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May 2, 1973

Mr. Dennis L. Ziemann, Chief
Operating Reactors Branch No. 2
Directorate of Licensing
U.S. Atomic Energy Commission
Washington, D.C. 20545

Subject: Dresden Station Special Report No. 25/
Quad-Cities Station Special Report No. 9,
"Rod Drop Accident Analyses for Dresden
Units 2 and 3 and Quad-Cities Units 1 and 2",
AEC Dkts 50-237, 50-249, 50-254 and 50-265

Dear Mr. Ziemann:

Your letter of February 2, 1973, requested information on the rod drop accident analysis for Dresden Units 2 and 3 and Quad-Cities Units 1 and 2 which apparently do not come under the General Electric generic documents NEDO-10527 and Supplements 1 and 2. The attached report is in response to your request.

The attached report provides an analysis for the rod drop accident for General Electric boiling water reactors of the Dresden and Quad-Cities class. This report provides justification for a limit of 0.014Δk for the allowable maximum worth on an in-sequence control rod. A request to change the Dresden Units 2 and 3 and Quad-Cities Units 1 and 2 Technical Specifications will be submitted after your staff has reviewed this report.

The out-of-sequence rod worth is not discussed in the report. The worth of the out-of-sequence rod will vary significantly depending on the conditions of operation and, based on judgment, a value greater than 0.03Δk is not expected for the operating conditions of Dresden and Quad-Cities.

3044

As discussed in Chapter 14.2 of the Dresden Final Safety Analysis Report, the control rod drop accident can only occur following multiple equipment malfunctions or operator errors. For the case of the out-of-sequence rod drop the following errors and malfunctions must occur.

1. The operator must select and withdraw a rod out of the preplanned withdrawal sequence. It is conservatively assumed that the worth of this out-of-sequence rod is greater than $0.014\Delta k$.

2. The rod worth minimizer or second operator fails to block or correct the selection error and full withdrawal of the out-of-sequence rod is allowed.

3. The control rod becomes unlatched from the drive mechanism.

4. The control rod sticks at the fully inserted position and the drive mechanism is fully withdrawn. The control rod then drops from the full in to full out position at the maximum velocity.

In considering the possibilities of a control rod drop accident only the rod worths of in-sequence rods are pertinent. These are the rods normally allowed by operating procedures and the rod worth minimizer to be moved. The non-scheduled (out-of-sequence) rods do not have a withdrawal permissive during the time their worths are greater than $0.014\Delta k$ so they are held fully inserted by the control rod drive and cannot drop from the core. If a non-scheduled rod were selected, the rod worth minimizer or second operator would block or stop movement; therefore the worth of the strongest rod which could be dropped is limited to less than $0.014\Delta k$. Limiting the worth of an in-sequence rod to $0.014\Delta k$ assures that the consequences of the rod drop accident are tolerable, that is, the resultant enthalpy is $<$ 280 cal/gm.

One signed original and 59 copies of this report are supplied for your use.

Very truly yours,

for Byron Lee, Jr.
Vice-President

DRESDEN SPECIAL REPORT NO. 25

QUAD-CITIES SPECIAL REPORT NO. 9

Rod Drop Accident Analyses for Dresden Units 2 & 3 and Quad-Cities 1 & 2

AEC Dockets

50-237
50-249
50-254
50-265

Commonwealth Edison Company

May, 1973

TECHNICAL BASIS FOR

ALLOWABLE ROD WORTH SPECIFIED

IN

TECHNICAL SPECIFICATION

(AEC ANSWER TO ROD DROP ACCIDENT QUESTIONS)

TECHNICAL BASIS FOR ALLOWABLE ROD WORTH SPECIFIED IN TECHNICAL SPECIFICATION

I INTRODUCTION

A topical report and two supplements (1), (2), (3) have been issued in the last year which document new techniques and models being used to analyze the Rod Drop Accident (RDA). The information in these documents have been used for the development of design approaches on new projects to make the consequences of the RDA acceptable to all concerned. In the case of the operating plants where safety analyses and resulting Technical Specifications were previously established with the old approaches, the new information in the topical reports was not easily applied. The purpose of this document is to bridge that gap and provide a technical basis and recommended Technical Specification with the current design basis safety philosophy applied to operating plants in the RDA area.

II SUMMARY & RECOMMENDATIONS

Recommendations have been provided to operating plants previously to establish a Technical Specification for a 1.5ΔK maximum allowable worth of in-sequence control rods based on judgement application of recent RDA work. This document provides supporting detail on how the 1.5%ΔK value could be specifically derived from detailed calculations on a plant-by-plant basis. However, in view of the fact that this would not be practical to do on all plants, a "worst case" comprehensive value of 1.4%ΔK is recommended for general and immediate application at all operating plants. This recommendation is obtained from a comparison of available specific plant calculations, based on operating data, to those used in deriving a

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* (1) NEDO-10527 "Rod Drop Accident Analysis for Large Boiling Water Reactor", C. J. Paone, et al, 3-72

(2) Suppl. 1 to Ref. 1, 7-72

(3) Suppl. 2 to Ref. 1, 1-73

280 cal/gm peak fuel enthalpy boundary for the RDA with the key parameters affecting the outcome of the RDA. The 1.4%ΔK value represents a combination of conservative inputs which are inherently-fixed (e.g. use of the Doppler coefficient corresponding to a Beginning-of-Life (BOL) condition, which will always be conservative and judgement inputs which could vary significantly in the future but are not expected to be "worse" than those picked (e.g. use of a maximum local peaking factor [P_L] of 1.30 for hot startup conditions).

III DISCUSSION

A. Design Basis

The design basis for evaluating the consequences of the RDA are described in the topical reports (pgs. 3/4 of ref. 3). The difference in the application of these bases between the new projects and the operating plants is in the definition of the worst single inadvertent operator error or equipment malfunction to cause the RDA. Previously for new projects and currently for the operating plants, the Rod Worth Minimizer (RWM) and operator were the redundant controls on rod selection so that a single failure could not cause the drop of an out-of-sequence rod; if the RWM were out of service, a second independent operator was acceptable as a substitute. This has not been accepted on new projects and a third system, the Rod Sequence Control System (RSCS), has been applied. Since this new system is not operative beyond the 50% rod density point, the design basis for new projects has shifted so that the drop of an out-of-sequence rod at that point is analyzed. If it cannot be assumed that the RWM or operator will prevent the selection of an out-of-sequence rod, then the worst case accident for new projects becomes the drop of an out-of-sequence rod at the point where the RSCS is no longer operative.

Since the contents of the topical report supplements were developed in conjunction with the new design basis on new projects, it became necessary to review and provide other means for applying the new RDA results to the current Technical Specification application on operating plants. i.e., The current Technical Specifications on operating plants are applied on the basis that the maximum reactivity value of any in-sequence rod must be limited in order to maintain the consequences of a RDA within those analyzed and accepted. The topical reports also covered only particular plants at particular reactivity/exposure conditions, and since this added more variable parameters to an analysis that already contained many variables, it became necessary to develop worst case values that would assuredly cover a wide range of conditions.

In this case, available data from calculations performed for particular operating plants and conditions was compared with the same parameters used in calculating RDA consequences for the topical reports. It was found that the TVA Beginning-of-Life (BOL) data described in ref. (2) was suitable as a worst case encompassing operating plant data and as a means of comparison. These parameters and comparisons are described in detail below.

B. Parameters Considered & Design Assumptions Used

Although there are many input parameters to the rod drop accident analysis, theresultant peak fuel enthalpy is most sensitive to the following input parameters:

1. Steady state accident reactivity shape function
2. Total control rod reactivity worth
3. Maximum inter-assembly local power peaking factor (P_L-normalized over four bundles)
4. Delayed neutron fraction

5. Scram reactivity shape function
6. Doppler reactivity feedback
7. Moderator temperature

For a fixed control rod drop velocity and scram insertion rate, these parameters can be varied and combined to yield a peak fuel enthalpy of 280 cal/gm. This was done using the data developed for the TVA BOL cases in ref. (2).

Rod drop velocity was assumed to be that justified by the statistical evaluation in the appendix of Ref. (1) i.e., the average measured value plus three standard deviations was used. Also, the current standard Technical Specification scram times tabulated below were used in developing the scram reactivity curves for the 280 cal/gm design limit boundary corresponding to the third basic condition specified below:

% of Rod Insertion	Time from De-Energization of Scram Solenoid Valve (sec.)
5	0.475
20	1.10
50	2.0
90	5.0

In order to meet the RDA design limit of 280 cal/gm the above parameters are combined to meet three basic conditions. These are (A) the accident reactivity characteristics, (B) the Doppler reactivity feedback, and (C) the scram reactivity feedback. If any one of these conditions are not satisfied, then a more detailed analysis would have to be performed to establish compliance with the 280 cal/gm design limit.

C. Three Basic Conditions

1. Accident Reactivity Characteristics - Accident reactivity shape function total control rod reactivity worth, inter-assembly local power peaking factor, and the delayed neutron fraction

The sensitivity of the rod drop accident to the first three parameters at cold startup and hot startup are shwon by Figures 1 and 2 and the effect of the delayed neutron fraction (beta) can be seen by comparing Figures 1 and 2 with Figures 3 and 4 respectively. To determine whether or not a specific condition will meet the 280 cal/gm design limit at cold startup or hot startup, the accident reactivity characteristics (i.e., accident shape function, local peaking, etc.) for the plant being analyzed should be matched to those presented in Figures 1 through 5. If the accident reactivity characteristic curves are equal to or less than those shown as solid lines in Figures 1 through 4, then one of the three conditions needed to conservatively ensure RDA peak fuel enthalpy equal to or less than 280 cal/gm is satisfied. If the actual plant accident reactivity characteristics are greater, a more detailed analysis would have to be performed.

When applying these functions a linear interpolation can be employed to determine intermediate points with regards to the local peaking factor and beta variables.

Some example curves resulting from calculations with operating plant data is also plotted as dotted lines on Figures 3 and 4 to demonstrate compliance with the condition, including the one with the highest K_{eff}. Other data (not plotted to avoid confusion) is shown in Table 1. Comparisons have been made on Figures 3 and 4 because the betas most closely coincide. The beta for Figures

1 and 2 correspond to Beginning-of-Life (BOL) conditions which no longer exist for operating plants. Although the betas associated with the operating plant curves are not precisely the same as the value used for the 280 cal/gm boundary curves, the differences are in the conservative direction, i.e., as shown in Table I, betas for operating plant conditions are generally higher than those used in Figures 3 and 4 for the 280 cal/gm boundary curves, thus allowing higher P_L's or rod worths within the boundary.

A typical plant local peaking factor map is shown in Figure 8. As can be seen the maximum value on this map is 1.217. While this is not the maximum that could be expected for a hot startup condition, values above 1.30 would not be expected to occur at any plant. Actual maximum local peaking factors (P_L) would be expected to be slightly higher in the cold startup condition than in the hot startup condition; however, as can be seen by comparison of Figures 3 and 4, a substantially higher P_L can be tolerated for cold startup conditions at the 280 cal/gm boundary, other conditions being equal. Thus, in reviewing the compensating factors involved, it is apparent that the "worst case", or lowest rod K_{eff} allowable at the 280 cal/gm boundary would be represented by the solid curves in Figure 4, which are for the hot startup condition with the minimum beta.

2. Doppler Reactivity Feedback

The Doppler reactivity coefficients used for these analyses to identify a 280 cal/gm boundary were held fixed at the beginning of life (BOL) condition. The Doppler reactivity coefficients for the cold and hot startup conditions are presented in Figure 5.

If the Doppler reactivity coefficeints are equal to or more negative than those given as solid lines in Figure 5, then another one of the three conditions needed to conservatively ensure RDA peak fuel enthalpy $\leq$280 cal/gm is satisfied.

Using the BOL Doppler reactivity coefficient will be conservative since the Doppler coefficient always becomes more negative with increasing exposure. This effect is typically demonstrated by the exposed core data shown as dotted lines on Figure 5, and is due primarily to the Pu-240 buildup and contribution as a function of exposure.

3. Scram Reactivity Feedback

The scram reactivity feedback function is unique in that the total scram feedback is not required to terminate the accident and limit peak fuel enthalpy in the time scale of interest. The combined Doppler and .01Δk scram will be more than sufficient to terminate the accident and bring the reactor core subcritical for control rod worths of interest. This is not meant to imply that total scram is not required for complete shutdown but rather to emphasize the fact that partial scram bank insertion would be sufficient to limit the resultant RDA peak fuel enthalpy to 280 cal/gm in the time scale of interest. Therefore, up to .01Δk, the actual plant scram reactivity feedback function must be equal to or greater than the data presented in Figures 6 and 7 for the cold and hot startup operating states respectively in order to satisfy the third of the three conditions needed to conservatively ensure RDA peak fuel enthalpy $\leq$ 280 cal/gm.

A typical example derived from operating plant data is also plotted on these figures as dotted lines to demonstrate that the condition is met in actual scram performance. Additional available data was not plotted to avoid graphic confusion, but is summarized with total scram worths in Table I.

D. Application of the 280 cal/gm Boundary

In summary, all three conditions 1, 2, and 3, as stated above, must be satisfied in order to conservatively stay within the 280 cal/gm design limit boundary. If any of the conditions are not met then a more detailed calculation would have to be performed to demonstrate compliance with the design limit.

Likewise, given a particular set of conditions, a maximum rod worth could be determined which could show compliance with a Technical Specification based on keeping RDA consequences below the peak fuel enthalpy design limit of 280 cal/gm.

As an example, assume the following conditions:

. Hot startup
. beta = .0055
. P_L = 1.20
. Doppler coefficient = Figure 5 solid curve for hot startup
. Scram reactivity = Figure 7 solid curve
. Accident reactivity shape = Figure 2 and 4 solid curves

For the above conditions linear interpolation between Figures 2 and 4 show that a rod worth of .01514Δk will satisfy the 280 cal/gm design limit. This example is conservative since the BOL Doppler feedback has been coupled with a typical end of cycle delayed neutron fraction. Therefore, for an operating reactor with scram and accident reactivity characteristics equal to or better than those described above, a .015Δk Technical Specification on allowable rod worth is justifiable.

It is important to recognize that there is no practical way to calculate all possible conditions or parametric values as they may occur during the cycle at a particular plant or plants. However, some calculations have been performed to obtain typical values as shown in this document and judgement can be exercised to obtain worst cases or perceive the effects of variations. On this basis, it would be reasonable to pick some worst case values of the key parameters in the RDA based on the approaches used in this document and derive a rod worth for Technical Specification application that could be widely used without recourse to lengthy repetitive calculations for each reactor and each fuel cycle.

Such a process was conducted in the course of preparing this document, with the following results:

1. Scram reactivity condition: While there could be significant variation in the shape and total worth of the scram reactivity curve, actual operation in the future is not likely to degrade down to the point where the net effect on a RDA calculation would be any less than that represented by the solid curves of Figures 6 and 7.

2. Doppler reactivity condition: The least effective (BOL) Doppler feedback has been assumed in the 280 cal/gm boundary cases calculated for this document and it would be simplest to maintain this assumption in deriving a comprehensive Technical Specification application. This conservatism would also serve to compensate for any concern in other areas where variations beyond the 280 cal/gm boundary might be postulated in extreme situations.

3. Accident reactivity characteristic condition: If it is assumed that the 280 cal/gm boundary conditions established in 1. & 2. above represent worst case values that no operating plants are likely to exceed, then selection of a recommended comprehensive Technical Specification on maximum allowable rod worth reduces to a consideration of the parameters associated with the accident reactivity characteristics discussed in C.1. above. There are four parameters considered for this 280 cal/gm boundary condition and it was established in C. 1 that the closest approach of actual plant operating parameters to this 280 cal/gm boundary was represented by Figure 4. It was also established that two of the parameters, the accident reactivity shape function and beta, derived from any actual plant operating data, generally could not reach those used in calculating the 280 cal/gm boundary shown in Figure 4. Thus, the maximum allowable rod worth can be derived by determining the maximum P_L in the hot startup condition and using the corresponding solid curve. As stated in C.1, a P_L above 1.30 would not be expected at any plant and a maximum allowable rod worth would,therefore, be 1.4%ΔK. This value is recommended for comprehensive Technical Specification application on a "worst case" basis in the absence of specific detailed calculations on each operating plant.

TABLE I

TYPICAL RELOAD OPERATING CORES NUCLEAR DATA

A. In-Sequence Control Rod Worth

PLANT	CONDITION	POINT IN CYCLE	MAX. ΔK_{eff}
A	Cold SU	BOC	0.007
B	Cold SU	BOC	0.011
B	Cold SU	EOC	0.003
C	Cold SU	BOC	0.005
B	Hot SU	BOC	0.003
C	Hot SU	BOC	0.005

B. Scram Bank Worth*

PLANT	CONDITION	POINT IN CYCLE	TOTAL NEG. ΔK_{eff}
A	Cold SU	BOC	0.071
B	Cold SU	BOC	0.049
B	Cold SU	EOC	0.051
A	Hot SU	BOC	0.131
B	Hot SU	BOC	0.125
B	Hot SU	EOC	0.121
D	Hot SU	BOC	0.147
D	Hot SU	MOC	0.143
D	Hot SU	EOC	0.141

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*Minus the dropping rod in the RDA

(Continued)

TABLE I

TYPICAL RELOAD OPERATING CORES NUCLEAR DATA

C. Delayed Neutron Fraction (β)

PLANT	CONDITION	POINT IN CYCLE	BETA
A	Hot SU	BOC	0.0059
A	Hot SU	EOC	0.0054
B	Hot SU	BOC	0.0059
B	Hot SU	EOC	0.0054
C	Hot SU	BOC	0.0060
C	Hot SU	EOC	0.0056

FIGURE 1

ACCIDENT REACTIVITY SHAPE FUNCTIONS WHICH WOULD RESULT IN PEAK ENTHALPIES OF 280 CAL/GM PARAMETERIZED AS A FUNCTION OF LOCAL PEAKING FACTORS FOR COLD STARTUP

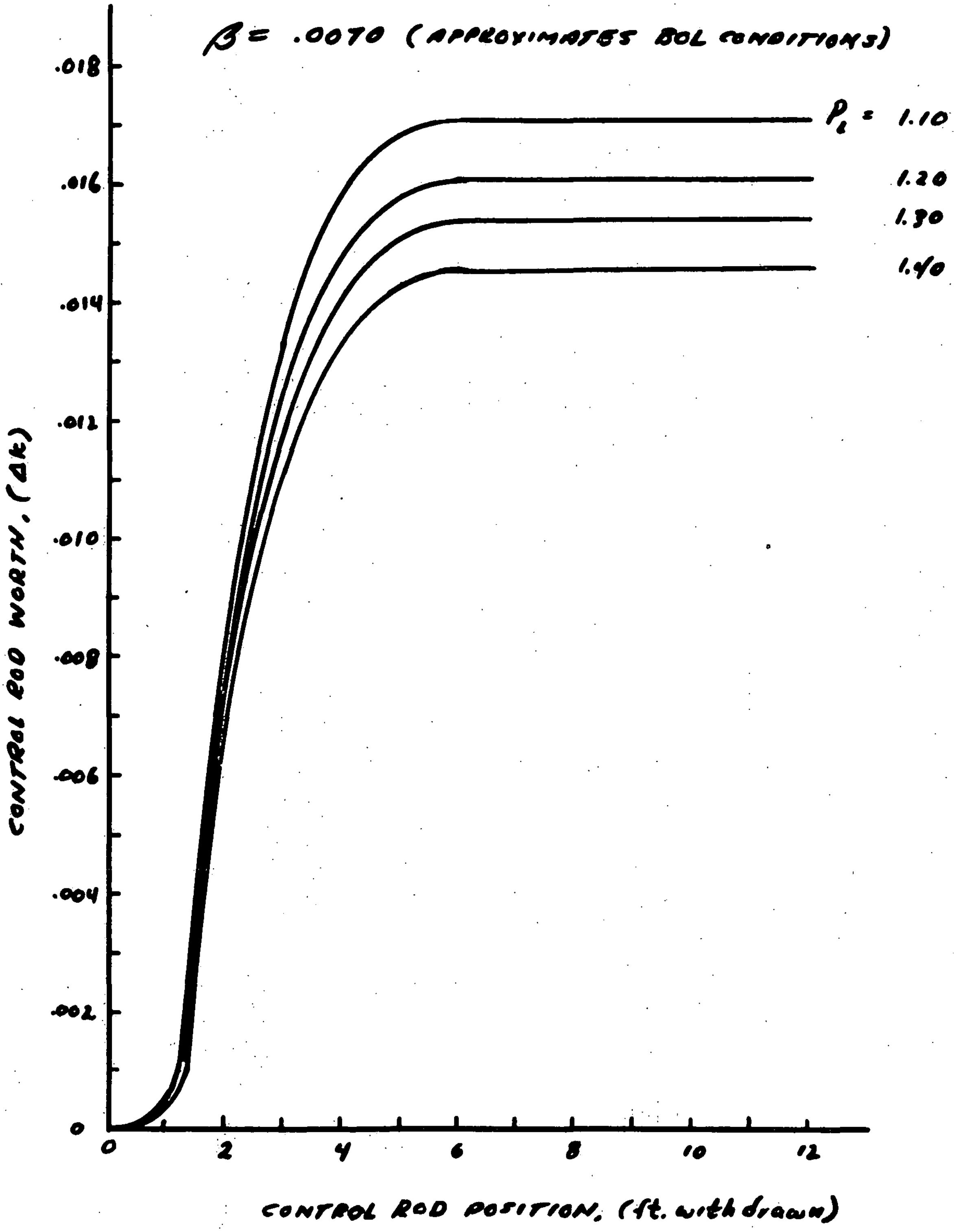


FIGURE 2

ACCIDENT REACTIVITY SHAPE FUNCTIONS WHICH WOULD RESULT IN PEAK FUEL ENTHALPIES OF 280 CAL/GM PARAMETERIZED AS A FUNCTION OF LOCAL PEAKING FACTORS FOR HOT STARTUP

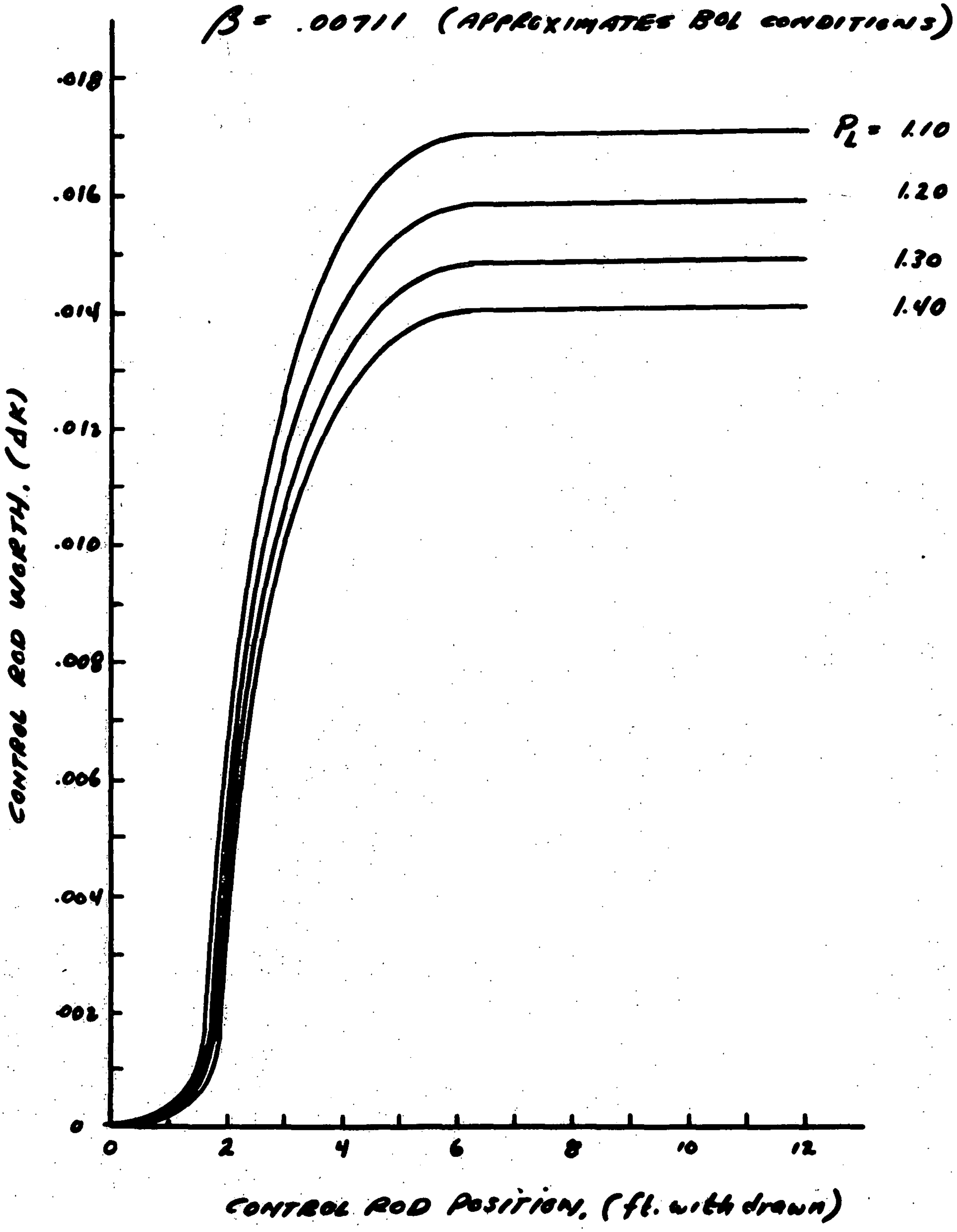


FIGURE 3

ACCIDENT REACTIVITY SHAPE FUNCTIONS FOR COLD STARTUP

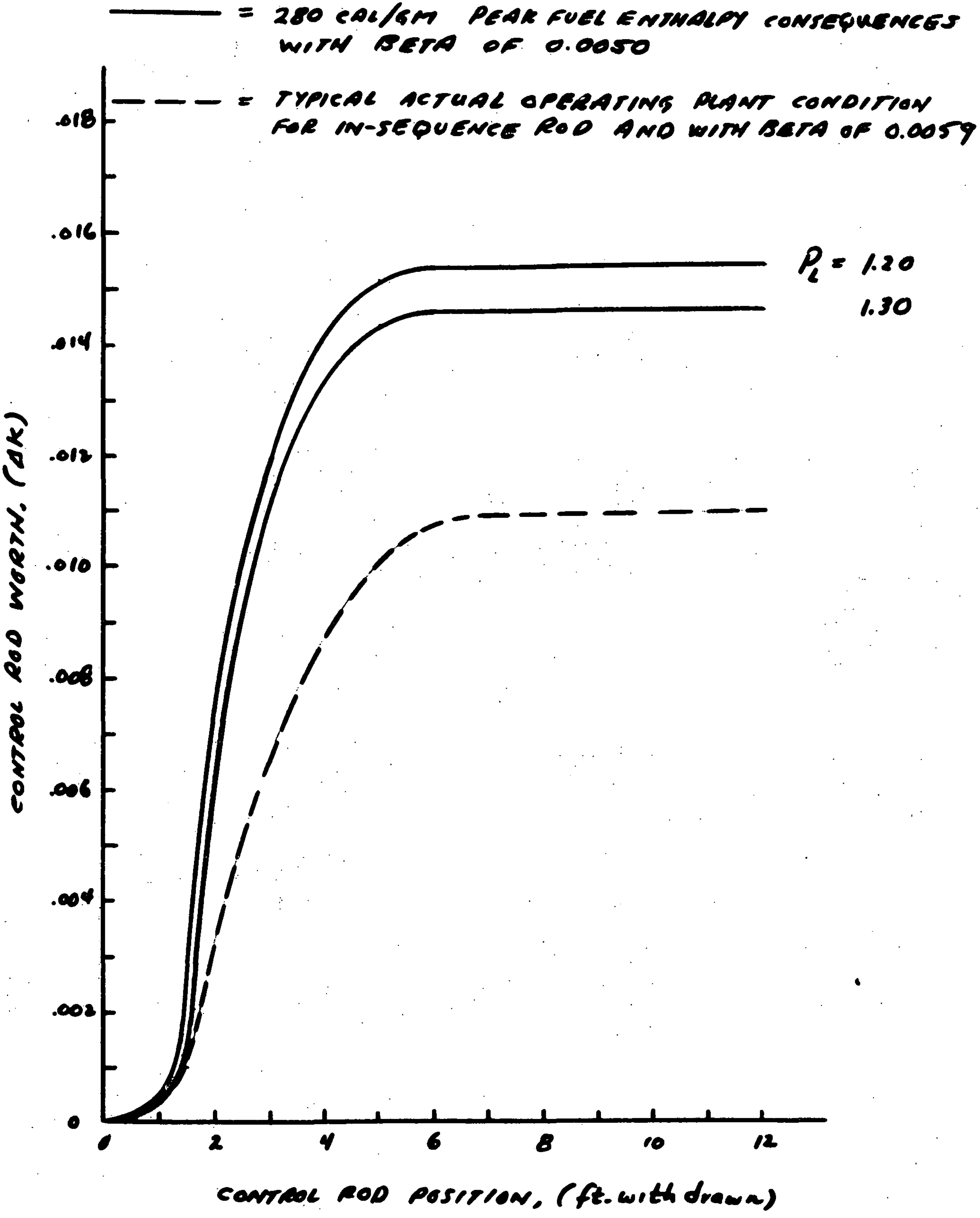


FIGURE 4

ACCIDENT REACTIVITY SHAPE FUNCTIONS FOR HOT STARTUP

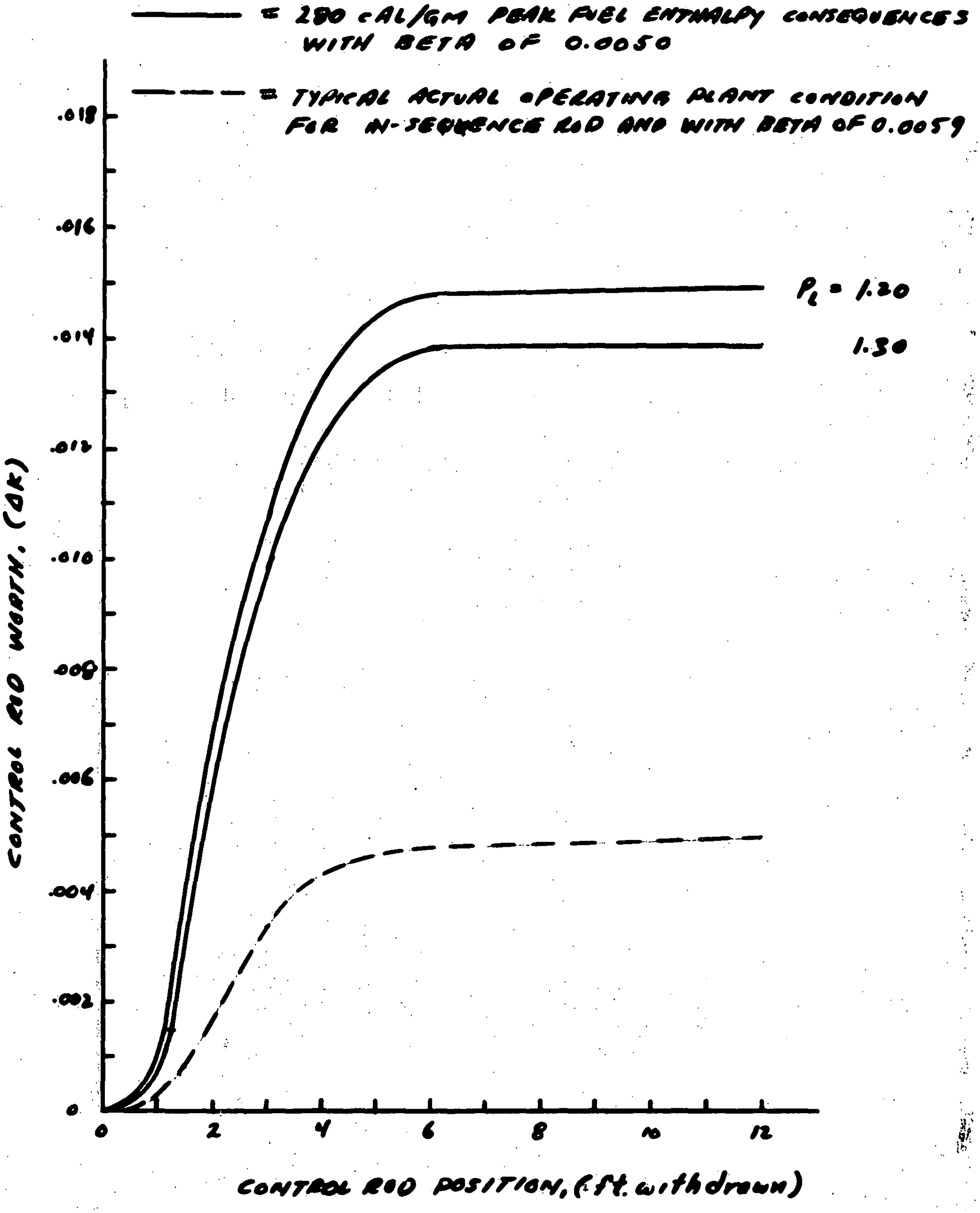


FIGURE 5

DOPPLER REACTIVITY COEFFICIENT VS AVERAGE FUEL TEMPERATURE AS A FUNCTION OF EXPOSURE AND MODERATOR CONDITION

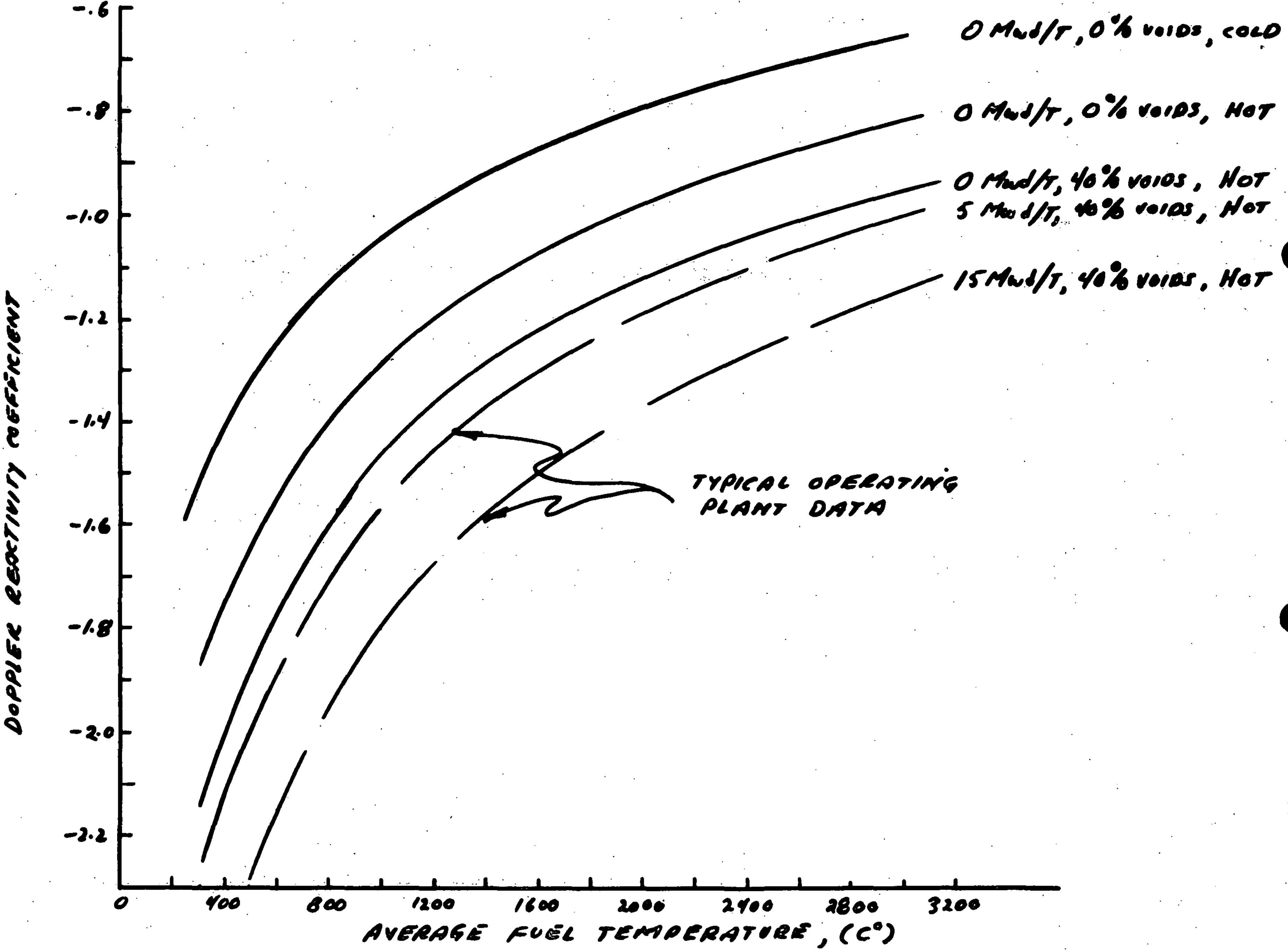
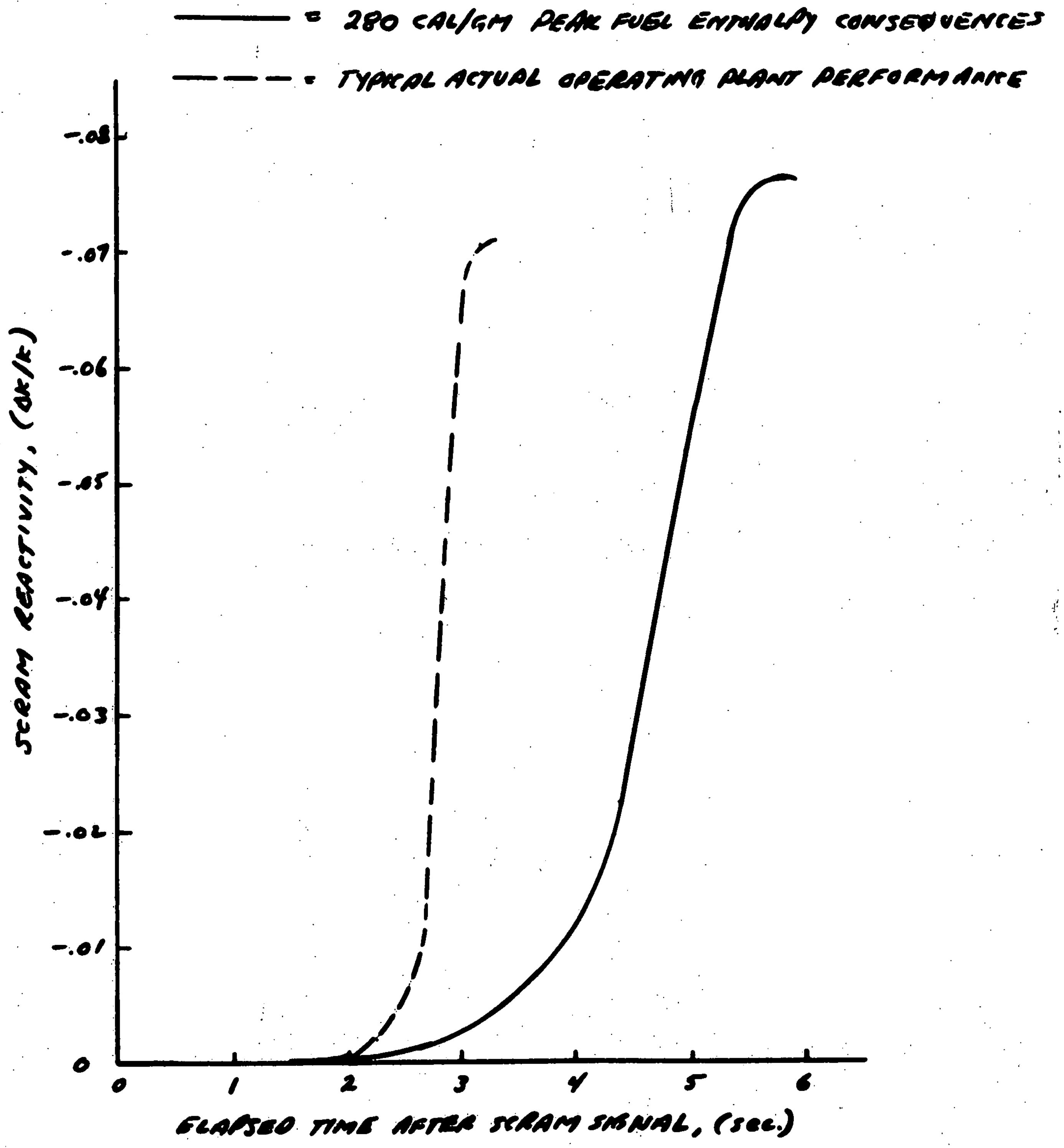


FIGURE 6

SCRAM REACTIVITY FUNCTION FOR COLD STARTUP



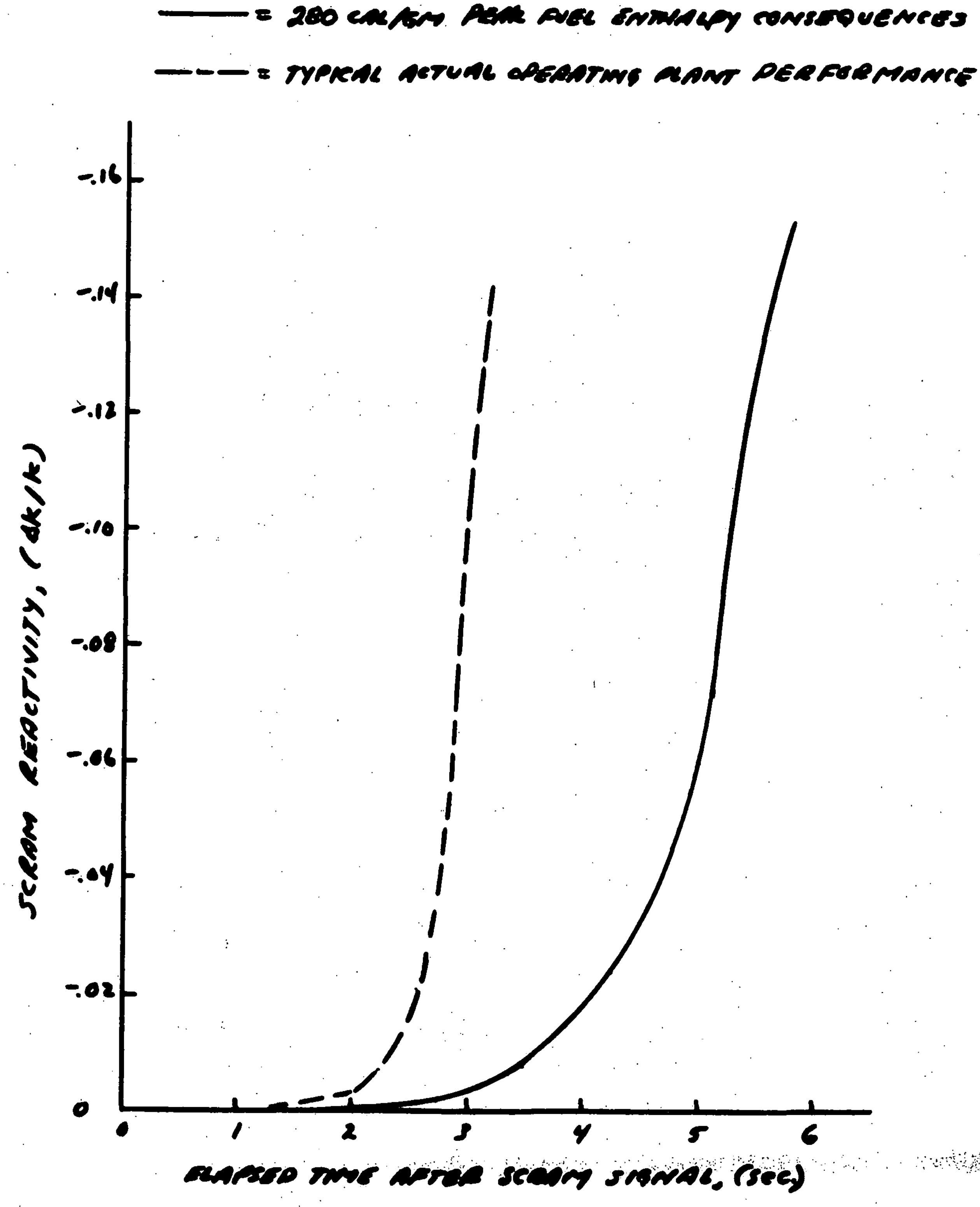


FIGURE 7

SCRAM REACTIVITY FUNCTION FOR HOT STARTUP

FIGURE 8

TYPICAL FOUR BUNDLE LOCAL PEAKING FACTOR MAP

HOT STARTUP - NORMALIZED TO TOTAL POWER

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*********************************************************   *********************************************************
*                                                       *   *                                                       *
* 1.139   1.174   1.063   1.146   1.149   1.202   1.210 *   * 1.161   1.027   0.986   0.958   1.009   0.913   1.019 *
*                                                       *   *                                                       *
* 1.174   1.033   1.098   1.072   1.099   1.171   1.090 *   * 0.986   1.064   1.004   1.017   0.818   0.930   0.913 *
*                                                       *   *                                                       *
* 1.063   1.098   0.285   0.860   0.907   0.953   1.181 *   * 1.140   0.969   0.905   0.892   0.961   0.818   1.009 *
*                                                       *   *                                                       *
* 1.146   1.072   0.860   0.830   0.806   0.279   1.071 *   * 1.075   0.915   0.854   0.855   0.892   1.017   0.958 *
*                                                       *   *                                                       *
* 1.149   1.099   0.907   0.806   0.828   0.888   1.114 *   * 1.080   0.918   0.855   0.854   0.905   1.004   0.986 *
*                                                       *   *                                                       *
* 1.202   1.171   0.953   0.279   0.888   1.014   1.217 *   * 1.120   0.982   0.918   0.915   0.969   1.064   1.027 *
*                                                       *   *                                                       *
* 1.210   1.090   1.181   1.071   1.114   1.217   1.138 *   * 1.001   1.120   1.080   1.075   1.140   0.986   1.161 *
*                                                       *   *                                                       *
*********************************************************   *********************************************************


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*                                                       *   *                                                       *
* 1.161   0.986   1.140   1.075   1.080   1.120   1.001 *   * 1.138   1.217   1.114   1.071   1.181   1.090   1.210 *
*                                                       *   *                                                       *
* 1.027   1.064   0.969   0.915   0.918   0.982   1.120 *   * 1.217   1.014   0.888   0.279   0.953   1.171   1.202 *
*                                                       *   *                                                       *
* 0.986   1.004   0.905   0.854   0.855   0.918   1.080 *   * 1.114   0.888   0.828   0.806   0.907   1.099   1.149 *
*                                                       *   *                                                       *
* 0.958   1.017   0.892   0.855   0.854   0.915   1.075 *   * 1.071   0.279   0.806   0.830   0.860   1.072   1.146 *
*                                                       *   *                                                       *
* 1.009   0.818   0.961   0.892   0.905   0.969   1.140 *   * 1.181   0.953   0.907   0.860   0.285   1.098   1.063 *
*                                                       *   *                                                       *
* 0.913   0.930   0.818   1.017   1.004   1.064   0.986 *   * 1.090   1.171   1.099   1.072   1.098   1.033   1.174 *
*                                                       *   *                                                       *
* 1.019   0.913   1.009   0.958   0.986   1.027   1.161 *   * 1.210   1.202   1.149   1.146   1.063   1.174   1.139 *
*                                                       *   *                                                       *
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