 6-5 were calculated in accordance with the methods described in Section 5. Based on these data, it is clear that the results are not always conservative relative to the results for the thirty-eight thimble case results. Therefore, it was necessary to use the percent penalty values to develop the incremental conservative factors as described in Section 5. These factors are summarized on Table 6-6. Additionally, percent penalty values and incremental conservative factors were derived based on a 95% probability and a 95% confidence level[2]. The results presented here were consistent or conservative relative to the results of that statistical treatment.

Case study data were also obtained for the average axial offset and the incore quadrant power tilt ratio. These results are presented in Tables 6-7 and 6-8, respectively. This information shows that the results for the twenty-six and thirty-two thimble case studies are in good agreement with the results for the thirty-eight thimble case studies. It was not

necessary to develop percent penalty values or incremental conservative factors for these parameters since the Surry and North Anna Technical Specifications do not specify limiting values for them.

TABLE 6-1

MAXIMUM F-delta-H RESULTS SUMMARY

26 Thimbles

Map	Measured	Mean	Minimum Value	Maximum Value	Standard Deviation	Mean - 3 * sigma	percent penalty
N1-2-01	1.5735	1.62221	1.53953	1.72121	0.03346	1.52183	-1.37
N1-2-16	1.3488	1.37701	1.34825	1.40534	0.01456	1.33333	0.08
N1-3-23	1.3827	1.39781	1.34008	1.45298	0.02185	1.33226	-0.10
N1-3-39	1.3777	1.38795	1.36187	1.45428	0.01580	1.34055	0.78
N2-1-54	1.2290	1.22508	1.21103	1.23528	0.00467	1.21107	0.53
S1-6-23	1.4469	1.45868	1.43732	1.50100	0.01166	1.42370	0.67
S1-6-28	1.3661	1.36931	1.35646	1.38234	0.00581	1.35188	0.75
S2-6-12	1.3318	1.33969	1.32261	1.38043	0.00808	1.31545	0.37

32 Thimbles

Map	Measured	Mean	Minimum Value	Maximum Value	Standard Deviation	Mean - 3 * sigma	percent penalty
N1-2-01	1.5735	1.61657	1.53985	1.70314	0.03057	1.52486	-1.58
N1-2-16	1.3488	1.36999	1.34138	1.40216	0.01323	1.33030	0.31
N1-3-23	1.3827	1.38149	1.33667	1.41848	0.01513	1.33610	-0.39
N1-3-39	1.3777	1.38467	1.36260	1.43099	0.01094	1.35185	-0.05
N2-1-54	1.2290	1.22712	1.21340	1.23415	0.00372	1.21596	0.34
S1-6-23	1.4469	1.45322	1.44082	1.48312	0.00834	1.42820	0.36
S1-6-28	1.3661	1.36870	1.36201	1.38004	0.00418	1.35616	0.43
S2-6-12	1.3318	1.33470	1.32147	1.35308	0.00538	1.31856	0.13

38 Thimbles

Map	Measured	Mean	Minimum Value	Maximum Value	Standard Deviation	Mean - 3 * sigma
N1-2-01	1.5735	1.60202	1.54820	1.71141	0.03361	1.50119
N1-2-16	1.3488	1.36088	1.34447	1.38734	0.00881	1.33445
N1-3-23	1.3827	1.38064	1.33087	1.44135	0.01386	1.33906
N1-3-39	1.3777	1.38307	1.36158	1.41781	0.01064	1.35115
N2-1-54	1.2290	1.22814	1.21749	1.23162	0.00220	1.22154
S1-6-23	1.4469	1.45104	1.44264	1.47583	0.00590	1.43334
S1-6-28	1.3661	1.36667	1.36253	1.38100	0.00154	1.36205
S2-6-12	1.3318	1.33319	1.32588	1.35263	0.00430	1.32029

TABLE 6-2

MAXIMUM Fq RESULTS SUMMARY

26 Thimbles

Map	Measured	Mean	Minimum Value	Maximum Value	Standard Deviation	Mean - 3 * sigma	percent penalty
N1-2-01	2.8565	3.04230	2.79113	3.42864	0.11047	2.71089	-2.85
N1-2-16	1.7594	1.80294	1.72230	1.87444	0.04344	1.67262	1.72
N1-3-23	1.7232	1.73611	1.66985	1.81171	0.02891	1.64938	0.96
N1-3-39	1.6022	1.61274	1.58231	1.67700	0.01286	1.57416	0.23
N2-1-54	1.4657	1.45850	1.43517	1.47379	0.00951	1.42997	0.63
S1-6-23	1.7875	1.79824	1.75267	1.84917	0.01278	1.75990	0.94
S1-6-28	1.6194	1.61900	1.59914	1.63195	0.00526	1.60322	0.79
S2-6-12	1.5982	1.62124	1.57549	1.67029	0.01858	1.56550	0.33

32 Thimbles

Map	Measured	Mean	Minimum Value	Maximum Value	Standard Deviation	Mean - 3 * sigma	percent penalty
N1-2-01	2.8565	2.99545	2.80678	3.29265	0.09875	2.69920	-2.41
N1-2-16	1.7594	1.78748	1.72347	1.87020	0.03351	1.68695	0.88
N1-3-23	1.7232	1.71462	1.67153	1.76953	0.02211	1.64829	1.03
N1-3-39	1.6022	1.60758	1.58786	1.64950	0.00842	1.58232	-0.28
N2-1-54	1.4657	1.46147	1.43642	1.47189	0.00850	1.43597	0.22
S1-6-23	1.7875	1.79329	1.77312	1.83104	0.00908	1.76605	0.19
S1-6-28	1.6194	1.62055	1.61298	1.62692	0.00297	1.61164	0.02
S2-6-12	1.5982	1.60773	1.58451	1.65243	0.01419	1.56516	0.35

38 Thimbles

Map	Measured	Mean	Minimum Value	Maximum Value	Standard Deviation	Mean - 3 * sigma
N1-2-01	2.8565	2.95265	2.79980	3.40912	0.10566	2.63567
N1-2-16	1.7594	1.76951	1.72155	1.81917	0.02255	1.70186
N1-3-23	1.7232	1.71899	1.66541	1.79722	0.01578	1.67165
N1-3-39	1.6022	1.60726	1.58201	1.63640	0.00981	1.57783
N2-1-54	1.4657	1.46418	1.43907	1.46887	0.00528	1.44834
S1-6-23	1.7875	1.79111	1.78211	1.81491	0.00725	1.76936
S1-6-28	1.6194	1.61974	1.61191	1.62447	0.00185	1.61419
S2-6-12	1.5982	1.60379	1.58643	1.65187	0.01106	1.57061

TABLE 6-3

MINIMUM Fq*P MARGIN RESULTS SUMMARY

26 Thimbles

Map	Measured	Mean	Minimum Value	Maximum Value	Standard Deviation	percent penalty
N1-2-01	22.7666	14.81517	-6.12567	24.76039	6.57356	0.41
N1-2-16	10.7506	8.54072	4.91333	12.63127	2.20379	-0.04
N1-3-23	11.3465	12.25722	8.53306	15.69538	1.43272	-0.22
N1-3-39	18.4665	15.78865	2.26301	20.83746	5.55923	0.50
N2-1-54	23.2444	19.74305	6.51814	24.90408	3.27899	0.19
S1-6-23	38.7310	38.72426	36.59909	40.11696	0.42286	0.75
S1-6-28	19.7723	19.76704	19.15126	20.26709	0.22090	0.12
S2-6-12	23.1964	21.58110	15.48689	24.28880	1.75123	0.53

32 Thimbles

Map	Measured	Mean	Minimum Value	Maximum Value	Standard Deviation	percent penalty
N1-2-01	22.7666	16.41630	-5.83231	24.52682	6.37929	0.18
N1-2-16	10.7506	9.32467	5.12854	12.57201	1.70001	-0.10
N1-3-23	11.3465	13.27566	10.66297	15.61026	1.13628	-0.31
N1-3-39	18.4665	15.14946	4.73440	20.63139	6.18373	0.29
N2-1-54	23.2444	21.96542	15.33199	24.66966	2.22322	-0.05
S1-6-23	38.7310	38.84861	37.66089	39.52805	0.35334	0.16
S1-6-28	19.7723	19.71588	19.40027	20.09106	0.14705	-0.05
S2-6-12	23.1964	22.66879	15.54896	23.85562	0.92154	0.09

38 Thimbles

Map	Measured	Mean	Minimum Value	Maximum Value	Standard Deviation
N1-2-01	22.7666	19.20266	-5.88434	24.34816	4.74481
N1-2-16	10.7506	10.23618	7.71726	12.66910	1.14383
N1-3-23	11.3465	13.17474	9.26499	15.91940	0.80875
N1-3-39	18.4665	15.81585	4.73955	20.34164	5.40113
N2-1-54	23.2444	22.91280	16.62109	24.71875	1.13715
S1-6-23	38.7310	38.69663	37.84724	39.36475	0.22224
S1-6-28	19.7723	19.75579	19.52148	20.14369	0.09167
S2-6-12	23.1964	22.92681	20.61821	23.76332	0.53242

NOTE: All margin values are in percent.

TABLE 6-4

MAXIMUM Fxy RESULTS SUMMARY

26 Thimbles

Map	Measured	Mean	Minimum Value	Maximum Value	Standard Deviation	Mean - 3 * sigma	percent penalty
N1-2-01	1.843	1.93856	1.81054	2.08973	0.05642	1.76930	-2.36
N1-2-16	1.580	1.62851	1.55655	1.69891	0.03093	1.53572	0.11
N1-3-23	1.517	1.54594	1.47834	1.62483	0.02592	1.46818	-0.56
N1-3-39	1.512	1.52803	1.49933	1.59592	0.01788	1.47439	0.61
N2-1-54	1.381	1.37521	1.35450	1.39568	0.00821	1.35058	0.76

32 Thimbles

Map	Measured	Mean	Minimum Value	Maximum Value	Standard Deviation	Mean - 3 * sigma	percent penalty
N1-2-01	1.843	1.91358	1.80896	2.05616	0.05719	1.74201	-0.78
N1-2-16	1.580	1.61271	1.55126	1.68710	0.02694	1.53189	0.36
N1-3-23	1.517	1.53692	1.47385	1.59440	0.02711	1.45559	0.30
N1-3-39	1.512	1.52147	1.49939	1.59098	0.01268	1.48343	0.001
N2-1-54	1.381	1.37811	1.35639	1.39158	0.00737	1.35600	0.36

38 Thimbles

Map	Measured	Mean	Minimum Value	Maximum Value	Standard Deviation	Mean - 3 * sigma
N1-2-01	1.843	1.88770	1.81106	2.02557	0.05304	1.72858
N1-2-16	1.580	1.59369	1.55107	1.63848	0.01874	1.53747
N1-3-23	1.517	1.52073	1.46770	1.58241	0.02026	1.45995
N1-3-39	1.512	1.52068	1.49641	1.58397	0.01241	1.48345
N2-1-54	1.381	1.38066	1.36087	1.38693	0.00430	1.36776

TABLE 6-5

MINIMUM Fxy MARGIN RESULTS SUMMARY

26 Thimbles

Map	Measured	Mean	Minimum Value	Maximum Value	Standard Deviation	percent penalty
N1-2-01	2.181	-2.90223	-10.92666	3.89314	2.99471	0.28
N1-2-16	-0.334	-3.41682	-7.88761	1.15274	1.96445	-0.35
N1-3-23	3.407	1.97300	-1.96618	5.85736	1.50555	-0.68
N1-3-39	4.062	3.10760	-0.60979	4.84392	0.92984	-0.19
N2-1-54	11.473	11.87570	10.56395	13.20271	0.52590	0.41

32 Thimbles

Map	Measured	Mean	Minimum Value	Maximum Value	Standard Deviation	percent penalty
N1-2-01	-0.334	-1.57597	-9.14464	3.97707	3.03572	0.11
N1-2-16	2.181	-2.41320	-7.13724	1.48910	1.71100	-0.01
N1-3-23	3.407	2.87956	0.01026	6.14316	1.32728	-0.39
N1-3-39	4.062	3.46057	1.07899	4.84029	0.72437	-0.19
N2-1-54	11.473	11.68959	10.82674	13.08195	0.47225	0.29

38 Thimbles

Map	Measured	Mean	Minimum Value	Maximum Value	Standard Deviation
N1-2-01	-0.334	-0.20252	-7.52087	3.86545	2.81548
N1-2-16	2.181	-1.20535	-4.05027	1.50067	1.18987
N1-3-23	3.407	3.34062	-0.77007	6.53482	1.09807
N1-3-39	4.062	3.48892	-0.52766	5.02913	0.78748
N2-1-54	11.473	11.52639	11.12447	12.79473	0.27558

Note: All margin values are in percent.

TABLE 6-6

INCREMENTAL CONSERVATIVE FACTORS FOR REDUCED DATA CASES

Maximum F-delta-H	1.01
Maximum Fq	1.02
Minimum Fq * P Margin	1.0%*
Maximum Fxy	1.01
(North Anna maps)	
Minimum Fxy Margin	1.0%*
(North Anna maps)	

* To be applied as a negative bias

TABLE 6-7

AVERAGE AXIAL OFFSET RESULTS SUMMARY

26 Thimbles

Map	Measured	Mean	Minimum Value	Maximum Value	Standard Deviation	Min - Meas	Max - Meas
N1-2-01	47.963	48.19846	47.22165	49.34341	0.30008	-0.741	1.380
N1-2-16	-7.267	-7.12161	-7.75098	-6.41297	0.23380	-0.484	0.853
N1-3-23	-5.422	-5.29266	-5.71196	-4.89387	0.15316	-0.290	0.528
N1-3-39	-3.225	-3.22555	-3.68119	-2.69379	0.17599	-0.456	0.531
N2-1-54	-0.426	-0.41376	-0.76181	-0.04274	0.11974	-0.336	0.383
S1-6-23	0.106	0.09841	-0.33934	0.49328	0.14701	-0.233	0.387
S1-6-28	-3.092	-3.04186	-3.63013	-2.53483	0.20014	-0.538	0.557
S2-6-12	-2.366	-2.41162	-2.84242	-1.90126	0.16802	-0.476	0.465

32 Thimbles

Map	Measured	Mean	Minimum Value	Maximum Value	Standard Deviation	Min - Meas	Max - Meas
N1-2-01	47.963	48.03935	47.47414	48.69701	0.20865	-0.489	0.734
N1-2-16	-7.267	-7.15923	-7.67807	-6.52845	0.16680	-0.411	0.739
N1-3-23	-5.422	-5.37599	-5.69516	-5.08666	0.11548	-0.273	0.335
N1-3-39	-3.225	-3.21560	-3.66716	-2.87522	0.12740	-0.442	0.350
N2-1-54	-0.426	-0.42594	-0.64994	-0.19916	0.08771	-0.224	0.227
S1-6-23	0.106	0.12808	-0.15938	0.40529	0.10705	-0.265	0.299
S1-6-28	-3.092	-3.09990	-3.43446	-2.78490	0.13868	-0.342	0.307
S2-6-12	-2.366	-2.41352	-2.70218	-2.04496	0.10997	-0.336	0.321

38 Thimbles

	Measured	Mean	Minimum Value	Maximum Value	Standard Deviation	Min - Meas	Max - Meas
N1-2-01	47.963	48.03550	47.60269	48.65215	0.14933	-0.360	0.689
N1-2-16	-7.267	-7.22055	-7.49768	-6.92163	0.09617	-0.231	0.345
N1-3-23	-5.422	-5.45077	-5.66420	-5.20620	0.08719	-0.242	0.216
N1-3-39	-3.225	-3.26271	-3.46228	-3.02999	0.08260	-0.237	0.195
N2-1-54	-0.426	-0.44666	-0.57007	-0.32754	0.04216	-0.144	0.098
S1-6-23	0.106	0.13118	-0.02694	0.36816	0.06795	-0.133	0.262
S1-6-28	-3.092	-3.09404	-3.29442	-2.86888	0.08020	-0.202	0.223
S2-6-12	-2.366	-2.35996	-2.55156	-2.14061	0.07855	-0.186	0.225

Note: All axial offset values are in percent.

TABLE 6-8

AVERAGE QUADRANT POWER TILT RESULTS SUMMARY

26 Thimbles

Map	Measured	Mean	Minimum Value	Maximum Value	Standard Deviation	Min - Meas	Max - Meas
N1-2-01	1.0808	1.08017	1.04302	1.11551	0.01183	-0.0379	0.0346
N1-2-16	1.0117	1.01115	1.00032	1.02293	0.00406	-0.0114	0.0112
N1-3-23	1.0067	1.01010	1.00293	1.02244	0.00385	-0.0038	0.0157
N1-3-39	1.0054	1.00725	1.00130	1.01891	0.00284	-0.0041	0.0135
N2-1-54	1.0018	1.00403	1.00056	1.01221	0.00205	-0.0012	0.0104
S1-6-23	1.0634	1.06261	1.05117	1.07108	0.00399	-0.0122	0.0077
S1-6-28	1.0045	1.00565	1.00059	1.01249	0.00230	-0.0039	0.0080
S2-6-12	1.0034	1.00657	1.00226	1.01675	0.00195	-0.0012	0.0133

32 Thimbles

Map	Measured	Mean	Minimum Value	Maximum Value	Standard Deviation	Min - Meas	Max - Meas
N1-2-01	1.0808	1.08010	1.04564	1.11529	0.00968	-0.0353	0.0344
N1-2-16	1.0117	1.01155	1.00461	1.01848	0.00264	-0.0071	0.0068
N1-3-23	1.0067	1.00754	1.00200	1.01681	0.00253	-0.0047	0.0101
N1-3-39	1.0054	1.00733	1.00190	1.01674	0.00294	-0.0035	0.0113
N2-1-54	1.0018	1.00301	1.00021	1.00910	0.00135	-0.0016	0.0073
S1-6-23	1.0634	1.06261	1.05341	1.07078	0.00315	-0.0100	0.0074
S1-6-28	1.0045	1.00452	1.00140	1.00918	0.00170	-0.0031	0.0047
S2-6-12	1.0034	1.00554	1.00238	1.01035	0.00138	-0.0011	0.0069

38 Thimbles

Map	Measured	Mean	Minimum Value	Maximum Value	Standard Deviation	Min - Meas	Max - Meas
N1-2-01	1.0808	1.07984	1.05556	1.09885	0.00637	-0.0253	0.0180
N1-2-16	1.0117	1.01135	1.00444	1.01937	0.00263	-0.0073	0.0077
N1-3-23	1.0067	1.00749	1.00250	1.01441	0.00197	-0.0042	0.0077
N1-3-39	1.0054	1.00573	1.00215	1.01212	0.00185	-0.0033	0.0067
N2-1-54	1.0018	1.00254	1.00050	1.00512	0.00092	-0.0013	0.0033
S1-6-23	1.0634	1.06277	1.05694	1.06709	0.00179	-0.0065	0.0037
S1-6-28	1.0045	1.00453	1.00179	1.00691	0.00096	-0.0027	0.0024
S2-6-12	1.0034	1.00435	1.00235	1.00777	0.00099	-0.0012	0.0043

SECTION 7 - CONCLUSIONS

As indicated by the summary of the data presented in Section 6, reliable flux map analysis results for the maximum values for F-delta-H, Fq, and Fxy, the minimum margin results for Fq*P and Fxy, the axial offset, and the quadrant power tilt may be obtained from maps based on as few as twenty-six monitored thimbles, with the requirement that there be at least four monitored thimbles per quadrant. Additionally, incremental conservative factors have been developed. These factors can be applied to the flux map analysis results associated with flux maps utilizing data from at least twenty-six thimbles but less than thirty-eight thimbles. By use of these factors the results will be equivalent to or conservative with respect to flux map analyses results obtained in accordance with the requirements of the current Technical Specifications for the Surry and North Anna power stations using thirty-eight thimbles. This conclusion is based on several factors. First, the study results were based on the analysis of flux map data that were taken from different reactor cores, over a wide range of power level, power distribution, core burnup, and control rod configurations. Second, the number of study cases that were run were sufficiently large so that the results have statistical significance. Third, two different methodologies were used to establish the values for the incremental conservative factors, and the results were consistent.

Finally, it is believed that the cases that were considered in this study are sufficiently diverse such that the results of this study are applicable to future flux map analyses for the Surry and North Anna nuclear units.

SECTION 8 - REFERENCES

1. W. D. Leggett, III and L. D. Eisenhart, "INCORE Code," WCAP-7149, December 1967.
2. J. G. Miller, "Derivation of Uncertainty Factors for Reduced Thimble INCORE Map Analysis Using 95/95 Tolerance Limits," Vepco, October, 1983.
3. T. C. Hartsfield, "Evaluation of Results From INCORE Number-of-Thimbles Study," Vepco memorandum, October 18, 1983.

APPENDIX 1 - STUDY BASIS FLUX MAPS

A description of the eight incore flux maps that were chosen as the reference data base for this study is presented below. These maps are representative of various operational conditions that have been experienced at the four Vepco nuclear units.

N. Anna Map ==>	N1-2-01	N1-2-16	N1-3-23	N1-3-39	N2-1-54
thermal power (MWt)	1	2733	2772	2725	2681
cycle burnup (MWD/MTU)	0	349	2232	8899	12607
control rod position	D/218	D/208	D/221	D/219	D/218
maximum quadrant power tilt ratio	1.09	1.0138	1.011	1.007	1.003
thimbles available	48	46	46	46	41
# 38 thimble cases	800	257	302	400	376
# 32 thimble cases	591	296	221	287	699
# 26 thimble cases	547	330	265	293	518

Surry Map ==>	S1-6-23	S1-6-28	S2-6-12
thermal power (MWt)	1660	2441	2368
cycle burnup (MWD/MTU)	5410	6472	3690
control rod position	D/197*	D/228	D/216
maximum quadrant power tilt ratio	1.0736	1.005	1.005
thimbles available	42	43	44
# 38 thimble cases	453	400	402
# 32 thimble cases	297	110	400
# 26 thimble cases	432	231	624

*Rod B-6 was fully inserted

APPENDIX 2 - VERIFICATION

The modified version of the INCORE code was benchmarked against the production version of the INCORE code by executing all of the eight reference flux maps with both versions of the code. Additionally, at least one of the randomly selected flux maps from each of the eight reference maps was analyzed using the production version of the INCORE code. In all cases, the results were consistant. An independent review[3] was also performed which consisted of a hand-picked random sampling of cases considered in the study. These maps were analyzed using the production version of the INCORE code in order to verify that the results would fall within the maximum and minimum bands of the parameters of interest. In all cases, the results of the hand-picked samples did fall within the maximum and minimum bands of the parameters.