ANALYSIS OF INPAX-II POWER PEAKING UNCERTAINTIES

FOR ST. LUCIE UNIT 1 CYCLE 11

1.0 INTRODUCTION

This evaluation presents the results of a power peaking uncertainty analysis of the INPAX-II computer code (used to monitor the core power distribution) for St. Lucie Unit 1 Cycle 11. The analysis of the INPAX-II power peaking uncertainty is based on calculations and operational data for St. Lucie Unit 1 Cycle 11 available up to April 1992. At that time 7 (15%) of 45 detectors strings were failed. The current Technical Specifications allow up to 25% of detector strings to be failed. This analysis was performed to evaluate the INPAX-II uncertainties with an increased number of failed detector strings, up to 50%, at St. Lucie Unit 1, during Cycle 11 operation only.

The current uncertainties in the St. Lucie Unit 1 Technical Specifications are based on the results from the analysis in Reference 6.1. In cycle 6 of St. Lucie Unit 1, Florida Power & Light Co. changed fuel vendors to Siemens Power Corp. (SPC), formerly Exxon Nuclear. To ensure that INPAX-II uncertainties for peaking factors were bounded by the current Technical Specifications and Safety Analysis values, an analysis was performed (Reference 6.2) which addressed uncertainties using the INPAX-II/XTG computer codes. This analysis was submitted to the Commission as part of Amendment No. 63. The results of the evaluation show a smaller uncertainty for Fq, Fr and Fxy than those currently being used in the Safety Analysis and Technical Specifications. At that time, the decision was made not to change Technical Specifications and continue to use the more conservative values. The following Table presents a comparison of the uncertainties between Reference 6.2, Reference 6.1, and the currently used values in the Safety Analysis and Technical Specifications.

Peaking Factor Uncertainties

	Currently Used	Reference 6.2	Reference 6.1
Fr	6.0% (Safety Analysis)	4.8%	6.0%
Fq (LHR)	7.0% (Technical Specifications)	5.0%	6.2%

The following analysis was performed with the INPAX-II/XTG computer code. An extension of the Reference 6.2 calculated measurement uncertainties was performed and new measurement uncertainties were calculated. These uncertainties were compared to the uncertainties currently used in the Technical Specifications and Safety Analysis. This analysis is only applicable to St. Lucie Unit 1 Cycle 11.

2.0 SUMMARY OF ANALYSIS RESULTS

The analysis results show that an additional 0.67% in Fr uncertainty, over that currently in use, is required if the number of failed detector strings reach 50%. For conservatism, this additional uncertainty was increased to 1.5% for Fr resulting in a total Fr uncertainty of 7.5%. Although the LHR uncertainty did not increase over the one currently being used, for conservatism it was increased by 1.0% over the one currently used in the Technical Specifications resulting in a total LHR uncertainty of 8.0%. These uncertainties were calculated based on 50% of detector strings being failed. However, for conservatism, these uncertainties will apply whenever the 25% detector string failure level has been exceeded. Figures 2.1 and 2.2 present the total Fr and Fq uncertainty as a function of detector string failure level in percent.

FIGURE 2.1 Fr Peaking Factor Uncertainty

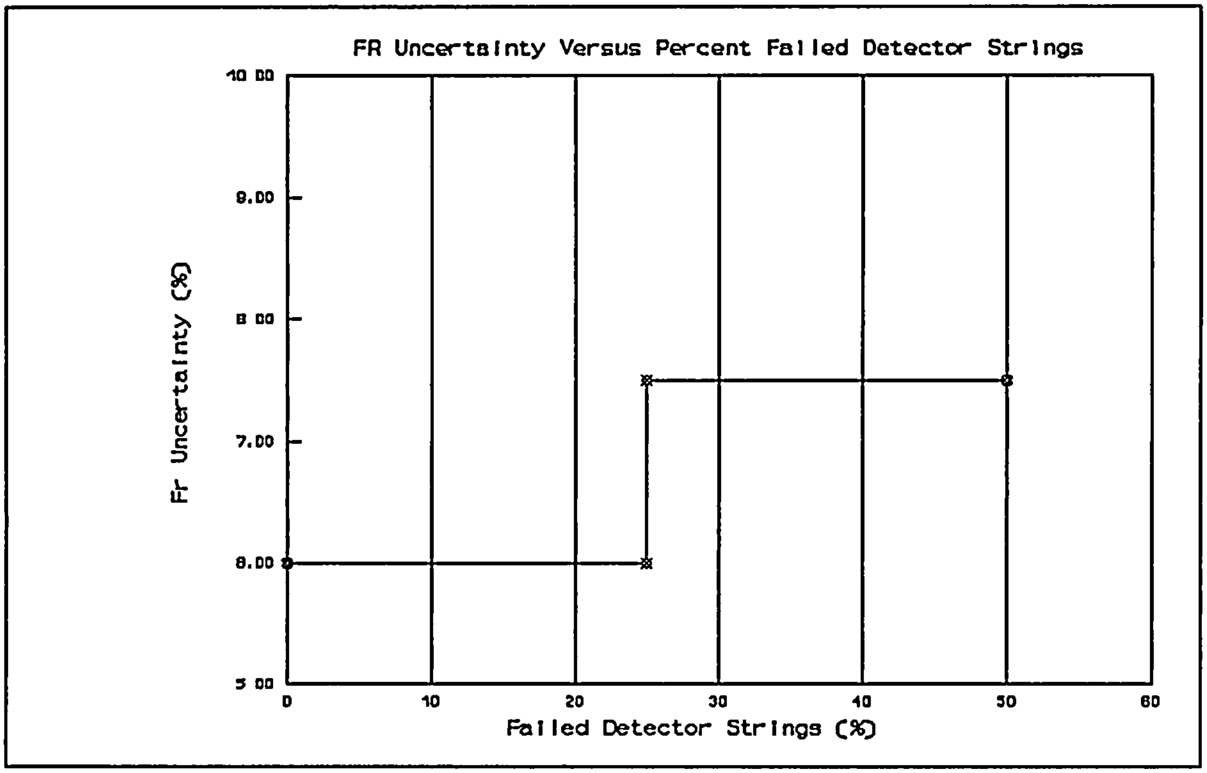
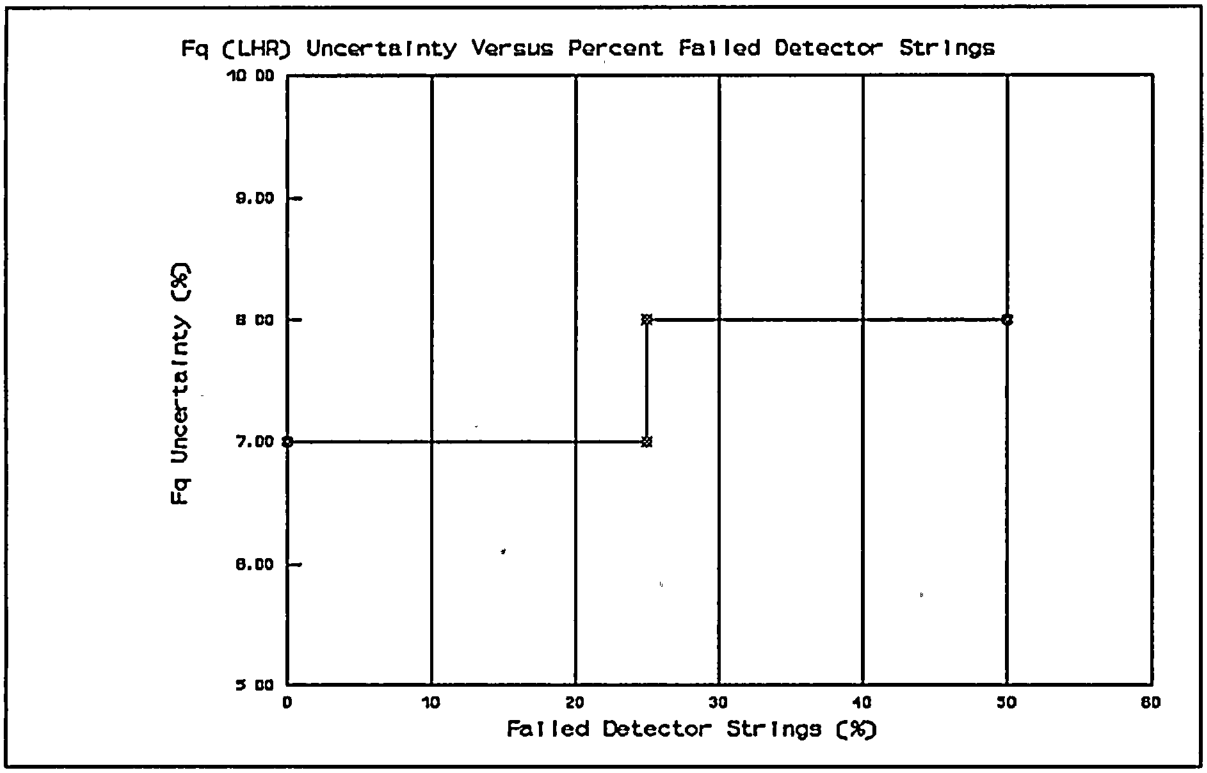


FIGURE 2.2 Fq Peaking Factor Uncertainty



3.0 RECOMMENDATIONS

Based on the results of the analysis, it is recommended that operation be allowed for Cycle 11 with an increased number of failed detector strings up to 50% with an increase in the INPAX-II uncertainties as presented in Figures 2.1 and 2.2. The increase in peaking factor uncertainties will, with greater than 25% of detector strings being failed, be accommodated by increasing the LHR uncertainty included in the incore alarm setpoint and by increasing the measured Fr before comparing it to the Technical Specification Limit.

4.0 ANALYSIS

The fixed incore detector instrumentation pattern for St. Lucie Unit 1 Cycle 11 and the current failed detector strings are presented in Figure 4.1. The detector failures are random with no systematic characteristics. Note that all detectors were replaced at the beginning of Cycle 10; all of these detectors have been in the core for one full cycle plus operation to date in cycle 11. All detectors are scheduled to be replaced at the end of cycle 11, early in 1993.

4.1 MEASUREMENT UNCERTAINTY COMPONENTS

Reference 6.2 uses the following equations in the determination of peaking factor uncertainties:

$$Fq = F_{sa}\ F_r\ F_z\ F_l$$

$$Fr = F_{sa}\ F_r\ F_l$$

where F_{sa}: Relative power associated with the average of the detector segments in an assembly.

F_r: Ratio of the assembly relative power to the average relative power of the detector segments in an assembly.

F_z: Ratio of the peak planar power in an assembly to the assembly power.

F_l: Peak local pin power in an assembly.

Note that F_{sa} can be interpreted as the extrapolation parameter or coupling factor from an instrumented to a non-instrumented assembly and F_r can be viewed as the power to reaction rate for the instrumented assembly.

Using this definition, the relative variance of Fq (LHR) and Fr can be expressed in the following equations:

$$S^2Fq = S^2F_{sa} + S^2F_r + S^2F_z + S^2F_l$$

$$S^2Fr = S^2F_{sa} + S^2F_r + S^2F_l$$

where S^2 is the relative variance for the random variable and each term is assumed to be independent.

The following Table presents the standard deviation of each of the parameters presented in the previous equations with its respective number of degrees of freedom. These values were obtained from Reference 6.2.

TABLE 1

Variable	Relative Standard Deviation	Number Degrees Freedom
F_{sa}	.0240	800
F_r	.0047	514
F_z	.0077	514
F_l	.0135	188
Fq	.0290	1180
Fr	.0279	1023

Note that for Fq and Fr the number of degrees of freedom was calculated using the Satterthwaite's formula presented in Reference 6.3.

4.2 EXTRAPOLATION UNCERTAINTY

The power extrapolation uncertainty is the only parameter affected by the increase in failed detector strings. Section 4.1 of Reference 6.2 provides the method utilized by SPC to calculate the extrapolation uncertainty. The method employed is to generate measured detector powers which are independent of inferred detector segment power for the same locations. The relative differences between the measured and inferred detector segment power is an estimate of the combined error in the measured and inferred detector segment power and therefore is a conservative estimate of the error in the inferred detector segment power. To generate the required information, first the core power distribution is generated utilizing all of the operable detectors to generate a power distribution which serves to define the measured power distribution for those locations having instruments. Second, the core power distribution is calculated utilizing all operable detectors except for those locations where all four axial detectors (detector string) are assumed to be failed. This second power distribution has inferred detector powers in the assembly location where the detectors were assumed to be failed which are not equal to, and are independent of the measured detector segment power in these locations determined from the first execution for the INPAX-II code. The previous procedure was utilized by Reference 6.2 to calculate the extrapolation uncertainty using a single instrumented assembly location failed at a time.

The methodology employed in this analysis is similar to that used by Reference 6.2 with the exception that 50% (22 detector strings) of the incore detectors are assumed to be failed. Specifically, 2 representative flux maps (1 at BOC and 1 at

MOC) are executed with different combinations of failed detectors. The 7 detector strings currently failed in the plant were assumed to be failed and the remaining 15 detector strings were chosen at random from the operable detectors.

The standard deviation estimate is calculated as follows:

$$STD = \{(\sum D^2 - ND^2_{AVG}) / (N - 1)\}^{1/2}$$

where

N = number of paired data points representing the inferred and measured assembly power

F^m= Measured relative assembly power associated with the average of four detector segments

F^i= Inferred relative assembly power associated with the average of four detector segments

$D = \ln (F^i / F^m)$

$D_{avg} = \sum D / N$

The standard deviation for each of the BOC and MOC cases is presented in Table 4.1 and Table 4.2, respectively. Note that the scatter for the standard deviation of the BOC cases is larger than expected. A review of the data indicates that the cases where the standard deviations are highest contain several detectors that have low relative power densities such that with a small change in total power, the percent difference with respect to the base case is large. Specifically, there are seven (7) locations with RPDs lower than 0.400 and one (1) location with RPD lower than .07. In these locations, even small differences in RPD units cause large percentage differences. This is why the standard deviation for the individual cases appear to have more scatter than expected. This also implies that the standard deviations are not dependent upon the number of operable detector locations, but on which detectors are operable. Since it is not likely that the detectors with the smallest deviations between measured and inferred would fail more often than those detectors with the large deviations, it is concluded that using all of the available data provides the best estimate of the true standard deviation.

Figures 4.2 and 4.3 present a histogram of the relative differences for the BOC and MOC cases, respectively. Figure 4.4 presents a histogram of the combined BOC and MOC data. These Figures show a reasonable normal distribution of the percentage difference between the measured and inferred power. The data points with the large differences (-17%) are due to the fuel assembly which has an RPD lower than 0.07.

The following table presents the results of the relative standard deviation associated with the extrapolation uncertainty.

Exposure Case	Relative Standard Deviation	Degrees of Freedom
BOC	.0387	585
MOC	.0338	556
Total	.0363	1141

4.3 PEAKING FACTOR UNCERTAINTIES

The F_{sa} parameter uncertainty was calculated in Reference 6.2 by deleting only one detector string at a time. Their results show an extrapolation standard deviation of 2.40% with 800 data points. The difference between the 3.63% and the 2.40% is the increase in uncertainty by allowing 50% of the detectors strings to be failed.

Using the 3.63% instead of the 2.40%, and using the SPC calculated uncertainties for the other parameters, the new calculated standard deviation for Fq and Fr, respectively, is 3.98% and 3.90%. Using the new calculated uncertainties to account for 50% of failed string detectors, the modified Table 1 is presented below:

TABLE 1 (modified)

Variable	Relative Standard Deviation	Number Degrees Freedom
F_{sa}	.0363	1141
F_r	.0047	514
F_z	.0077	514
F_1	.0135	188
Fq	.0398	1466
Fr	.0390	1363

The effective number of degrees of freedom was calculated using the Satterthwaite's formula presented in Reference 6.3. The tolerance factors for both Fq and Fr is 1.71. The one-sided 95/95 tolerance limit for Fq and Fr using 50% of failed detector strings are therefore, 6.81% and 6.67%, respectively.

5.0 CONCLUSIONS

This analysis concludes that a conservative increase in measured peaking factor uncertainties will accommodate operation with up to 50% failed incore detector strings.

For conservatism, these peaking factor uncertainties will be increased to 8.0% and 7.5% for Fq and Fr, respectively. Using these values, the following table 5.1 is constructed:

TABLE 5.1

Condition	Fq (LHR) Uncertainty	Fr Uncertainty
< 25% failed detectors	7.0%	6.0%
between 25% and 50% failed	8.0%	7.5%

FIGURE 4.1

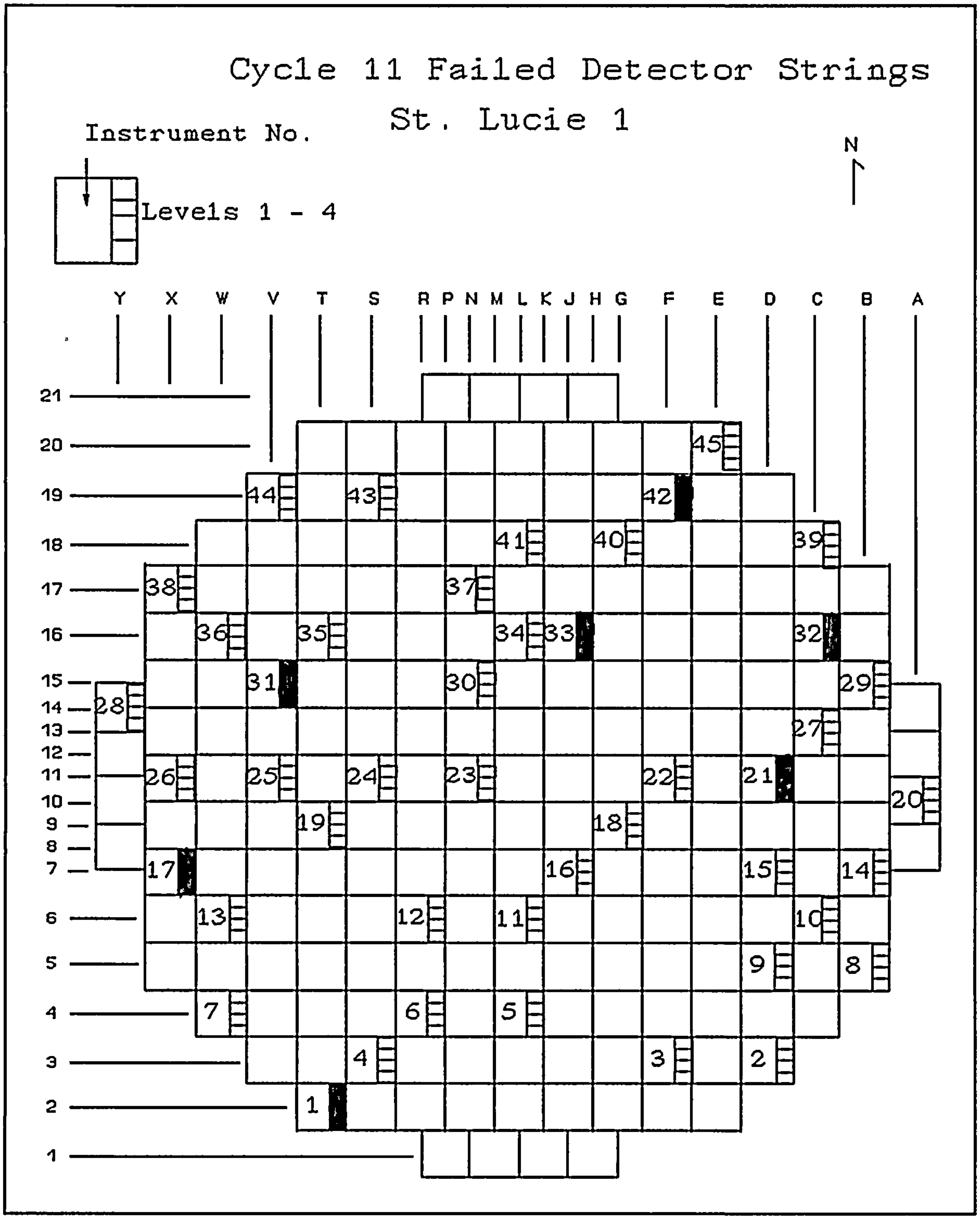

Cycle 11 Failed Detector Strings
St. Lucie 1
Instrument No.
Levels 1 - 4
N
Y X W V T S R P N M L K J H G F E D C B A
21 20 19 18 17 16 15 14 13 12 11 10 9 8 7 6 5 4 3 2 1
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45

FIGURE 4.2 Histogram of Percent Difference Between Measured and Inferred Values

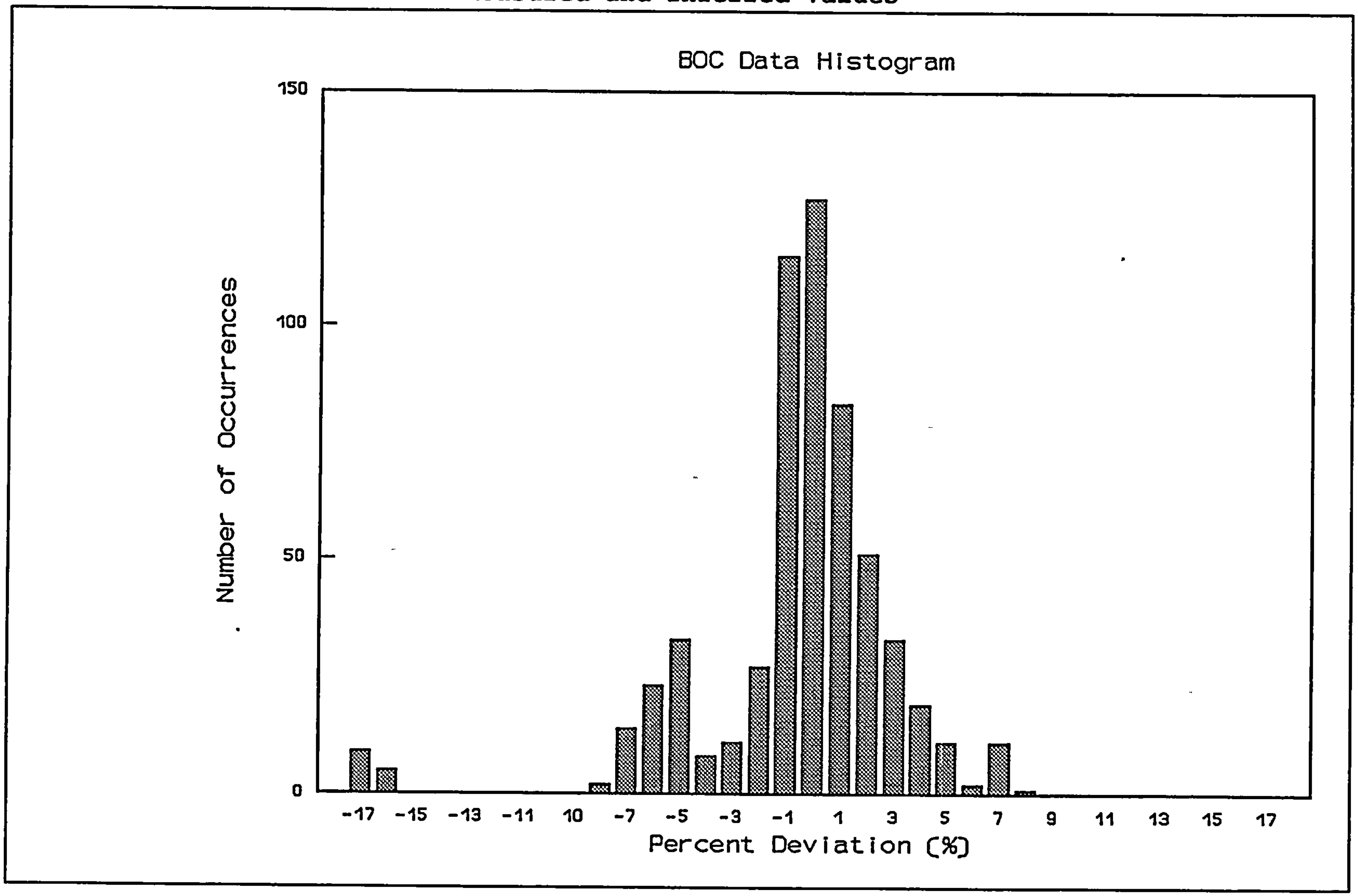


FIGURE 4.3 Histogram of Percent Difference Between Measured and Inferred Values

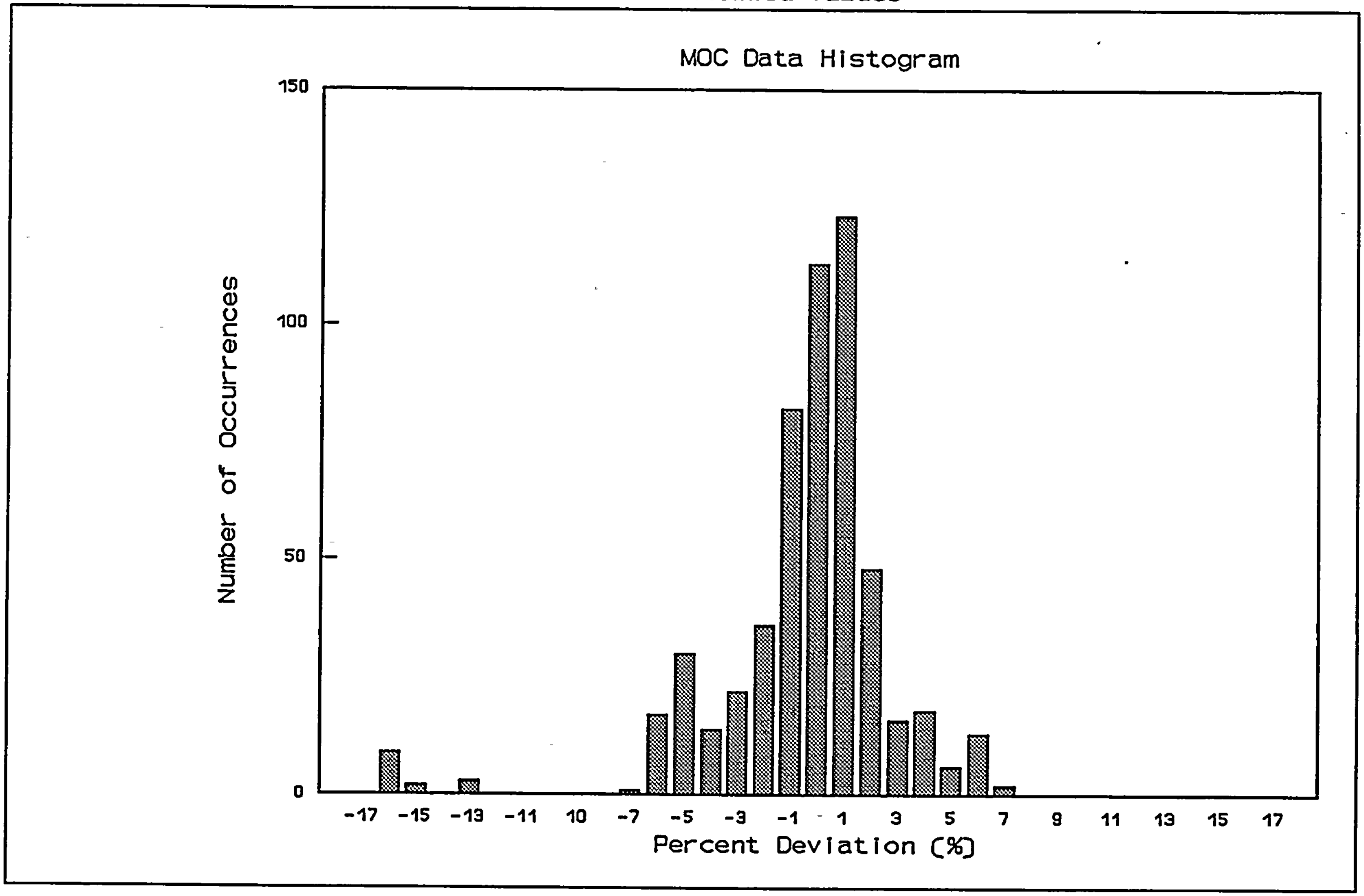


FIGURE 4.4 Histogram of Percent Difference Between Measured and Inferred Values

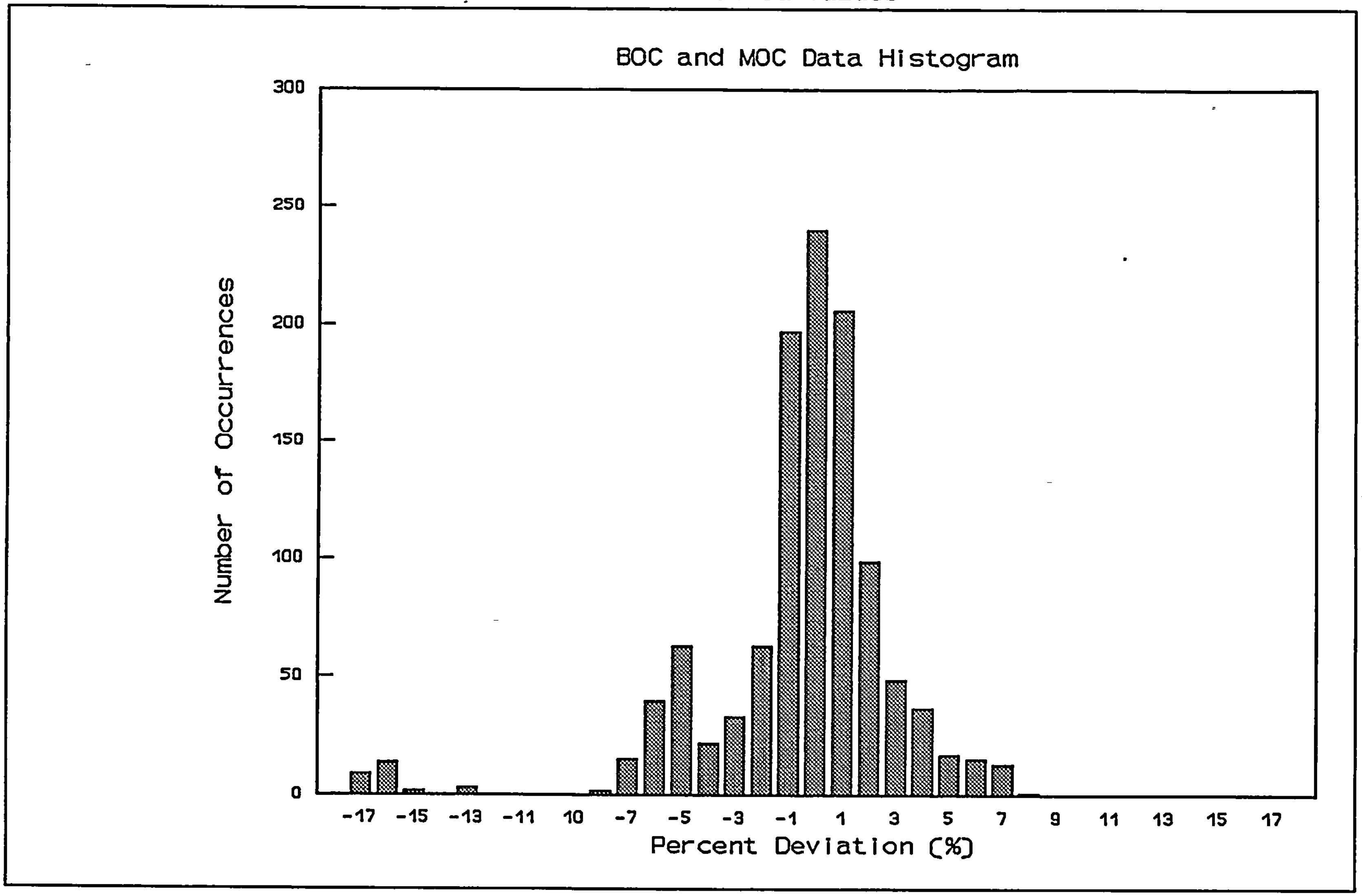


TABLE 4.1

Summary of Standard Deviation Results (BOC Cases)

Case #	STD %	Variance
1	3.556	0.0013
2	4.966	0.0025
3	4.803	0.0023
4	4.198	0.0018
5	3.072	0.0009
6	2.215	0.0005
7	1.532	0.0002
8	3.207	0.0010
9	2.466	0.0006
10	3.406	0.0012
11	4.690	0.0022
12	5.048	0.0025
13	3.299	0.0011
14	2.377	0.0006
15	4.781	0.0023
16	2.522	0.0006
17	2.796	0.0008
18	2.045	0.0004
19	5.197	0.0027
20	3.475	0.0012
21	3.356	0.0011
22	4.888	0.0024
23	3.569	0.0013
24	2.443	0.0006
25	5.171	0.0027
26	5.834	0.0034
27	5.592	0.0031
28	2.931	0.0009
29	3.709	0.0014
30	3.041	0.0009
31	4.930	0.0024
32	2.140	0.0005
33	2.482	0.0006
34	2.892	0.0008
35	5.022	0.0025
36	3.251	0.0011
37	4.846	0.0023
38	5.212	0.0027
39	3.018	0.0009

Total Standard Deviation 3.87%

TABLE 4.2

Summary of Standard Deviation Results (MOC Cases)

Case #	STD%	Variance
1	2.638	0.0007
2	4.285	0.0018
3	2.753	0.0008
4	2.315	0.0005
5	4.301	0.0018
6	2.877	0.0008
7	2.524	0.0006
8	2.455	0.0006
9	4.958	0.0025
10	1.904	0.0004
11	2.318	0.0005
12	3.202	0.0010
13	4.623	0.0021
14	4.505	0.0020
15	2.058	0.0004
16	4.614	0.0021
17	3.255	0.0011
18	2.252	0.0005
19	4.513	0.0020
20	2.887	0.0008
21	4.515	0.0020
22	4.465	0.0020
23	4.792	0.0023
24	2.395	0.0006
25	3.154	0.0010
26	3.144	0.0010
27	4.869	0.0024
28	2.032	0.0004
29	4.722	0.0022
30	2.984	0.0009
31	4.168	0.0017
32	1.866	0.0003
33	2.781	0.0008
34	2.236	0.0005
35	2.627	0.0007
36	4.444	0.0020
37	2.294	0.0005

Total Standard Deviation 3.38%

6.0 REFERENCES

6.1 CENPD-153-P Revision 1-P-A, "Evaluation of Uncertainty in the Nuclear Power Peaking Measured by the Self-Powered, Fixed Incore Detector System," May 1980.

6.2 XN-NF-83-01(P), Exxon Nuclear Analysis of Power Distribution Measurement Uncertainty for St. Lucie Unit 1," January 1983.

6.3 F. E. Satterthwaite, "An Approximate Distribution of Estimates of Variance Components," Biometrics Bull. 2 (1946), 110-114.

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