NEDO-30813
CLASS I
MARCH 1985

GENERAL ELECTRIC BWR LICENSING REPORT: AVERAGE POWER RANGE MONITOR, ROD BLOCK MONITOR AND TECHNICAL SPECIFICATION IMPROVEMENT (ARTS) PROGRAM FOR THE DUANE ARNOLD ENERGY CENTER

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AVERAGE POWER RANGE MONITOR, ROD BLOCK MONITOR AND TECHNICAL SPECIFICATION IMPROVEMENT (ARTS) PROGRAM FOR THE DUANE ARNOLD ENERGY CENTER

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ABBREVIATIONS, ACRONYMS AND DEFINITIONS

APRM	Average Power Range Monitor
ARTS	Average Power Range Monitor, Rod Block Monitor, Technical Specification Improvement Program
BWR	Boiling Water Reactor
CMFLPD	Core Maximum Fraction of Limiting Power Density
CPR	Critical Power Ratio
DAEC	Duane Arnold Energy Center
EBT	Early Boiling Transition
ECCS	Emergency Core Cooling System
ELLLA	Extended Load Line Limit Analysis
FRP	Fraction of Rated Power
FWCF	Feedwater Controller Failure
GE	General Electric Company
GESTAR	General Electric Standard Application for Reactor Fuel
GETAB	General Electric Thermal Analysis Basis
GEXL	Ceneral Electric Critical Quality Boiling Length Correlation
HPCI	High Pressure Coolant Injection
IELP	Iowa Electric Light and Power Company

IMCPR	Initial Minimum Critical Power Ratio
IRM	Intermediate Range Monitor
K_P	Power Dependent MCPR Multiplier
LFWH	Loss of Feedwater Heater
LOCA	Loss-of-Coolant Accident
LPRM	Local Power Range Monitor
LRNBP	Load Rejection No Bypass
$MAPFAC_F$	Flow Dependent MAPLHGR Factor
$MAPFAC_P$	Power Dependent MAPLHGR Factor
MAPLHGR	Maximum Average Planar Linear Heat Generation Rate
MAPLHGR(F)	MAPLHGR Limit as a Function of Flow
MAPLHGR(P)	MAPLHGR Limit as a Function of Power
$MAPMULT_F$	Flow Dependent MAPLHGR Factor
MCHFR	Minimum Critical Heat Flux Ratio
MCPR	Minimum Critical Power Ratio
$MCPR_F$	Flow Dependent MCPR Limit
MCPR(F)	MCPR Limit as a Function of Flow
MCPR(P)	MCPR Limit as a Function of Power

$MFRPD_F$	Flow Dependent MAPLHGR Factor
ODYN	One-Dimensional BWR Core Transient Model
OLMCPR	Operating Limit MCPR
P_{BYPASS}	Power level below which the reactor scram signals from turbine stop valve closure and turbine control valve fast closure are bypassed
PCIOMR	Preconditioning Interim Operating Management Recommendations
PCT	Peak Cladding Temperature
RBM	Rod Block Monitor
REDY	Reactor Dynamics Model
RPT	Recirculation Pump Trip
RWE	Rod Withdrawal Error
SLMCPR	Safety Limit MCPR
SLO	Single-Loop Operation
SRM	Source Range Monitor
W_C	Core Flow
W_D	Recirculation Drive Flow

1. SUMMARY

The Duane Arnold Energy Center (DAEC) Average Power Range Monitor (APRM), Rod Block Monitor (RBM), and Technical Specification Improvements (ARTS) program is a comprehensive project with the objectives of:

a. increasing plant operating efficiency,

b. updating thermal limits requirements and administration,

c. improving plant instrumentation responses and accuracy, and

d. improving the man/machine interface involved in plant operation.

These objectives are attained by making the following improvements (the objectives met by each improvement are given in parentheses at the end of each item):

a. a power dependent minimum critical power ratio (MCPR) limit similar to that used by BWR/6 (Reference 1) is implemented (updates thermal limits administration),

b. the average power range monitor (APRM) trip setdown requirement is replaced by more meaningful limits to reduce the need for manual setpoint adjustments and to allow more direct limits administration (improves man/machine interface, updates thermal limits administration, and increases plant operating efficiency),

c. the flow biased rod block monitor trips are replaced with power dependent trips (improves man/machine interface, updates thermal limits administration, and improves plant instrumentation response and accuracy),

d. the rod withdrawal error analysis is performed in a manner consistent with the system changes and more accurately reflects actual plant conditions (updates thermal limits administration),

* e.

f. modern electronic components are installed in the RBM (improves instrument accuracy),

g.

h. the RBM logic is improved to eliminate the need for manual trip reset (improves man/machine interface), and

i. "Limiting Rod Pattern" is defined to simplify RBM operability requirement decisions (updates thermal limits administration).

The analyses which justify these changes and which determine instrument setpoints and operating limits consistent with their implementation are discussed in detail in this document and the supporting references. These include abnormal operational transient analyses, rod withdrawal error analyses, and loss-of-coolant accident (LOCA) analyses.

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2. INTRODUCTION

Factors which restrict the flexibility of a BWR during power ascension from the low power/low core flow condition are:

a. the APRM flow biased rod block line,

b. the RBM flow biased rod block line,

c. Preconditioning Interim Operating Management Recommendations (PCIOMRs), and

d. the APRM scram and flow biased rod block and RBM setdown requirements.

If the rated load line control rod pattern is maintained as core flow is increased, increasing xenon concentrations will result in less than rated power at rated core flow. In addition, fuel pellet-cladding interaction considerations may inhibit withdrawal of control rods at high power levels. The combination of these factors may require difficult and time consuming maneuvers to achieve rated power.

The DAEC Extended Load Line Limit Analyses (ELLLA) are described in Reference 2 and provide the analytical bases for raising the APRM rod block lines at the bottom of the flow control range by reducing the flow biasing slopes from 0.66 to 0.58 and for extending the operating envelopes to include the region bounded by the new 108% APRM rod block line, the rated power line, and the rated load line. In this report, rated power is defined as 1658 Mwt which is consistent with the DAEC Power Uprate Analysis (Reference 3).

This report supplements and builds on those documents to allow full utilization of the extended operating region, to update thermal limits administration, to improve instrumentation response and accuracy, and to improve the man/machine interface for plant operation.

The bases for these changes are provided by the DAEC APRM/RBM/Technical Specifications Improvement Program (DAEC ARTS) which is described in this report. This document provides the analytical bases for:

a. substitution of power biased RBM setpoints for flow biased setpoints,

b.

c. implementation of power and flow dependent limits to support elimination of the APRM trip setdown requirements and to support the power dependent RBM trips,

d. definition of a "limiting rod pattern," in terms of the measurable actual plant parameter, MCPR, for RBM bypass decisions, and

e. introduction of an improved rod withdrawal error analysis.

3. APRM SYSTEM IMPROVEMENTS

3.1 SYSTEM DESCRIPTION

The functions of the APRM System are to:

a. generate trip signals which will automatically scram the reactor during bulk neutron flux level transients before the actual bulk neutron flux level exceeds the safety analysis design bases to prevent fuel damage from single operator errors or equipment malfunctions; and

b. block control rod withdrawal when core power significantly exceeds design bases and approaches the scram level; and

c. provide an indication of the bulk thermal power level of the reactor in the power range.

The DAEC APRM System calculates an average of in-core LPRM chamber signals using analog electronics. The LPRMs are averaged such that the APRM signal is proportional to core average neutron flux and can be calibrated as a means of measuring core thermal power. The APRM signals are compared to a fixed scram trip and to a recirculation drive flow biased control rod withdrawal block trip. Shown in Figure 3-1 are the DAEC APRM scram and rod block trips as they will exist following implementation of the ELLLA (Reference 2).

The DAEC Technical Specifications require that the flow biased APRM trips be lowered (set down)* when the core maximum fraction of limiting power density (CMFLPD) exceeds the fraction of rated power (FRP). The basis for this "APRM setdown" requirement originated from the now obsolete Hench-Levy Minimum Critical Heat Flux Ratio (MCHFR) thermal limit criterion.

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*Alternately accomplished by APRM gain increases.

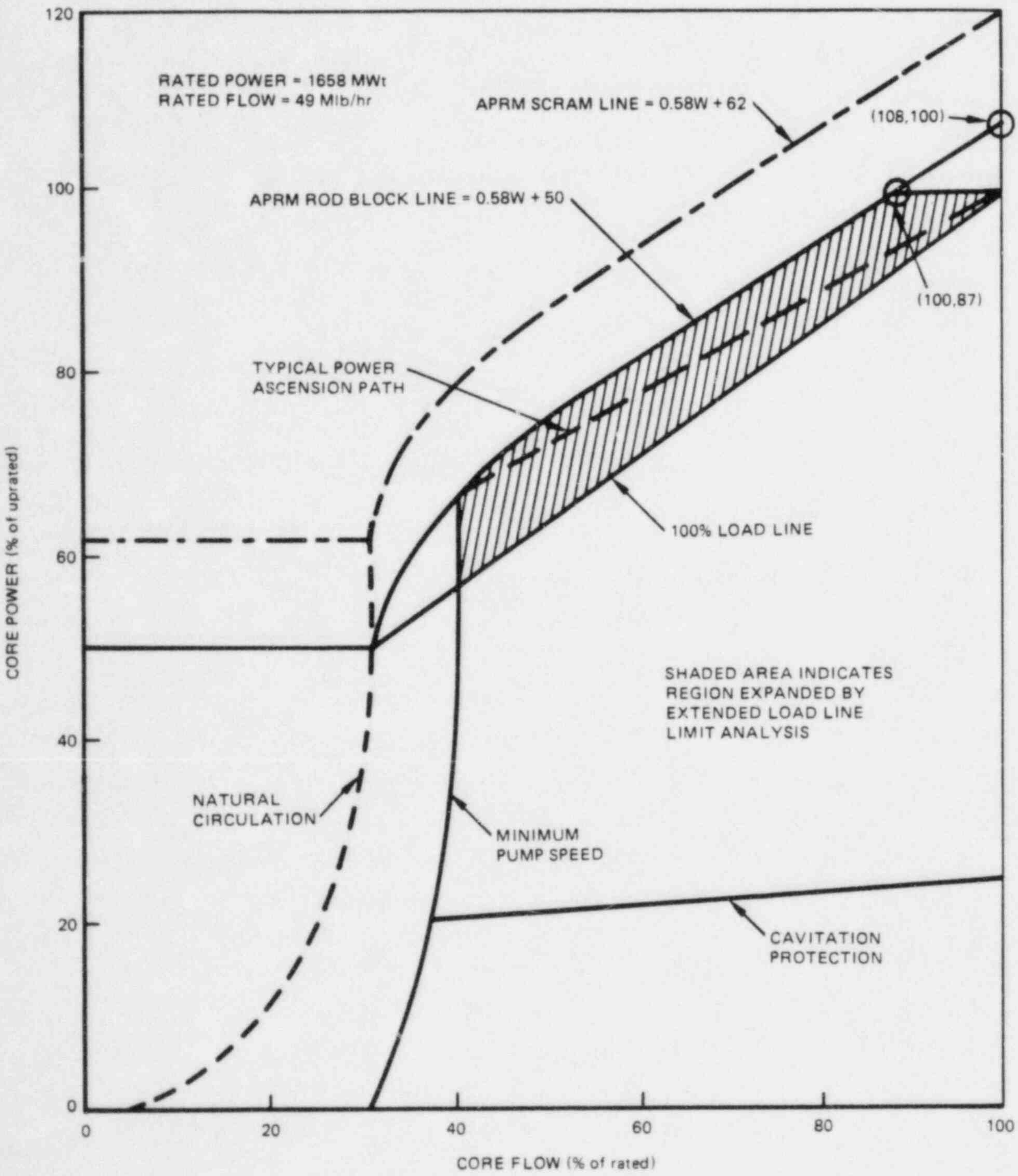

Figure 3-1. Proposed APRM Limits for the DAEC

The change to GETAB/GEXL with its deemphasis of local thermal hydraulic conditions and the move to secondary reliance on flux scram for licensing transient evaluations (for transients terminated by anticipatory or direct scram) has provided more effective and operationally acceptable alternatives to the setdown requirement. The DAEC ARTS program uses transient analyses to define thermal limits initial conditions (operating limits) which conservatively assure that all licensing criteria are satisfied without setdown of the APRM scram and flow biased rod block trips.

3.2 SYSTEM EVALUATION

3.2.1 Objectives

The objective of this evaluation is to justify removal of the peaking factor setdown requirement. Those licensing areas which might be affected by the elimination of the setdown requirement are:

a. fuel thermal-mechanical integrity, and

b. loss-of-coolant accident.

The following criteria assure satisfaction of the applicable licensing requirements and were applied to demonstrate the acceptability of elimination of the setdown requirement.

a. MCPR safety limit shall not be violated as a result of any abnormal operating transient,

b. All fuel thermal-mechanical design bases shall remain within the licensing limits described in GESTAR-II (References 1 and 4), and

c. peak cladding temperature and maximum cladding oxidation fraction following a LOCA shall remain within the limits defined by the applicable regulations (10CFR50.46).

3.2.2 Evaluations

The safety evaluations include abnormal operational transients and LOCA analysis.

3.2.2.1 Loss-of-Coolant Accident

Previous LOCA analyses applicable to the DAEC are documented by References 3, 5, 6, 7 and 8. The effects of a LOCA initiated from less than rated core flow for all classes of GE BWRs are evaluated in References 6 and 7. Standard exposure dependent maximum average planar linear heat generation rate (MAPLHGR) limits are generated from LOCA analyses initiated from rated power and flow conditions. The DAEC Cycle 8 LOCA analyses (References 3 and 5) were initiated from a power level of 1691 Mwt or 102% of rated power (consistent with Chapter 10, Part 50, Appendix K of the Code of Federal Regulations). For core flows lower than a critical value, boiling transition at the limiting fuel node can occur sooner than during the standard LOCA evaluations; this phenomenon is referred to as early boiling transition (EBT). The EBT increases the low heat transfer period before final water level recovery. If the initial fuel heat flux is high enough, the resultant peak cladding temperature (PCT) can exceed the standard LOCA results. In this case, it may be necessary to apply an "MAPLHGR multiplier" for operation in certain flow ranges. Previous LOCA core flow effects analyses (References 6 and 7) assumed that the core is operated on or below the proposed flow biased APRM rod block line, $(0.58W_D + 50) \cdot (FRP/CMFLPD)$. This represented a conservatively higher power than the typical $(0.66W_D + 42) \cdot (FRP/CMFLPD)$ APRM rod block line. In addition, fractional recirculation drive flow, W_D, in the equation was conservatively taken as core flow, W_C, since the fraction of rated drive flow is always less than or equal to the fraction of rated core flow. These assumptions results in an initial MAPLHGR given by

$$(0.58W_C + 50) \times \frac{FRP}{CMFLPD} \times \frac{\text{MAPLHGR limit}}{100} \text{ kW/ft.}$$

For the DAEC, it had been found that EBT does not occur above 70% core flow. At this and lower core flows, a conservative LOCA analysis (References 6 and 7) determined that a 0.95 MAPLHGR multiplier was necessary to avoid EBT.

With the introduction of ARTS, the setdown factor, FRP/CMFLPD, is removed from the APRM rod block equation and

However, the recent LOCA analysis for the DAEC Power Uprate Program (Reference 3) had shown substantial PCT margin for the limiting break at rated core flow conditions. Reevaluation of the low core flow effect on ECCS performance showed a similar improvement in PCT margin.

3.2.2.2 Transients

A large data base was used to study the trend of transient severity (ΔCPR and heat flux) without the average power range monitor (APRM) core peaking factor setdown. This data base was established by analyzing limiting transients over a range of power and flow conditions and was used to develop plant operating limits (MCPR and MAPLHGR) which will assure that margins to fuel integrity limits are equal to or larger than those in existence at the present time.

All transient analyses were performed using the standard reload licensing methodology (References 1 and 4) except the loss of feedwater heating (LFWH). The LFWH has been analyzed using methodology described in a generic LFWH report submitted by GE in July 1983 (Reference 9).

Results from the above transient analyses were used to establish the limits

The DAEC specific transient analyses were performed at power levels consistent with the DAEC Power Uprate Program (Reference 3).

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3.3 PLANT OPERATING LIMITS

3.3.1 Power Dependent MCPR Limit

Even with the transient severity increase included, large margins still exist between the required thermal limits and expected operating plant performance at lower power levels. Accordingly, above P_{Bypass}, bounding power dependent trend functions have been developed. These trend functions are multipliers on the rated MCPR operating limits and MAPLHGR limits. The DAEC analyses documented in this report have verified the large margins and the applicability of the multipliers.

Therefore, below P_{Bypass}, a set of MCPR operating limits are provided for both high and low core flow. No thermal monitoring is required below 25% power.

The power dependent MCPR limits for the DAEC are shown in Figure 3-2. Above P_{Bypass}, Figure 3-2 shows the power dependent MCPR multiplier (K_p). The operating MCPR limit at any given power is equal to the operating limit at rated power (option A or option B) multiplied by K_p. Below P_{bypass}, the actual MCPR operating limits for high and low core flow are illustrated in Figure 3-2.

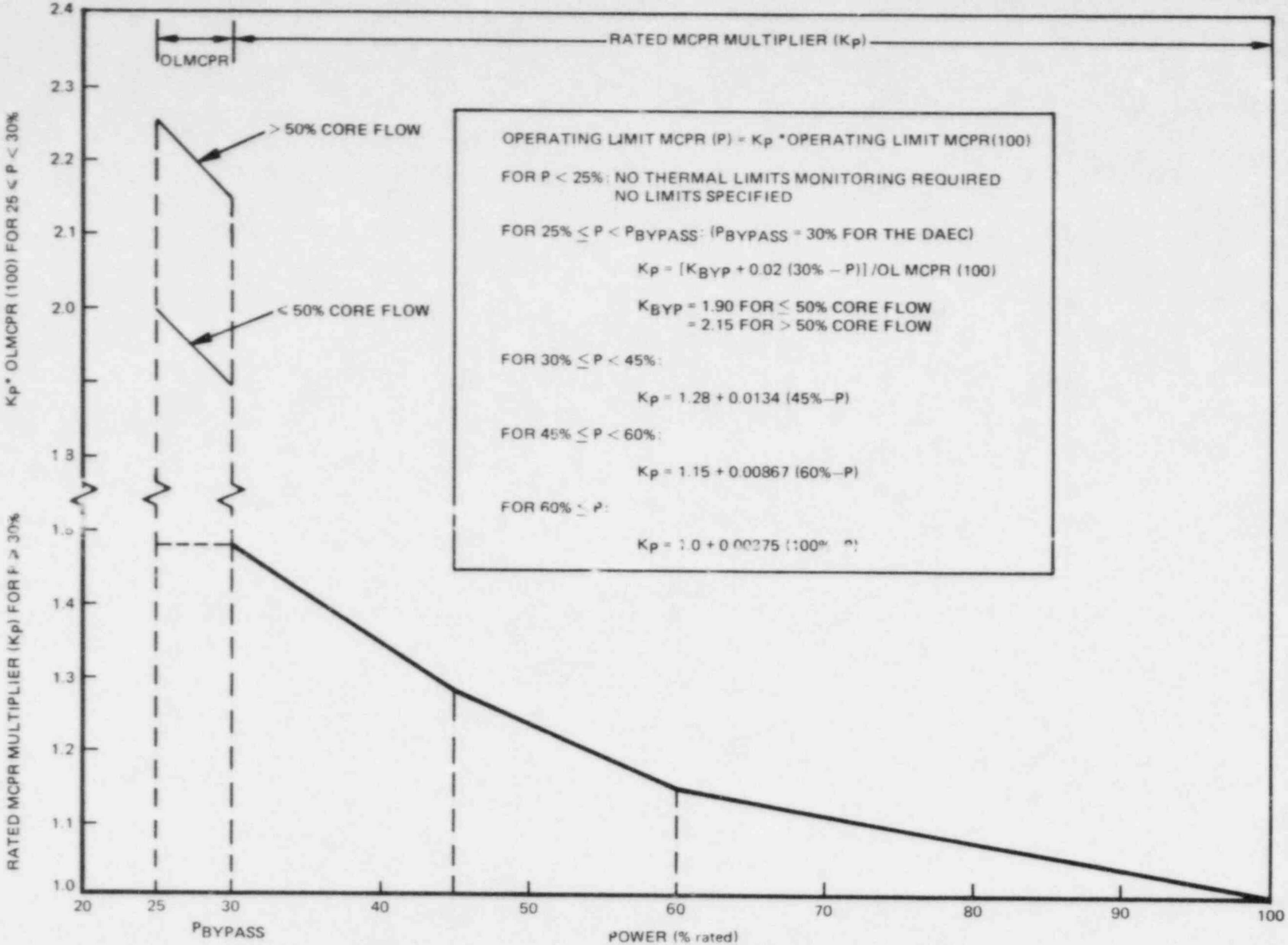


Figure 3-2. Power Dependent MCPR for the DAEC (K_p)

The peak core heat fluxes and maximum ΔCPRs for the pressurization transients are presented in Table 3-1. Comparison of the table values with Figure 3-2 verifies that the K_P curve is conservative for the DAEC.

3.3.2 Power Dependent MAPLHGR Limit

In the absence of the APRM scram setdown requirement, special limits are substituted to assure adherence to the fuel thermal-mechanical design bases.

Therefore, below P_{Bypass} both high and low core flow $MAPFAC_P$ limits are provided.

This limit is derived to assure that the peak transient MAPLHGR for any transient is not increased above the rated power fuel design basis transient values.

The actual power dependent MAPLHGR factor ($MAPFAC_P$) for the DAEC is shown in Figure 3-3.

3.3.3 Flow Dependent MCPR Limit

Flow dependent MCPR limits are necessary to assure that the safety limit MCPR is not exceeded during flow runout events. The design basis flow runout event is a slow flow/power increase event which is not terminated by scram, but which stabilizes at a new core power corresponding to the maximum possible core flow. The DAEC flow dependent MCPR ($MCPR_F$) limit is shown in Figure 3-4.

Flow runouts were analyzed along a constant Xenon flow control line assuming an equilibrium plant heat balance at each flow condition.

Table 3-1

DAEC TRANSIENT ANALYSIS RESULTS

Table 3-2

DAEC LIMITING TRANSIENT POWER DEPENDENT $MAPFAC_P$[a] REQUIREMENTS

Power (%)	$MAPFAC_P$ Limit
30	0.50
30	0.60
25	0.47
25	0.57
30	0.66

[a] $MAPFAC_P = \dfrac{\text{Required MAPLHGR(P)}}{\text{MAPLHGR Limit at Rated Power}}$

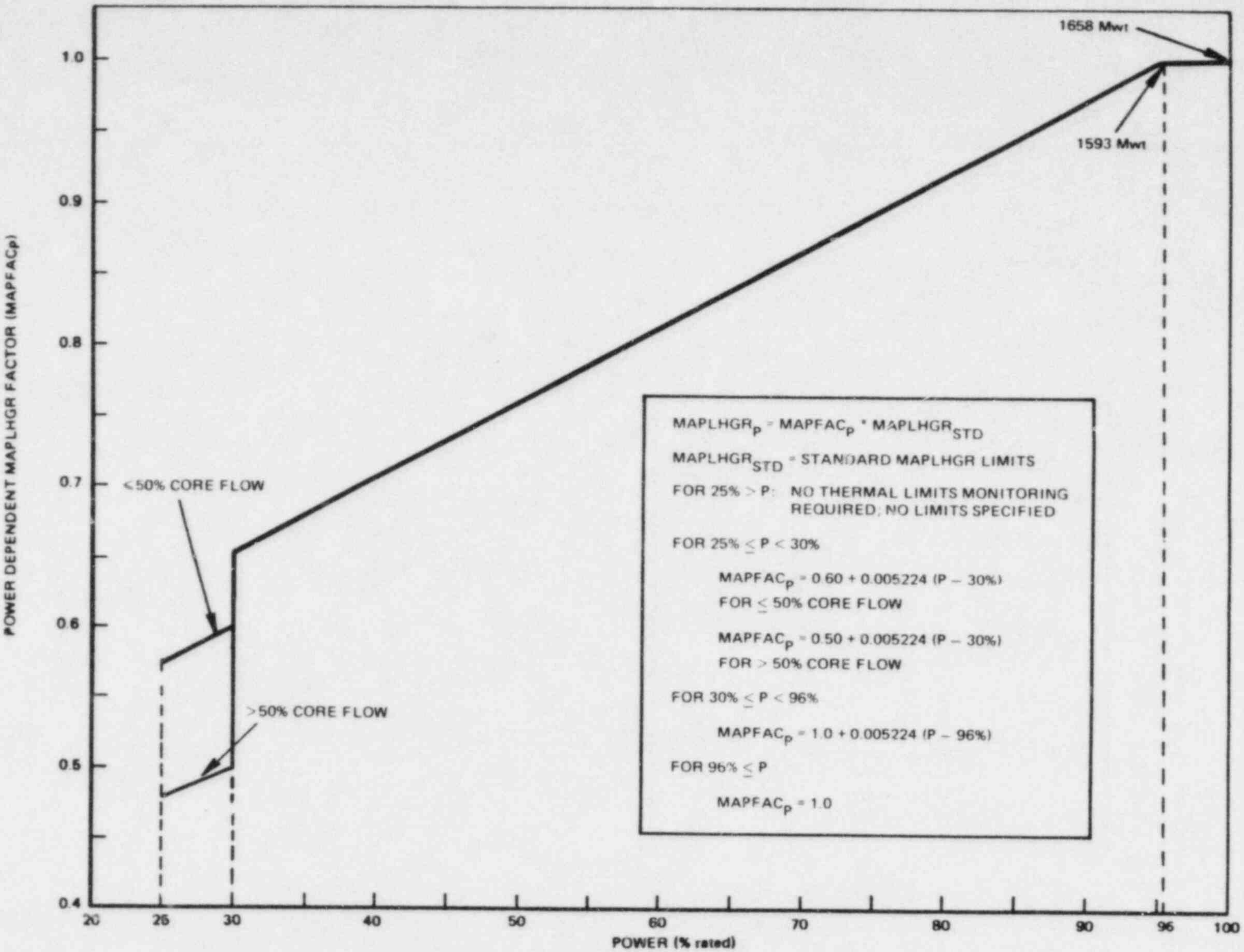


Figure 3-3. Power Dependent MAPLHGR for the DAEC (MAPFAC$_P$)

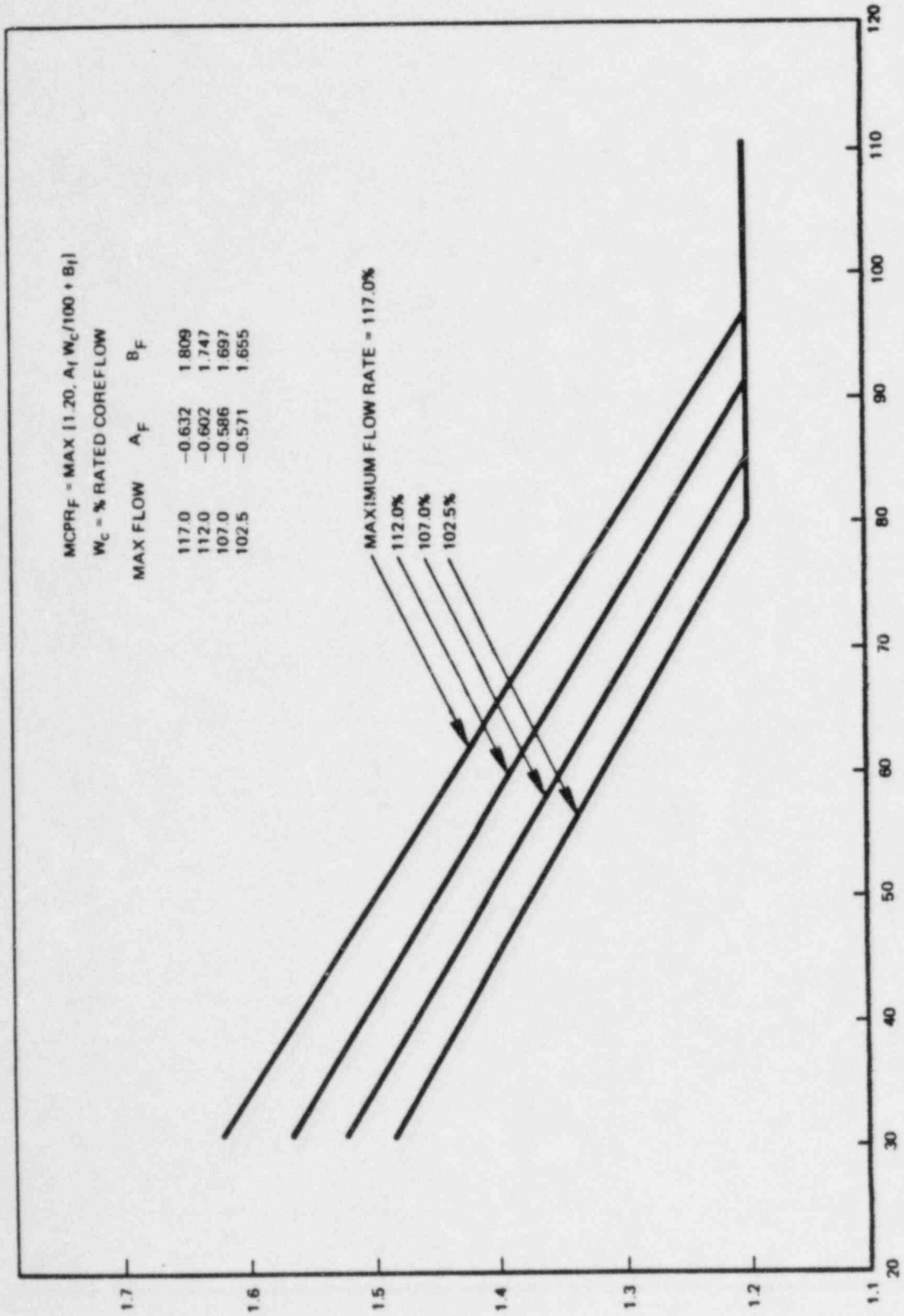


Figure 3-4. Flow Dependent MCPR for the DAEC (MCPR$_F$)

3.3.4 <u>Flow Dependent MAPLHGR Limit</u>

Flow dependent MAPLHGR factor ($MAPFAC_F$) requirements which assure adherence to the fuel thermal-mechanical design bases

The flow dependent MAPLHGR factors for the DAEC are presented in Figure 3-5. Like the power dependent MAPLHGR factors, these factors were derived such that the peak transient MAPLHGR during these events is not increased above the fuel design basis values.

As discussed in Subsection 3.2.2.1,

the limits shown in Figure 3-5.

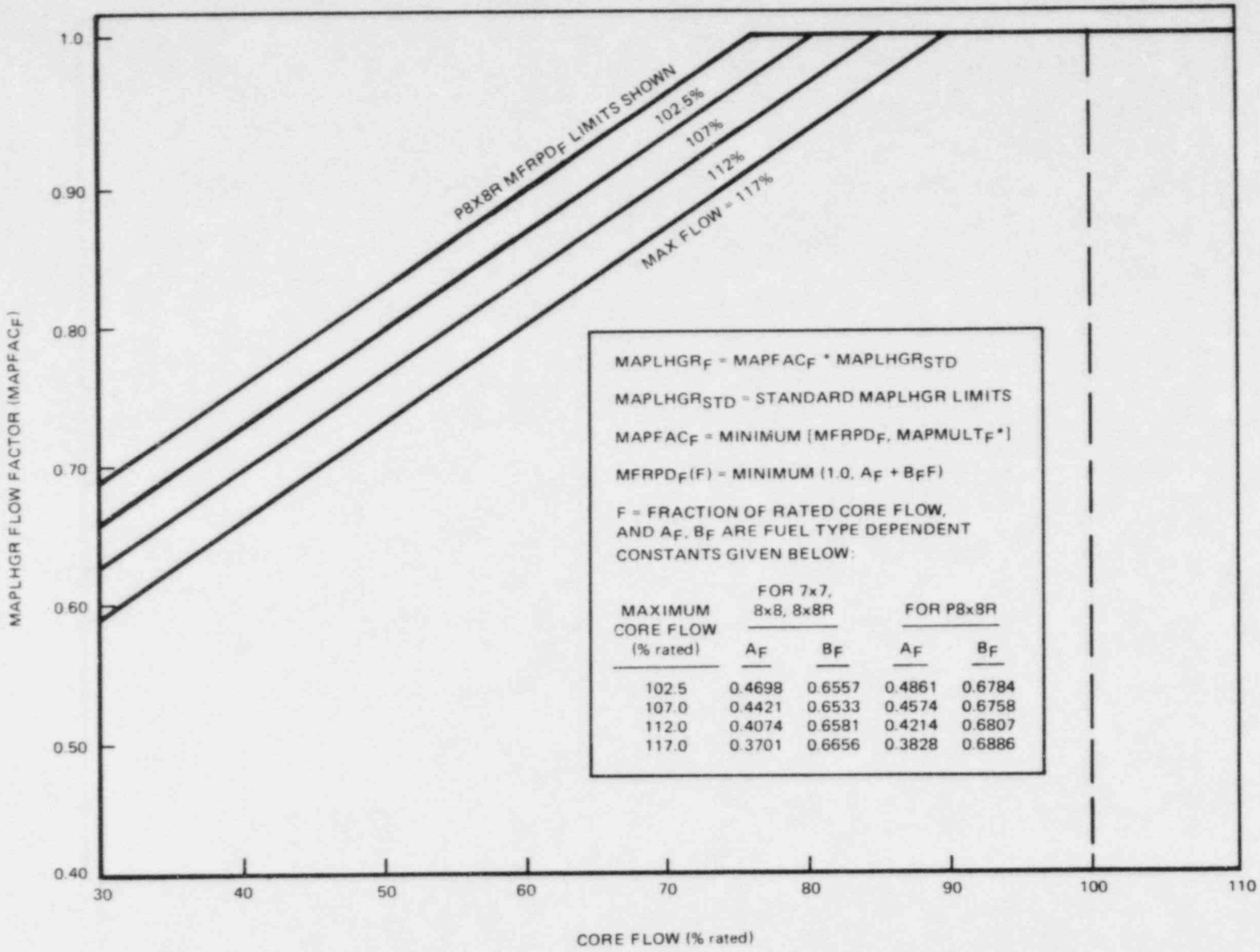


Figure 3-5. Flow Dependent MAPLHGR for the DAEC (MAPFAC$_F$)

3.3.5 Governing Overall Limit

At any given power/flow state, (P, F), all four limits must be determined: MCPR(P), MCPR(F), MAPLHGR(P), and MAPLHGR(F). The most limiting MCPR and the most limiting MAPLHGR (maximum of MCPR(P) and MCPR(F) and minimum of MAPLHGR(P) and MAPLHGR(F)) will be the governing limit.

For Single-Loop Operation (SLO), the most restrictive of the SLO or ARTS MAPLHGRs will define the limiting condition of operation. Any MCPR adjustments required for SLO shall be applied to overall MCPR limits as previously defined.

The MCPR limits shown in Figure 3-4, however, assume a SLMCPR of 1.07, and any required increases in the safety limit for SLO should be reflected in the MCPR operating limit.

In addition, ARTS power dependent MAPLHGR and MCPR limits (based on SLMCPR = 1.07) are defined to cover certain transient events that can have a larger fractional power increase when initiated from power levels less than rated.

4. ROD BLOCK MONITOR SYSTEM IMPROVEMENTS

The function of the Rod Block Monitor (RBM) System is to assist the operator in safe plant operation in the power range by:

a. initiating a rod block to prevent violation of the fuel integrity safety criteria during withdrawal of a single control rod, and

b. providing a signal to permit operator evaluation of the change in local relative power during control rod movement.

4.1 CURRENT RBM SYSTEM DESCRIPTION

To provide the measure of local power change, the RBM System uses the set of LPRMs that are displayed to the operator in the four-rod display. There are two RBM circuits (designated Channel A and Channel B); one uses the LPRM detectors from the A&C level detectors and the other uses the B&D level detectors. The RBM has between four and eight LPRM inputs depending upon whether it is operating on a center or near periphery rod.

The RBM computes the analog average of all assigned unbypassed LPRMs, in much the same manner as the APRM. The average of the input chambers is modified automatically to read the same as a reference APRM by a separate gain adjustment in the RBM whenever a control rod is selected. This gain adjustment factor can never be less than one. Thus, the LPRM average will never be adjusted below the APRM. There is a momentary rod block while the gain adjustment is made. This gain is held constant until a new control rod is selected.

The RBM automatically limits the local thermal margin changes by allowing the local average neutron flux indications to increase by a controlled amount. If the change is too great, the rod withdrawal permissive is removed.

Only one of the two RBM channels is required to trip to prevent rod motion.

The RBM has three drive flow-biased trip levels (rod withdrawal permissive removed). The trip levels may be adjusted and are nominally 8% of reactor power apart. Typical settings might be 108%, 100%, and 92% at 100% flow. For the DAEC, the high trips are cycle dependent. Each trip level is automatically varied with recirculation system flow to protect against fuel damage at lower flows. The operator may encounter any number (up to three) of trip points depending on the starting power of a given control rod withdrawal. The lower two points may be successively bypassed (acknowledged) by manual operation of a pushbutton. The reset permissive is actuated, and indicated by a light, when the RBM reaches 2% power less than the trip point. The operator should then assess the local power and either bypass the trip or select a new rod. The highest trip point cannot be bypassed.

A count of the active LPRMs is made automatically and the RBM declared inoperative if too few detectors are available for use. The rod withdrawal permissive is removed if the RBM is inoperative and not bypassed. Only one RBM channel may be manually bypassed at any time. If the reference APRM is indicating less than 30% power, the RBM is bypassed automatically. The RBM also is bypassed if the control rod has one or more adjacent fuel bundles located in the outer boundary of the reactor core. In this case, the high neutron leakage prevents overlimit conditions. An RBM reading downscale and not automatically bypassed by the APRM low power feature is considered to have failed and withdrawal of the selected rod is not permitted.

The RBM has outputs to recorders located on the reactor operator's console, local meters, trip units and the on-line computer.

The signal conditioning electronics for the RBM forms the average of the LPRM chambers as described above. The detectors are assigned upon selection of a control rod by a selection matrix. The matrix receives a voltage signal corresponding to the selected rod group. The selection of the rod routes the proper LPRM signals to the meter displays and to the assigned RBM.

The power for the RBM is supplied from low voltage power supplies located in the same cabinet as the RBM. Although the RBM has no reactor protection system outputs, each RBM channel is assigned to a separate trip system and the ac power for the RBM low voltage power supply is supplied from independent sources.

The trip unit utilizes the output voltage from a flow converter to drive the linear variation of the trip set points with flow. The slope of the rod block trip is variable between 0.52 and 0.78 with a current setting of 0.66 for the DAEC.

One RBM channel may be manually bypassed by operator action. As discussed in Subsection 4.1, automatic bypass occurs if the APRM level is below a prescribed value or reactor core outer boundary control rods are selected. All trips are bypassed if the reactor mode switch is in any position other than "RUN."

A schematic of the current DAEC RBM System is presented in Figure 4-1.

4.1.1 Limitations of Current RBM System

The DAEC RBM System was designed in the middle 1960s. Since that time there have been significant technological advances in the fields of two-phase flow, heat transfer and the entire field of electronics. The GETAB/GEXL Critical Power Ratio has replaced the Hench-Levy Critical Heat Flux Ratio as the preferred means of determining departure from nucleate boiling. This means that optimum evaluation of fuel thermal margins can no longer be performed solely on a local basis, but requires both local information and information about the entire fuel bundle. For the RBM to fulfill its intended function, changes in the RBM signal(s) must correlate closely with the thermal margin changes during control rod withdrawal. The current RBM signals do not always correlate well with thermal margin changes during control rod withdrawal, and the system performs its function only at the expense of significant operational penalties.

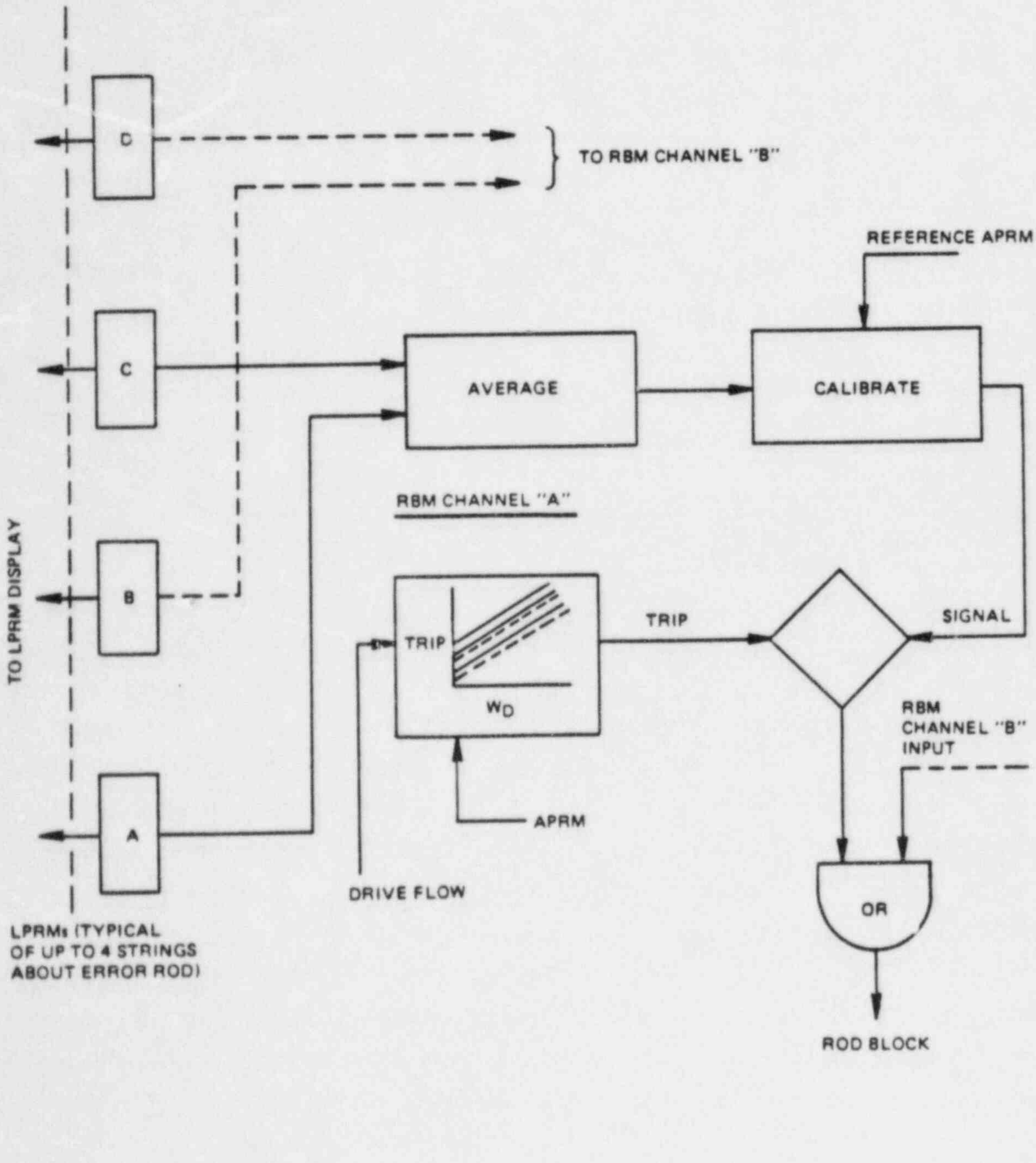


Figure 4-1. Conceptual Illustration of Current DAEC Flow Dependent RBM System with AC/BD LPRM Assignment

For determination of trip setpoints, the most responsive channel is assumed to be bypassed and the setpoints are determined by the operating (least responsive) channel. It is also assumed that some of the LPRMs assigned to the operating channel have failed. This further diminishes the response of this channel. The RBM setpoint chosen is the one which blocks rod withdrawal before violation of the Safety Limit Minimum Critical Power Ratio (SLMCPR), based on the response of the least responsive channel with maximum allowable LPRM failures. However, when this setpoint is actually implemented at the plant, both RBM channels typically will be in operation and the number of failed LPRMs will be less than assumed in the analysis. The more responsive channel actually blocks rod withdrawals at much shorter withdrawal increments and unnecessarily restricts control rod movements. This results in complicated and time consuming plant maneuvers to reach the full-power rod pattern.

The problem of failed LPRMs is addressed in the analysis of the rod withdrawal error (RWE).

When a control rod is selected, rod withdrawal is blocked by the current RBM System until the proper LPRM signals have been routed to the RBM averaging electronics, and a variable gain has been applied to the channel responses which normalizes them to read the same as the reference ARPM channels (Figure 4-1). Normalization of the signal and trips to the reference APRM provides a method of mapping RBM setpoints over a broad range of power and flow conditions (Figure 4-2). Three flow-biased trip lines are provided; the one selected is determined by the power and recirculation drive flow at the time of selection. At a given flow, the RBM trip line immediately above the APRM measured power is selected for enforcement. If the APRM measured power is within the 2% reset band immediately below the two lower trip lines, the next higher RBM trip line is automatically selected for enforcement. Similarly, manual reset

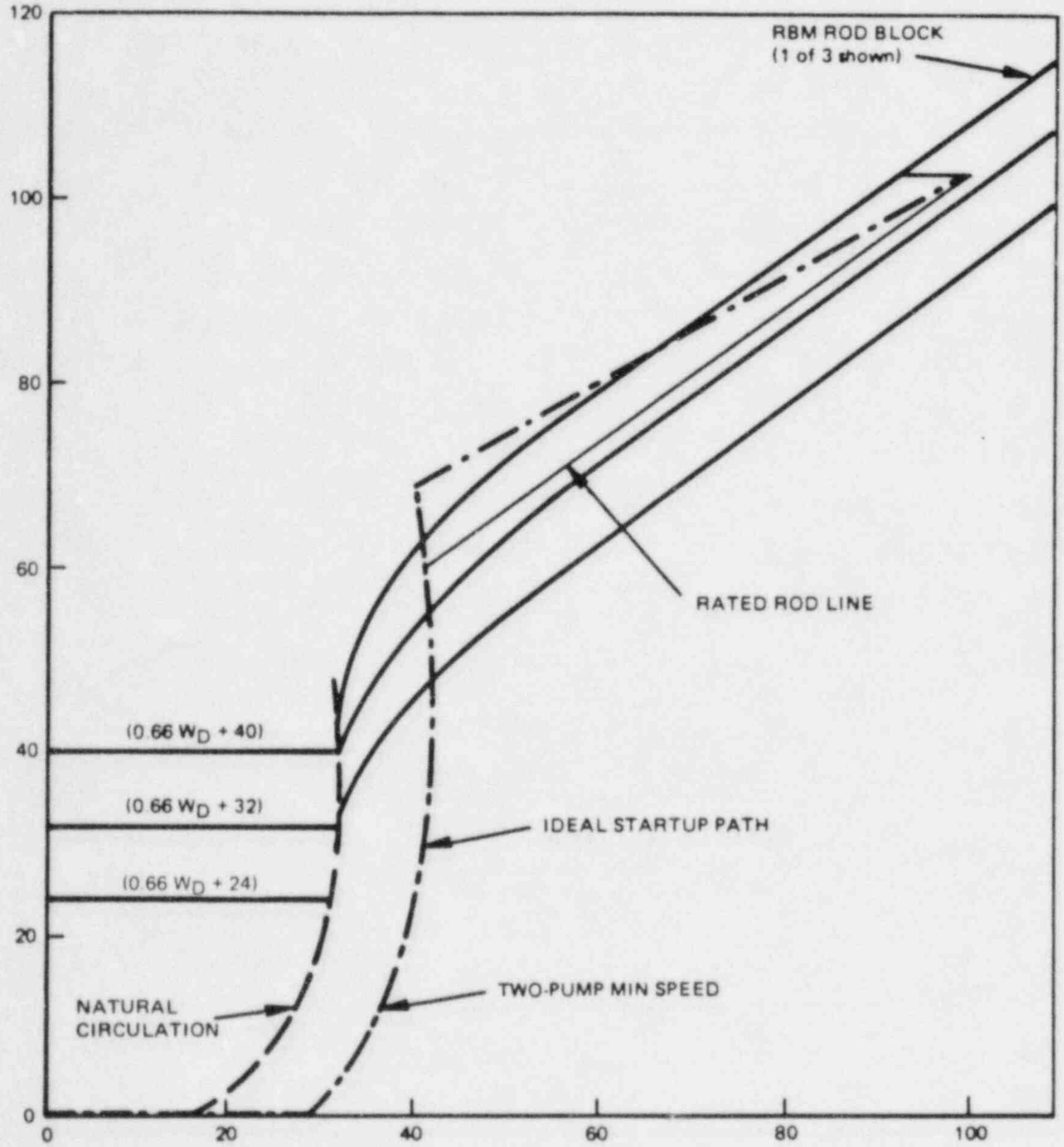


Figure 4-2. Current RBM Limits (Typical for 106 Setpoint)

of the lower trip to the next higher trip is allowed when the local power reaches the 2% band as a result of rod withdrawal. In this case, the operator verifies that adequate thermal margins exist before resetting the trips. These reset features are a necessary result of the normalization of the signals to the APRM. If the APRM power is just below the trip, random noise in the signals may cause the trip to be exceeded and no withdrawal will be possible. Since the flow-biased trip lines roughly parallel the flow control lines, it would be very difficult to increase core power above an RBM trip line without the reset features. Resets are possible only for the two lower trip lines; the high trip cannot be reset. Since the highest trip line cannot be reset, another direct consequence of the normalization of the RBM signals to the reference ARPM is that control rod withdrawal is not permitted when the reference APRM exceeds the highest RBM trip line.

Figure 4-2 illustrates an ideal startup path in which rated power is attained without control rod movement after recirculation flow has been increased above the minimum pump speed. Figure 4-2 also shows the relationship between the RBM trip lines and the ideal startup path relative to the highest RBM trip line. Because these two lines cross at low flow, the RBM prevents withdrawal of control rods necessary to attain the ideal startup path. These control rods must currently be withdrawn at higher powers resulting in unnecessary fuel duty and are often prohibited by PCIOMR's.

Summarized in Table 4-1 are the limitations of the current DAEC RBM System, the impact and the proposed improvements.

Table 4-1

ROD BLOCK MONITOR SYSTEM IMPROVEMENTS

Current Design	Impact	Improvement
•	•	•
	• Low Trip Setpoints	
	• Unnecessary Rod Blocks	
•	•	•
• Flow Biased Trips	•	• Power Biased Trips (Like BWR/6)
•	• Gross Core Power Limited	•

4.2 NEW RBM SYSTEM DESCRIPTION

The changes which ARTS will make to the DAEC RBM System will:

a. eliminate the restrictions imposed on gross core power by the current flow-biased RBM trips (this function will be fulfilled by the APRM flow-biased rod block),

b. enhance operator confidence in the system by reducing the frequency of non-essential rod blocks and by making occurrence of rod blocks more predictable and therefore avoidable, and

c. upgrade the performance of the system such that the RWE will never be the limiting transient.

Advances in electronics have made it possible to efficiently specify system performance requirements which were not possible in the mid-60s. The ARTS Program takes advantage of these advances to make changes in the DAEC RBM hardware which controls the trip logic and LPRM averaging to enhance the instrumentation accuracy and to improve the signal to thermal margin correlation. Further improvements in the capability of the RBM to perform its intended function of assisting the operator in safe operation of the plant are obtained by improving the methodology used to determine the required trip setpoints.

As in the original system, an RBM downscale trip level is defined to detect abnormally low signal levels.

reselecting another rod, as reselection will result in a recalibration to the reference signal.

Figure 4-3. (General Electric Company Proprietary Information)

In Figure 4-6 the individual channel responses are compared for a typical high worth control rod withdrawal.

To the maximum extent possible, while achieving the above objectives (a-e), the new RBM System design meets the same separation and isolation requirements (Reference 8) as the previous RBM system.

A count of active LPRMs is made automatically and the RBM channel declared inoperative if too few detectors are available.

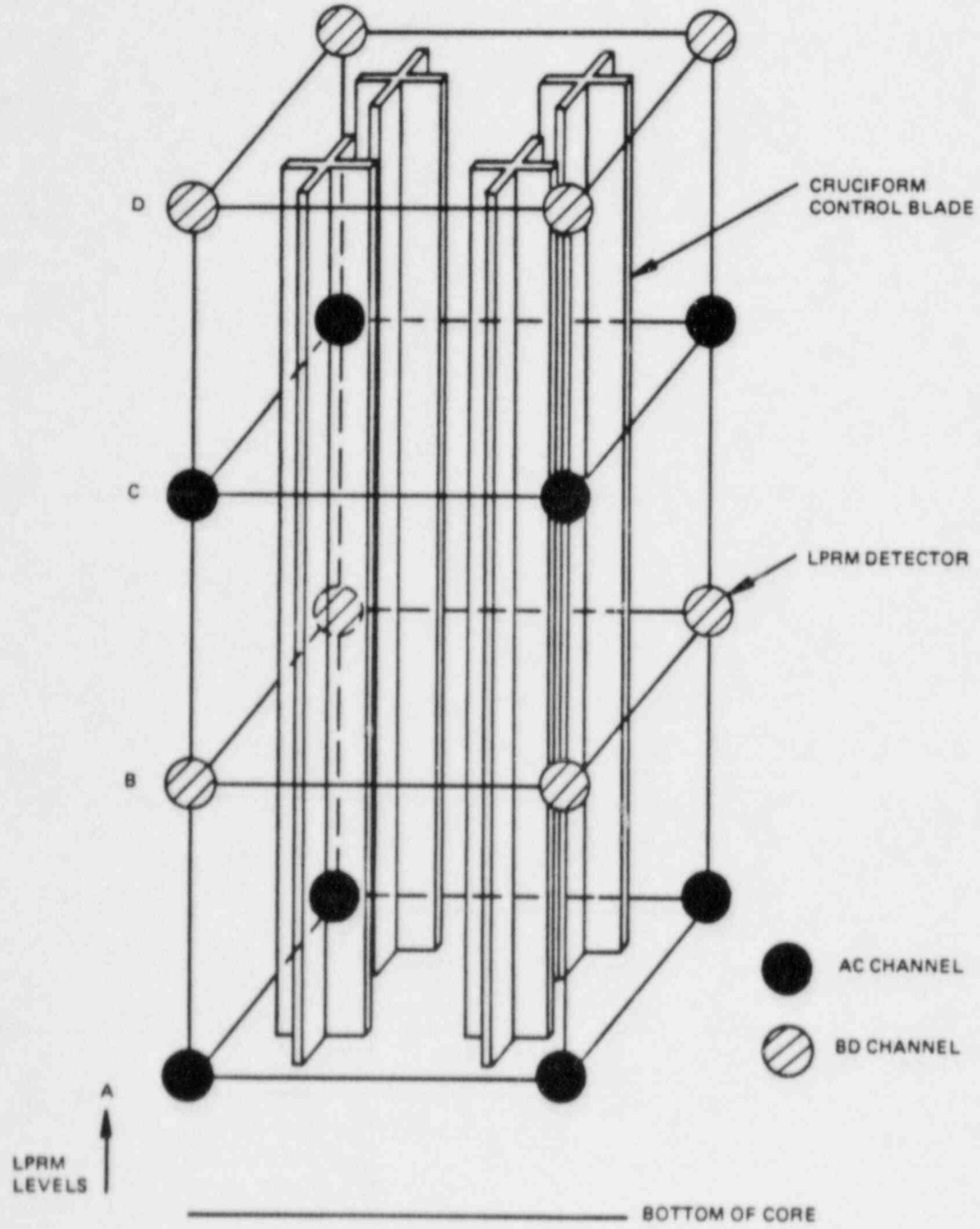


Figure 4-4. DAEC RBM Current AC/BD LPRM Assignment

Figure 4-5. (General Electric Company Proprietary Information)

Figure 4-6. Typical RBM Channel Responses, Old versus New

The new DAEC RBM System is easily understood, possesses readily predictable behavior, and will limit the thermal margin reduction during rod withdrawals, but will not restrict rod withdrawals on the basis of gross core power level (Figure 4-7). Limitations on gross core power levels are now imposed by the safety grade APRM flow-biased rod block; this system will remain unchanged.

The RWE evaluations necessary to establish the CPR limit and the trip setpoints for each power interval are discussed in the following subsections.

4.3 ROD WITHDRAWAL ERROR ANALYSIS

4.3.1 Analysis

The deterministic, bounding, cycle specific analysis is replaced with a statistical analysis valid for application to all DAEC cores utilizing General Electric fuel designs through P8X8R.

The data base was drawn from actual plant operating states and covers the spectrum of plant designs and power densities (BWR/2, 3, 4, and 5) and currently utilized fuel designs. Cases were selected with low MCPRs and high MAPLHGRs in bundles near deep control rods (State A) to yield meaningful results. All State A cases were selected near rated power and rated flow. The actual rod patterns were modified to reduce the MCPR(s) of bundle(s) near the deep rods to approximately 1.20. To cover the power/flow map, two other power/flow

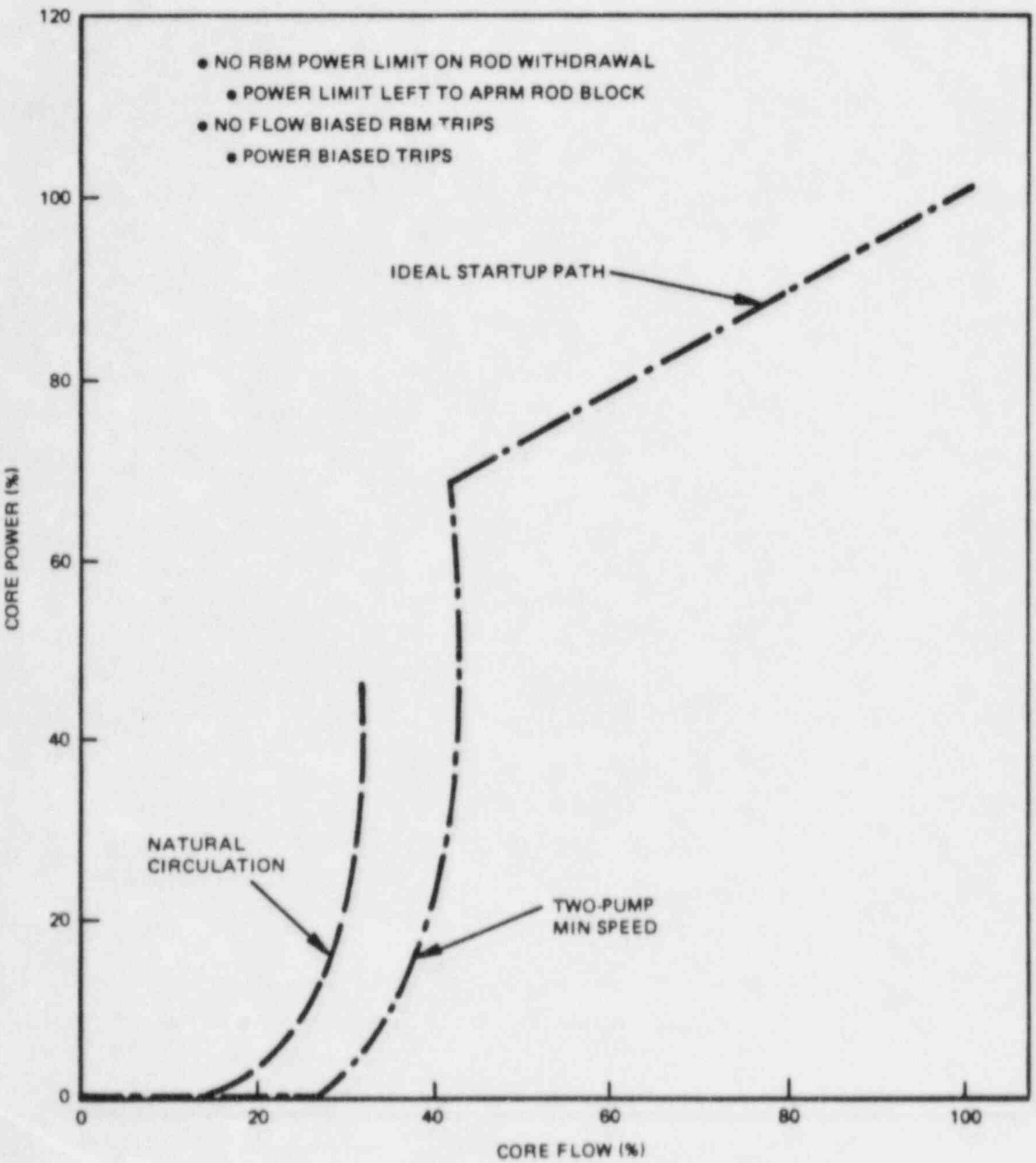


Figure 4-7. New DAEC RBM System Core Power Limit

points were included in the database.

A sensitivity study was also performed on LPRM failures and is discussed in Subsection 4.3.2.2. This study shows that the new system is fairly insensitive to LPRM failure rates.

The RBM responses were generated for both channels for each RWE analyzed. From these responses, error rod position at the rod block trip level was generated as a function of RBM setpoint. The results were tabulated as functions of RBM setpoint.

The overall results were determined for each power/flow point for each RBM channel.

For the DAEC, SLMCPR = 1.07.

The results for both RBM channels, for each power/flow state, for a range of RBM setpoints are summarized in Table 4-2. Also shown is the bounding MCPR requirement for each setpoint. This bounding MCPR requirement was used to generate the design basis MCPR requirement as a function of RBM setpoint (Figure 4-8).

The results in Table 4-2 show that, for setpoints of interest, the MCPR limits do not vary significantly over the power/flow map.

This value was chosen to assure that RWE will not significantly limit plant operation. Figures 4-8 and 4-9 were used to determine the RBM setpoints such that the RWE-required MCPR is less than or equal to the core wide transient power-dependent MCPR requirement. The RBM downscale trip setpoint was selected to detect abnormally low RBM signal conditions. Control rod withdrawal is blocked when the RBM is downscale. The resultant DAEC power-dependent RBM setpoint requirements are shown in Figure 4-10.

4.3.2 Sensitivity Analyses

4.3.2.1 Peripheral Rod Groups

The RBM setpoints given in the previous section(s) were based on analysis of RWEs occurring in four rod cells surrounded by four LPRM strings. The RBM

Table 4-2

ROD WITHDRAWAL ERROR ANALYSIS RESULTS

Figure 4-8. Design Basis RWE MCPR Requirement versus RBM Setpoint

Figure 4-9. Design Basis MCPR Requirement for RWE (DAEC ARTS)

Figure 4-10. DAEC RBM Setpoints versus Power cells near the core periphery may possess fewer than four control rods and have one, two, or three LPRM strings.

A study was performed to verify that the results obtained in the previous sections are valid for peripheral cells with less than four LPRM strings. The locations of LPRM strings and control rods in the DAEC core are shown in Figure 4-11. The rod group geometries and error rods studied are shown in Figure 4-12. A single case was selected from the database used to establish the RBM setpoints. This case was reanalyzed with the various geometries of Figure 4-12 substituted for the standard 4-string geometry. For this study, the RBM setpoint was fixed at 108. The results are given in Table 4-3 and show no significant differences between the base (4-string) case and the limiting peripheral geometries.

4.3.2.2 LPRM Failures

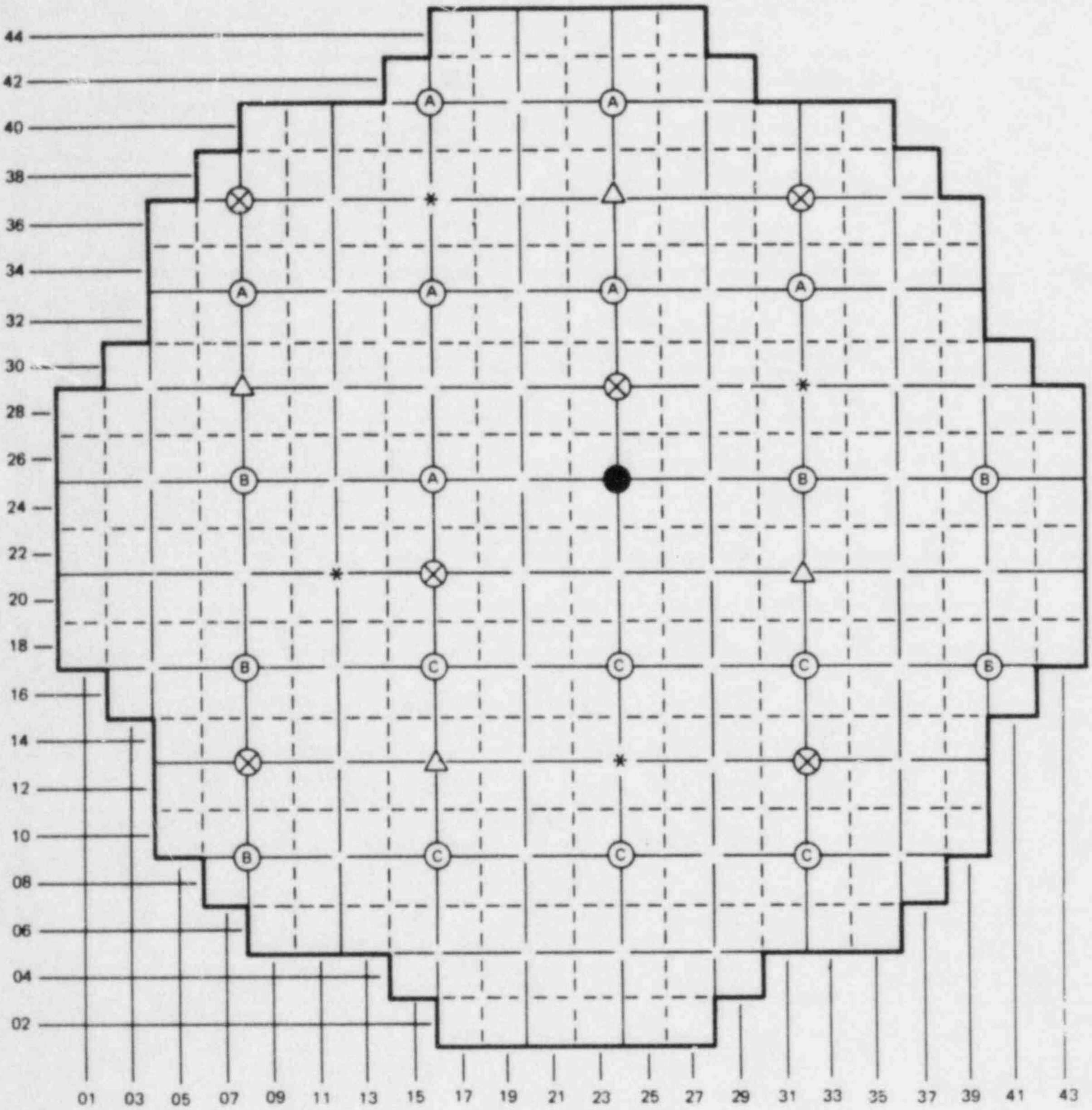
A study was performed to determine the sensitivity of the MCPR requirement to the failure probability.

The mean and "2σ" MCPR requirement for a 108% RBM setpoint are shown as functions of LPRM failure probability in Figure 4-13, which demonstrates the low sensitivity to LPRM failure probability.

It is concluded that the RBM setpoints are adequate for any realistically expected incidence of LPRM failures.

Table 4-3

RWE ANALYSIS RESULTS FOR PERIPHERAL ROD GROUPS



● LPRM LOCATION (COMMON LOCATION FOR ALL TIP MACHINES)

○ LPRM LOCATION (LETTER INDICATES TIP MACHINE)

⊗ IRM LOCATION

△ SRM LOCATION

✱ SOURCE LOCATION

Figure 4-11. DAEC Neutron Monitoring System

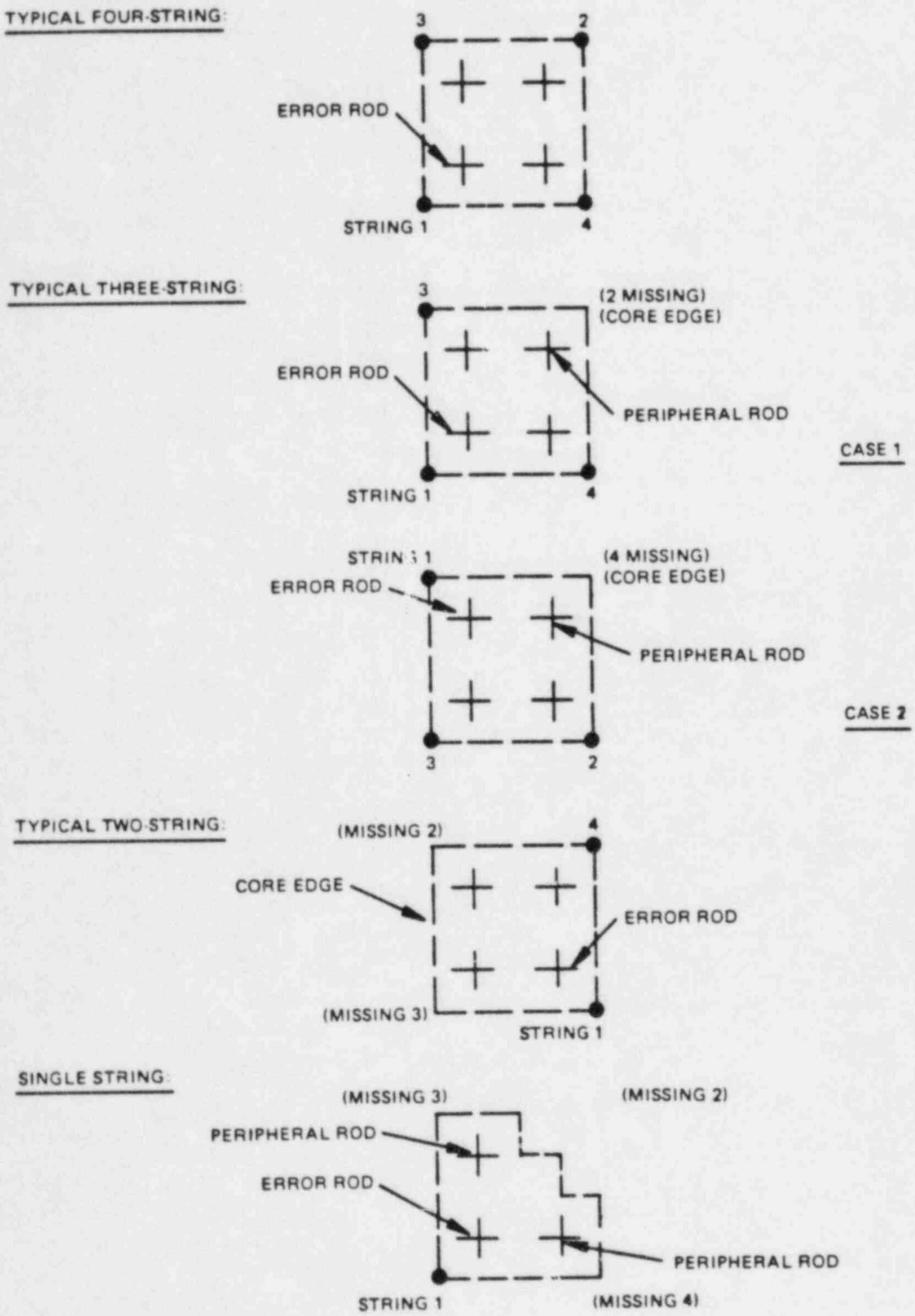


Figure 4-12. Rod Block Monitor Rod Group Geometries

Figure 4-13. Results of LPRM Failure Rate Sensitivity Study

4.3.2.3 (General Electric Company Proprietary Information)

* The setpoints here are "Analytical Limits." Other adjustments are recommended for inaccuracy, calibration, and drift effects to obtain the "Nominal Trip Setpoint." Some adjustment ranges have been fixed by design such that surveillance can be performed by simply establishing that the adjustments are in the limiting position.

Table 4-4

(General Electric Company Proprietary Information)

4.4 (General Electric Company Proprietary Information)

Table 4-5

RBM SYSTEM SETUP

Setpoint	Analytical Limit	Allowable Value	Nominal Trip Setpoint
LPSP	30		
IPSP	65		
HPSP	85		
LTSP			
ITSP			
HTSP			
DTSP			
t_{d2}			Set at minimum (<2.0 sec)
LPSP	30		
IPSP	65		
HPSP	85		
LTSP			115.1
ITSP			109.3
HTSP			105.5
DTSP			94 (recommended)
t_{d2}			<2.0 sec (minimum)

[a] N/L - no limitations;

Table 4-6
RBM SETUP SETPOINT DEFINITIONS

LPSP	Low power setpoint; RBM System trips automatically bypassed below this level
IPSP	Intermediate power setpoint
HPSP	High power setpoint
LTSP	Low trip setpoint
ITSP	Intermediate trip setpoint
HTSP	High trip setpoint
DTSP	Downscale trip setpoint
t_{d2}	Time delay 2;

Table 4-6

RBM SETUP SETPOINT DEFINITIONS (Continued)

Figure 4-14. Power Dependent RBM Trip Nomenclature

4.5 RBM OPERABILITY REQUIREMENT

The RBM System design objective is to block erroneous control rod withdrawal initiated by the operator before the Safety Limit MCPR is violated. When any control rod in the core would violate this limit upon complete withdrawal, operability of the RBM System was required. Such a condition is a "limiting control rod pattern" because RBM operation is required. The RBM System basis is limited to consideration of single control rod withdrawal errors and cannot accommodate multiple errors. Therefore, in defining "limiting control rod patterns," only single control rod withdrawals are considered. The entire generic RWE analysis database was evaluated to determine the pre-RWE MCPR margin that would assure that the complete withdrawal of any single control rod would not violate the safety limit. The requirements were evaluated at the 95% probability and 95% confidence level as follows:

a. First the 95/95 maximum MCPR changes were determined for complete rod withdrawal:

b. Then the pre-RWE MCPR requirement was determined:

Safety Limit MCPR = 1.07 was used.

The following limiting MCPR values were determined to provide the required margin for full withdrawal of any control rod:

For $P < 90\%$: MCPR must be ≥ 1.70

For $P \geq 90\%$: MCPR must be ≥ 1.40

Whenever operating MCPR is below the proceding values, the plant is on a "limiting control rod pattern" requiring that the RBM System be operable; whenever the operating MCPR is above these values, complete RBM bypass is justified.

5. TECHNICAL SPECIFICATION CHANGES

The following changes to the DAEC Technical Specifications are required for implementation of the ARTS Program:

a. Delete the requirement for setdown of the APRM scram and rod blocks.

b. Change slope and intercept of APRM flow biased rod block to 0.58 and 50, respectively; change slope and intercept of APRM flow biased scram to 0.58 and 62, respectively.

c. Replace RBM flow biased trip equation with power dependent setpoint definitions

d. Add new RBM bypass requirements including definition of limiting rod pattern.

e. Add new power dependent MCPR limit K_P.

f. Replace K_F with new $MCPR_F$.

g. Add definition of governing MCPR limit, $MCPR_F$ and $MCPR_P$.

h. Add new $MAPLHGR_P$, $MAPLHGR_F$ and definition of governing MAPLHGR.

i. Delete or modify affected bases.

6. REFERENCES

1. General Electric Standard Application for Reactor Fuel, April 1983 (NEDE-24011-P-A-6) and NEDO-24011-A-6, April 1983.

2. General Electric Boiling Water Reactor Extended Load Line Limit Analysis for Duane Arnold Energy Center, Cycle 8, May 1984 (NEDC-30626).

3. Duane Arnold Energy Center Power Uprate, October 1984 (NEDC-30603-P-1) and NEDO-30603-1, December 1984.

4. General Electric Standard Application for Reactor Fuel (Supplement for United States), April 1983 (NEDE-24011-P-A-US-6) and NEDO-24011-A-US-6, April 1983.

5. Loss-of-Coolant Accident Analysis Report for Duane Arnold Energy Center (Lead Plant) June 1984 (NEDO-21082-03 Appendix A).

6. R.L. Gridley (GE), Letter to D. G. Eisenhut (NRC), "Review of Low-Core Flow Effects on LOCA Analysis for Operating BWRs," May 8, 1978.

7. D.G. Eisenhut (NRC), Letter to R.L. Gridley, enclosing "Safety Evaluation Report Revision of Previously Imposed MAPLHGR (ECCS-LOCA) Restrictions for BWRs at Less Than Rated Flow," May 19, 1978.

8. Updated Final Safety Analysis Report - Duane Arnold Energy Center, Docket No. 50-331.

9. Letter, J.S. Charnley (GE) to F.J. Miraglia (NRC), "Loss of Feedwater Heating Analysis," July 5, 1983 (MFN-125-83).

10. "General Electric Boiling Water Reactor Supplemental Reload Licensing Submittal for Duane Arnold Energy Center, Reload 7," June 1984 (23A1739).

APPENDIX A
RBM HARDWARE DESCRIPTION

A.1 DESCRIPTION

A.1.1 General

The Rod Block Monitor (RBM) System is designed to automatically detect and block control rod withdrawal that could violate Technical Specification safety limits during a single control rod withdrawal error (RWE) transient. Upon operator selection of a control rod for withdrawal, the system begins comparing RBM signals to predefined trip levels. The RBM signals are the averages of local power range monitor (LPRM) in-core signals in the immediate core region of the selected control rod. An increase in the RBM signals during control rod withdrawal indicates a local power increase, and will, therefore, inversely correlate to local thermal margins changes. Rod block trip levels are determined by analysis to limit the thermal margin reductions to assure fuel limits are not violated. It is assumed that the core is operated in compliance with plant Technical Specifications before the RWE event. The plant operator is relied on to verify that he is in compliance with Technical Specification fuel thermal limits before resetting the rod block trip. Once reset, the RBM System reinitializes and allows further control rod withdrawal consistent with the design basis fuel thermal margin reduction increments. Design basis fuel thermal margin reduction increments represent the differences between the Technical Specification safety limits, and the Technical Specification operating limits.

In addition to the above function, the RBM provides continuous display of RBM signals to the operator as an indication of local power change during rod movement.

A.1.2 Application

The following addresses those major features of the modified RBM System. Areas not addressed are unchanged from the standard RBM design.

A.1.2.1 LPRM Assignment and Functional Description

Thus, eight inputs are retained per circuit as in the standard system for a typical central region control blade. Note, however, that some control rods near the core edge do not have the complete complement of 16 surrounding LPRMs and that some control rod selections result in 8 LPRMs in each RBM, others have 6 LPRMs in each RBM and finally some result in only 4.

This gain is held until a new control rod is selected. The RBM automatically limits the local power change by allowing the local average neutron flux indications to increase by a controlled amount. If the change is too great, the rod withdrawal permissive is removed. This is accomplished by implementing the rod block upscale trips relative to the same reference source signal used for RBM signal normalization.

Trip time delay is short enough to limit rod movement well below that which could cause a thermal limits violation.

As in the original system, the downscale trip automatically detects abnormally low RBM signals and also removes the rod withdrawal permissive.

A count of the active LPRMs is automatically made and the RBM declared inoperative if too few detectors are available for use. Up to half of the input LPRMs are allowed to be bypassed in an RBM channel (circuit) before a channel is declared inoperative.

The rod withdrawal permissive is not issued if the RBM is not operative and not bypassed. During operation with a limiting rod pattern, only one RBM channel may be manually bypassed at any time. Analyses performed for the rod block trips assume that only the least responsive RBM channel is in operation. At some low reactor power, fuel damage cannot occur for any single rod withdrawal; hence, if the reference APRM is indicating below this value, the RBM System is automatically bypassed. The RBM is also automatically bypassed if the control rod has one or more adjacent fuel bundles comprising the outer boundary of the reactor core. In this case, the high neutron leakage prohibits overlimit conditions. In addition, an RBM reading downscale and not automatically bypassed by the APRM low power feature is considered to have failed and the rod withdrawal permissive is not given.

A.1.2.2 Signal Conditioning Equipment

The signal conditioning electronics for the RBM forms the average of the LPRM chambers as described above. The detectors are assigned upon selection of a control rod by a selection matrix. The matrix receives a signal corresponding to the selected control rod group. The selection of the rod routes the proper LPRM signals to the meter displays and to the RBM.

A signal generated at the change of rod selection causes the RBM to reinitiate the null sequence. The rod withdrawal permissive is not present during the nulling sequence. Once the gain adjustment is accomplished, this gain setting is maintained until a new gain adjust required signal (new rod selection) is received. The RBM has outputs to recorders located on the reactor operator's console, local meters, trip units and the on-line computer. The output to the upscale trip unit can be delayed for a short time to allow small rod adjustments despite abnormally high noise.

The accuracy of RBM outputs in percent of full scale including drift, environmental changes, and supply voltage variation within the normal operating conditions is at least as good as the standard RBM designs. The averaging circuit response time is also equal to or shorter than standard RBM designs. Overall system quality equals or exceeds that of the RBM being replaced. The overall reliability of the RBM System in performing its rod block function when required is equalled or increased.

A.1.2.3 Power Supply and Trip Characteristics

The power for the RBM is supplied from low voltage power supplies located in the same cabinet as the RBM. Although the RBM has no reactor protection outputs, each RBM is nominally assigned to a separate trip system and the ac power for the low voltage power supply is supplied from that source. There is no required difference in RBM circuitry between large and small plants. However, variations in RBM circuits may exist from plant to plant to accommodate plant specific configuration requirements, solid state versus relay components, or other unique plant features.

The trip unit allows for adjustment of the three power biased trip levels and the power ranges over which each is implemented as previously discussed. The accuracy of the trips (the point at which the trip circuits operate) equals or exceeds that of the RBM System being replaced. The trips (functions described in the previous section) include too few inputs, downscale rod withdrawal block, upscale rod withdrawal block, instrument inoperative, mode switch in other than "Operate," a module removed, number of unbypassed inputs too few, and failure to null to the reference source signal. The response time of the trip logic and drift of the setpoints equals or is less than that of the logic being replaced.

A.1.3 Interface

The RBM compares the signal of each channel with a preset alarm level which is chosen in respect to the magnitude of the reference signal. If the RBM signal exceeds the alarm level, a rod block signal will be provided to the Reactor Manual Control System. The RBM also provides the averaged values to the Process Computer.

A.2 DESIGN/PERFORMANCE OF ELECTRONICS HARDWARE

A.2.1 The RBM has been designed to provide information about the local neutron flux level in the vicinity of a control rod that has been selected for withdrawal or insertion and to provide alarm signals used to inhibit rod withdrawal if the signal change reaches a predetermined level. This level shall be one of three RBM upscale trip levels which are to be enforced over the range of core power level from 30% to 100%. The RBM shall provide appropriate readout and annunciation for operator action and attention. The number of RBM channels is two (RBM Channels A and B).

A.2.2 Input Signals

The RBM equipment has been designed so that upon selection of a rod for withdrawal or insertion, a group of 16 (maximum) conditioned LPRM signals are automatically fed into the two RBM channels.

A.2.3 Circuit Isolation

The equipment has been designed so that any single short or open circuit of any single LPRM input to the RBM shall not affect any other LPRM inputs to the same RBM.

A.2.4 LPRM Auto-Bypass

The RBM has been designed so that each LPRM input level is sensed and compared with a predetermined reference level. If the LPRM input signal to an RBM averaging circuit is below this level, the LPRM input in question is automatically removed from the RBM signal conditioner and the gain of the signal conditioner automatically adjusted to compensate for the bypassed LPRM input signal. The bypass function in no way affects the LPRM from which the signal bypass was derived. White indicator lights are associated with the LPRM Meter Group Display and are illuminated when the RBM/LPRM input auto-bypass occurs. If the number of auto-bypassed LPRM inputs to the RBM averaging circuit exceeds the number specified, the RBM instrument inoperative alarm will be actuated.

A.2.5 Reference Signal

Each RBM is furnished with a reference APRM signal. This reference signal will be used to automatically select the corresponding RBM upscale trip. One APRM signal from each RPS bus supplies this reference signal for the RBM on the same bus. In the event of APRM bypass, another APRM on the same reactor protection bus is substituted automatically.

A.2.6 Bypass

A.2.6.1 The RBM equipment is designed such that when peripheral rods are selected for withdrawal or insertion, the RBMs are automatically bypassed.

A.2.6.2 One RBM channel may be manually bypassed by operating the remote RBM bypass switch.

A.2.6.3 Bypass is indicated on a local indicator by a white light and remotely indicated by a white display pilot light.

A.2.7 Signal Conditioning Equipment

The signal conditioning equipment for the RBM has been designed to process, condition and control with signals provided from the selected LPRMs, the reference APRM, rod selection switch, and bypass and other controlling functions, as illustrated in Figure A-1.

A.2.7.1 The number of conditioned LPRM signals selected as input to the RBM channel may vary from a minimum of two to a maximum of eight. Over this range of number of inputs, the equipment has been designed to meet the performance requirements specified.

A.2.7.2 The LPRM signals are allowed to vary their full range allowance.

A.2.7.3 The signal conditioning equipment of the RBM is designed to have a sensitivity compatible with the minimum LPRM signal, the accuracy requirements and the minimum number of LPRM inputs.

A.2.7.4 The RBM equipment as been designed so that the signal conditioner gain is automatically adjusted with the output level of the RBM signal

Figure A-1. RBM Functional Block Diagram (Illustration Only) conditioner always corresponding to a constant level whenever a control rod is selected. This gain is held until a new control rod is selected. The change of the RBM signal is constrained within the limit specified by an upscale alarm setpoint which varies with the APRM reference value.

A.2.7.5 During the period that the gain of the RBM signal conditioner is being adjusted, withdrawal of the selected control rod will be inhibited. The period of time required for this gain adjustment shall not exceed
If gain adjustment is not accomplished during this interval, an instrument inoperative alarm is initiated.

A.2.7.6 Over the normal control room environmental range, the actual RBM output does not deviate from the specified output (defined as the design center output) by more than

A.2.7.7 The RBM signal conditioning equipment has been designed so that at the design center environmental conditions, the short-term drift does not exceed

A.2.7.8

A.2.7.9

A.2.7.10 Input signals required by the RBM and furnished by the Reactor Manual Control System are serialized signals which will allow the RBM to determine which rod is selected, and from that, determine whether:

a. No rod is selected.

b. One rod is selected.

c. Rod is part of a group surrounded by two or three LPRM detector assemblies.

d. Peripheral rod selected.

A.2.7.11 The signal conditioning equipment has been designed to provide the following signal outputs at the levels indicated.

A.2.7.11.1 An appropriate signal to provide for readout, on, or near, the signal conditioning equipment. The signal is switachable and switching shall not affect the operation of the RBM.

A.2.7.11.2 A 0-to-1.0-volt signal for 0 to 125% (full scale) has been provided for use by a remotely located recorder. The signal is switchable and switching shall not affect the operation of the RBM.

A.2.7.11.3 A 0-to-160-mV signal for 0 to 125% (full scale) has been provided to the Performance Monitoring and Control System.

A.2.7.11.4 An inhibit withdraw (RBM Gain Adjust in Process) signal has been provided for use by the Reactor Manual Control System.

A.2.7.11.5 A 0-to-1-volt signal for 0 to 125% of the constant reference signal level and proportional to the average of LPRM inputs of each RBM channel has been provided. This signal is presented to a recorder and is switchable. The switching does not affect the alarm level setting.

A.2.8 Trip Function

The RBM provides the alarm functions listed in this paragraph.

A.2.8.1 All alarms are of the nonseal-in type (nonlatching) except the upscale level alarm (Rod Block) which can be reset by activating a reset switch or selecting another rod. Signal gain adjustment occurs only on rod selection and is not a function of the reset.

A.2.8.2 Locally Mounted Alarm Display Lights. The equipment is designed so that locally mounted alarm status display lights are located on or near the RBM signal conditioner. These display lights are color coded as follows:

a. Upscale Level Alarm (Rod Block) - Amber

b. Downscale Level Alarm - White

c. Instrument Inoperative Alarm - White

A.2.8.2.1.1

a.

b.

c.

A.2.8.2.1.2

a.

b.

c.

A.2.8.2.1.3 Accuracy. Over the normal control room environmental range, the actual alarm level does not deviate from the ideal alarm level more than

A.2.8.2.1.4 <u>Calibration</u>. The quality of freedom from error to which the alarm level is calibrated with respect to the true desired setting does not exceed

A.2.8.2.1.5 <u>Drift</u>. The alarm level drift does not exceed over the maximum surveillance test period.

A.2.8.2.2 Downscale Level Alarm

Design is unchanged from the current RBM design.

A.2.8.2.3 Instrument Inoperative Alarm

In the event that a particular RBM channel is out-of-service, an instrument inoperative alarm will be activated. Conditions causing an instrument inoperative alarm are as follows:

a. Calibrate-operate switch in other than operate position.

b. Any interlock in the equipment open.

c. Auto-bypassed LPRM exceeds the number specified.

A.4.8.2.4 Remotely mounted display pilot lights and annunciators are unchanged from the current RBM design.

A.2.8.2.5 Bypass

RBM upscale, downscale and inoperative alarms are automatically bypassed in the event that the channel is bypassed.

A.2.9 Environment Requirements

The equipment has been designed to function within the normal control room environmental conditions.

A.2.10 Power Distribution

Power connection to the RBM is unchanged. Power bus separation is desired and the equipment is designed to prevent inadvertent power bus interconnection.

A.2.11 Susceptibility

The equipment is designed such that interaction between the systems and subsystems of the Neutron Monitoring System (NMS) is minimized. In addition, the equipment is designed to operate within these specifications in the appropriate nuclear power plant environment. Sufficient equipment testing has been performed during the design of the equipment to assure that these requirements are met.

A.2.12 Statement of Accuracy

The statements of accuracy contained herein pertain to equipment upon which statistical determination of accuracy has been made. The accuracy of the equipment is within the figure stated herein with a probability of 95%.

A.2.13 Maintainability

The RBM channels require normal customer maintenance.

GENERAL ELECTRIC