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FORT ST. VRAIN
NUCLEAR DETECTOR DECALIBRATION
- CYCLE 2 -

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1. SUMMARY

Power-range nuclear detector signals are used in the Fort St. Vrain reactor to monitor core power during steady state and transient conditions and in the automatic control system to initiate plant protective system (PPS) action.

For cycle 1 operation of the FSV reactor, significant decalibration of these power-range detectors, due to motion of control rod groups, was predicted and measured. This decalibration results from the location of the six detectors symmetrically around the core, in the PCRV. This means that each detector "sees" neutrons from principally a few fuel columns near the core boundary. As a result of this detector decalibration, a "floating" trip point was recommended for cycle 1 operation to assure the reactor trips at or below 140% thermal power. Reference 1 describes the operation of the "floating" trip point and details the associated circuitry hardware. Since the floating trip point hardware was not installed during cycle 1, the detector decalibration was accomodated by a reduction in the fixed PPS setpoints.

Because of the different control rod withdrawal sequence in cycle 2 and the different core fuel loading distribution, it is necessary to re-evaluate the detector decalibration to determine if the cycle 1 PPS floating trip setpoints are adequate for cycle 2 operation. Results of these analyses indicate that, with an additional requirement that the detectors be calibrated prior to the withdrawal of control rod group 3C, the PPS floating setpoints recommended for cycle 1 are adequate for cycle 2 operation. This cycle 2 analysis followed the same calculational procedure as that used for the cycle 1 analysis (Ref. 1). No transient

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analyses were done here since Reference 1 reports that detector decalibration produces minimal changes in cycle 1 plant response to transient events such as ramp load changes, loop trips, and turbine trips. It is assumed that the cycle 2 plant response would not be significantly different. Furthermore, it is assumed that the uncertainties and safety margins reported for cycle 1 are adequate for cycle 2.

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2. INTRODUCTION

The nuclear detector decalibration problem at FSV results from the positioning of the six nuclear detectors located symmetrically around the core in the PCRV, i.e., each detector "sees" neutrons from only a few columns located on the core boundary (calculations indicate that >99% of the signal comes from the nearest nine fuel columns). Thus, when control rods are moved to change power, the detector response is dictated by the change in power (or flux) in the adjacent fuel columns. Specifically, this means that when control rods near the core center are withdrawn the detectors under-respond to the power change and when control rods are withdrawn in the outer ring of the core (ring 4) the nearest detectors over-respond to the change in power. The opposite effect is, of course, true when control rods are inserted. This change in individual detectors has been calculated and measured (Ref. 1) in cycle 1.

This decalibration of the power range detectors with control rod positions merits both operational and safety considerations.

2.1 Operational

Potential operational problems result from the inability of the operator to monitor accurately the power level following a power change which requires significant control rod motion. This problem is of most concern during power changes involving motion of control rods in the outermost ring (ring 4). Not only do motions of these control rods have the largest effect on the detector response but typically these ring 4 rods have a small reactivity worth and require more motion for a given power level change. The two control rod groups which cause the most

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severe decalibration problems are groups 4D and 4A, i.e., the two groups nearest the detectors. In cycle 1, calibration of the detector was typically required several times during the withdrawal of group 4A to avoid an RWP (PPS setpoints have been lowered for operation until the installation of the proposed floating setpoint hardware).

It is anticipated that the operational problems due to withdrawal of ring 4 control rods will not be as severe in cycle 2 since all of the ring 4 control rods are withdrawn earlier in the rod withdrawal sequence. In fact, groups 4D and 4A are withdrawn prior to criticality and are of no concern on the power range detectors. However, the sequential withdrawal of the four ring 3 rod groups is expected to result in significant detector decalibration.

2.2 Safety

Potential safety problems result from the use of the power range detectors as input to the PPS. The PPS uses this instrumentation for high power scram, low power control rod withdrawal prohibit (RWP), and for high power RWP. As a result, positive detector decalibration (over-response) may result in a spurious RWP and negative detector decalibration (under-response) may delay the PPS response to a Rod Withdrawal Accident (RWA).

Only under-response detector decalibration is considered in this study since over-response decalibration is not a safety problem.

This report describes the cycle 2 analyses performed in order to justify the use of the cycle 1 PPS floating trip setpoints for cycle 2 operation.

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3. LOCATION AND FUNCTION OF POWER RANGE DETECTORS

The locations of the ex-core detectors are shown in Figure 1. The twelve power range detectors are located symmetrically at 60° intervals around the core in steel-lined wells in the PCRV (2 detectors per wall). The power range detectors serve two functions:

1. The six PPS detectors are fission chambers, one located in each of the six wells shown in Figure 1 (identified as NE-1133 through NE-1138) at about the core axial midplane. Their range is from 1.5% to 150% of full power. The six detector signals are combined into three channels for PPS use, each channel combining the signals from two 180°-opposed detectors. Thus, NE-1133 and NE-1136 feed channel A, NE-1134 and NE-1137 feed channel B, and NE-1135 and NE-1138 feed channel C. These channels provide a trip signal at 140% of full power on a two-out-of-three channel logic; each channel is tripped on a single high detector reading. Signals from these six detectors are also fed to six separate indicators on the operator control panel.

2. Plant control detectors are a separate set of six fission chambers with a range from 1.5% to 150% of full power located in the same wells as the linear range detectors at about the same axial position. Signals from these detectors (identified as NE-1133-2 through NE-1138-2) are averaged to form a single input to the flux controller NC-1199 (Ref. 2) which, in turn, regulates the position of the central control rod pair and runback rod group* to control the power

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* Runback rods are rods from two rod groups (six rod pairs) preselected for automatic insertion when the plant control system demands a power reduction of more than 10%.

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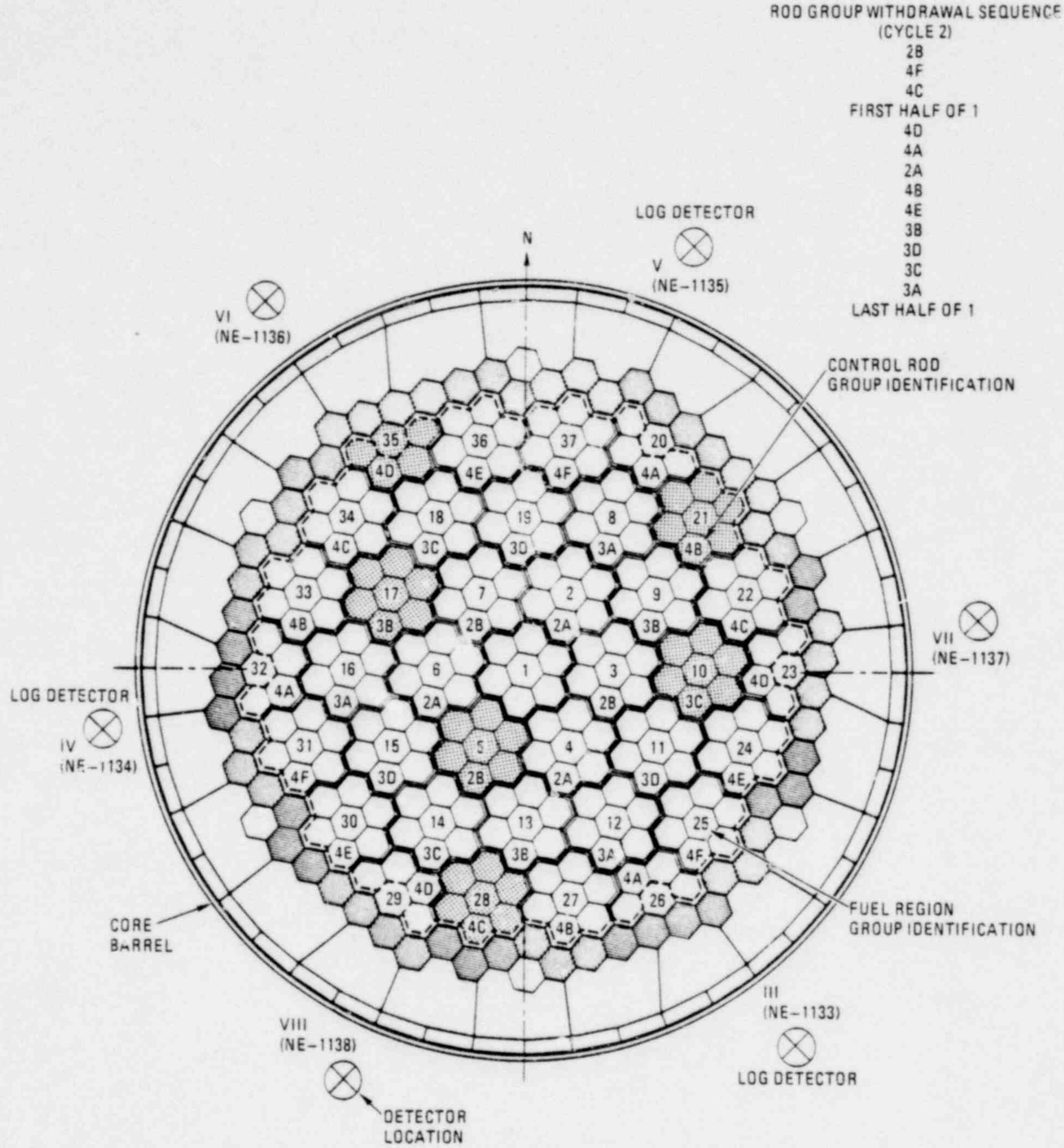

Fig. 1 FSV core layout and locations of ex-core detectors (shaded regions denote cycle 2 reload regions)

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level in the core. The averaged flux level is also sent to the flux recorder (NR-1199), the flux integrator (NM-1199), and the power/flow module (XMS-11262). The flux integrator, in turn, feeds the megawatt-hour meter (NQ-1199) (Ref. 2).

In addition to the PPS trip setpoints, the rod withdrawal prohibits (RWP) will be affected by detector decalibration. One of the RWPs is activated on high reactor power (120%) with signals from the linear range detectors in the same manner as the PPS trip signal at 140% of full power. The other RWPs are activated if the power level is not within the range permitted by three positions of the interlock sequence switch (ISS). The purpose of the RWP is to ensure that the correct sequence of protective actions is engaged during the rise to full power. The ISS incorporates three positions with RWP functions:

1. Startup. An RWP will be encountered at 5% power to ensure startup with adequate neutron flux indication and proper rate of increase in the flux. This RWP is activated by a high signal from two non-opposite linear range detectors and can be cleared by switching to Low Power mode.

2. Low Power. An RWP will be encountered in this mode if two non-opposite linear power detectors indicate power levels above 30% of full power. This prohibit can be cleared by switching to the Power Operation mode, which activates the PPS trips required for PPS action. Once in the Power Operation mode, power must be increased to the point at which all six linear power detectors indicate greater than 30%; otherwise, a subsequent reduction below 30% power will reactivate this RWP.

3. Power Operation. Once all detectors indicate above 30% of full power, the RWP on Low Power will only be activated if the power level drops below 10%. This permits normal operation and load changes with power overshoot, while still ensuring correct protective

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function action following a shutdown or reduction to a power level below the range where electrical power is produced.

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4. ANALYSIS OF DETECTOR DECALIBRATION

4.1 Calculational Method

The detector decalibration factor (DF) is defined as the ratio of the detector indicated power level to the true power (heat-balance power). These DFs are calculated using the GAUGE (Ref. 3) diffusion theory code along with influence coefficients representing the contribution of adjacent columns to the detector response. The column power (normalized to the average core power) is multiplied by the column contribution (or influence coefficient) to the detector response and summed over the contributing fuel columns to obtain a relative response for each detector. The ratio of the response for each detector, normalized to the calculated average core power, from two calculations is then the DF, i.e., the ratio of the detector indicated power level to the true power level. This, of course, gives the DF for a particular rod withdrawal or insertion - assuming the detectors were calibrated prior to this particular rod configuration. DFs for a combination of several events are obtained by multiplying the DFs for each of the individual events.

The influence coefficients used in these analyses are reported in Reference 4. In the cycle 1 analyses, these coefficients were reduced to the nine (9) fuel columns with the major contribution to the detector response (representing >99% of the detector signal). The influence coefficients for each contributing fuel column and region are given in Table 1 for the six (6) detectors. The column numbering scheme is shown in Figure 1A.

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Table 1

Fuel Column Contribution to Detector Response

Detector						Block Number*	Block Contribution or Influence Coefficient
III	IV	V	VI	VII	VIII		
Reg. 25	Reg. 31	Reg. 37	Reg. 34	Reg. 22	Reg. 28	1	0.015
↓	↓	↓	↓	↓	↓	2	0.110
						3	0.080
						4	0.010
						7	0.078
Reg. 26	Reg. 32	Reg. 20	Reg. 35	Reg. 23	Reg. 29	1	0.149
↓	↓	↓	↓	↓	↓	3	0.032
						5	0.018
						6	0.508

* GAUGE block numbering scheme

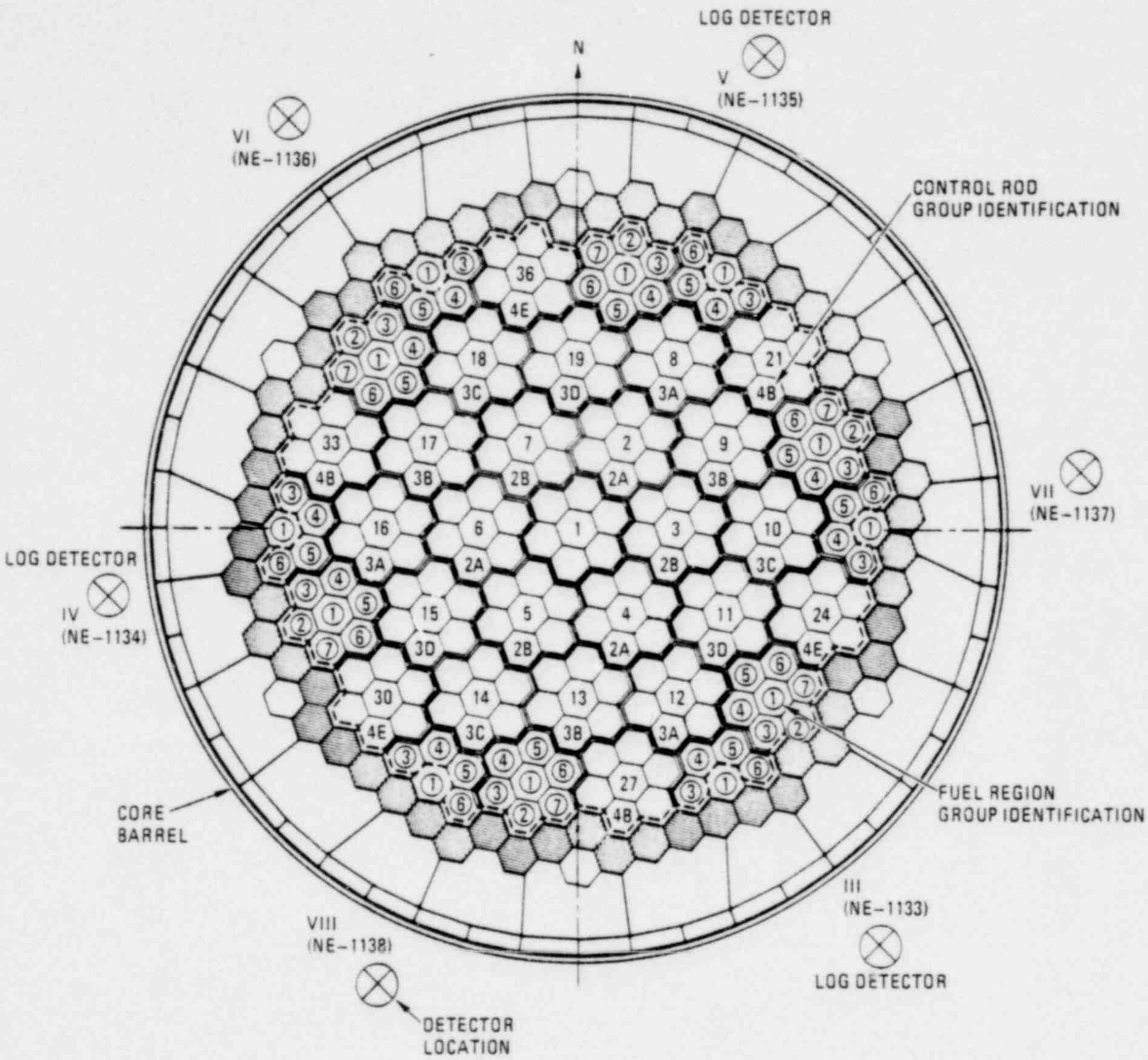

Fig. 1a Column numbering scheme

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All analyses reported here (unless otherwise noted) assume a control rod or rod group to be fully withdrawn or fully inserted. This assumption has been proven to be adequate, since cycle 1 measured DFs were shown to be essentially linear with distance inserted or withdrawn (Ref. 1).

The DFs reported here were calculated at five days into the cycle, at a fuel temperature of $1065^{\circ}K$, and are assumed to be only a function of control rod position. However, the effect of fuel temperature and time-in-cycle on the DFs was also investigated and is discussed below.

Figure 2 shows the six detector decalibration factors as a function of fuel temperature for the withdrawal of control group 4B. These data indicate that there is some dependence of fuel temperature on DF. The DF for detectors IV, V, VI, VII decreases with temperature with a maximum change of $\leq 5\%$. The DFs for detectors III and VIII increase with temperature with maximum change of $\sim 11\%$. However, a fuel temperature of $1065^{\circ}K$ is considered to be adequate for all calculations since these data show that to be conservative, i.e., the $1065^{\circ}K$ data result in the lowest DF and hence the lowest PPS setpoint*.

Figures 3 and 4 show the six detector decalibration factors as a function of time-in-cycle for the withdrawal of control group 4B and 3B, respectively. These data indicate that there is some dependence of time-in-cycle on DF. The DF for the withdrawal of group 4B decreases with time-in-cycle for four of the detectors and increases for two detectors. Calculations at five days into the cycle are considered adequate here since the PPS setpoint does not have to be lowered for this rod configuration, i.e., the DF is greater than unity. The DF for the withdrawal of group 3B decreases with time-in-cycle for three detectors and increases for three. This means that the calculation at

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* It is assumed that this temperature dependence is essentially the same for all control rod configurations.

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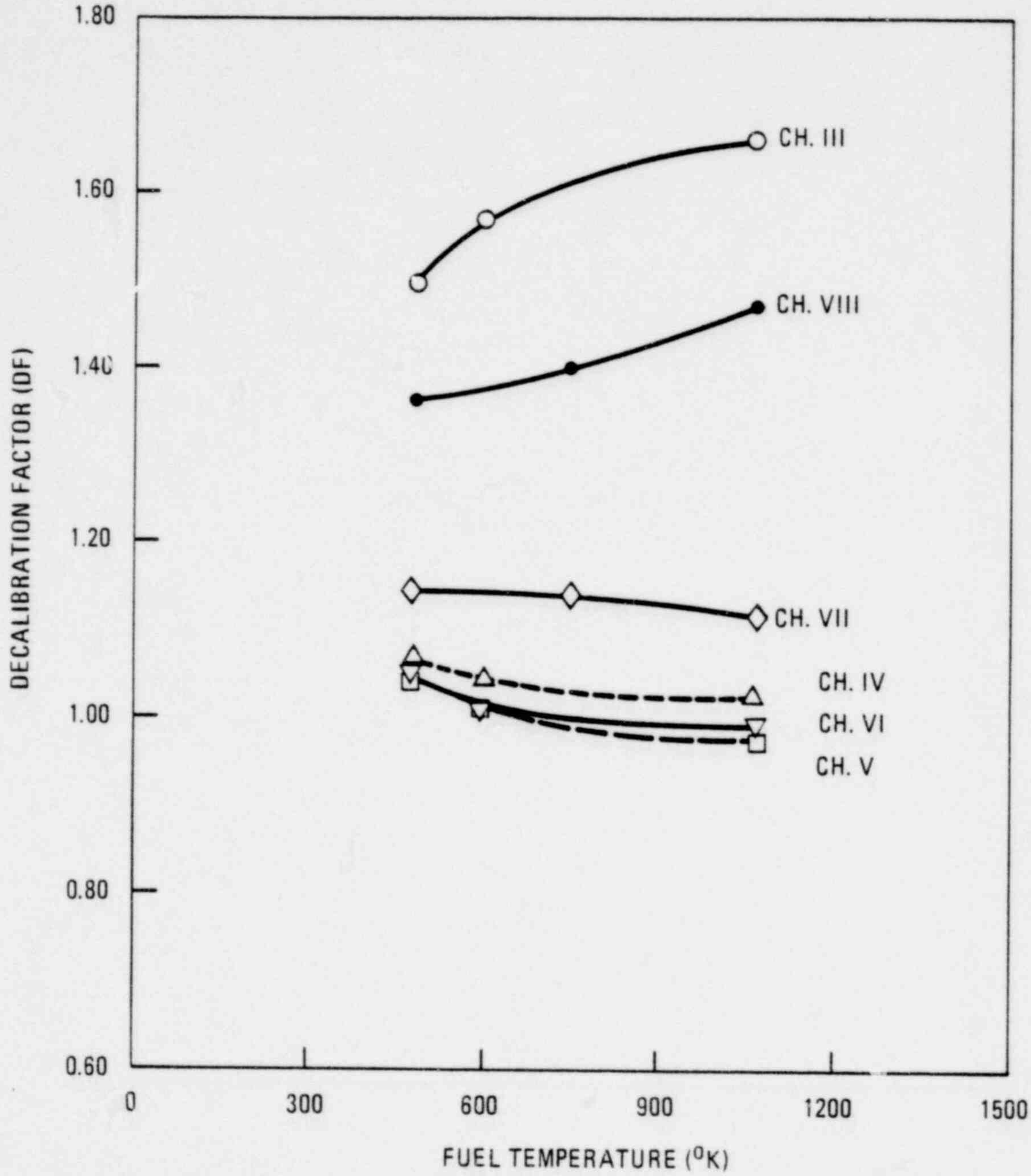

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Fig. 2 Detector decalibration factor as a function of fuel temperature (DF for withdrawal of group 4B, assumes proper calibration prior to removal of 4B)

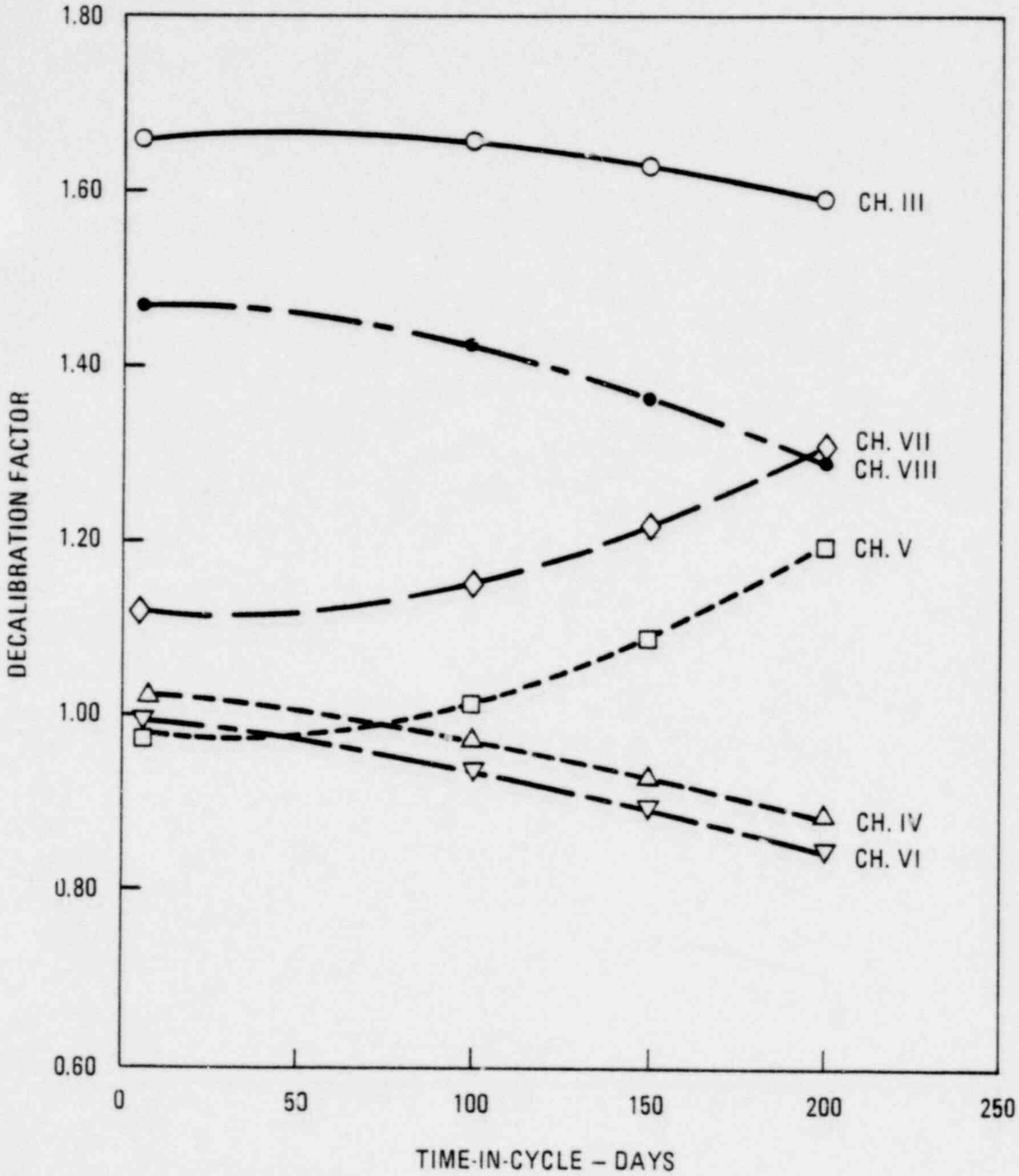

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Fig. 3 Detector decalibration factor as a function of time-in-cycle (DF for withdrawal of group 4B)

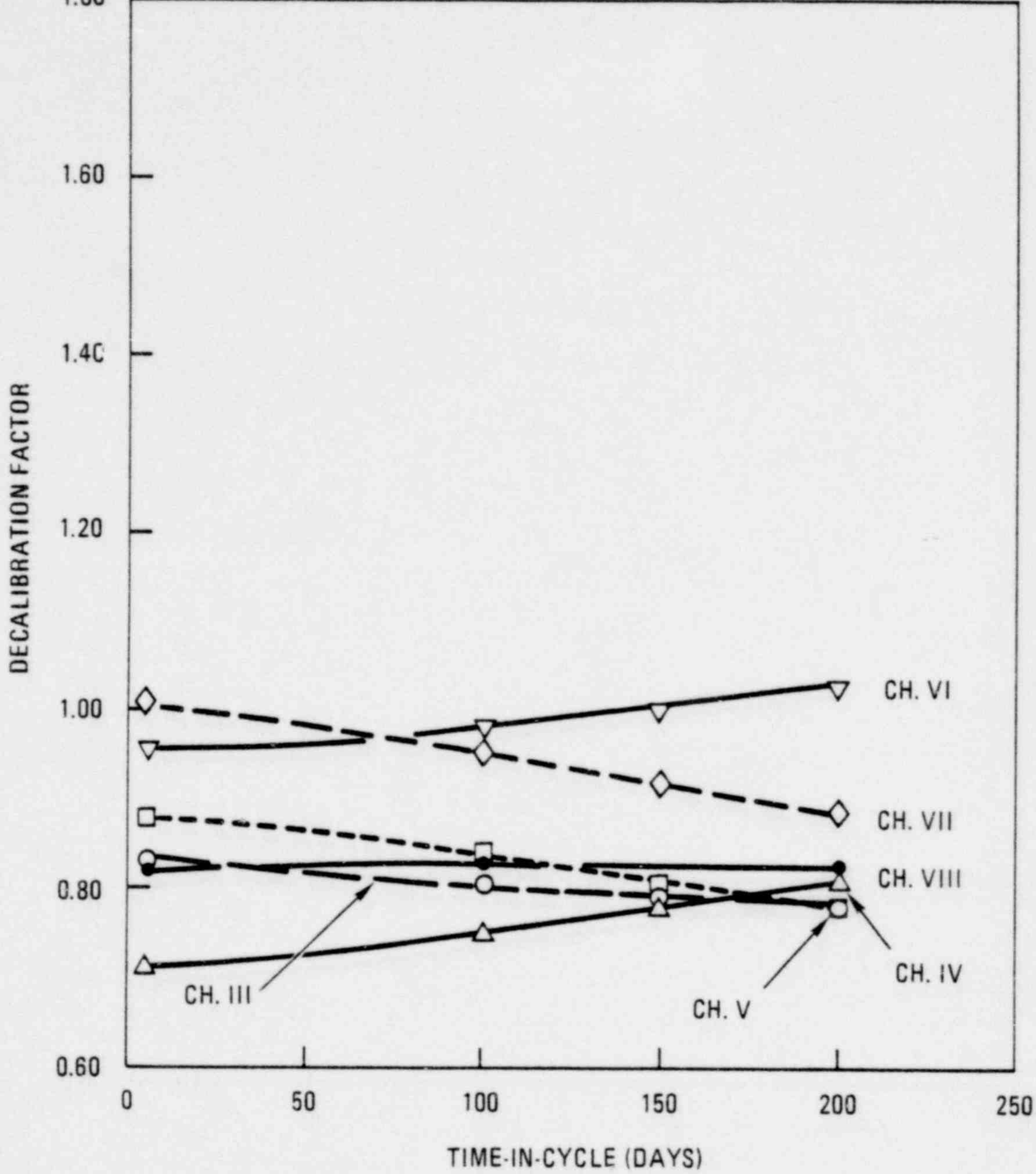

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Fig. 4 Detector decalibration factor as a function of time-in-cycle (DF for withdrawal of group 3B)

five days into the cycle is not conservative since four of the DFs are less than unity. However, the required PPS setpoint for five days is only ~6% higher than for 200 days and it will be shown in Section 5 that this setpoint is not as restrictive as that for cycle 1.

Even though it has been shown that the fuel temperature and time-in-cycle do have an effect on the calculated decalibration factor they are not large effects. Therefore, for this study, it is assumed that a calculation at five days into the cycle and a fuel temperature of 1065°K is acceptable.

4.2 Results of Analysis

The results of this study are presented in this section by comparing the detector decalibration factors for cycle 2 to those for cycle 1. The objective here is to show that, for the worst cases, the required reduction in PPS setpoint for cycle 2 is less than the reduction required for cycle 1, i.e., that the cycle floating trip setpoints are adequate for cycle 2. Cycle 1 data are obtained from Reference 1, where the measured DFs are used for control groups 3A through 4E and the calculated DFs are used for the remaining rod groups. In all cases, it is assumed that no more than three rod groups are inserted or withdrawn without calibration of the detectors. Because of the requirement for daily calibration, and based on cycle 1 operating history, this is a reasonable assumption.

Two sets of data are given as described below.

1. The first set of data gives the decalibration factor which determines the PPS trip setting for a trip of the third PPS channel at 140% of true power. Only the DFs with a value less than unity are considered here, since these are the ones which cause a delay in the PPS trip. Therefore, a data point is given only if four (4) of the detectors have a DF less than unity. The DF for a given rod configuration is determined by grouping opposite detectors and

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auctioneering their signals. For instance, when the DF for detectors III through VIII are 0.83, 0.71, 0.88, 0.95, 1.01, and 0.82, channels A, B, and C would register signals with DFs of 0.95, 1.01, and 0.88, respectively. Thus, the DF which determines the PPS setpoint for the third PPS channel to trip at 140% true power is 0.88. Although only two out of three channels are required to trip before a scram, this study assumes that all three channels must trip, i.e., one channel fails in a non-tripped mode. This means that the trip setpoint is determined by the lowest decalibration factor - a conservative assumption.

2. The second set of data gives the <u>average</u> decalibration factor which produces the reactor power signal to the flux controller. This average DF is simply the average of the six detector DFs. DFs both >1.0 and <1.0 are considered here since both may cause operational difficulties. Decalibration factors are given only for rod withdrawals. The DFs for rod insertions would, of course, be the inverse of these values.

4.2.1 Detector Decalibration due to Sequential Control Rod Withdrawal and Insertion

The detector decalibration factors for each of the six detectors and for the average of the six detectors are shown in Tables 2 and 3 for sequential rod group withdrawal and insertion. The cycle 2 rod withdrawal sequence is shown in Figure 1. Detector decalibration factors are given for each rod group (after criticality) assuming that the detectors are calibrated before each group, before two groups, and before three groups are withdrawn and inserted in sequence, i.e., up to three rod groups may be withdrawn or inserted without calibration of the detectors.

A comparison of cycle 1 and cycle 2 decalibration factors which determines the trip of the third PPS channel at 140% true power is shown

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Table 2

Detector Decalibration Factors for Sequential Rod Withdrawal

	Detector Indicated Power / True Power						
	III	IV	V	VI	VII	VIII	Avg. of 6 Det.
Pull 2A-Calib-Pull 4B	1.66	1.03	0.99	0.98	1.12	1.47	1.21
Then Pull 4E	1.74	1.36	0.84	0.89	1.19	1.76	1.30
Then Pull 3B	1.45	0.97	0.74	0.85	1.20	1.45	1.11
Pull 4B-Calib-Pull 4E	1.05	1.32	0.86	0.90	1.06	1.20	1.07
Then Pull 3B	0.87	0.94	0.76	0.86	1.07	0.98	0.91
Then Pull 3D	0.79	0.88	0.80	0.74	0.[illegible]2	0.74	0.81
Pull 4E-Calib-Pull 3B	0.83	0.71	0.88	0.95	1.01	0.82	0.87
Then Pull 3D	0.76	0.67	0.93	0.82	0.87	0.62	0.78
Then Pull 3C	0.65	0.60	0.72	0.90	0.91	0.73	0.75
Pull 3B-Calib-Pull 3D	0.91	0.94	1.06	0.86	0.86	0.75	0.90
Then Pull 3C	0.78	0.85	0.82	0.95	0.90	0.89	0.87
Then Pull 3A	0.95	0.96	0.89	0.79	0.74	0.78	0.85
Pull 3D-Calib-Pull 3C	0.86	0.90	0.77	1.10	1.05	1.19	0.98
Then Pull 3A	1.05	1.03	0.84	0.91	0.86	1.04	0.96
Then Pull 1/2 RR*	1.00	0.98	0.82	0.89	0.84	0.98	0.92
Pull 3C-Calib-Pull 3A	1.22	1.14	1.09	0.83	0.82	0.87	0.99
Then Pull 1/2 RR	1.16	1.09	1.07	0.81	0.80	0.83	0.96
Pull 3A-Calib-Pull 1/2 RR	0.95	0.96	0.98	0.98	0.97	0.95	0.97

* 1/2 RR withdrawal, throughout this report, refers to withdrawal from the nominal operation position of 115 inches to full out.

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Table 3

Detector Decalibration Factors for Sequential Rod Insertion

	Detector Indicated Power / True Power						
	III	IV	V	VI	VII	VIII	Avg. of 6 Det.
Pull 2A-Calib-Insert 2A	1.35	1.43	1.69	1.69	1.54	1.59	1.55
Pull 4B-Calib-Insert 4B	0.60	0.97	1.02	1.01	0.89	0.68	0.86
Then Insert 2A	0.81	1.39	1.72	1.72	1.37	1.08	1.34
Pull 4E-Calib-Insert 4E	0.95	0.76	1.16	1.11	0.94	0.83	0.96
Then Insert 4B	0.57	0.74	1.19	1.12	0.84	0.57	0.84
Then Insert 2A	0.78	1.05	2.00	1.89	1.30	0.90	1.32
Pull 3B-Calib-Insert 3B	1.20	1.41	1.14	1.05	0.99	1.22	1.17
Then Insert 4E	1.15	1.06	1.32	1.16	0.93	1.02	1.11
Then Insert 4B	0.69	1.03	1.35	1.18	0.83	0.69	0.96
Pull 3D-Calib-Insert 3D	1.10	1.06	0.94	1.16	1.16	1.33	1.13
Then Insert 3B	1.32	1.49	1.08	1.22	1.15	1.61	1.31
Then Insert 4E	1.27	1.14	1.25	1.35	1.09	1.35	1.24
Pull 3C-Calib-Insert 3C	1.16	1.11	1.30	0.91	0.95	0.84	1.05
Then Insert 3D	1.28	1.18	1.22	1.05	1.11	1.12	1.16
Then Insert 3B	1.54	1.67	1.39	1.11	1.10	1.37	1.36
Pull 3A-Calib-Insert 3A	0.82	0.88	0.92	1.20	1.22	1.15	1.03
Then Insert 3C	0.95	0.97	1.19	1.10	1.16	0.96	1.06
Then Insert 3D	1.05	1.04	1.12	1.27	1.35	1.28	1.19
Pull RR-Calib-Insert 1/2 RR	1.05	1.04	1.02	1.02	1.03	1.05	1.04
Then Insert 3A	0.86	0.92	0.93	1.23	1.25	1.20	1.07
Then Insert 3C	1.00	1.02	1.22	1.12	1.19	1.02	1.10

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in Figures 5, 6, and 7. Data are given for cases where the detectors are calibrated and then one, two, and three control rod groups are withdrawn or inserted in sequence. A DF of 1.0 indicates that the detectors are calibrated and therefore indicate true power. These DFs are given as a function of control group for each cycle. It should be pointed out that the cycle 1 and cycle 2 groups, as shown on the graphs, do not correspond to the same power level. Figure 5 shows that there is no significant decalibration in cycle 1 or 2 when the detectors are calibrated before a single rod group is withdrawn or inserted. However, the decalibration is more significant when two or three rod groups are withdrawn or inserted between detector calibrations. This is seen in Figures 6 and 7. Typically, the decalibration is worse (DF < 1.0) when inserting rod groups in cycle 1 and when withdrawing rod groups in cycle 2. For instance, the data on Figure 7 indicates a DF of 0.60 when rod groups 4C, 4A, and 4E are inserted in cycle 1 and a DF of 0.73 when rod groups 3B, 3D, and 3C are withdrawn in cycle 2. In cycle 1, because the DF is significantly >1.0 when the ring 4 rod groups are withdrawn, it is necessary to calibrate the detectors several times during the withdrawal of these groups. In order to avoid changing the cycle 1 trip and RWP floating setpoints for cycle 2, it may be necessary to require a detector calibration before some of the ring 3 rod groups are withdrawn. This is not an unreasonable requirement, since a daily calibration is currently required and it is rare when as many as three high worth rod groups are withdrawn during a 24 hour period.

A comparison of the cycle 1 and cycle 2 average decalibration factor is shown in Figures 8, 9, and 10 for the cases where the detectors are calibrated before withdrawal of one, two and three groups, respectively. DFs of <1.0 and >1.0 are plotted here since both are important from an operational standpoint. These data show that, for all three cases, the DF is typically >1.0 (over-response) for withdrawal of rod groups in cycle 1 and <1.0 (under-response) for withdrawal of rod groups in cycle 2.

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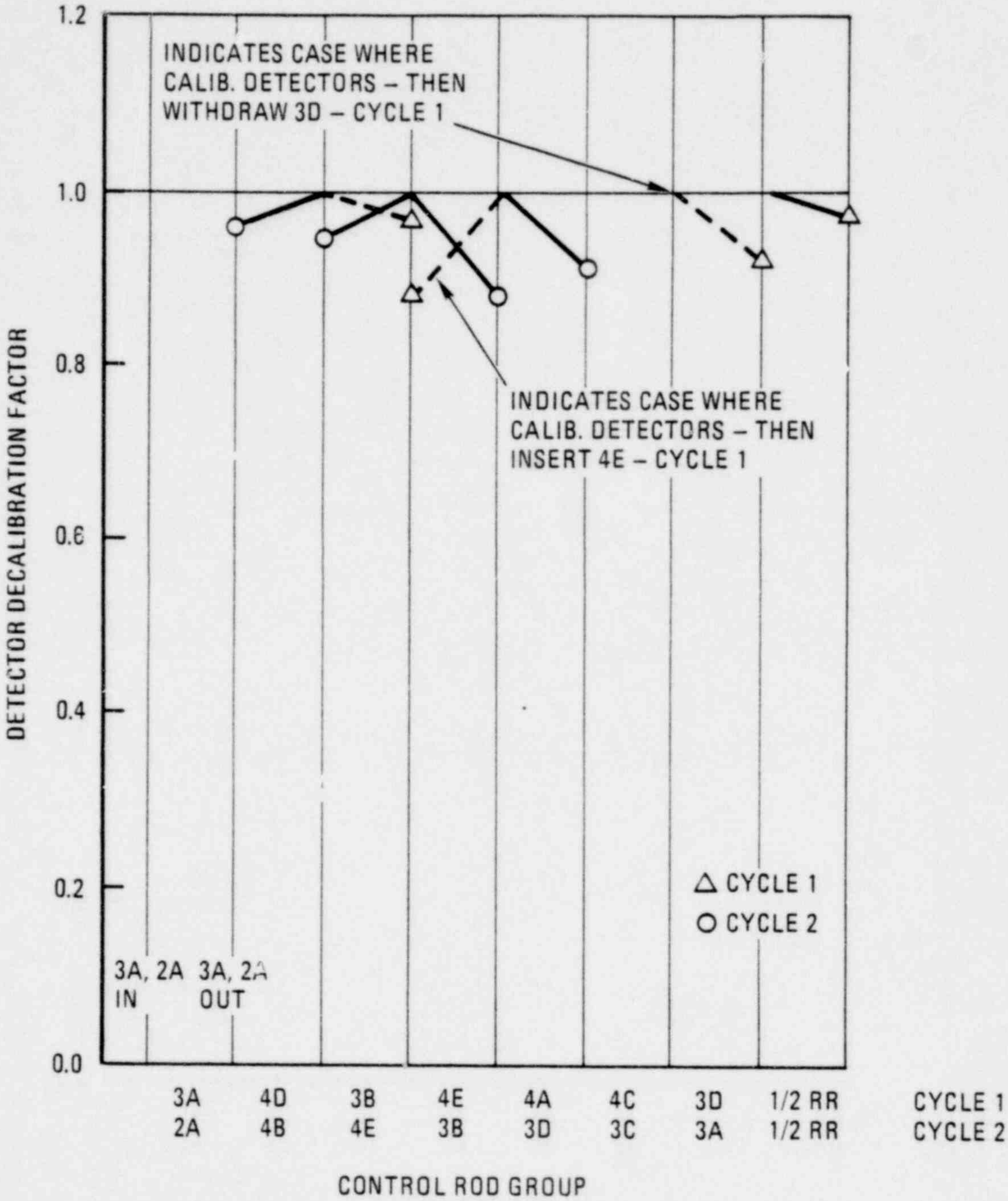

Fig. 5 Comparison of cycle 1 and cycle 2 detector decalibration factors for sequential rod withdrawal and insertion
- decalibration factor for trip of third PPS channel
- detectors calibrated before one group withdrawn and inserted

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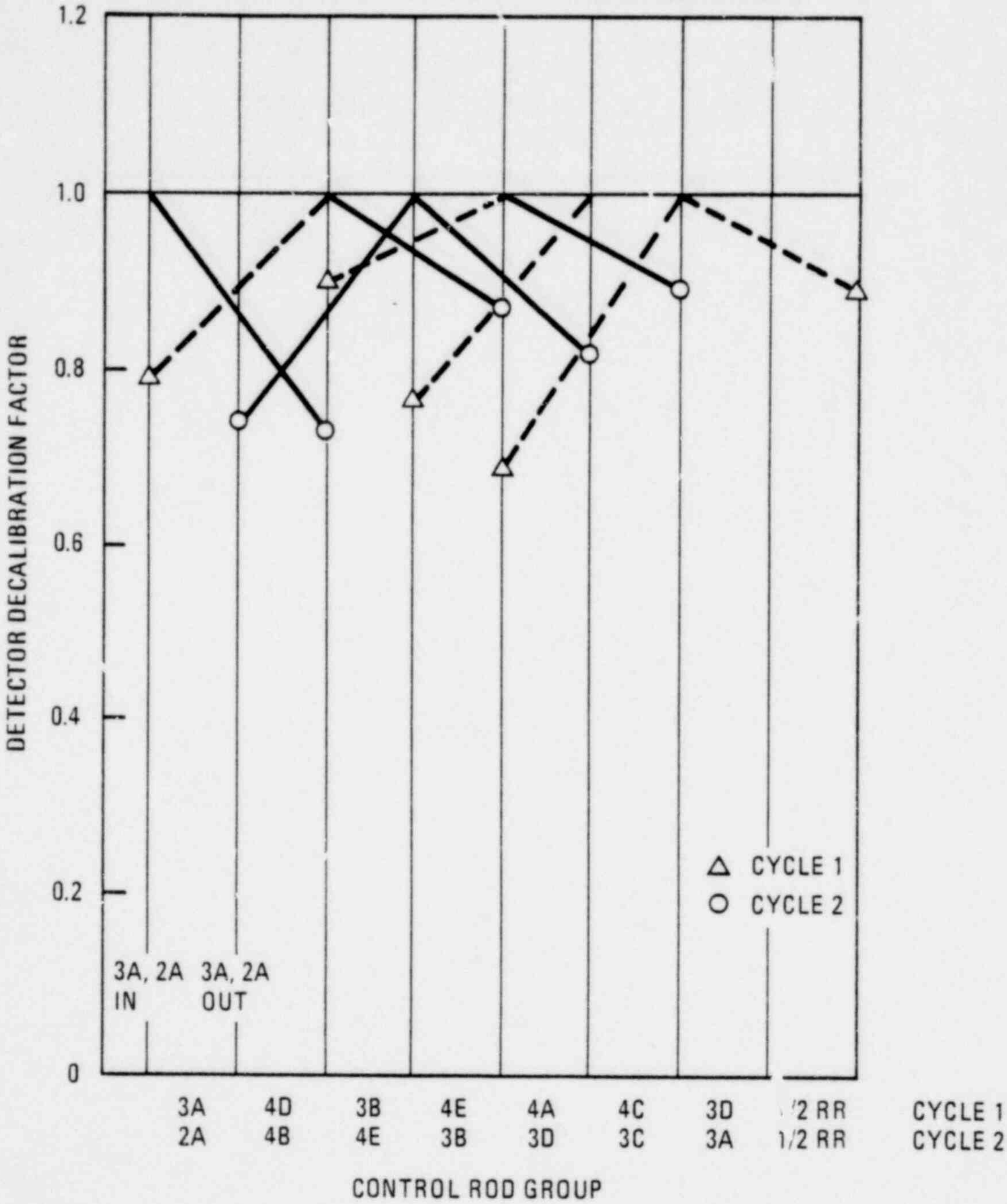

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Fig. 6 Comparison of cycle 1 and cycle 2 detector decalibration factor for sequential rod withdrawal and insertion
- decalibration factor for trip of third PPS channel
- detectors calibrated before two groups withdrawn or inserted

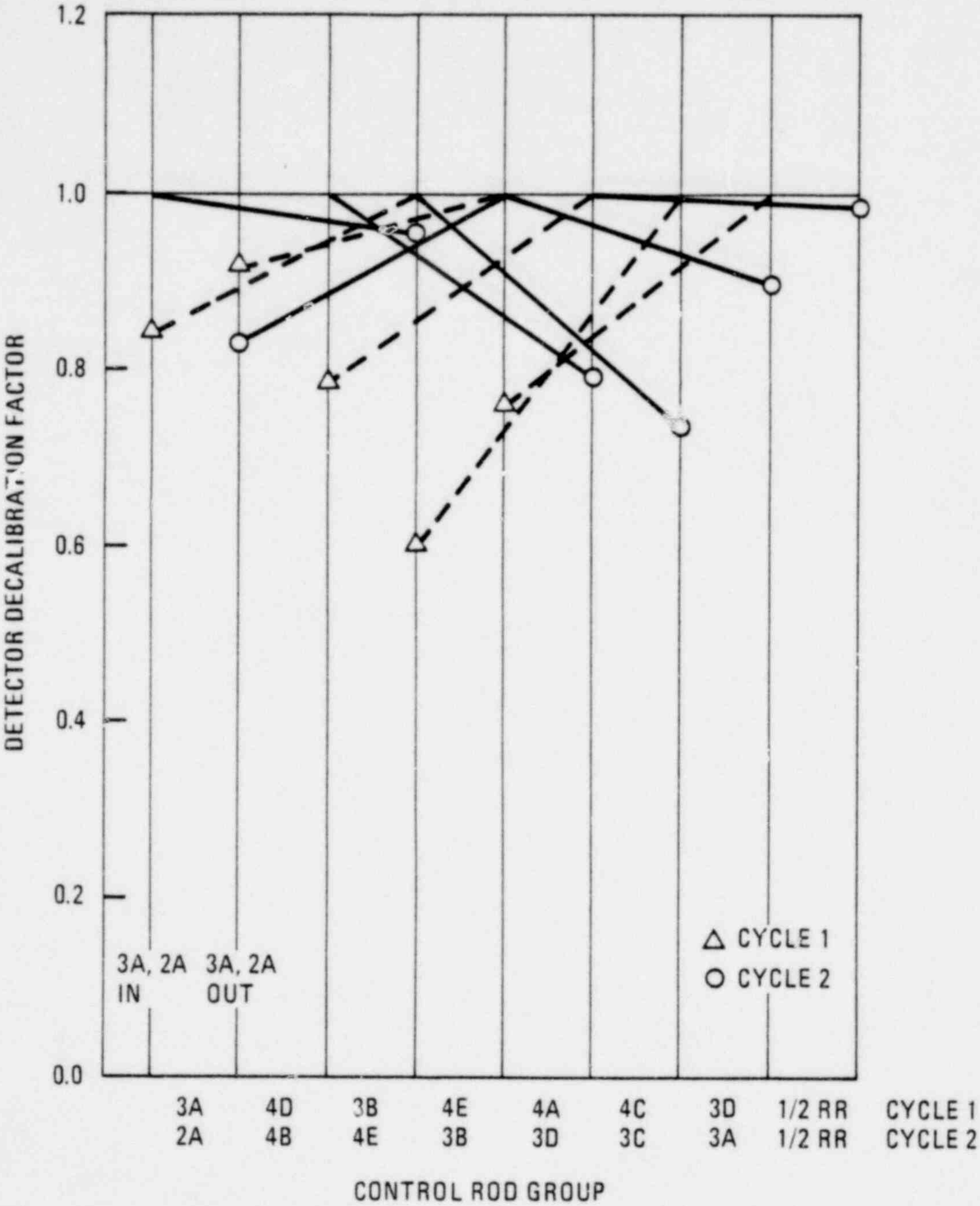

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Fig. 7 Comparison of cycle 1 and cycle 2 detector decalibration factor for sequential rod withdrawal and insertion
- decalibration factor for trip of third PPS channel
- detectors calibrated before three groups withdrawn or inserted

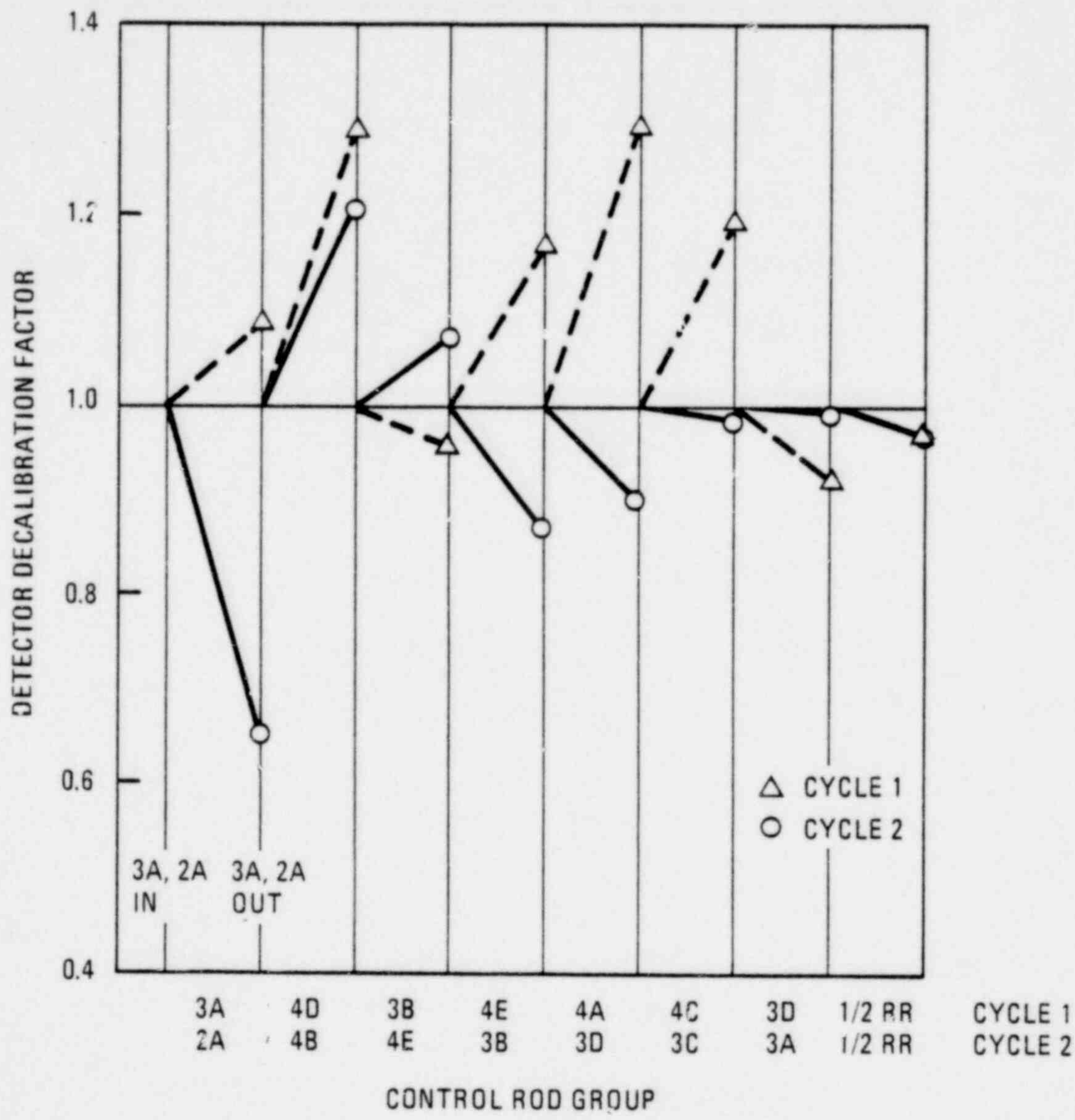

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Fig. 8 Comparison of cycle 1 and cycle 2 average detector decalibration factor for sequential rod withdrawal
- detectors calibrated before one group withdrawn

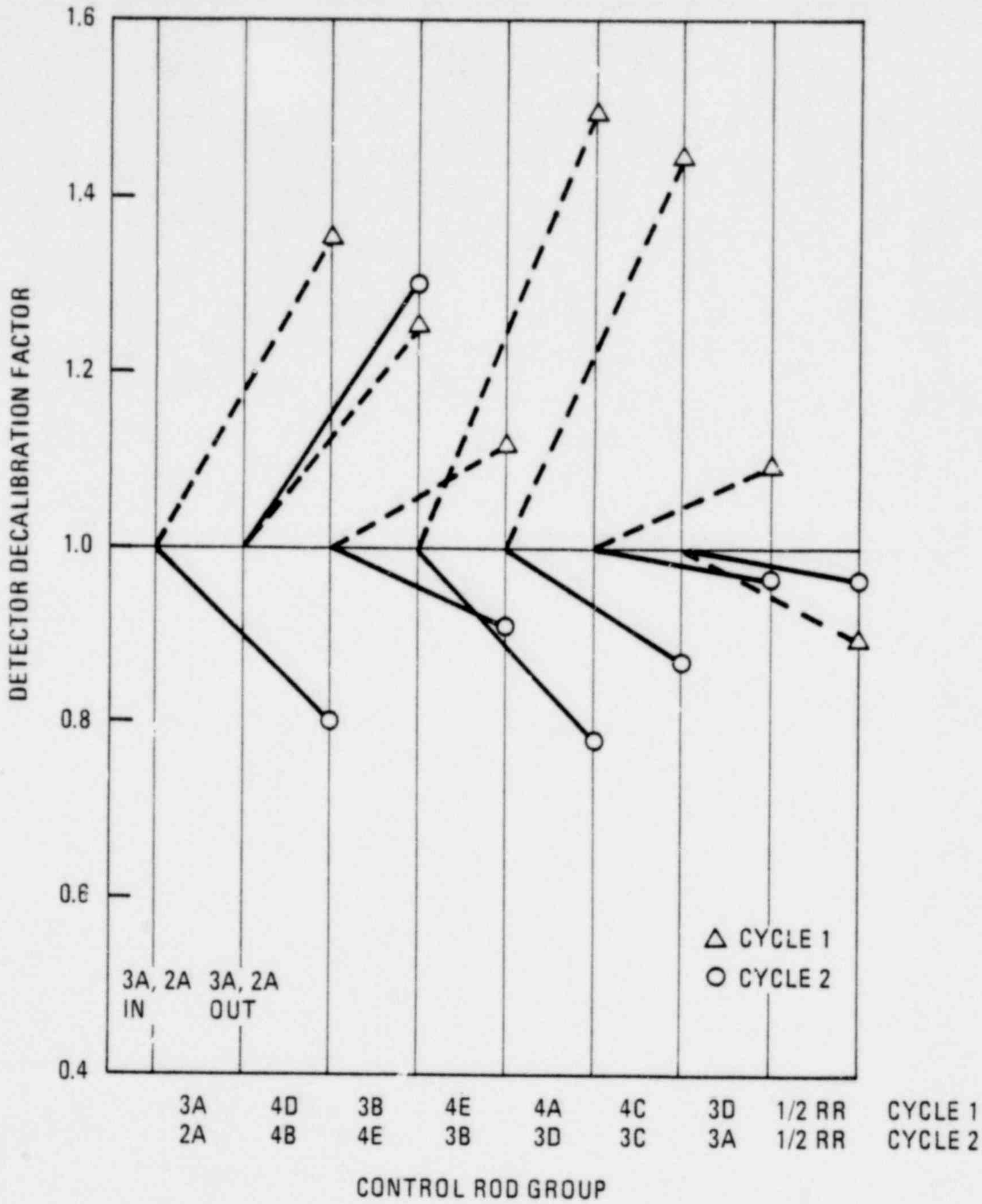

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Fig. 9 Comparison of cycle 1 and cycle 2 average detector decalibration factor for sequential rod withdrawal
- detectors calibrated before two groups withdrawn

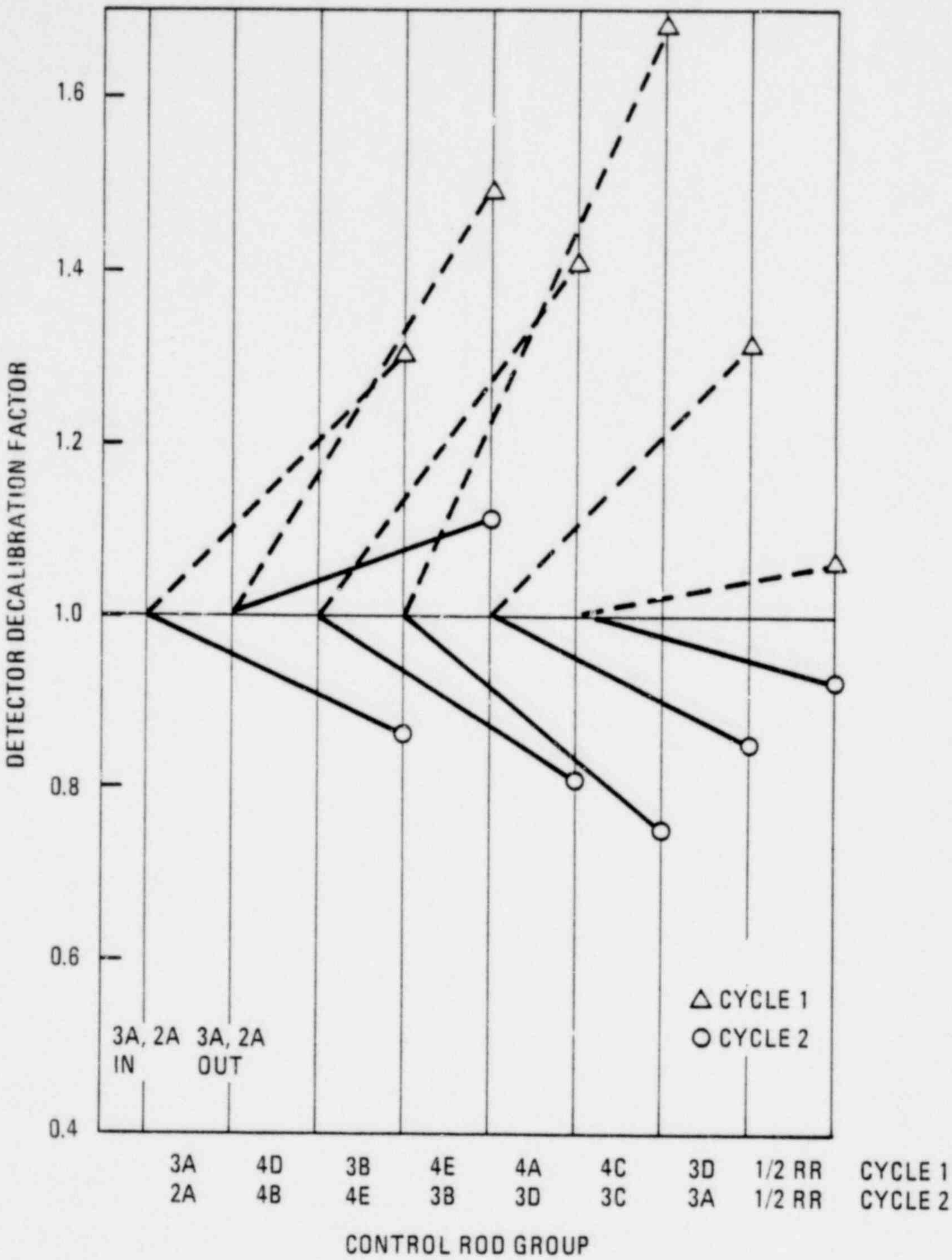

Fig. 10 Comparison of cycle 1 and cycle 2 average detector decalibration factor for sequential rod withdrawal
- detectors calibrated before three groups withdrawn

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4.2.2 Detector Decalibration due to a Single Rod Withdrawal Accident

Calculations were done to determine the worst decalibration due to a single RWA for control rod groups 2A through 3A fully withdrawn. In all cases, it is assumed that the RWA results in complete withdrawal of the control rod, i.e., the worst case. Tables 4 through 10 give the DFs for RWAs from several starting conditions for each rod group, i.e., up to three rod groups inserted, without recalibration of the channels, prior to the RWA. For the cases where insertion of the rod groups does not result in a DF <1.0, data are not given, since this does not represent a safety problem. All these data assume that a specific rod group is withdrawn, the detectors are calibrated and an RWA occurs, or that the detectors are calibrated and control groups are sequentially inserted and then an RWA occurs. The control rods chosen for the RWA analysis are those whose withdrawal would most delay the PPS trip.

A comparison of cycle 1 and cycle 2 DFs, for RWAs which determine the trip of the third PPS at 140% true power, is shown in Figure 11. These data represent the DF due only to the RWA and indicate that at low power levels the decalibration is more severe in cycle 2 than in cycle 1.

A comparison of the "worst case" for RWAs in cycle 1 and cycle 2 is given in Figure 12, i.e., the DF due to an RWA after sequential rod group insertions. Again, these data indicate that at low power levels the decalibration is slightly more severe in cycle 2 than in cycle 1. However, it will be shown in Section 5 that these DFs do not require a reduction in the cycle 1 PPS floating trip setpoints.

Table 4

Detector Decalibration Factors for RWA with Group 2A Out

	Detector Indicated Power / True Power							Worth of Stuck Rod, Δk
	III	IV	V	VI	VII	VIII	Avg. of 6 Det.	
Pull 2A-Calib-RR Out	0.90	0.86	0.83	0.84	0.86	0.87	0.86	0.0090
Pull 2A-Calib-#19 Out	0.56	0.61	1.55	1.02	0.76	0.51	0.84	0.0165
Pull 2A-Calib-#27 Out	2.73	0.79	0.58	0.59	0.75	2.45	1.32	0.0070
Pull 2A-Calib-#12 Out	2.73	0.74	0.67	0.64	0.93	1.29	1.17	0.0070

1470 091

Table 5

Detector Decalibration Factors for RWA from Several Conditions with Group 4B Out

	Detector Indicated Power / True Power							Worth of Stuck Rod, Δk
	III	IV	V	VI	VII	VIII	Avg. of 6 Det.	
Pull 4B-Calib-RR out	0.86	0.92	0.90	0.92	0.90	0.85	0.89	0.0056
Calib-Insert 4B-RR out	0.52	0.89	0.92	0.93	0.80	0.58	0.78	
Pull 4B-Calib-#12 Out	2.72	0.49	0.38	0.35	0.62	1.60	1.03	0.0165
Calib-Insert 4B-#12 Out	1.63	0.48	0.39	0.35	0.55	1.09	0.75	
Pull 4B-Calib-#30 Out	0.93	1.81	0.60	0.86	0.60	1.60	1.07	0.0065
Calib-Insert 4B-#30 Out	0.56	1.76	0.61	0.87	0.53	1.09	0.91	
Pull 4B-Calib-#19 Out	0.52	0.72	1.51	1.03	0.92	0.49	0.87	0.0118
Calib-Insert 4B-#19 Out	0.31	0.70	1.54	1.04	0.82	0.33	0.80	

1470 092

Table 6

Detector Decalibration Factors for RWA from Several Conditions with Group 4E Out

	Detector Indicated Power / True Power							Worth of Stuck Rod, Δk
	III	VI	V	VI	VII	VIII	Avg. of 6 Det.	
Pull 4E-Calib.-RR Out	0.89	0.91	0.96	0.96	0.93	0.88	0.92	0.0039
Calib-Insert 4E-RR Out	0.85	0.69	1.11	1.07	0.87	0.73	0.89	
Calib-Insert 4E, 4B-RR Out	0.51	0.67	1.14	1.08	0.78	0.50	0.78	
Pull 4E-Calib-#12 Out	2.24	0.58	0.49	0.43	0.91	1.20	0.98	0.0133
Calib-Insert 4E-#12 Out	2.13	0.44	0.57	0.48	0.86	1.00	0.91	
Calib-Insert 4E, 4B-#12 Out	1.28	0.43	0.58	0.48	0.76	0.68	0.70	
Pull 4E-Calib-#16 Out	0.52	1.96	0.58	1.27	0.44	0.87	0.94	0.0127
Calib-Insert 4E-#16 Out	0.49	1.49	0.67	1.41	0.41	0.72	0.87	
Calib-Insert 4E, 4B-#16 Out	0.30	1.45	0.69	1.42	0.37	0.50	0.79	
Pull 4E-Calib-#19 Out	0.52	0.61	1.80	1.27	0.85	0.46	0.92	0.0118
Calib-Insert 4E-#19 Out	0.49	0.46	2.09	1.41	0.80	0.38	0.94	
Calib-Insert 4E, 4B-#19 Out	0.30	0.45	2.14	1.42	0.71	0.26	0.88	

1470 093

Table 7

Detector Decalibration Factors for RWA from Several Conditions with Group 3B Out

	Detector Indicated Power / True Power						Worth of Stuck Rod, Δk
	III	IV	V	VI	VII	VIII	Avg. of 6 Det.	
Pull 3B-Calib-RR Out	0.85	0.94	0.95	0.96	0.94	0.91	0.93	0.0039
Pull 3B-Calib-#11 Out	1.41	0.69	0.83	0.66	1.20	0.89	0.95	0.0075
Calib-Insert 3B-#11 Out	1.69	0.97	0.95	0.69	1.19	1.09	1.10	
Calib-Insert 3B, 4E-#11 Out	1.62	0.73	1.10	0.77	1.12	0.91	1.04	
Calib-Insert 3B, 4E, 4B-#11 Out	0.97	0.71	1.12	0.78	1.00	0.61	0.87	
Pull 3B-Calib-#12 Out	2.20	0.66	0.51	0.47	0.77	1.38	1.00	0.0127
Calib-Insert 3B #12 Out	2.64	0.93	0.58	0.49	0.76	1.68	1.18	
Calib-Insert 3B, 4E-#12 Out	2.53	0.70	0.67	0.55	0.72	1.41	1.10	
Calib-Insert 3B, 4E, 4B-#12 Out	1.52	0.68	0.69	0.55	0.64	0.95	0.84	
Pull 3B-Calib-#16 Out	0.58	2.07	0.64	1.35	0.52	0.84	1.00	0.0110
Calib-Insert 3B-#16 Out	0.70	2.92	0.73	1.42	0.51	1.02	1.22	
Calib-Insert 3B, 4E-#16 Out	0.67	2.19	0.84	1.57	0.48	0.86	1.10	
Calib-Insert 3B, 4E, 4B-#16 Out	0.40	2.13	0.86	1.59	0.43	0.58	1.00	

1470 094

Table 8

Detector Decalibration Factors for RWA from Several Conditions with Group 3D Out

	Detector Indicated Power / True Power							Worth of Stuck Rod, Δk
	III	IV	V	VI	VII	VIII	Avg. of 6 Det.	
Pull 3D-Calib-RR Out	0.93	0.95	0.95	0.96	0.94	0.93	0.94	0.0039
Pull 3D-Calib-#12 Out	1.71	0.68	0.57	0.53	0.91	1.30	0.95	0.0116
Pull 3D-Calib-#16 Out	0.63	2.00	0.67	1.21	0.56	0.98	1.01	0.0103
Pull 3D-Calib-#18 Out	0.62	0.93	1.12	1.79	0.73	0.66	0.98	0.0092
Calib-Insert 3D-#18 Out	0.68	0.99	1.05	2.08	0.85	0.88	1.09	

1470 095

Table 9

Detector Decalibration Factors for RWA from Several Conditions with Group 3C Out

	Detector Indicated Power / True Power							Worth of Stuck Rod, Δk
	III	IV	V	VI	VII	VIII	Avg. of 6 Det.	
Pull 3C-Calib-RR Out	0.95	0.96	0.97	0.97	0.96	0.94	0.96	0.0031
Pull 3C-Calib-#8 Out	0.78	0.71	1.68	0.99	1.09	0.65	0.98	0.0074
Calib-Insert 3C-#8 Out	0.90	0.79	2.18	0.90	1.04	0.55	1.06	
Pull 3C-Calib-#12 Out	1.82	0.80	0.69	0.64	0.97	1.15	1.01	0.0081
Calib-Insert 3C-#12 Out	2.11	0.89	0.90	0.58	0.92	0.97	1.06	
Pull 3C-Calib-#16 Out	0.72	1.72	0.79	1.12	0.65	1.01	1.00	0.0075

1470 096

Table 10

Detector Decalibration Factors for RWA from Several Conditions with Group 3A Out

	Detector Indicated Power / True Power							Worth of Stuck Rod, Δk
	III	IV	V	VI	VII	VIII	Avg. of 6 Det.	
Pull 3A-Calib-RR Out	0.95	0.96	0.98	0.98	0.97	0.95	0.97	0.0027
Calib-Insert 3A-RR Out	0.78	0.84	0.90	1.18	1.18	1.09	1.00	

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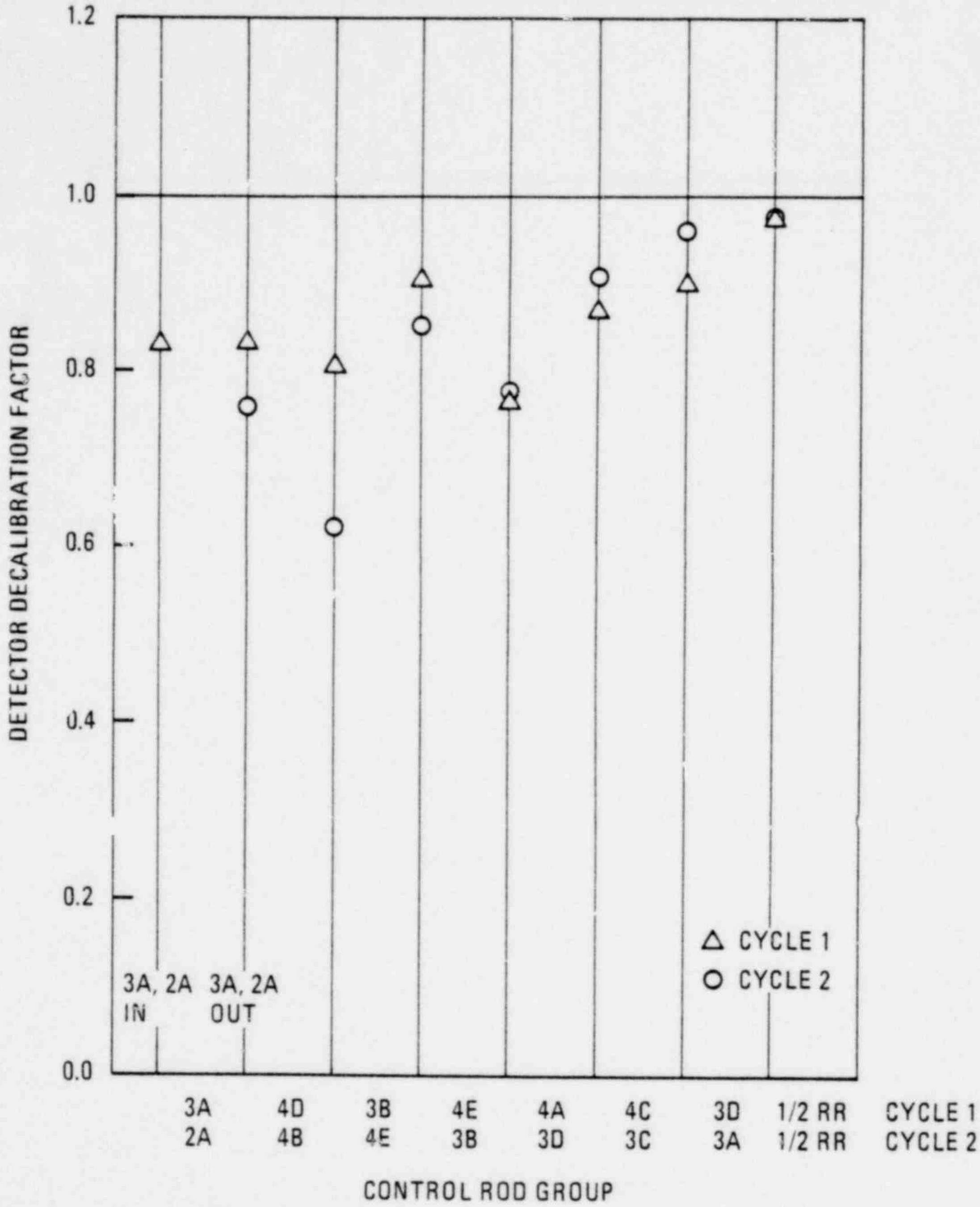

Fig. 11 Comparison of cycle 1 and cycle 2 detector decalibration factors for a single rod RWA

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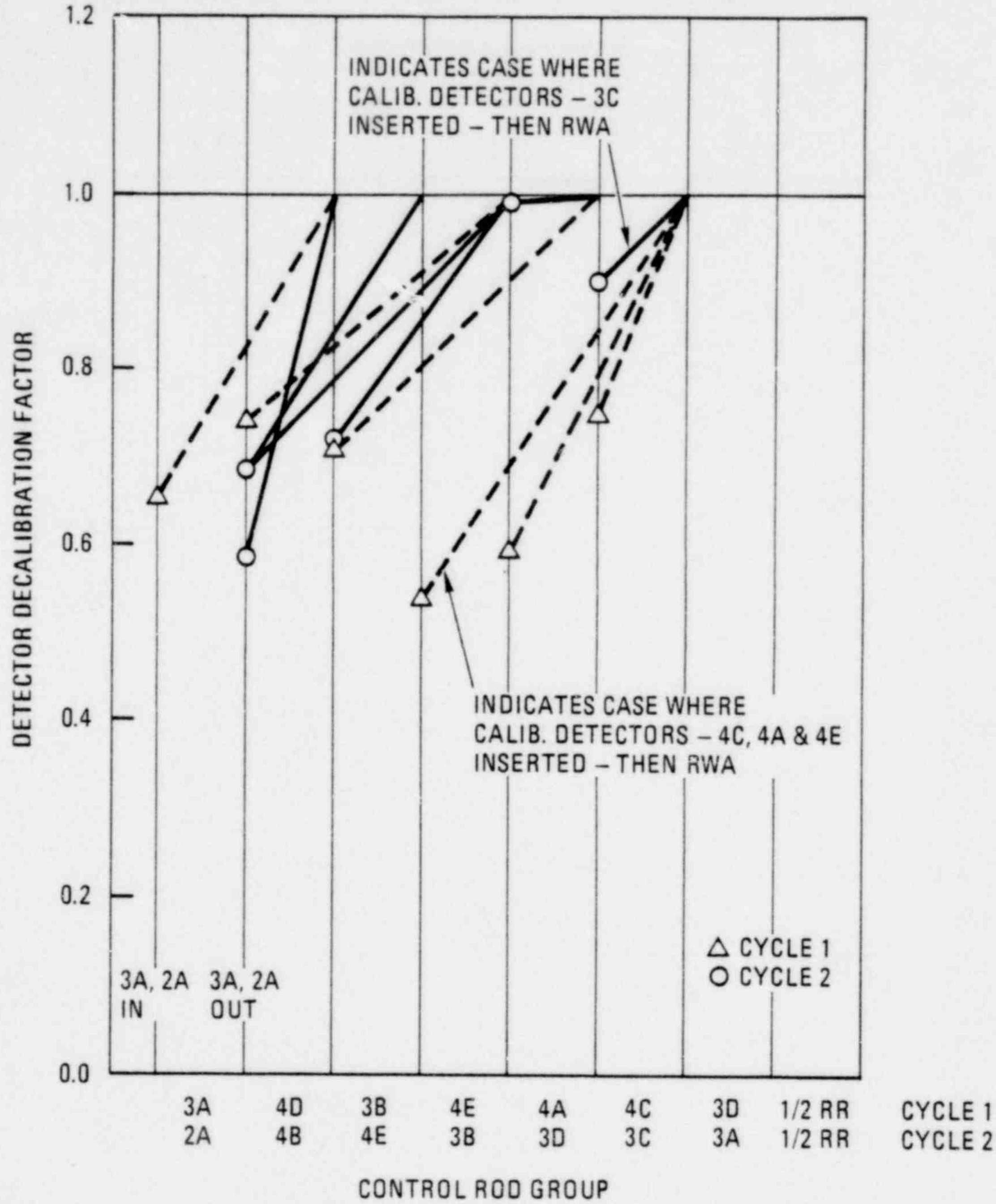

Fig. 12 Comparison of cycle 1 and cycle 2 detector decalibration factors for a single rod RWA from various starting conditions

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4.2.3 Detector Decalibration due to the Insertion of the Runback Rod Group

In cycle 1, the insertion of the runback rods posed no safety problem since the detector decalibration resulted in DFs greater than unity. This is also true for cycle 2 except for the case where rod groups are withdrawn through group 4B. For this case, insertion of the run back rod groups (2B and 4F) results in DFs < 1.0. This is due to the fact that a ring 4 rod group is designated as a runback group, but this is necessary since only one rod group other than ring 4 groups is withdrawn prior to criticality.

Table 11 gives the DFs for two starting conditions, i.e., the insertion of the runback rods after group 4B is withdrawn and the detectors are calibrated and after the detectors are calibrated and group 4B is inserted. It is seen from these data that the worst (under-response) DF is 0.76, which assumes that the detectors are calibrated after group 4B is withdrawn, group 4B is inserted and then the regulating rod and runback rods are fully inserted. This DF is greater than the DF for an RWA with group 4B withdrawn, so it is not a limiting case. Furthermore, during cycle 1 operation, it has never been reported that the runback rods and regulating rod are simultaneously <u>fully</u> inserted. The data in Table 11 show that a less restrictive PPS setpoint is indicated after an RWA with the runback rods and the regulating rod only one-half inserted, a more probable configuration.

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Table 11

Detector Decalibration Factors for Insertion of Runback Rods from Several Conditions with Groups 4B Out

	Detector Indicated Power / True Power						
	III	IV	V	VI	VII	VIII	Avg. of 6 Det.
Pull 4B-Calib-RB Rods & RR 1/2 in*	1.63	0.69	0.57	1.00	1.05	2.17	1.19
Then Insert 4B	0.98	0.67	0.58	1.01	0.98	1.48	0.95
Pull 4B-Calib-RB Rods & RR Full In	2.17	0.48	0.33	0.71	0.82	3.26	1.30
Then Insert 4B	1.30	0.47	0.34	0.72	0.76	2.22	0.97
Pull 4B-Calib-RB Rods 1/2 In & RR Full In	1.89	0.65	0.51	0.90	0.99	2.55	1.25
Then Insert 4B	1.13	0.63	0.52	0.91	0.92	1.73	0.97
Pull 4B-Calib-RB Rods Full In & RR 1/2 In	1.75	0.51	0.37	0.80	0.88	2.99	1.22
Then Insert 4B	1.05	0.49	0.38	0.81	0.82	2.03	0.93

* RR 1/2 inserted refers to the nominal regulating rod position, i.e., 115 inches withdrawn.

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5. DETERMINATION OF PPS TRIP SETPOINTS

The data given in the previous sections indicate that for a few cases the decalibration factors for cycle 2 are less conservative than for cycle 1. However, as mentioned earlier, sequential rod groups in cycle 1 and cycle 2 do not necessarily correspond to the same power level. The reactivity as a function of rod group for the two cycles has been estimated, using cycle 1 data.

Figure 13 shows the rod groups' positions for cycle 1 vs cycle 2 for equal cumulative reactivity worth. This correlation was obtained by assuming the total bank worth is the same for the two cycles and then normalizing the group worths given in Reference 5 to the cycle 1 total worth. The control rod worths reported in Reference 5 are not precise since all calculations were done at full power core conditions. Furthermore, these control rod worths are given as ΔK and were converted to $\Delta\rho$ by using the calculated k_{eff} values from Reference 6. Using this correlation, the cycle 1 and cycle 2 rod groups were applied to Figure 2 of Reference 7 to obtain power level as a function of rod group for both cycles. These results are shown in Figure 14 where power level is given as a function of cycle 1 and cycle 2 rod group for various core conditions. It is recognized that this is not precise, since the reactivity vs power is cycle 1 data, but does serve as a basis for comparison. Figure 15 shows the maximum starting power for an RWA to attain 140% true power. These, also, are cycle 1 data but would not be expected to change significantly for cycle 2 and will therefore be used in this analysis. A comparison of the "worst case" decalibration factors (i.e., under-response) as a function of rod group for cycle 1 and cycle 2 is shown in Figure 16. The rod groups for cycle 1 and cycle 2 are indicated for equal reactivity,

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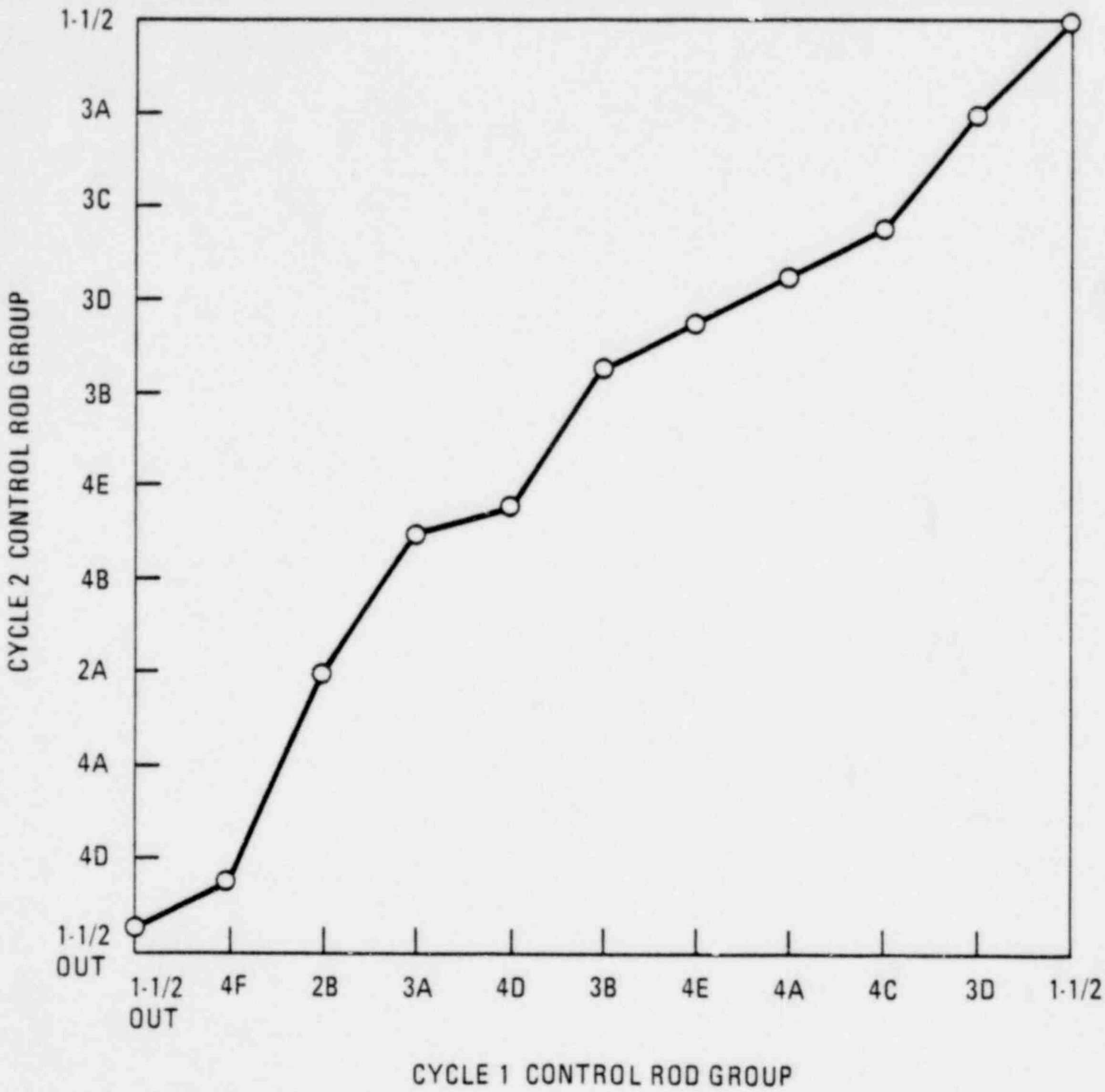

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Fig. 13 Cycle 1 and cycle 2 control rod group position for equal cumulative worth (uses only total bank worth and assumes linear for each bank)

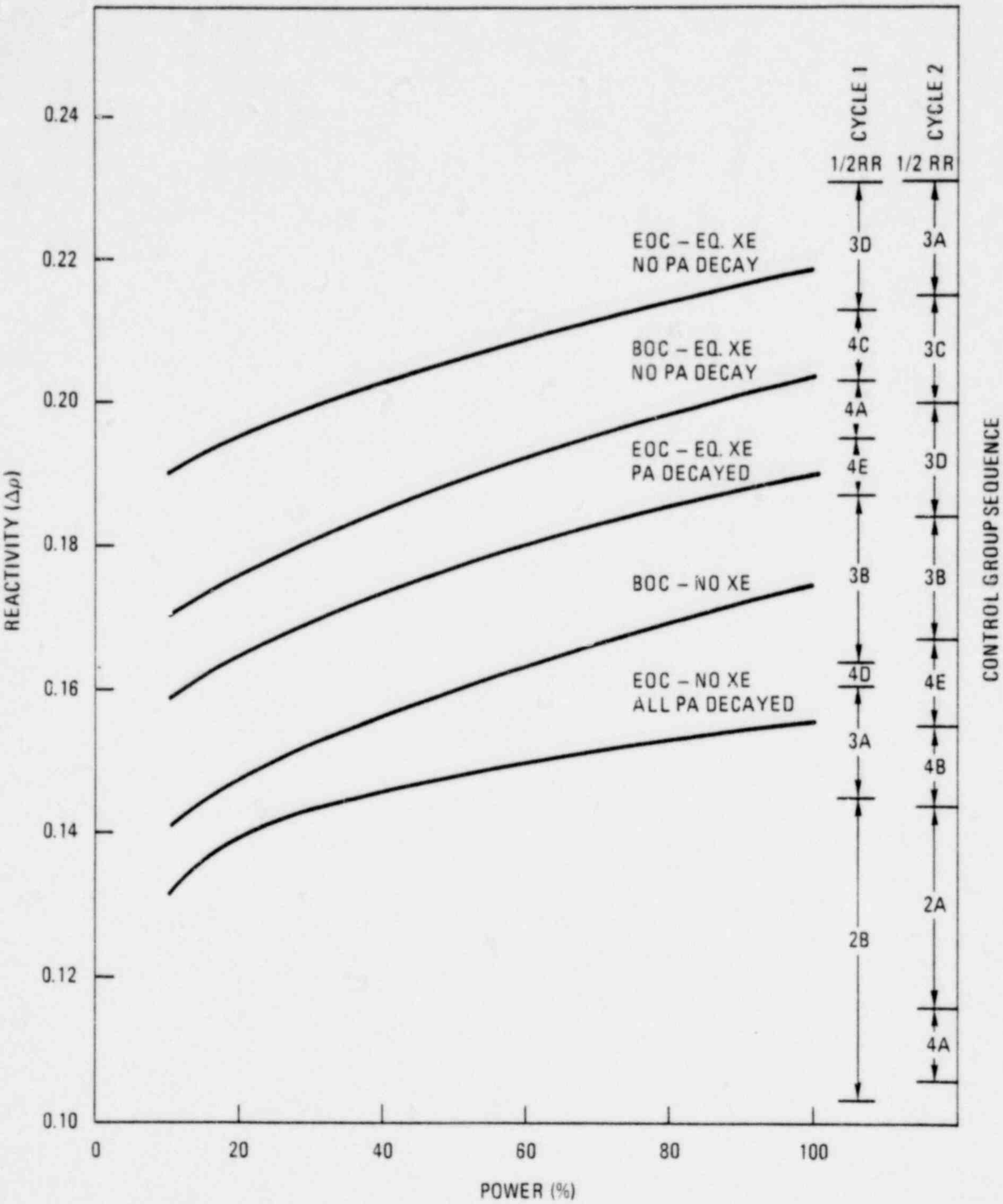

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Fig. 14 Reactivity as a function of power (initial core)

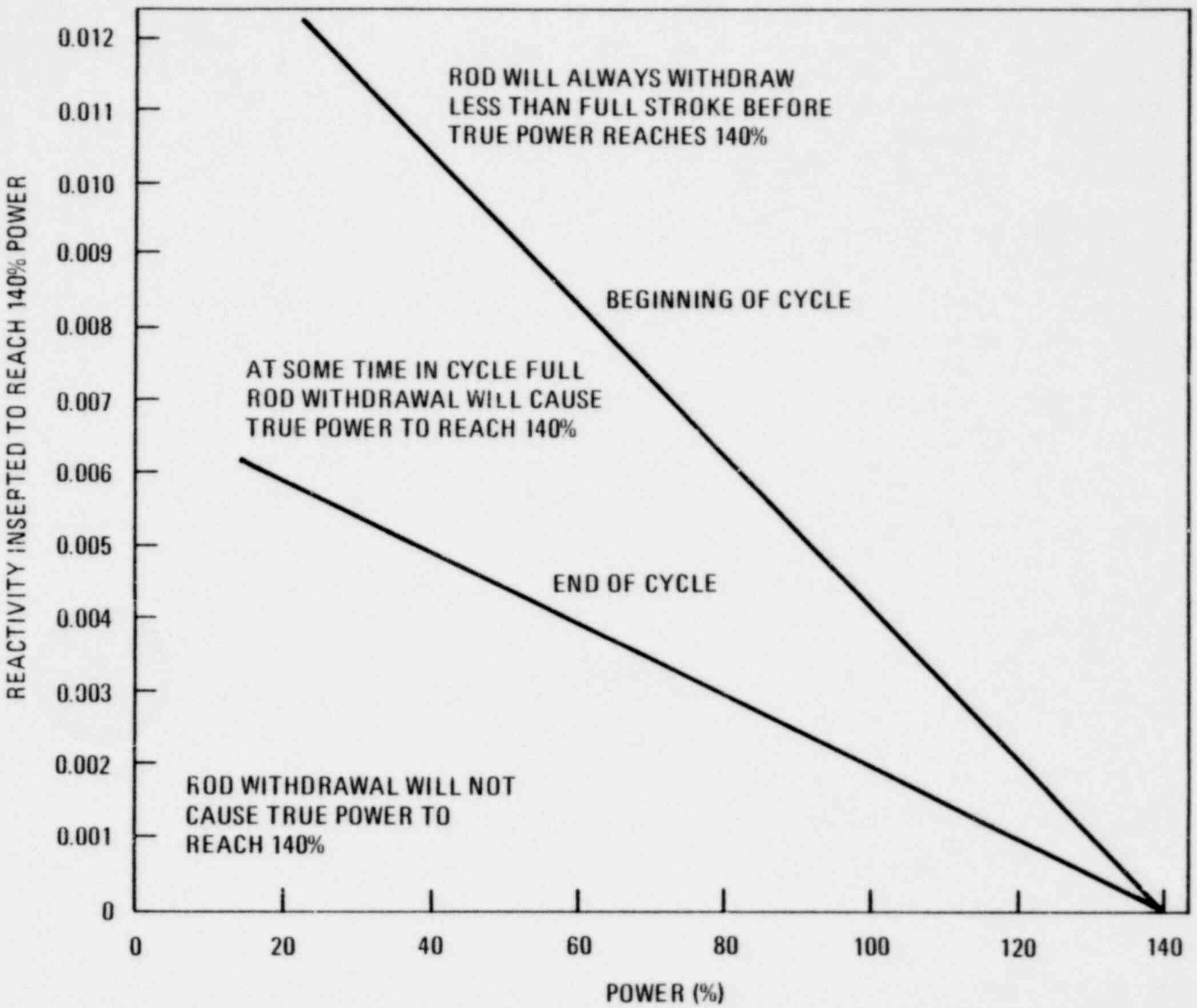

Fig. 15 Minimum required starting power for RWA to attain 140% true power

as obtained from Figure 14. A solid line is drawn through the minimum DF for each rod group in cycle 1. These minimum DFs determine the PPS floating trip setpoints for cycle 1. It is seen that three (3) cycle 2 data points fall below this line, indicating that a lower PPS trip setpoint is required. However, there are two reasons why a lower setpoint is not required for the cases with rod groups 2A and 4B withdrawn. First, the lowest setpoint for cycle 1 is obtained from the case with a DF of 0.54, i.e., a 0.94% $\Delta\rho$ RWA occurs after the insertion of rod groups 4C, 4A, and 4E without detector calibration. For cycle 1, this minimum setpoint was extended back to a zero indicated power (denoted by the dotted line in Figure 16), which means that the cycle 2 data points for group 2A and 4B withdrawn do not require a PPS trip setpoint as low as the cycle 1 setpoint. Second, the minimum DF of 0.55 for cycle 2 represents the case in which a 1.83% $\Delta\rho$ RWA occurs after rod group 4B is inserted and it can be easily shown from the data on Figures 14 and 15 that the rod cannot be fully withdrawn before reaching 140% true power from the maximum starting power level. This, of course, would cause less decalibration and therefore the required PPS setpoint would be higher.

The cycle 2 DF of 0.73, which falls below the cycle 1 data, represents the case in which rod groups 3B, 3D, and 3C are withdrawn, in sequence, without calibrating the detectors. This data point clearly indicates that a lower setpoint is required. However, referring back to Figure 14, it is seen that rod group 3C fully withdrawn in cycle 2 is approximately equivalent to rod group 4C fully withdrawn in cycle 1. At about 165 EFPDs in cycle 1, rod group 4C had never been fully withdrawn. This is due to the limit on power level to <70% of full power and the resulting lower fuel temperatures, i.e., the temperature defect is lower than at full power operation. This means that, for a maximum power level of ~65% full power, the withdrawal of rod group 3C in cycle 2 would occur over the period of a few days or weeks and may never be fully withdrawn. Furthermore, the required daily calibration would reduce problems due to detector decalibration. However, to assure that the detector decalibration does not cause an unsafe situation, an additional

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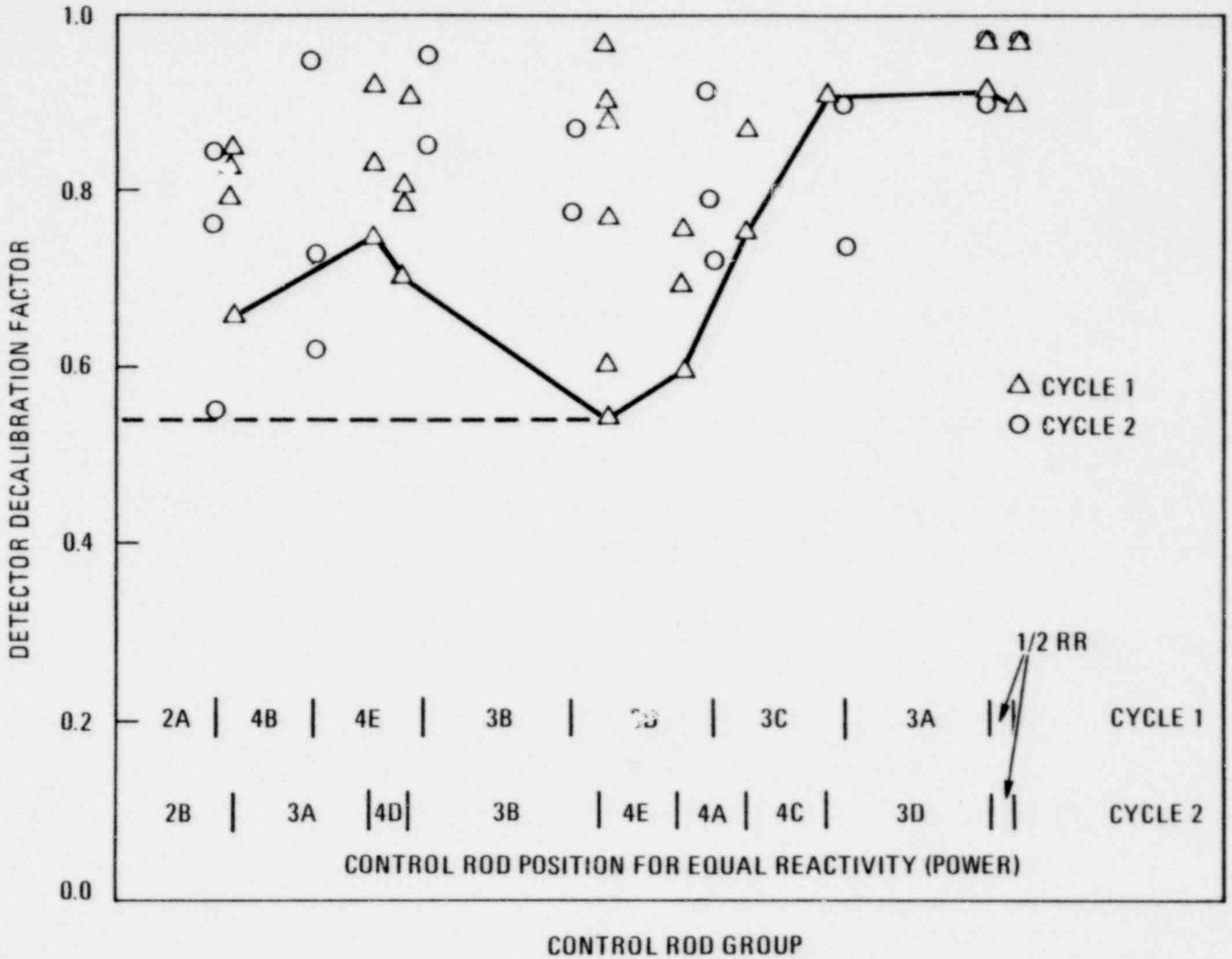

Fig. 16 Comparison of cycle 1 and cycle 2 "worst case" detector decalibration factor as a function of control rod group

calibration measurement is imposed, i.e., calibrate the detectors prior to withdrawal of control rod group 3C.

The recommended floating trip points (see next section) are very conservative at the higher power levels because these setpoints are based on the assumption that up to three rod groups are withdrawn without calibration. This is a highly unlikely occurrence as discussed above.

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6. RECOMMENDATIONS

As a result of the significant power-range detector decalibration in cycle 1, the use of a reactor trip setpoint which varies with indicated power level (floating trip setpoint) was recommended. This proposed floating trip setpoint as a function of indicated power is shown in Figure 17 (Ref. 1). In addition, it was recommended that the detectors be calibrated prior to specific events during an increase or decrease in reactor power. These specific events are given below:

1. At least one calibration during every 24-hour period when operating in Low Power or Power modes.

2. To prevent or clear RWPs which occur due to inaccurate detector readings, a calibration should be done whenever any channel approaches or reaches an RWP setpoint.

3. To ensure that the ISS is switched at the proper power level, the following requirements are made:
   - A. With the ISS in the Startup mode, a calibration is required when heat-balance power is between 2% and 4% of rated power. The methods to determine heat-balance power level are given in Reference 8.
   - B. When increasing power with the ISS in the Low Power mode, a calibration is required when heat-balance power is between about 24% and about 28% of rated power.
   - C. When decreasing power with the ISS in the Power mode, a calibration is required when heat-balance power drops below about 36% of rated power.

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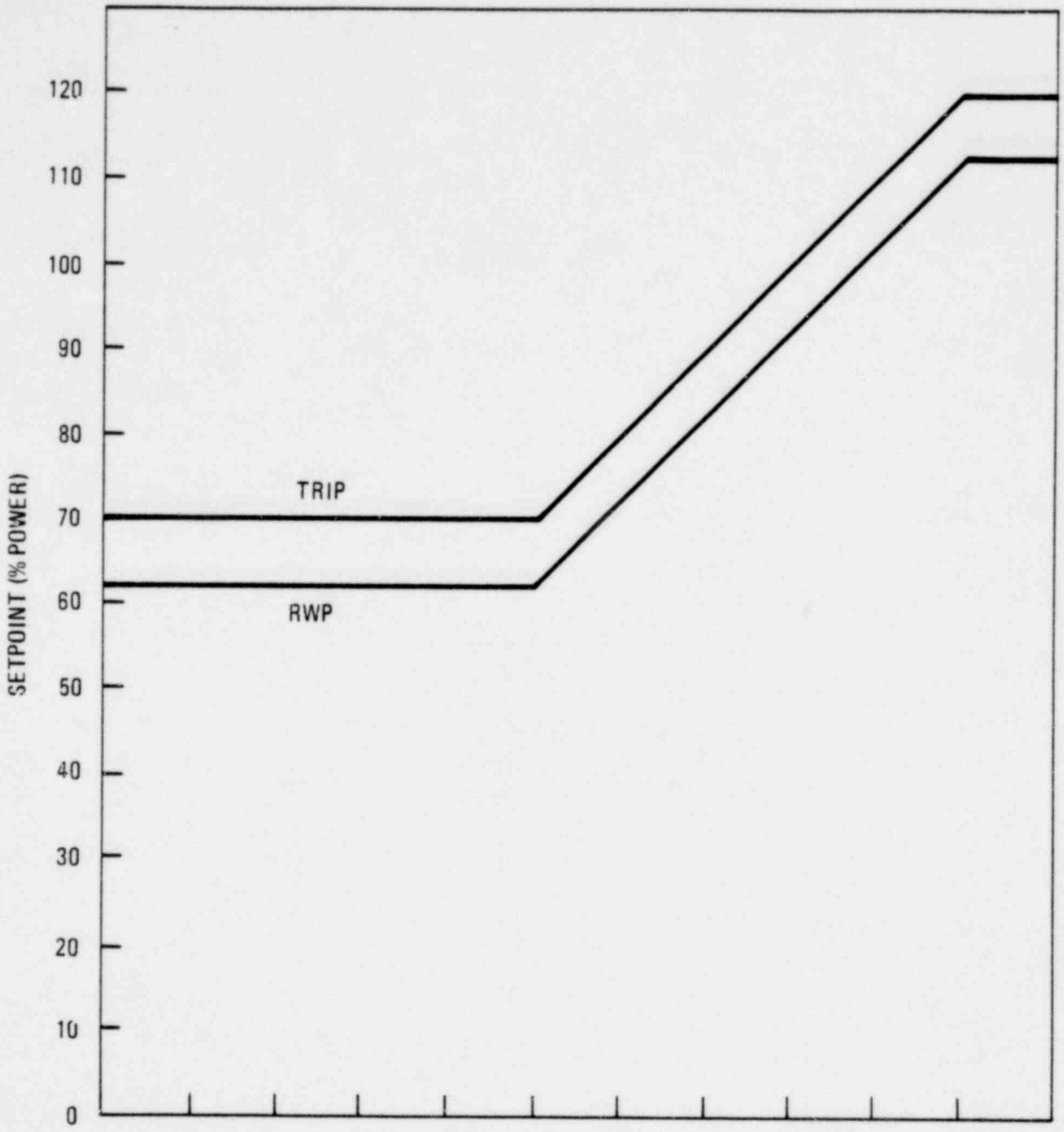

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Fig. 17 Recommended program for trip and RWP setpoints

In addition, calibration should be done, although not required, whenever the operator has reason to believe that one or more detectors are giving anomalous readings. When individual detectors differ by more than 10%, the proper functioning of channels should be verified.

Since the recommended floating trip point hardware was not installed for cycle 1 operation, the detector decalibration was accommodated by a reduction in the fixed PPS setpoints.

For cycle 2 operation, it is recommended that floating trip setpoint and the detector calibration frequency recommended for cycle 1 be used, with the additional requirement that a detector calibration be done prior to the withdrawal of rod group 3C. This floating trip setpoint and calibration frequency will ensure that a reactor trip is always initiated before true reactor power reaches the trip point at 140% rated power, as required by the Technical Specification. In the event that the floating trip hardware is not installed for cycle 2 operation, a reduction in the fixed PPS setpoints will be required.

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