# SALEM UNIT 2 CYCLE 11

# THIMBLE DELETION STUDY

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## EVALUATION OF THIMBLE DELETION ON PEAKING FACTORS

### Introduction

A study utilizing flux maps from the Salem Units 1 and 2 plants was undertaken to assess incremental peaking factor measurement uncertainties. This study accounts for a reduction to a minimum of 29 of the 58 movable detector (M/D) thimbles. The large database used in this study is intended to quantify the measured peaking factor uncertainties specifically for operation of the Salem Unit 2 Cycle 11 core.

Section 1 of this study presents the methodology and results of randomly deleting thimbles from actual INCORE maps to quantify the uncertainties. Section 2 quantifies the minimum number of thimbles per quadrant required in order to improve the ability to distinguish between random and systematic thimble deletion events and to establish the bounds of applicability of Section 1.

This study includes actual INCORE maps for Salem Unit 2 Cycle 11 in order to confirm applicability of this cycle to the study described herein. Review of current cycle flux maps indicate that measurement to predicted peaking factors are well within the required measurement uncertainties and indicate the core is behaving as predicted. Based on this, it is not anticipated that the core will not perform as expected for the remainder of the cycle. It is not expected that the additional uncertainties on the peaking factors will result in any violation of the limits. Even with the increased measurement uncertainty applied as a result of the thimble deletion study, the Salem Unit 2 Cycle 11 Peaking Factor Surveillance Technical Specification ($F_{\Delta H}$, $F_Q$, and $F_{xy}$) will provide necessary protection.

When referring to percentages in Sections 1 and 2, they refer to the percentage from a total of 58 thimbles unless otherwise specified.

## SECTION 1

### METHODOLOGY - GENERAL

To assess the additional peaking factor measurement uncertainties associated with as few as 50% of the M/D thimbles available, fifteen reference full core INCORE flux maps from Salem Unit 1 and Unit 2 were used. This included 5 maps each from two completed cycles of Salem Unit 1 and Unit 2 as well as 5 maps from Salem Unit 2 Cycle 11. The selection of maps from the completed cycles was made to cover the entire burnup ranges for these two completed cycles; that of Salem Unit 2 Cycle 11 was made from available maps through the current burnup range (approximately through the middle of cycle operation). For each of the reference INCORE maps, five separate random deletions were made, giving a total of 75 thimble deletion cases with 50% of the thimbles available. Five separate random deletions were also done with this same set of reference INCORE maps for the completed cycles of Salem Unit 1 and Unit 2 giving 50 thimble deletion cases with 75% of the thimbles available.

The thimble locations to delete for the thimble deletion cases were randomly determined. Where less than 100% of available thimbles were present in the reference maps, thimble deletion cases were run deleting a fixed number of thimble locations relative to the 100% complement of thimbles (e.g. 58). For 50% of the reference thimble locations available, 29 thimble locations were deleted for all thimble deletion cases. For 75% of the reference thimble locations available, 15 thimble locations were deleted for all thimble deletion cases.

The measured peaking factors for the thimble deletion maps were then compared with the measured peaking factors in the reference maps. Figure 1 shows the M/D locations for the Salem plants. Table 1 provides additional information on the 15 reference maps used in the study. The comparisons for 50% of the reference thimble locations available were used to define the additional measurement uncertainties to be applied to $F_{\Delta H}$, $F_Q$, and $F_{xy}$. The comparisons for 75% of the reference thimble locations available were used to confirm that the existing measurement peaking factor uncertainties (e.g. 4.0% for $F_{\Delta H}$ and 5.0% for $F_Q$ and $F_{xy}$) remain valid. Thimble deletion effects on the INCORE measured axial offset and quadrant tilt were addressed in a similar manner.

METHODOLOGY - STATISTICAL

The percent error between the reference peaking factor value, Fα(Reference) and the thimble deletion case peaking factor value, Fα(T.D.) is defined in Equation 1 as

$$\%\ Error\ (T.D.) = \left(1 - \frac{F\alpha(T.D.)}{F\alpha(Reference)}\right) x\ 100 \qquad (Eq.\ 1)$$

where Fα is $F_{\Delta H}$, $F_Q$, or $F_{xy}$ and T.D. refers to 75% or 50% of available thimbles in the reference case. A positive value of error implies that the peaking factor from the thimble deletion map is non-conservative relative to the reference.

In the following paragraphs the error will be denoted $X_{ij}$ where i refers to one of the reference flux maps (10 for 75% available thimbles and 15 for 50% available thimbles) and j refers to one of the 5 thimble-deletion cases for each reference map. The percent error between the reference value and the thimble deletion case value for quadrant tilt and axial offset are defined in Equations 2 and 3 as

Error (T.D.) = (Ref. - Deleted) x 100 for QUAD Tilt (Eq. 2)

Error (T.D.) = (Ref. - Deleted) for A.O. (Eq. 3)

The mean error for map i, $\overline{X}_i$; and the percent relative sample standard deviation for map i, $S_i$, are defined in Equations 4 and 5, respectively.

$$\overline{X}_i = \frac{1}{5} \sum_{j=1}^{5} X_{ij} \qquad (Eq.\ 4)$$

$$S_i = \left( \frac{\sum_{j=1}^{5} (x_{ij} - \overline{x}_i)^2}{5-1} \right)^{1/2} \qquad (Eq.\ 5)$$

After computing $\overline{X}_i$ and $S_i$ for each map, for each parameter of interest, and for both 50% and 75% thimble deletion cases, the data is combined. The combined mean for all maps, $\overline{X}_{combined}$, is given by Equation 6 as:

$$\overline{X}_{combined} = \frac{1}{N} \sum_{i=1}^{N} \overline{X}_i \qquad (Eq.6)$$

where: N = total number of reference maps
= 15 for the 50% thimbles available and
= 10 for the 75% thimbles available

The combined percent relative sample standard deviation of all maps is given by Equation 7 as:

$$S_{combined} = \left( \left( \frac{\sum_{n=1}^{N} ((N_i - 1) S_i^2 + N_i \overline{X}_i^2)}{N_T} - \overline{X}^2_{comb.} \right) \frac{N_T}{N_T - 1} \right)^{1/2} \qquad (Eq.7)$$

where: N = total number of reference maps
$N_i$ = Number of random deletion cases of each map = 5
$N_T$ = Total number of datapoints = N x $N_i$
= 15 maps x 5 deletions/map = 75 for the 50% thimbles available and
= 10 maps x 5 deletions/map = 50 for the 75% thimbles available

Equations 6 and 7 are constructed in such a manner that if one were to directly compute the mean and standard deviation for all $N_T$ datapoints, the same numeric results would be obtained.

After $\overline{X}_{combined}$ and $S_{combined}$ have been obtained for each parameter of interest, and for both 50% and 75% thimble deletion cases, 95% confidence/ 95% probability one-sided upper tolerance limits are constructed to quantify the thimble deletion uncertainty component (See Equation 8).

$$\text{Thimble Deletion Uncertainty Component (\%)} = \overline{X}_{combined} + kS_{combined} \qquad \text{(Eq. 8)}$$

Where: k = the one-sided 95% confidence/95% probability tolerance limit factor
= 1.976 for 74 degrees of freedom (50% thimbles available)
= 2.065 for 49 degrees of freedom (75% thimbles available)

Application of the above methodology is presented in the "Results" section of this report. The statistical combination of the thimble deletion uncertainty component with INCORE measurement is discussed in the "Thimble Deletion Uncertainty" section of this report.

## RESULTS

Table 2a provides the peaking factors sample mean (%) for each map (see Equation 4) and the sample standard deviation (%) for each map (see Equation 5) for the 50% thimbles available case. The combined sample mean (%) and the combined standard deviation (%) for each parameter of interest, as calculated per Equations 6 and 7, are also shown. Table 2b presents the analogous information for the 75% thimbles available case. Tables 2c and 2d provide the sample mean and the sample standard deviation for quadrant tilt and axial offset over the same database.

Thimble deletion uncertainty components (i.e. the 95% probability, 95% confidence tolerance limit) for $F_{\Delta H}$, $F_Q$, and $F_{xy}$ are calculated in Appendix A using Equation 8 and are based upon the data of Tables 2a and 2b. The Total Measurement Uncertainty including the Thimble Deletion Uncertainty Component (%) is plotted in Figure 2 as a function of Percentage of Thimbles Available. This figure is provided for information only and is not directly used in the uncertainty application.

## THIMBLE DELETION UNCERTAINTY

Current flux map peaking factor measurement uncertainties include allowance for down to 75% thimbles available. Accordingly, an incremental thimble deletion uncertainty penalty from 75% to 50% of thimbles available could be considered to be appropriate. However, for conservatism and simplicity, the full thimble deletion uncertainty penalty from 100% to 50% thimbles available will be used. The Thimble Deletion Uncertainty Component (50% T.D.) discussed in the preceding section is combined with the appropriate flux map measurement uncertainty to obtain a total uncertainty.

## $F_{\Delta H}$ UNCERTAINTY

The following discussions and equations are provided for the hot rod ($F_{\Delta H}$) total peaking factor uncertainty ($F^U_{\Delta H}$). Analogous equations apply to $F^U_Q$ and $F^U_{xy}$.

The appropriate equation for combining statistically independent uncertainty components is

$$F^U_{\Delta H}(50\%) = 1 + F_{\Delta H\,T.D.\,Bias} + ((F^{MU}_{\Delta H} - 1)^2 + (KS)^2_{T.D.})^{1/2} \qquad (Eq.\ 9)$$

For conservatism, a negative value of T.D. Bias will be treated as zero. Evaluating the above expression yields the following result

[ ]$^{(a,c)}$

For conservatism, $F^U_{\Delta H}$ (50%) will be rounded up to 1.05. This value can be interpreted as a 95% probability tolerance limit at a high confidence level. This 1.0 percent incremental thimble deletion penalty is linearly applied from 75% to 50% thimbles available (i.e., 1.04 at 44 thimbles and 1.05 at 29 thimbles available).

$F_Q$ UNCERTAINTY

[ ]$^{(a,c)}$

$F_{xy}$ UNCERTAINTY

[ ]$^{(a,c)}$

for conservatism, $F_{xy}^{U}(50\%)$ and $F_{Q}^{U}(50\%)$ will be rounded to 1.06. This 1.0 percent incremental thimble deletion penalty is linearly applied from 75% to 50% thimbles available (i.e., 1.05 at 44 thimbles and 1.06 at 29 thimbles available).

## AXIAL OFFSET AND QUADRANT TILT

The mean change in quadrant tilt with 29 of the thimbles available was found to be only [ ][a,c]. Similarly, the mean change in axial offset with 50% of the thimbles available was also quite small at [ ][a,c]. Note that all uncertainties on A.O. and tilt are absolute values and not percentages. These values indicate that thimble deletion has a negligible impact on the core average axial power shape measurement. Changes of this magnitude are not significant and will not adversely affect excore detector calibration.

## CONSERVATIVE ASSUMPTIONS

For convenience a summary of conservative assumptions employed in this study are provided below:

1) Available maps from Salem Unit 2 Cycle 11 were explicitly used which included the thimbles unavailable at the time of each map. These were included with the maps from two additional Salem cycles to generate a large database of results from thimble deletion cases.

2) Thimble deletion uncertainty results were rounded up and negative bias values were set to zero.

3) [

]$^{(a,c)}$

4) [

]$^{(a,c)}$

5) [

]$^{(a,c)}$

## SECTION 2

This section quantifies the number of thimbles per quadrant required for Salem Unit 2 in order to improve the ability to distinguish between random and systematic thimble deletion events and to establish the bounds of applicability of the incremental peaking factor uncertainties. The peaking factor measurement uncertainty analysis described in Section 1 makes the assumption that thimbles were randomly deleted from the core. If thimbles are somehow systematically deleted from the core then the calculated peaking factor measurement uncertainties will not apply.

The assumption of random deletion of thimbles is an important one. If removal of instrumentation thimbles in the core is completely random, then each thimble in the core has an equal probability of being removed from operation. Therefore, if 50 percent of the thimbles in the core were to be deleted randomly, a random pattern of thimbles would result. On the other hand, if there were some function driving the removal of the thimbles the result would not be a random pattern of thimbles. This systematic deletion of thimbles could conceivably result in large areas of the core being uninstrumented.

The current Technical Specification requirement of a minimum of 2 M/D thimbles per core quadrant is not sufficient to distinguish between random and systematic deletion events with high confidence. To help insure that thimble deletion is random, a restriction can be placed on the number of thimbles that must remain operable in each quadrant. By defining the quadrant in such a manner as to essentially place a requirement on each 1/8th core, the ability to distinguish between random and systematic events will be significantly enhanced.

If, for example, for 50% thimbles remaining, the requirement of 4 or more thimbles per quadrant is satisfied, then in all likelihood a random deletion occurred and incremental thimble deletion peaking factor measurement uncertainties are appropriate. On the other hand, if there are less than 4 thimbles per quadrant, then it is possible that a systematic thimble deletion occurred and that the impact on measured quadrant peaking factors, may be larger than quantified in Section 1.

### METHODOLOGY - COMPUTER SIMULATION

A short computer program for determining the probability distribution of thimbles remaining has been used in the past. Since the results are dependent on the in-core M/D pattern, the program keeps track of interior, axis, and diagonal thimbles (see 4-LOOP PROBLEM DESCRIPTION following) to allow for a different number of thimbles per quadrant. This program has been used to determine the number of thimbles per quadrant for all of Westinghouse Thimble Deletion Analyses.

Starting with $n_T$ thimbles in the core and randomly deleting down to $r_T$ thimbles constitutes one case. After deleting $n_T$ - $r_t$ thimbles from the core, the number of thimbles remaining in each of the eight quadrants (defined in Figures 3 and 4) is determined, after which the quadrant with the minimum number of thimbles is found. A large number of cases is run in order to determine the probability distribution of thimbles remaining.

## 4-LOOP PROBLEM DESCRIPTION

The maximum possible number of available thimbles for a 4-loop Westinghouse PWR is 58. The initial distribution of these thimbles is provided in the following table. Figures 3 and 4 should also help in visualization.

| | | |
|---|---|---|
| No. of Interior Thimbles in QI | 11 | |
| No. of Interior Thimbles in QII | 10 | |
| No. of Interior Thimbles in QIII | 11 | |
| No. of Interior Thimbles in QIV | 11 | |
| No. of Axis Thimbles QI-QII | 4 | |
| No. of Axis Thimbles QII-QIII | 4 | |
| No. of Axis Thimbles QIII-QIV | 3 | |
| No. of Axis Thimbles QIV-QI | 4 | |
| | 58 | Total |

| | | |
|---|---|---|
| No. of Interior Thimbles in QA | 11 | |
| No. of Interior Thimbles in QB | 14 | |
| No. of Interior Thimbles in QC | 12 | |
| No. of Interior Thimbles in QD | 12 | |
| No. of Diagonal Thimbles QA-QB | 1 | |
| No. of Diagonal Thimbles QB-QC | 3 | |
| No. of Diagonal Thimbles QB-QD | 2 | |
| No. of Diagonal Thimbles QD-QA | 3 | |
| | 58 | Total |

Note that all thimbles are counted as whole values even if they lie on an axis or diagonal. Axis or diagonal thimbles retained in the computer simulation are counted in both adjacent quadrants. This is appropriate provided that the flux mapping analysis procedure and computer simulation are consistent. Twenty-nine (29) thimbles are randomly deleted from each case.

## 4-LOOP PROBLEM RESULTS

A 3000 case simulation was run to obtain the probability distribution of the minimum number of thimbles left after having reduced to 29 thimbles available. Results are summarized in Table 3.

As seems reasonable there is negligible probability of 0 or 1 thimbles remaining and only [ ]$^{(a,c)}$ Therefore, a requirement that 4 or more thimbles per quadrant be available is appropriate. Assuming random thimble deletion, it is unlikely that with 29 thimbles remaining overall, fewer than 4 thimbles will be available over the 8 quadrants.

## CONCLUSION

It is concluded that operation of the movable detector system with a minimum of 50% of the thimbles available is acceptable provided that additional peaking factor uncertainties of 1.0% for $F_{\Delta H}$ and 1.0% for $F_Q$ and $F_{xy}$ be applied to the INCORE measured peaking factors. However, when fewer than 75% of the thimbles are available there should be a minimum of 4 thimbles per quadrant where quadrant includes both horizontal-vertical quadrants and diagonally bounded quadrants. This requirement increases the ability to distinguish between random and systematic thimble deletion events. In addition, the confidence on the appropriateness of the incremental thimble deletion peaking factor uncertainty values is increased provided that 4 or more thimbles per quadrant are observed to be available, and counting thimbles on the axis and diagonal as whole values.

TABLE 1

INCORE DETECTOR THIMBLE DELETION REFERENCE MAPS

| | | Burnup (MWD/MTU) | Core Power (%) | Percent Thimbles Available |
|---|---|---|---|---|
| **Unit 2 Cycle 10** | | | | |
| | Map 1 | 534 | 99.0 | 89.7 |
| | Map 2 | 4025 | 100.0 | 91.4 |
| | Map 3 | 8970 | 99.9 | 91.4 |
| | Map 4 | 13637 | 99.5 | 89.7 |
| | Map 5 | 17727 | 99.9 | 89.7 |
| **Unit 1 Cycle 13** | | | | |
| | Map 1 | 415 | 99.7 | 87.9 |
| | Map 2 | 4107 | 99.7 | 87.9 |
| | Map 3 | 9385 | 100.0 | 89.7 |
| | Map 4 | 13409 | 99.8 | 87.9 |
| | Map 5 | 16753 | 100.0 | 87.9 |
| **Unit 2 Cycle 11** | | | | |
| | Map 1 | 249 | 99.5 | 79.3 |
| | Map 2 | 1069 | 99.8 | 79.3 |
| | Map 3 | 2985 | 99.9 | 81.0 |
| | Map 4 | 5073 | 99.9 | 77.6 |
| | Map 5 | 8267 | 100.0 | 77.6 |

TABLE 2a

SAMPLE STANDARD DEVIATION AND MEAN FOR INCORE MAPS
WITH 50% OF THE THIMBLE AVAILABLE FOR FOUR LOOP
REACTOR CORE PARAMETERS

| | | | $F_{\Delta H}$ | | $F_Q$ | | $F_{xy}$ | |
|---|---|---|---|---|---|---|---|---|
| Unit | Cycle | Map | $\overline{X}_i$ (%) | $S_i$ (%) | $\overline{X}_i$ (%) | $S_i$ (%) | $\overline{X}_i$ (%) | $S_i$ (%) |
| 2 | 10 | 1 | | | | | | |
| 2 | 10 | 2 | | | | | | |
| 2 | 10 | 3 | | | | | | |
| 2 | 10 | 4 | | | | | | |
| 2 | 10 | 5 | | | | | | |
| 1 | 13 | 1 | | | | | | |
| 1 | 13 | 2 | | | | | | |
| 1 | 13 | 3 | | | | | | |
| 1 | 13 | 4 | | | | | | |
| 1 | 13 | 5 | | | | | | |
| 2 | 11 | 1 | | | | | | |
| 2 | 11 | 2 | | | | | | |
| 2 | 11 | 3 | | | | | | |
| 2 | 11 | 4 | | | | | | |
| 2 | 11 | 5 | | | | | | |
| $\overline{X}_{comb}$ and $S_{comb}$ | | | | | | | | |

(a,c)

TABLE 2b

SAMPLE STANDARD DEVIATION AND MEAN FOR INCORE MAPS
WITH 75% OF THE THIMBLE AVAILABLE FOR FOUR LOOP
REACTOR CORE PARAMETERS

| | | | $F_{\Delta H}$ | | $F_Q$ | | $F_{xy}$ | |
|---|---|---|---|---|---|---|---|---|
| Unit | Cycle | Map | $\overline{X}_i$ (%) | $S_i$ (%) | $\overline{X}_i$ (%) | $S_i$ (%) | $\overline{X}_i$ (%) | $S_i$ (%) |
| 2 | 10 | 1 | | | | | | |
| 2 | 10 | 2 | | | | | | |
| 2 | 10 | 3 | | | | | | |
| 2 | 10 | 4 | | | | | | |
| 2 | 10 | 5 | | | | | | |
| 1 | 13 | 1 | | | | | | |
| 1 | 13 | 2 | | | | | | |
| 1 | 13 | 3 | | | | | | |
| 1 | 13 | 4 | | | | | | |
| 1 | 13 | 5 | | | | | | |
| $\overline{X}_{comb}$ and $S_{comb}$ | | | | | | | | |

(a,c)

TABLE 2c

SAMPLE STANDARD DEVIATION AND MEAN FOR INCORE MAPS
WITH 50% THIMBLES AVAILABLE FOR FOUR LOOP
REACTOR CORE PARAMETERS

| | | | **Axial Offset*** | | **Quadrant Tilt+** | |
|---|---|---|---|---|---|---|
| Unit | Cycle | Map | $\overline{X}_i$ (%) | $S_i$ (%) | $\overline{X}_i$ (%) | $S_i$ (%) |
| 2 | 10 | 1 | | | | |
| 2 | 10 | 2 | | | | |
| 2 | 10 | 3 | | | | |
| 2 | 10 | 4 | | | | |
| 2 | 10 | 5 | | | | |
| 1 | 13 | 1 | | | | |
| 1 | 13 | 2 | | | | |
| 1 | 13 | 3 | | | | |
| 1 | 13 | 4 | | | | |
| 1 | 13 | 5 | | | | |
| 2 | 11 | 1 | | | | |
| 2 | 11 | 2 | | | | |
| 2 | 11 | 3 | | | | |
| 2 | 11 | 4 | | | | |
| 2 | 11 | 5 | | | | |
| | $\overline{X}_{comb}$ and $S_{comb}$ | | | | | |

(a,c)

\+ Standard deviation for Quadrant Tilt about ΔTilt = (Ref. - Deleted) x 100%.

* Standard deviation for Axial Offset about ΔAxial Offset = (Ref. - Deleted).

TABLE 2d

SAMPLE STANDARD DEVIATION AND MEAN FOR INCORE MAPS WITH 75% OF THE THIMBLE AVAILABLE FOR FOUR LOOP REACTOR CORE PARAMETERS

| | | | **Axial Offset*** | | **Quadrant Tilt+** | |
|---|---|---|---|---|---|---|
| Unit | Cycle | Map | $\overline{X}_i$ (%) | $S_i$ (%) | $\overline{X}_i$ (%) | $S_i$ (%) |
| 2 | 10 | 1 | | | | |
| 2 | 10 | 2 | | | | |
| 2 | 10 | 3 | | | | |
| 2 | 10 | 4 | | | | |
| 2 | 10 | 5 | | | | |
| 1 | 13 | 1 | | | | |
| 1 | 13 | 2 | | | | |
| 1 | 13 | 3 | | | | |
| 1 | 13 | 4 | | | | |
| 1 | 13 | 5 | | | | |
| | | $\overline{X}_{comb}$ and $S_{comb}$ | | | | |

(a,c)

\+ Standard deviation for Quadrant Tilt about ΔTilt = (Ref. - Deleted) x 100%.

* Standard deviation for Axial Offset about ΔAxial Offset = (Ref. - Deleted).

TABLE 3

4-LOOP CORE SUMMARY

3000 CASE THIMBLE DELETION SIMULATION

29 THIMBLES DELETED

| Minimum Number of Thimbles Left per Quadrant | Number of Cases | Percent of Cases | Cumulative Percentage |
|---|---|---|---|
| 0 | | | |
| 1 | | | |
| 2 | | | |
| 3 | | | |
| 4 | | | |
| 5 | | | |
| 6 | | | |
| 7 | | | |
| 8 | | | |
| 9 | | | |
| 10 | | | |

(a,c)

FIGURE 1
MOVEABLE DETECTOR LOCATIONS

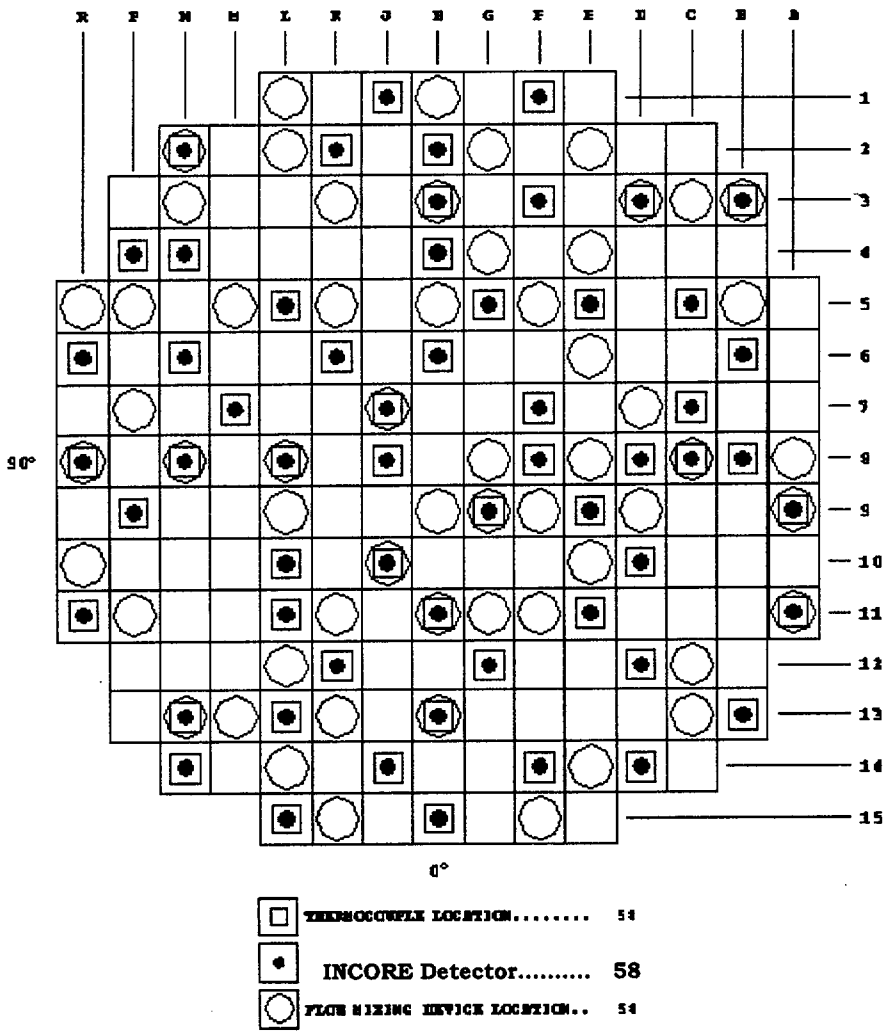


FIGURE 2
TOTAL MEASUREMENT UNCERTAINTY VERSUS
PERCENTAGE OF THIMBLES AVAILABLE

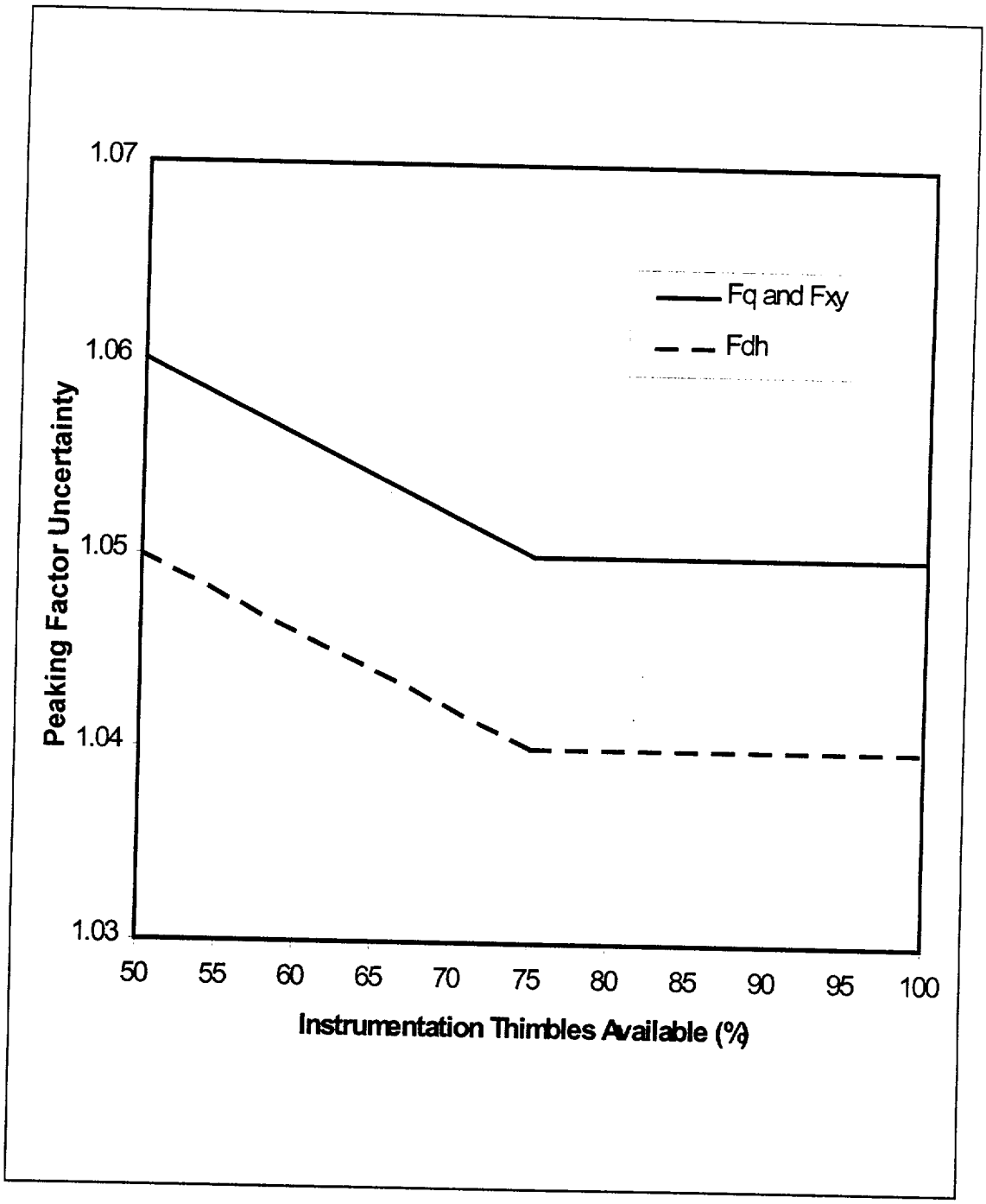


FIGURE 3
MOVEABLE DETECTOR LOCATIONS
HORIZONTAL AND VERTICAL QUADRANTS I, II, III, IV

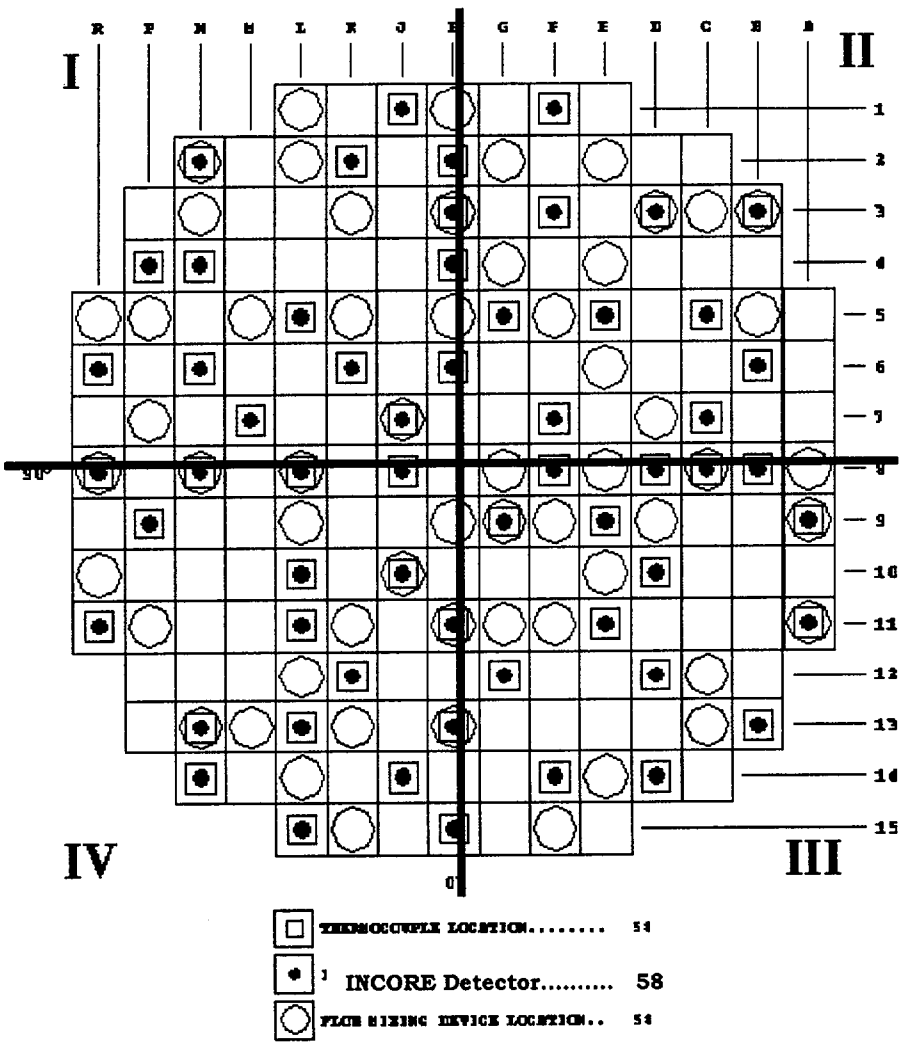
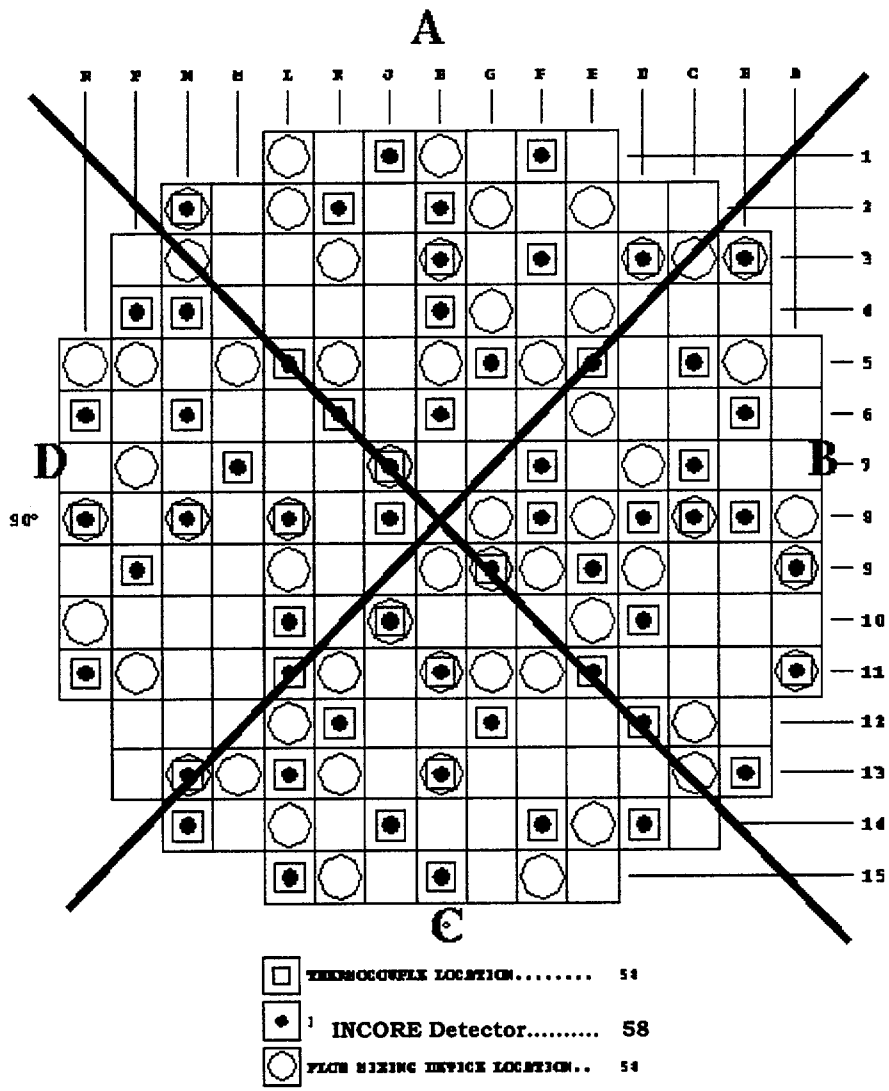


FIGURE 4
MOVEABLE DETECTOR LOCATIONS
DIAGONAL QUADRANTS A, B, C, D



# APPENDIX A

## THIMBLE DELETION UNCERTAINTY COMPONENTS

95% PROBABILITY AND 95% CONFIDENCE ( $\overline{X}_{comb} + kS_{comb.}$ )

NORMAL (TYPICAL) FLUX MAPS

| | | | |
|---|---|---|---|
| $F_{\Delta H}$ Thimble Deletion Uncertainty Component | 75% | [redacted] | (a,c) |
| | 50% | | |
| $F_Q$ Thimble Deletion Uncertainty Component | 75% | [redacted] | (a,c) |
| | 50% | | |
| $F_{xy}$ Thimble Deletion Uncertainty Component | 75% | [redacted] | (a,c) |
| | 50% | | |

# APPENDIX B

## TWO-SIDED 95% CONFIDENCE LIMITS ON MEAN ΔTILT AND MEAN ΔA.O.

$\overline{X}_{comb} \pm t_{.025}\ s_{comb.} / \sqrt{N}$ (approximate t by z)

tilt or A.O. tilt or A.O.

| | | | |
|---|---|---|---|
| Quadrant Tilt Uncertainty Component | 75% | [redacted] | [redacted] (a,c) |
| | 50% | | |
| Axial Offset Uncertainty Component | 75% | [redacted] | [redacted] (a,c) |
| | 50% | | |