EBR-II CODES FOR PROCESSING REACTIVITY DATA
AT FULL AND REDUCED COOLANT FLOWS

by

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ABSTRACT

Comparing measurements of power-reactivity decrements (PRD) at full and reduced coolant flows requires that corrections be applied for thermal expansion of the bank of control-rod handles, bulk-sodium temperature, fuel burnup, flow variations, control-rod calibrations, and several instrument calibrations. Computerized methods for calculating these corrections in a uniform and orderly manner have been developed. The sequence of calculations is: determination of control-rod worths; determination of rod-bank position; correction for effects of thermal expansion of control-rod handles; determination of reactor power, position of control rods, and PRD for a control-rod configuration; and determination of an effective thermal-expansion parameter of fuel from data for reduced coolant flows. This parameter is an effective average expansion coefficient for driver and experimental fuels in the core.

I. INTRODUCTION

Reactivity data are the principal indicators of overall reactor behavior. Our judgment of whether a reactor is behaving normally depends on the interpretation of these data. They are used to define important safety criteria and operating limits and to disclose long-term trends in reactor behavior.

Reactivity data consist of measurements of the configuration of positions of the control rods that will maintain level reactor power under various operating conditions. To make these data meaningful, that is, to make the measurements comparable with each other over short or long periods, the following steps are required: (a) the rod positions must be

translated into conventional reactivity units by use of suitable calibration factors; (b) the reactor conditions must be reduced to certain standard values of coolant flow and temperature; and (c) instrument calibrations must be appropriately applied. In addition, certain reactor conditions introduce reactivity effects that must be reduced to standard values to permit meaningful comparisons among reactivity measurements. Among these effects are the position and worth of all control rods other than the main controlling one and the burnup from the start of the run.

In short, processing of reactivity data has become so complex that adoption of standardized methods of handling the data is required for comparisons among measurements. The best way to ensure such standardized processing and at the same time reduce the risk of numerical errors is to program the data processing.

The programs described in this report include all reactivity corrections that have been found to be significant, and they provide the necessary standardization in applying the corrections.

The sequence of the code and of the description in this report follow closely the sequence used in hand calculations of the same results. First, the control-rod worth for a given control-rod configuration is determined by use of previously measured rod-calibration factors and calculated corrections for expansion of the control-rod handles. Power then is determined from instrument readings that are calibrated against a heat balance, if this information is available. The power-reactivity decrement (PRD)* then is computed by use of final corrections for burnup and for deviations of the bulk-sodium temperature from normal. When hand calculations are used, a smooth curve is fitted to the PRD data by subjective approximation. In the computerized data reduction, this step is replaced by a least-squares fit to a fourth-order polynomial.

If reactivity data have been obtained at conditions of reduced coolant flow, the above sequence is a prerequisite to interpretation of the reduced-flow data. The program processes data for reduced coolant flow together with a sequence of PRD measurements for full coolant flow to yield a parameter that represents the effective thermal-expansion coefficient of the mixture of driver and experimental fuels in the reactor. During this calculation, the appropriate correction for the expansion of the bank of control-rod handles at each reduced-flow condition is determined, a step that had

*The integral with respect to power of the power coefficient of reactivity.

been only roughly approximated in previous hand calculations.

Figure 1 shows the flow sheet for the main program. A FORTRAN listing for the code (including subroutines) and input and output for a sample problem are given in the Appendix.

For background information on PRD calculations and other EBR-II criticality data, see Refs. 1 and 2.

II. CONTROL-ROD WORTHS

Repeated measurements on EBR-II have shown that the shape of the calibration curve of the control rods has not changed significantly from run to run. The characteristic shape for odd-numbered* rods differs somewhat from that for even-numbered rods, and magnitudes of worths of individual rods vary for different runs. The worth of a rod at any position can, therefore, be determined from the original curves of rod worth vs position, scaled according to the current calibration value. Rods are calibrated by period measurements.

The code therefore introduces as its initial data set the reference values of control-rod worth for odd- and even-numbered rods at increments of 0.1 in. The computer interpolates linearly by subroutine WORTH (Fig. 2) between these values as needed.

III. DETERMINATION OF ROD-BANK POSITION

Subroutine BAPOS (Fig. 3) checks the position of each rod and whether each is fueled or unfueled. The parameter BANK is the position of the bank of rods and is taken as the position of the highest-numbered fueled rod not being used for control.

IV. CORRECTION FOR EFFECTS OF THERMAL EXPANSION OF CONTROL-ROD HANDLES

In subroutine RECORR (Fig. 4), data necessary to correct for expansion of the handles of the control rods are inserted after the reference values for control-rod worths. The correction is based on the principle that thermal expansion of the handles causes the top-mounted rods to move effectively lower into the core than their position indicators show.³ Figure 5 shows how the

* Odd-numbered rods are at the corners of the fifth hexagonal row of the core, and even-numbered rods are on the flats.

Fig. 1. Flow Chart for Main Program, PROCPRD

Fig. 2. Flow Chart for Subroutine WORTH

Fig. 3. Flow Chart for Subroutine BAPOS

Fig. 4. Flow Chart for Subroutine RBCOOR

Fig. 5. EBR-II Control-rod Suspension System

rods are mounted with respect to the reactor core and vessel. If the effective position of a control rod at zero power is taken as the reference geometry, the effective control-rod position at power is equal to the position indicated by the selsyn minus the change caused by thermal expansion of components. This change in position does not occur during control-rod calibration, which is performed at essentially zero power.

Since the worth of the control rod in its banked position is not linear with respect to the rod length inserted into the core, the amount of reactivity contributed by the thermal expansion is different depending on the length inserted. Thus, if power-reactivity decrements at different control-rod bank positions are to be compared, expansion effects must be taken into account.

The calculated rise in sodium temperature in the control subassembly follows the pattern described in ANL-5719 (Addendum),⁴ Fig. C-4. For 82% insertion, 62.5 MWt, and a 67-subassembly core, the calculated rise in mixed mean temperature is 225°F. The calculated flux pattern indicates that at the row-5 location of the control rods the local specific power varies little with the number of subassemblies. The rise in sodium temperature (T_c) above the core-inlet temperature of 700°F in the control subassembly may be calculated by the following equation:

$$T_c = 225 (P/62.5) (1.03/F) (Y/0.96286),$$

where P = reactor power, megawatts

F = fraction of full flow in the control element (from Fig. C-4, Ref. 4)

Y = fraction of full power in the control subassembly; it depends on the distance the subassembly is inserted into the core.

The factor 1.03 is the fraction of full flow at 82% insertion, and

0.96286 is the corresponding fraction of full control-subassembly power.

The total thermal expansion, ΔL , is divided as follows: Over the length designated as " χ " (see Fig. 5), the distance the control rod is inserted in the core, the average cladding temperature is assumed to be $T_c/2$. The expansion of this section is $\alpha \chi T_c/2$ (α is the linear-expansion coefficient-- 10^{-5} for stainless steel--and χ is the indicated control-rod position).

The temperature of the metal over the entire length (41.94 in.) of the hexagonal tube of the control-rod subassembly above the control element is assumed to be T_c . The thermal expansion of this section is, therefore,

$41.94 \alpha T_c$. From the top of the hexagonal tube to the cover plate, the temperature of the metal handle is assumed to be the outlet-plenum temperature, $T_p = 2.93P$; therefore, the expansion of this portion of the shaft is $2.93 (24.11 - X)P$. 24.11 in. is the distance from the top of the hexagonal tube to the cover plate when the rod is in the down position.

The top of the 34.25-in.-thick reactor-vessel cover is at bulk-sodium temperature, and the bottom is at outlet-plenum temperature. The average temperature of the control-rod extension shaft in this region is expected to be nearer the plenum temperature than the bulk-sodium temperature, owing to the flow of plenum sodium within clearances around the shaft. The temperature in this region was assumed to be $0.9 T_p$; therefore, the expansion of this section is $0.9 \times 2.93 \times 34.25 Pa$.

Control-rod fuel is displaced more than core fuel also because the control rods are cooled more than average core subassemblies are (a difference of about 29°F at 45 MWt). The upward expansion of the core fuel is greater than that of the control rods; this difference results in an additional shift in position at power. This displacement, computed from the expansion coefficient of fuel, was added to the other displacements.

The calculations for overall expansion neglect the contraction or expansion of the primary tank and core-support structure with increases in power, because information on temperature available from earlier runs is insufficient for an accurate calculation. Temperature profiles were taken of the primary-tank walls in run 26 to improve the accuracy of the expansion calculations, but the pattern is not complete enough to support a detailed analysis. In lieu of a complete set of measured temperatures of the reactor vessel or its support structure, horizontal temperature stratification in the bulk sodium was assumed. Under this assumption, temperatures of the upper parts of the control-rod extension shafts above the reactor cover and of the core-support structure below the grid plates are the same as primary-tank temperatures at the same level, so that there is no differential expansion correction to be applied outside these levels. The measurements of primary-tank temperatures between these levels indicate that the contribution to the relative displacement of the core and control rods by primary-tank expansion is less than 10% of that by the control-rod extension shafts.

The five displacements described above are summed in Table I to aid in determining the thermal expansion as a function of rod-bank position, power, and flow.

TABLE I. Calculated Displacement of Control Rods Due to Thermal Expansion of Control-rod Handles

<u>Rod Position, in.</u>	<u>ΔL (Thermal Expansion for 45 MWt, Full Flow), in.</u>
4	0.132
5	0.134
6	0.134
10	0.137
12	0.140
14	0.143

The expansion effects shown in Table I may be translated into reactivity by using the individual worths of the control rods versus position. This reactivity effect is the calculated effect of rod-bank expansion.

Data required as input for the subroutine for rod-bank correction consist of the total worth, in inhours, for each control rod; identification as to whether it contains fuel or inert material (no correction for the expansion of the rod handle is applied to unfueled rods); and identification of the rod number and the date of its most recent calibration.

In support of this calculational procedure, experimental data from run 35 have indicated that the reactivity effect of the expansion of the rod handles is: proportional to the ratio of power to primary flow, independent of burnup, and of the magnitude calculated.⁵

V. DETERMINATION OF REACTOR POWER

Subroutine POWER (Fig. 6) is used in this calculation. Data taken in the control room for each PRD usually have included the temperature rise and the flow rate of the sodium, as well as the readings of certain key nuclear instruments. The heat balance on the sodium coolant is regarded as the basic measurement of power. There is an uncertainty in the zero reading of the temperature rise for sodium, however, because the measuring instrument has a negative reading (equivalent to about -1 MWt at zero power which apparently is due to the location of the thermocouples in an area with a local variation of the coolant flow pattern. Therefore, temperature rise is a somewhat uncertain measurement of power, particularly in the low

Fig. 6. Flow Chart for Subroutine POWER

ranges. In addition, on some occasions the temperature recorded was out of calibration by as much as 1 MWt; thus a further uncertainty was incorporated in the power-output measurement.

The nuclear instruments have been more reliably reproducible from day to day than measurements of coolant temperatures, and the instruments are carefully calibrated over the entire operating range. Channel 7, which is based on a gamma-compensated ion chamber, type GE-NA09, is particularly suitable for power measurements. However, its response to power is changed from loading to loading as a result of flux tilting and shielding effects. The best procedure for determination of power, therefore, is to: perform a careful heat balance at full power at the beginning of each run; calibrate the channel-7 nuclear instrument accordingly; and use channel 7 as a power monitor until the next loading change.

The code provides three options for estimating the power from instrument readings: (1) $P = 0.341T$; (2) $P = 0.333T + 1$; and (3) $P = AC$. P is the power level in megawatts and T is the temperature rise in the sodium. Thus, the first option provides a proportional relation between power and temperature and the second adds a 1-MWt correction to a proportional relationship. This second option, based on many previous heat balances, is thought to be the best way of estimating power if no information from nuclear instruments is available. In the third option, C is the reading on channel 7, in amperes, and A is a conversion factor, MWt/ampere, determined from a heat balance. This option is the best if the nuclear-instrument readings are recorded reliably and an adequate heat balance is available.

VI. DETERMINATION OF THE PRD FOR A CONTROL-ROD CONFIGURATION

Subroutine PCRITD (Fig. 7) accepts information taken to determine the PRD during an increase or a decrease in power. First, the numbers of controlling rods and their calibration factors are specified. The appropriate burnup factor (BUF) then is entered. This factor is to correct all PRD measurements to the burnup that existed at the first measurement of the series. The appropriate factor is usually 0.15 Ih/MWd at the beginning of a run after a shutdown long enough for ^{239}Np to have decayed. In the latter part of a run, when ^{239}Np has reached equilibrium, the usual factor is 0.12 Ih/MWd. Both of these factors may depend somewhat on the distribution

Fig. 7. Flow Chart for Subroutine PCRTD

of the worth of fuel in the particular loading. A zero correction for the PRD calculations also is entered. Since the PRD calculation refers all values to the first input point, the actual PRD for this point can be estimated and used as a zero correction for the others. If the first point is measured at 0.05 MWt, no zero correction would be necessary; but if the first point is measured at 0.50 MWt, a zero correction of about 1.5 Ih is used. The number of points in the PRD measurement is entered as NMAX. Cue information for a sequence of additional problems, for reduced-flow calculations, and for the option used in the power calculation is entered along with the above data.

The input stream next contains the sequence of data taken in the control room for the PRD measurements. This sequence consists of: the time each measurement was made, the temperature rise or channel-7 reading as appropriate to define the power level, the control-rod positions, the total burnup in MWd from the start of the run to the measurement, and the correction in inhours for the bulk-sodium temperature. This correction is entered as a positive number if the bulk-sodium temperature is above 700°F and as a negative number if below, usually at the rate of one inhour per °F. The lowest-power point must be entered first, and the highest-power point should be entered last; thus, for a descending PRD measurement, it is best to enter the points in time-reversed order.

The subroutine calculates the worth of the control rods at each power level, corrected for burnup, bulk-sodium temperature, and expansion of the control-rod handles.

VII. FITTING A POLYNOMIAL TO THE PRD DATA

Subroutine PRDFIT (Fig. 8) fits a fourth-order polynomial to the PRD data and prints out the difference between the fitted curve and each measured point. The polynomial is used in subroutine LSALP to calculate effects of bowing. The five constants that determine the fitted fourth-order polynomial are evaluated by a method given by Scarborough.⁶ If the experimentally measured PRD points are fewer than four, the fitting procedure is meaningless. Scarborough's method performs best when a set of constants that approximately describe the desired fourth-order polynomial is furnished initially. These constants were determined from a typical PRD curve and

NOTE: THE METHOD USED IS DESCRIBED IN:
NUMERICAL MATHEMATICAL ANALYSIS, 5th
 EDITION, SCARBOROUGH, ART. 169, PAGE 539

Fig. 8. Flow Chart for Subroutine PRDFIT

incorporated into the program. The least-squares method is then used to determine the set of linear equations defining the modifications to these standard constants that are necessary to make them fit the PRD data. Sensitivity studies have shown that moderate variations in the set of standard constants do not change the fitted polynomial. The linear equations are solved by a subroutine INV, for solving a system of simultaneous linear equations or for matrix inversion by the Gauss-Jordan method. This subroutine was published by McCormick and Salvadori,⁷ who attribute it to Mrs. Sharon Good of the David Taylor Model Basin staff.

VIII. DETERMINATION OF AN EFFECTIVE THERMAL-EXPANSION PARAMETER FOR FUEL FROM DATA AT REDUCED COOLANT FLOWS

A. Subroutine LSALP: Summary

If the cue for this analysis has been entered, the code looks for a set of reduced-flow PRD data in the input stream. After title and identification information, these data consist of a reference point (criticality information for full flow at the approximate power level of the reduced-flow points) followed by criticality information for each of the reduced-flow points. The identification information consists of a set or sets of constants that enter into the calculation of the linear portion of the PRD at reduced flow through Eq.1, which is developed in section VIII-B. Typical sets of these constants are given in Table II.

TABLE II. Constants for Reduced-flow Calculations

Constant	Depleted-uranium Radial Blanket; Stainless-steel Axial Blanket	Stainless-steel Radial and Axial Blankets
A	1.153	1.208
B	22823	20938
C ₁ (used only in a tight-core analysis)		
C ₂	4687	4299
D ₁	13446	12337
F	844.0	774.5
A _{rg} (used only in a tight-core analysis)		

Other terms are:

E = the linear portion of the PRD (other than the correction for expansion of rod-bank handles), Ih

Q = the power level, MWt

R = the fraction of full flow

α = the effective thermal-expansion coefficient of the fuel, $^{\circ}\text{C}^{-1}$

k = COND, an input parameter, the effective thermal conductivity of the fuel.

This is usually taken as 0.06 cal/sec-cm- $^{\circ}\text{C}$ at the beginning of a run and 0.05 cal/sec-cm- $^{\circ}\text{C}$ after about 1500 MWd of operation in a run.

The subroutine uses least-squares fitting to find the linear component of the power coefficient that will best fit the reduced-flow data, under the assumption that any nonlinear (bowing) components are a function only of the ratio of power to flow. The polynomial resulting from PRDFIT is used to determine bowing effects at full coolant flow to compare with the corresponding points at reduced flow. A correction for the expansion of the control-rod handles at reduced flow is included in the calculation. With the linear component determined, calculated values of all expansion effects except that of the fuel are subtracted, leaving an effective fuel-expansion parameter as the result. This parameter can be interpreted as a thermal-expansion coefficient for the fuel, although it is actually an effective average of driver-fuel and experimental-fuel effects.

B. Subroutine LSALP: Details

Interpretation of data for reduced coolant flows is based on the development of analytic expressions for the expansion portion of the power coefficient, E/Q, in inhours per megawatt of total power, and an algebraic solution of a least-squares-fitting problem.⁸ These (Fig. 9) developments are given below.

First, the expansion effect is regarded as consisting of six major components for which the analytic expressions are:

1. Reactivity change due to expansion of sodium in the core:

$$\frac{g_1}{R} \frac{\partial E}{\partial t_N}.$$

The term g_1 is the average temperature rise of the core sodium at full flow, 1.139 $^{\circ}\text{C}/\text{MWt}$; R is the fraction of full flow; and $\frac{\partial E}{\partial t_N}$ is the change in reactivity with the temperature of core sodium.

2. Reactivity change due to expansion of sodium in the radial blanket:

$$\frac{g_1}{R} \frac{\partial E}{\partial t_{\text{rad} \cdot N}}.$$

The term $\frac{\partial E}{\partial t_{\text{rad} \cdot N}}$ is the change in reactivity with the temperature of the sodium in the radial blanket. In this analysis, the same value of g_1 has been used for the radial blanket as for the core, which is approximately correct for the inner, most important, row of the radial blanket.

3. Reactivity change due to expansion of sodium in the upper axial reflector:

$$\frac{2g_1}{R} \frac{\partial E}{\partial t_{\text{ax} \cdot N}}.$$

The term $\frac{\partial E}{\partial t_{\text{ax} \cdot N}}$ is the change in reactivity with the temperature of the sodium in only the upper axial reflector.

4. Reactivity change due to lengthwise expansion of the fuel:

$$\left(\frac{g_1}{R} + \frac{g_2}{R^{0.4}} + \frac{\ln r_s/r_p}{2\pi k_s \ell N 4.186 \times 10^{-6}} + \frac{10^6}{8\pi k \ell N 4.186} \right) \alpha \ell \frac{\partial E}{\partial \ell}.$$

The term g_2 is the average temperature difference between the core sodium and the outer surface of the cladding at full flow, 0.234°C/MWt . This temperature difference varies inversely with the 0.4 power of the flow fraction, R . The constants r_s and r_p are the radii of the surface of the cladding and of the pin, respectively, so that $\ln r_s/r_p$ is 0.1892; k_s is the thermal conductivity of the cladding, $0.0475 \text{ cal/cm-sec-}^\circ\text{C}$; ℓ is the average fuel-pin length; and N the effective number of pins in the core. The product $N\ell$ is inferred from the critical mass of the core; $N\ell = 2.257 \times 10^5 \text{ cm}$ has been found to be reasonably accurate for a variety of loadings. The thermal conductivity and effective expansion coefficient of the fuel are k and α , and the change in reactivity with the fractional change in length of the fuel is $\ell \frac{\partial E}{\partial \ell}$.

5. Reactivity change due to the displacement of core sodium by the radial expansion of individual fuel pins:

$$\left(\frac{g_1}{R} + \frac{g_2}{R^{0.4}} + \frac{\ln r_s/r_p}{2\pi k_s \ell N 4.186 \times 10^{-6}} + \frac{10^6}{8\pi k \ell N 4.186} \right) 2\alpha \frac{V_p}{V_N} \frac{\partial E}{\partial \rho_N}.$$

The ratio V_p/V_N is the ratio of the volume fraction of the pins to the sodium

in the core, 0.653. The term $\frac{\partial E}{\partial \rho_N}$ is the change in reactivity with core-sodium density. It is assumed that clearance between core elements is sufficient that radial expansion of the fuel pins does not expand the radius of the core as a whole.

6. Reactivity effect due to the displacement of sodium from the upper axial reflector by the expansion of steel:

$$\frac{4g_1}{R} \alpha_s \frac{V_{ax.s}}{V_{ax.N}} \frac{\partial E}{\partial \rho_{ax.N}}.$$

The ratio $V_{ax.s}/V_{ax.N}$ is the volumetric ratio of steel to sodium in the axial reflector, 1.5; $\frac{\partial E}{\partial \rho_{ax.N}}$ is the change in reactivity with density of sodium in the upper axial reflector only; and α_s is the linear thermal-expansion coefficient of stainless steel.

Two other small effects are included in the calculation; their magnitudes are based on numerical calculations for several reactor loadings. The values are the same for both stainless-steel or depleted-uranium radial blankets. The effects are:

7. Reactivity effect of change in density of stainless steel in the upper axial reflector:

$$\frac{0.044}{R} \text{ Ih/Mwt.}$$

8. Reactivity effect of change in density of stainless steel and depleted uranium in the radial blanket:

$$\frac{0.021}{R} \text{ Ih/Mwt.}$$

In the above expressions, the derivatives of E with respect to the changes in temperature and density were calculated numerically by 2-D diffusion theory in six groups for several different core-loading sizes and blanket configurations.

The sum of all the components making up the quantity E can be grouped according to whether the terms contain α , k, or both, and according to whether R enters as the -1.0 power, -0.4 power, or not at all.

Thus,

$$E = -Q \left(\frac{A}{R} + \frac{B\alpha}{R} + \frac{C_1}{R^{0.4}} + \frac{C_2\alpha}{R^{0.4}} + D_1\alpha + F \frac{\alpha}{k} + A_{rg} \right). \quad (1)$$

Table II illustrates two sets of these constants obtained from diffusion calculations. Although the terms involving C_1 and A_{rg} are zero in the above development, they have been included in the programming to provide the optional flexibility of calculating the effects of expanding a tightly packed core.

The complete expression for the power-reactivity decrement (including bowing effects, B, and the effects of expansion of the control-rod handles, D) can be written as:

$$P(\theta) = E(\theta) + D(\theta) + B(\theta), \quad (2)$$

where θ is the ratio of power to flow fraction, Q/R .

If the bowing and rod-handle expansion at reduced flow are assumed to be the same as those at whatever power would give the same rise in sodium temperature at full flow, then:

$$D(\theta) + B(\theta) = P_F(\theta) - E_F(\theta), \quad (3)$$

where the subscript F denotes the full-flow values of P and E at the power level numerically equal to Q/R .

Consequently,

$$P(\theta) = E(\theta) - E_F(\theta) + P_F(\theta). \quad (4)$$

Now $E_F(\theta)$ can be written in a form corresponding to Eq. 1 as:

$$E_F = -\frac{Q}{R}(A + B\alpha + C_1 + C_2\alpha + D_1\alpha + F\frac{\alpha}{k} + A_{rg}). \quad (5)$$

Thus, by combining Eqs. 1, 4, and 5, $P(\theta)$ can be rewritten:

$$P(\theta) = P_F(\theta) + Q\left\{C_1\left(\frac{1}{R} - \frac{1}{R^{0.4}}\right) + A_{rg}\left(\frac{1}{R} - 1\right) + \alpha\left[C_2\left(\frac{1}{R} - \frac{1}{R^{0.4}}\right) + D_1\left(\frac{1}{R} - 1\right)\right] + \frac{\alpha}{k}\left(\frac{1}{R} - 1\right)F\right\}. \quad (6)$$

More simply,

$$P(\theta_i) = P_F(\theta_i) + Q_i (a_i + b_i\alpha + c_i \alpha/k), \quad (7)$$

in which

$$a_i = C_1(1/R - 1/R^{0.4}) + A_{rg} (1/R - 1)$$

$$b_i = C_2(1/R - 1/R^{0.4}) + D(1/R - 1)$$

$$c_i = F(1/R - 1).$$

Or still more simply,

$$P(\theta_i) = e_i + d_i \alpha, \quad (8)$$

in which

$$e_i = P_F(\theta_i) + Q_i a_i$$

$$d_i = Q_i(b_i + c_i/k).$$

The subscript i denotes any one of a set of reduced-flow situations for which P is to be calculated. Corresponding to any reduced-flow point, the full-flow value P_F is taken from the curve fitted to the values for measurements of PRD versus power at full flow.

From any single measured PRD at reduced flow, $P(\theta_i)$, a value of α can be calculated from Eq. 8.

If the $P(\theta_i)$ is a set of observed (measured) values for PRD at conditions of reduced coolant flow and the $P_c(\theta_i)$ are the corresponding values for PRD calculated from Eq. 6, the sum of the squares of the differences between measured and calculated values can be minimized by the appropriate choice of α in Eq. 8.

That is, for

$$\begin{aligned}\Sigma [P_c(\theta_i) - P(\theta_i)]^2 &= \Sigma [e_i + d_i \alpha - P(\theta_i)]^2 \\ &= \Sigma e_i^2 + \alpha^2 \Sigma d_i^2 + \Sigma P^2(\theta_i) \\ &\quad + 2\alpha \Sigma e_i d_i - 2 \Sigma e_i P(\theta_i) - 2\alpha \Sigma d_i P(\theta_i)\end{aligned}$$

to be a minimum,

$$\alpha = \frac{\Sigma d_i [e_i - P(\theta_i)]}{\Sigma d_i^2} \quad (9)$$

Through the use of the empirical curve for PRD at full flow with the calculated expansion effects, this procedure has fitted the data to a function that is nonlinear and not even necessarily analytic with power.

The subroutine LSALP calculates the linear average value of α by applying Eq. 8 to each measured reduced-flow point and the least-squares-fitted α from Eq. 9.

Sensitivity studies of the effect of flow variations have shown that variations within the probable accuracy of the flow meters can lead to errors in the computed effective α of the order of $\pm 2 \times 10^{-6}$. This error is probably the limit of accuracy in interpreting these experiments.

IX. CONCLUSION

The main advantages associated with this package of codes have been the uniformity of treatment of the data, reliability of application of correction factors, and reduction in the possibility of arithmetical errors. Subjective judgments required at many stages of the hand-processing treatment have been eliminated.

As a result, comparisons of reactivity data over extended periods are more dependable. The compilations and interpretations of reactivity data cited in Refs. 1 and 2 made extensive use of these codes.

APPENDIX

FORTRAN Listing and Sample Problem for PROCPRD

FORTRAN LISTING

FORTRAN IV G LEVEL 18

MAIN

DATE = 70223

14/51/49

	C	PROGRAM TO CORRECT MEASURED PRD DATA, ALSO TO CALCULATE	1000
	C	ALPHA FROM REDUCED FLOW DATA	1001
	C		1002
0001		IMPLICIT REAL*8 (A-H,O-Z)	1003
0002		DIMENSION BW(141,2), G(10,2), PRD(24), NR(2), RCAL(2), PD(24),	1004
		1 ROD(2,24), TEMC(24), TITLE(20), IT(24), W(12), R(12), ID(12), DATE(12),	1005
		2 XCON(5), PA(30), QA(30), RA(30), A(8), B(8), C(8), C2(8), D(8), F(8),	1006
		3 ARG(8), CONDO(8), PP(24), AMWD(24), PEX(24), ABANK(24), XW(140), YW(140)	
0003		DATA XW/130.00, 129.41, 128.81, 128.20, 127.58, 126.94, 126.30, 125.64,	
		1 124.96, 124.28, 123.58, 122.87, 122.15, 121.41, 120.66, 119.90, 119.13,	
		2 118.34, 117.54, 116.73, 115.90, 115.06, 114.20, 113.34, 112.45, 111.55,	
		3 110.64, 109.72, 108.78, 107.82, 106.85, 105.87, 104.87, 103.86, 102.83,	
		4 101.79, 100.73, 99.66, 98.58, 97.48, 96.37, 95.25, 94.11, 92.96, 91.80,	
		5 90.63, 89.44, 88.25, 87.05, 85.83, 84.61, 83.38, 82.15, 80.91, 79.66,	
		6 78.41, 77.16, 75.90, 74.65, 73.39, 72.14, 70.89, 69.65, 68.41, 67.19,	
		7 65.97, 64.76, 63.57, 62.40, 61.24, 60.55, 59.32, 58.07, 56.82, 55.56,	
		8 54.30, 53.03, 51.76, 50.49, 49.22, 47.95, 46.69, 45.43, 44.17, 42.93,	
		9 41.69, 40.46, 39.24, 38.03, 36.83, 35.65, 34.48, 33.33, 32.19, 31.06,	
		A 29.96, 28.87, 27.80, 26.75, 25.72, 24.71, 23.72, 22.76, 21.81, 20.88,	
		C 19.98, 19.10, 18.24, 17.40, 16.59, 15.79, 15.02, 14.27, 13.55, 12.84,	
		C 12.16, 11.50, 10.85, 10.23, 9.63, 9.05, 8.48, 7.94, 7.41, 6.89, 6.39, 5.91,	
		D 5.44, 4.98, 4.53, 4.09, 3.66, 3.24, 2.83, 2.41, 2.01, 1.60, 1.19, 0.78, 0.37/	
0004		DATA YW/156.98, 156.39, 155.78, 155.14, 154.49, 153.82, 153.12, 152.39,	
		1 151.64, 150.86, 150.06, 149.23, 148.38, 147.49, 146.58, 145.65, 144.68,	
		2 143.69, 142.68, 141.64, 140.57, 139.49, 138.37, 137.24, 136.08, 134.91,	
		3 133.71, 132.50, 131.26, 130.01, 128.75, 127.46, 126.17, 124.86, 123.54,	
		4 122.21, 120.87, 119.52, 118.16, 116.80, 115.42, 114.05, 112.67, 111.28,	
		5 109.89, 108.50, 107.10, 105.71, 104.31, 102.91, 101.51, 100.11, 98.71,	
		6 97.31, 95.90, 94.50, 93.09, 91.67, 90.26, 88.84, 87.41, 85.98, 84.54,	
		7 83.08, 81.62, 80.14, 78.64, 77.13, 75.60, 74.04, 72.40, 71.07, 69.71,	
		8 68.34, 66.94, 65.52, 64.09, 62.65, 61.20, 59.73, 58.26, 56.79, 55.31,	
		9 53.83, 52.35, 50.88, 49.41, 47.95, 46.49, 45.05, 43.62, 42.20, 40.79,	
		A 39.40, 38.03, 36.68, 35.35, 34.04, 32.75, 31.48, 30.24, 29.03, 27.84,	
		B 26.67, 25.54, 24.43, 23.34, 22.29, 21.27, 20.27, 19.31, 18.37, 17.46,	
		C 16.58, 15.73, 14.90, 14.11, 13.34, 12.59, 11.87, 11.18, 10.51, 9.86, 9.23,	
		D 8.62, 8.03, 7.45, 6.89, 6.34, 5.80, 5.28, 4.75, 4.23, 3.71, 3.19, 2.67, 2.14,	
		E 1.60, 1.04, 0.47/	
	C		1008
	C	J. K. LONG'S ODD AND EVEN CONTROL ROD DATA	1009
	C		1010
0005		DD 21 I = 1, 140	
0006		BW(I,1) = XW(I)	
0007		BW(I,2) = YW(I)	
0008	21	CONTINUE	
0009		BW(141,1) = 0.	
0010		BW(141,2) = 0.	
	C		1021
	C	PRD DATA TITLE CARD (2 TO 80 COL.)	1022
0011		17 READ 99, (TITLE(I), I=1,20)	1023
0012		99 FORMAT(20A4)	1024
	C		1025
	C	ROD BANK CORRECTION DATA	1026
0013		READ 98, (W(I), R(I), ID(I), DATE(I), I=1,12)	1027
0014	98	FORMAT(2E12.5, I6, A8)	1028
	C	ROD WORTH = W	E12.5 1029
	C	ROD POSITION = R	E12.5 1030
	C	FUEL OR NON-FUEL = ID 1 OR 0	16 1031
	C	DATE CALIBRATED = DATE	A8 1032
	C		1033
0015		READ 97, NR(1), RCAL(1), NR(2), RCAL(2), BUF, ZC	1034
0016	97	FORMAT(I6, E12.5, 2E12.5)	1035
	C	CONTROLLING ROD NUMBER = NR	16 1036
	C	ROD CALIBRATION = RCAL	E12.5 1037
	C	BURN UP CORRECTION = BUF	E12.5 1038
	C	ZERO POWER CORRECTION = ZC	E12.5 1039
	C		1040
0017		READ 96, RF, CH7, NMAX, IRF, JP, NEW	1041
0018	96	FORMAT(I2E12.5, 4I6)	1042
	C	REACTOR FLOW = RF	E12.5 1043
	C	CHANNEL 7 CAL. = CH7	E12.5 1044
	C	NUMBER OF PRD'S = NMAX	16 1045
	C	NUMBER OF REDUCED FLOW POINTS INCLUDING REF. CASE OR	1046
	C	IF = 0 NO REDUCED FLOW CAL. = IRF	16 1047
	C	METHOD FOR CAL. POWER = JP	16 1048
	C	NEW PROBLEM = NEW	16 1049
	C	NEW = 0 ONLY ONE SET OF DATA FOR INPUT	1050
	C	NEW = 1 ANOTHER SET OF DATA TO BE INPUT	1051
	C		1052
	C		1053

FORTRAN IV G LEVEL	18	MAIN	DATE = 70223	14/51/49
	C	FOLLOWING CARDS MUST START WITH ZERO AND END WITH HIGHEST		1054
	C	POWER LEVEL		1055
0019		READ 95,(IT(I),PP(I),ROD(1,I),ROD(2,I),AMWD(I),TEMC(I),I=1,NMAX)		1056
0020	95	FORMAT(15,5E10.3)		1057
	C	TIME = IT	15	1058
	C	CHANNEL 7 = PP	E10.3	1059
	C	CONTROLLING ROD POSITION = ROD	2E10.3	1060
	C	MEGAWATT DAYS = AMWD	E10.3	1061
	C	BULK NA CORRECTION = TEMC	E10.3	1062
	C			1063
0021		CALL POWER (NMAX,JP,PP,CH7,PO,P)		1064
0022		CALL BAPOS (ID,NR,ROD,R,BANK,NMAX)		1065
0023		CALL RBCORR (W,R,ID,DATE,RF,P,BANK,TITLE,DA,IRF)		1066
0024		CONTINUE		1067
0025		CALL PCRITD (AMWD,BUF,NR,RCAL,PO,BW,TITLE,IT,TEMC,ROD,ZC,NMAX, 1 PRD,DA)		1068
		CONTINUE		1069
0026		CALL PROFIT (PO,PRD,NMAX,XCON,IT)		1070
0027		CONTINUE		1071
0028		NSET=0		1072
0029		IF(IRF)17,15,16		1073
0030				1074
0031	16	CONTINUE		1075
	C			1076
	C	REDUCED FLOW CALCULATION		1077
	C			1078
0032		READ 150,JMAX,NSET,(A(I),B(I),C1(I),C2(I),D(I),F(I),ARG(I),COND(I 1),I=1,JMAX)		1079
0033	150	FORMAT(216/(4E12.6))		1080
	C			1081
	C	NUMBER OF SETS OF CONSTANTS = JMAX	16	1082
	C	NUMBER OF REDUCED FLOW SET WITH SAME PRD	16	1083
	C			1084
	C	TWO CARDS FOR EACH SET OF CONSTANTS		1085
	C	A, B, C1, C2	4E12.6	1086
	C	D, F, ARG, COND	4E12.6	1087
	C			1088
0034		DO 184 ISET=1,NSET		1089
	C			1090
	C	REDUCED FLOW DATA TITLE (2 TO 80 COL.)		1091
0035		READ 99,(TITLE(I),I=1,20)		1092
0036		NMAX=1		1093
	C			1094
	C	REDUCED FLOW DATA, FIRST CARD MUST BE REF. CASE		1095
0037		READ 151,(PEX(I),AMWD(I),TEMC(I),PRD(I),PP(I),ABANK(I),IT(I), 1 I=1,IRF)		1096
0038	151	FORMAT(6E12.6,16)		1097
	C	PRIMARY FLOW = PEX	E12.6	1098
	C	MEGAWATT-DAYS = AMWD	E12.6	1100
	C	BULK NA TEMP = TEMC	E12.6	1101
	C	CONTROLLING ROD POS. = PRD	E12.6	1102
	C	REACTOR POWER = PP	E12.6	1103
	C	ROD BANK POS. = ABANK	E12.6	1104
	C	CONTROLLING ROD NUMBER = IT	16	1105
0039		DO 170 I=i,IRF		1106
0040		II=I		1107
0041		CALL POWER (II,JP,PP,CH7,PO,P)		1108
0042		QA(I)=P		1109
0043		RA(I)=PEX(I)		1110
0044		IF(BANK-ABANK(I))177,178,177		1111
	C	IF ROD BANK CHANGES BETWEEN REDUCED FLOW POINTS		1112
	C	CONTROL ROD POSITIONS MUST BE INPUT		1113
0045	177	READ 152,(R(I2),I2=1,12)		1114
0046	152	FORMAT(6E12.6)		1115
	C	CONTROL ROD POSITIONS = R	6E12.6	1116
	C			1117
0047	178	IR=IT(I)		1118
0048		R(I2)=PRD(I)		1119
0049		BANK=ABANK(I)		1120
0050		PF=PEX(I)		1121
0051		CALL RBCORR(W,R,ID,DATE,PF,P,BANK,TITLE,DA,IRF)		1122
0052		K=0		1123
0053		DO 171 J=1,2		1124
0054		K=K+1		1125
0055		IF(IR-NR(J))171,172,171		1126
	C	IF CONTROLLING ROD IS CHANGE BETWEEN REDUCED FLOW POINTS		1127
	C	NEW ROD CALIBRATION MUST BE INPUT		1128
0056	171	CONTINUE		1129
0057		NR(K)=IR		1130
0058		READ 152,RCAL(K)		1131
	C	ROD CALIBRATION = RCAL	E12.6	1132
	C			1133
				1134

FORTRAN IV G LEVEL		18	MAIN	DATE = 70223	14/51/49
0059	172	CALL WORTH (II,K,NR,PRD,BW,WA,RCAL)			1135
0060		WNA=TEMC(1)-700.0			1136
0061		WSU=(AMWD(1)-AMWD(1))\$DUF			1137
0062		WA=WA+WNA+WSU			1138
0063		PEX(1)=WA+(QA(1)/RA(1)*DA)			1139
0064		IF(I-1)170,174,170			1140
0065	174	X=QA(1)/RA(1)			1141
0066		KKK=S			1142
0067		PY=1.0			1143
0068		PRD2=XCON(5)			1144
0069		DO 175 JJ=1,4			1145
0070		PY=PY*X			1146
0071	175	PRD2=PRD2+PY*XCON(KKK-JJ)			1147
0072		PEX(1)=PEX(1)-PRD2			1148
0073	170	CONTINUE			1149
0074		IRF=IRF-1			1150
0075		DO 176 I=1,IRF			1151
0076		PA(1)=PEX(1)-PEX(I+1)			1152
0077		QA(1)=QA(I+1)			1153
0078	176	RA(1)=RA(I+1)			1154
0079		CALL LSALP (IRF,JMAX,A,B,C1,C2,D,F,ARG,COND,XCON,QA,RA,PA,TITLE)			1155
0080		IRF=IRF+1			1156
0081	184	CONTINUE			1157
0082	15	IF(NEW)17,140,17			1158
0083	140	RETURN			1159
0084		END			1160

FORTRAN IV G LEVEL		18	WORTH	DATE = 70223	14/51/49
0001		<u>SUBROUTINE WORTH (II,K,NR,POS,BW,W,RCAL)</u>			1161
	C				1162
	C				1163
	C				1164
0002		IMPLICIT REAL*8 (A-H,O-Z)			1165
0003		DIMENSION BW(141,2),POS(24),NR(2),RCAL(2)			1166
0004		MA=NR(K)/2			1167
0005		MA=2*MA			1168
0006		IF(NR(K)-MA) 11,10,11			1169
0007	10	J=2			1170
0008		GO TO 6			1171
0009	11	J=1			1172
0010	6	L=POS(I)*10.0			1173
0011		AL=L			1174
0012		DIF=10.0*POS(I)-AL			1175
0013		W=(BW(L+1,J)-DIF*(BW(L+1,J)-BW(L+2,J)))*RCAL(K)			1176
0014		RETURN			1177
0015		END			1178

FORTRAN IV G LEVEL		18	POWER	DATE = 70223	14/51/49
0001		<u>SUBROUTINE POWER (NMAX,JP,PP,CH7,PO,P)</u>			1179
	C				1180
	C				1181
	C				1182
0002		IMPLICIT REAL*8 (A-H,O-Z)			1183
0003		DIMENSION PP(24),PO(24)			1184
0004		DO 5 I=1,NMAX			1185
0005		GO TO (3,31,4),JP			1186
0006	31	PO(I)=0.333*PP(I)+1.0			1187
0007		GO TO 5			1188
0008	3	PO(I)=0.341*PP(I)			1189
0009		GO TO 5			1190
0010	4	PO(I)=CH7*PP(I)			1191
0011	5	CONTINUE			1192
0012		P=PO(NMAX)			1193
0013		RETURN			1194
0014		END			1195

FORTRAN IV G LEVEL		18	BAPOS	DATE = 70223	14/51/49
0001			<u>SUBROUTINE BAPOS</u> (ID,NR,ROD,R,BANK,NMAX)		1196
	C				1197
	C		FINDS BANK POSITION FOR SUBROUTINE RBCORR		1198
	C				1199
0002			IMPLICIT REAL*8 (A-H,O-Z)		1200
0003			DIMENSION ID(24),NR(2),ROD(2,24),R(24)		1201
0004			DO 6 I=1,12		1202
0005			IF(ID(I))7,6,7		1203
0006		7	IF(I-NR(I))8,9,8		1204
0007		9	R(I)=ROD(I,NMAX)		1205
0008			GO TO 6		1206
0009		8	IF(I-NR(2))10,11,10		1207
0010		10	BANK=R(I)		1208
0011			GO TO 6		1209
0012		11	R(I)=ROD(2,NMAX)		1210
0013		6	CONTINUE		1211
0014			RETURN		1212
0015			END		1213

FORTRAN IV G LEVEL		18	RBCORR	DATE = 70223	14/51/49
0001			<u>SUBROUTINE RBCORR</u> (W,R,ID,DAVE,PF,P,BANK,TITLE,DA,IRF)		1214
	C				1215
	C		CALCULATES ROD BANK CORRECTION		1216
	C				1217
0002			IMPLICIT REAL*8 (A-H,O-Z)		1218
0003			DIMENSION W(12),R(12),RE(12),DLT(12),A(12,4),B(12),ID(12),		1219
		1	DATE(12),TITLE(20),FP(14),MAP(14),WBP(14),WCP(14)		1220
0004			IJK=0		1221
0005			SUM=0.0		1222
0006			SUM1=0.0		1223
0007			DO 1 I=1,12		1224
0008			IF(ID(I))41,42,41		1225
0009		42	A(I,1)=0.0		1226
0010			A(I,2)=0.0		1227
0011			B(I)=0.0		1228
0012			DLT(I)=0.0		1229
0013			GO TO 1		1230
0014		41	W1=W(I)*0.189		1231
0015			IJK=IJK+1		1232
0016			DO 18 J=1,2		1233
0017			GO TO (44,45),J		1234
0018		44	X=R(I)		1235
0019			GO TO 46		1236
0020		45	X=11.0		1237
0021		46	X1=X		1238
0022			X2=X1*X		1239
0023			X3=X2*X		1240
0024			X4=X3*X		1241
0025			X5=X4*X		1242
0026			Y=0.3762173 + 0.0466419*X + 0.00281453*X2 - 0.000211674*X3		1243
0027			F=-.14493E-04*X5+.75014E-03*X4-.1493E-01*X3+.13708*X2-.52537*X1+		1244
		1	1.43197		1245
0028			F=F*PF		1246
0029			TC=3.851026*P*Y/F		1247
0030			DLH=7C*41.94E-05		1248
0031			DLP=1.0E-05*TC*(24.11-X)		1249
0032			DLC=1.0E-05*0.9*TC*34.25		1250
0033			DLCF=7.344E-05*P/PF		1251
0034			DLCH=0.5E-05*TC*X		1252
0035			GO TO (47,48),J		1253
0036		47	DLT(I)=DLH+DLP+DLC+DLCF+DLCH		1254
0037			RE(I)=R(I)-DLT(I)		1255
0038			GO TO 18		1256
0039		48	DTT=DLH+DLP+DLC+DLCF+DLCH		1257
0040			RB=X		1258
0041			RA=X-DTT		1259
0042		18	CONTINUE		1260
0043			DO 3 J=1,4		1261
0044			GO TO (20,21,77,78),J		1262
0045		77	X=RB		1263
0046			GO TO 22		1264
0047		78	X=RA		1265
0048			GO TO 22		1266
0049		20	X=R(I)		1267
0050			GO TO 22		1268
0051		21	X=RE(I)		1269
0052		22	X1=X		1270
0053			X2=X1*X		1271
0054			X3=X2*X		1272
0055			X4=X3*X		1273
0056			X5=X4*X		1274

FORTRAN IV G LEVEL	18	RBCORR	DATE = 70223	14/51/49
0057	G=1			1275
0058	D=G/2.0			1276
0059	IN=D			1277
0060	DD=IN			1278
0061	IF(D-00)23,24,23			1279
0062	23 A(I,J)=-1.16431E-05*X5+4.54364E-04*X4-3.73727E-03*X3			1280
0063	A(I,J)=(A(I,J)-1.31935E-02*X2-2.55026E-01*X1+5.2194)*W1			1281
0064	GO TO 3			1282
0065	24 A(I,J)=-8.92965E-06*X5+3.94531E-04*X4-3.75867E-03*X3			1283
0066	A(I,J)=(A(I,J)-7.19696E-03*X2-2.61066E-01*X1+5.03054)*W1			1284
0067	3 CONTINUE			1285
0068	B(I)=A(I,1)-A(I,2)			1286
0069	E=A(I,3)-A(I,4)			1287
0070	SUM=SUM+B(I)			1288
0071	SUM1=SUM1+E			1289
0072	1 CONTINUE			1290
0073	PPF=PF*100.			1291
0074	ANS=SUM/P			1292
0075	ANP=SUM1/P			1293
0076	DD 36 I=1,14			1294
0077	IF(I-1)70,71,70			1295
0078	71 FP(I)=0.0			1296
0079	GO TO 72			1297
0080	70 FP(I)=FP(I-1)+5.0			1298
0081	IF(I-14)72,73,72			1299
0082	73 FP(I)=62.5			1300
0083	72 WBP(I)=FP(I)*ANS			1301
0084	WAP(I)=FP(I)*ANP			1302
0085	36 WCP(I)=WAP(I)-WBP(I)			1303
0086	DA=WCP(14)/62.5*PF			1304
0087	PRINT 100,(TITLE(I),I=1,20),P,PPF,BANK,SUM,(I,R(I),DATE(I),W(I),			1305
0088	1 DLT(I),A(I,1),A(I,2),B(I),I=1,12)			1306
	PRINT 101,BANK,(FP(I),WBP(I),WAP(I),WCP(I),I=1,14),IJK			1307
	C			1308
0089	100 FORMAT(IH1,T26,'ROD EXPANSION CORRECTION FOR'/T27,'POWER-REACTIVI			1309
	TY DECREMENT'//20A4//T14,'POWER =' ,F8.2,T40,'PERCENT FLOW =' ,F8.2/			1310
	2T14,'BANK POSITION =' ,F5.2,T40,'BANK CORR. =' ,F8.3//T2,'ROD',T10,			1311
	3 'ROD',T20,'DATE',T31,'WORTH',T42,'DL',T51,'IH',T60,'IH',T71,'CORR			1312
	4,'/T2,'NO.',T10,'POS',T20,'CAL',T31,'IH',T42,'IN',T51,'X',T59,			1313
	5'X-DL',T71,'IH')/12(I3,F10.2,3X,A8,F11.2,F11.4,F10.2,F9.2,F12.3,/			1314
	6//)			1315
0090	101 FORMAT (			1316
	1 ///T9,'POWER',T25,'BANK CORR',T42,'PURE BANK CORR',T62,'BANK CORR			1317
	7'/T10,'MW',T26,'AT',F6.2,T44,'AT 11.00 %',T62,'TO 11.00'/14(F12.2,			1318
	8 3F10.3//T6,'%',I3,T12,'CONTROL RODS AT 11.00')			1319
0091	RETURN			1320
0092	END			1321

FORTRAN IV G LEVEL	18	PCRITD	DATE = 70223	14/51/49
0001	SUBROUTINE PCRITD (BUC,BUF,NR,RCAL,PO,BW,TITLE,IT,TEMC,ROD,ZC,			1322
	1 NMAX,PRO,DI			1323
	C			1324
	C			1325
	C	PROCESS POWER REACTIVITY DECREMENT DATA		1326
0002	IMPLICIT REAL*8 (A-H,O-Z)			1327
0003	DIMENSION BUC(24),PRD(24),WA(24),RBNK(24),NR(2),PO(24),ROD(2,24),			1328
	1 BW(141,2),RCAL(2),TEMC(24),TITLE(20),IT(24)			1329
0004	BUCR=BUC(1)			1330
0005	IF (BUF) 49,50,49			1331
0006	49 BUCR=BUF*BUC(1)			1332
0007	50 CONTINUE			1333
0008	N=1			1334
0009	9 K=1			1335
0010	IF (BUF) 59,60,59			1336
0011	60 BUC(N)=BUC(N)-BUCR			1337
0012	GO TO 61			1338
0013	59 BUC(N)=BUF*BUC(N)-BUCR			1339
0014	61 WA(N)=0.0			1340
0015	RBNK(N)=PO(N)*D			1341
0016	18 MA=NR(K)/2			1342
0017	MA=2*MA			1343
0018	IF (NR(K)-MA) 11,10,11			1344
0019	10 J=2			1345
0020	GO TO 6			1346
0021	11 J=1			1347
0022	6 L=ROD(K,N)*10.			1348
0023	AL=L			1349
0024	DIF=10.*ROD(K,N)-AL			1350

FORTRAN IV G LEVEL	18	PCRITD	DATE = 70223	14/51/49
0025		WA(N)=(8W(L+1,J)-DIF*(8W(L+1,J)-BW(L+2,J)))*RCAL(K)+WA(N)		1351
0026		IFINR(2)) 7,7,17		1352
0027	17	K=K+1		1353
0028		IF (K-2) 18,18,7		1354
0029	7	WA(N)=WA(N)+TEMC(N)+BUC(N)+RBNK(N)		1355
0030		IF (N-1) 20,21,20		1356
0031	21	WR=WA(N)+ZC		1357
0032	20	PRD(N)=WA(N)-WR		1358
0033		N=N+1		1359
0034		IF (N-NMAX) 9,9,41		1360
0035	41	PRINT 100,(TITLE(I),I=1,20),(NR(I),RCAL(I),I=1,2),NR(1),NR(2),		1361
	1	(IT(I),PO(I),ROD(1,I),ROD(2,I),TEMC(I),BUC(I),RBNK(I),WA(I),PRD(I)		1362
	2	,I=1,NMAX)		1363
0036	100	FORMAT(1H1/20A4//2(I18,'ROD NO.',I3,T35,'CAL.',F6.3//T3,'TIME		1364
		1POWER ROD NO.',I3,T28,'ROD NO.',I3,T40,'TEMP CORR BURN-UP ROD		1365
		2BANK EXCESS PRD*/T4,'HRS',T9,'MW',T16,'POS. (IN.)',T28,'POS. (		1366
		3IN.)',T43,'IH',T51,'CORR. 1K',T61,'CORR. IH',T73,'IH',T81,'IH'//		1367
		4(I6,F6.2,F9.2,2F12.2,F11.2,2F10.2,F8.1))		1368
0037		RETURN		1369
0038		END		1370

FORTRAN IV G LEVEL	18	PROFIT	DATE = 70223	14/51/49
0001		<u>SUBROUTINE PROFIT (X,Y,N,XCON,IT)</u>		1371
	C			1372
	C	FITS PRD DATA FROM SUBROUTINE PCRITD TO 4 TH ORDER EQUATION		1373
	C			1374
0002		IMPLICIT REAL*8 (A-H,O-Z)		1375
0003		DIMENSION X(20),Y(20),Y2(20),DIFF(20),SUMB(10,1),SUMA(10,10),		1376
	1	R(20),X1(4),XCON(5),IT(24)		1377
0004		A=1.1420412E-05		1378
0005		B=-1.5993419E-03		1379
0006		C=7.2540045E-02		1380
0007		D=-2.9505606		1381
0008		E=0.259858		1382
0009		DO 4 J=1,4		1383
0010		SUMB(J,1)=0.0		1384
0011		DO 4 K=1,4		1385
0012	4	SUMA(J,K)=0.0		1386
0013		DO 3 I=1,N		1387
0014		X1(4)=X(I)		1388
0015		X1(3)=X1(4)*X(I)		1389
0016		X1(2)=X1(3)*X(I)		1390
0017		X1(1)=X1(2)*X(I)		1391
0018		YY=A*X1(1)+B*X1(2)+C*X1(3)+D*X1(4)+E		1392
0019		R(I)=Y(I)-YY		1393
0020		DO 5 J=1,4		1394
0021		SUMB(J,1)=SUMB(J,1)+R(I)*X1(J)		1395
0022		DO 5 K=1,4		1396
0023	5	SUMA(J,K)=SUMA(J,K)+X1(J)*X1(K)		1397
0024	3	CONTINUE		1398
0025		CALL INV(SUMA,4,SUMB,1,DET,1D)		1399
0026		A=A+SUMB(1,1)		1400
0027		B=B+SUMB(2,1)		1401
0028		C=C+SUMB(3,1)		1402
0029		D=D+SUMB(4,1)		1403
0030		DO 6 I=1,N		1404
0031		X2=X(I)		1405
0032		X3=X2*X(I)		1406
0033		X4=X3*X(I)		1407
0034		X5=X4*X(I)		1408
0035		Y2(I)=A*X5+B*X4+C*X3+D*X2+E		1409
0036	6	DIFF(I)=Y(I)-Y2(I)		1410
0037		XCON(1)=A		1411
0038		XCON(2)=B		1412
0039		XCON(3)=C		1413
0040		XCON(4)=D		1414
0041		XCON(5)=E		1415
0042		PRINT 600,(IT(I),X(I),Y(I),Y2(I),DIFF(I),I=1,N)		1416
0043		PRINT 601,A,B,C,D,E		1417
0044	600	FORMAT(///T21,'CURVE FIT TO PRD DATA'//T3,'TIME',T10,'POWER',		1418
	1	T19,'MEASURED PRD',T37,'FIT PRD DATA *',T54,'MEAS. - FIT'//		1419
	2	T4,'HRS',T11,'MW',T20,'DATA (IH)',T41,'(IH)',T58,'(IH)',//I6,		1420
	3	F7.2,F14.3,9X,F9.3,9X,F9.4))		1421
0045	601	FORMAT(//T3,'* EQUATION FOR PRD'//T3,'PRD = A*X**4 + B*X**3 + C*		1422
		1X**2 + D*X + E'//T3,'A = ',E12.6,/T3,'B = ',E12.6/T3,'C = ',E12.6		1423
		3 /T3,'D = ',E12.6/T3,'E = ',E12.6)		1424
0046		RETURN		1425
0047		END		1426

FORTRAN IV G LEVEL 18		INV	DATE = 70223	14/51/49
0001		SUBROUTINE INV(A,N1,B,M1,DET,ID)		1427
0002		IMPLICIT REAL*8 (A-H,O-Z)		1428
0003		DIMENSION A(10,10),B(10,1),IN(10,3)		1429
0004		EQUIVALENCE (IR,JR),(IC,JC),(AM,T,SW)		1430
0005		M=M1		1431
0006		N=N1		1432
0007		DET=1.		1433
0008		DO 20 J=1,N		1434
0009	20	IN(J,3)= 0		1435
0010		DO 550 I=1,N		1436
0011		AM=0.		1437
0012		DO 105 J=1,N		1438
0013		IF(IN(J,3).EQ.1) GO TO 105		1439
0014		DO 100 K= 1,N		1440
0015		IF(IN(K,3)-1) 80,100,715		1441
0016	80	IF(AM.GE.DABS(A(J,K))) GO TO 100		1442
0017		IR=J		1443
0018		IC=K		1444
0019		AM= DABS(A(J,K))		1445
0020	100	CONTINUE		1446
0021	105	CONTINUE		1447
0022		IN(IC,3)=IN(IC,3)+1		1448
0023		IN(I,1)=IR		1449
0024		IN(I,2)=IC		1450
	C			1451
	C	JUST FOUND PIVOTAL ELEMENT, NOW INTERCHANGE ROWS TO PUT PIVOTAL		1452
	C	ELEMENT ON DIAGONAL		1453
	C			1454
0025		IF(IR.EQ.IC) GO TO 310		1455
0026		DET=-DET		1456
0027		DO 200 L=1,N		1457
0028		SW=A(IR,L)		1458
0029		A(IR,L)=A(IC,L)		1459
0030	200	A(IC,L)=SW		1460
0031		IF(M)310,310,210		1461
0032	210	DO 250 L=1,M		1462
0033		SW=B(IR,L)		1463
0034		B(IR,L)=B(IC,L)		1464
0035	250	B(IC,L)=SW		1465
	C			1466
	C	DIVIDE PIVOT ROW BY PIVOTAL ELEMENT		1467
	C			1468
0036	310	PIV=A(IC,IC)		1469
0037		DET=DET*PIV		1470
0038		A(IC,IC)=1.		1471
0039		DO 350 L=1,N		1472
0040	350	A(IC,L)=A(IC,L)/PIV		1473
0041		IF(M)380,380,360		1474
0042	360	DO 370 L=1,M		1475
0043	370	B(IC,L)=B(IC,L)/PIV		1476
	C			1477
	C	REDUCE NON-PIVOT ROWS		1478
	C			1479
0044	380	DO 550 L1=1,N		1480
0045		IF(L1.EQ.IC) GO TO 550		1481
0046		T=A(L1,IC)		1482
0047		A(L1,IC)=0.		1483
0048		DO 450 L=1,N		1484
0049	450	A(L1,L)=A(L1,L)-A(IC,L)*T		1485
0050		IF(M)550,550,460		1486
0051	460	DO 500 L=1,M		1487
0052	500	B(L1,L)=B(L1,L)-B(IC,L)*T		1488
0053	550	CONTINUE		1489
	C			1490
	C	INTERCHANGE COLUMNS		1491
	C			1492
0054		DO 710 I=1,N		1493
0055		L=N+1-I		1494
0056		IF(IN(L,1).EQ.IN(I,2)) GO TO 710		1495
0057		JR=IN(I,1)		1496
0058		JC=IN(L,2)		1497
0059		DO 705 K=1,N		1498
0060		SW = A(K,JR)		1499
0061		A(K,JR)=A(K,JC)		1500
0062		A(K,JC)=SW		1501
0063	705	CONTINUE		1502
0064	710	CONTINUE		1503
0065		DO 73 K=1,N		1504
0066		IF(IN(K,3).EQ.1) GO TO 73		1505
0067	715	ID=2		1506
0068		GO TO 74		1507
0069	73	CONTINUE		1508
0070		ID=1		1509
0071	74	RETURN		1510
0072		END		1511

```

FORTRAN IV G LEVEL 18          LSALP          DATE = 70223          14/51/49

0001      SUBROUTINE LSALP (NR,JMAX,A,B,C1,C2,D,F,ARG,COND,XCON,QA,RA,PA, 1512
1 TITLE) 1513
C 1514
C ALPHA BY LEAST SQUARES FIT TO REDUCED FLOW POINTS. 1515
C 1516
0002      IMPLICIT REAL*8 (A-H,O-Z) 1517
C 1518
0003      DIMENSION PA(30),QA(30),RA(30),A(8),B(8),C1(8),C2(8),D(8),F(8), 1519
1 ARG(8),COND(8),PCL(30),ES(30),DS(30),PRD(30),P(30),XCON(5), 1520
2 TITLE(20) 1521
0004      DO 52 K=1,24 1522
0005      ES(K)=0.0 1523
0006      DS(K)=0.0 1524
0007      52 PCL(K)=0.0 1525
0008      DO 6 J=1,JMAX 1526
0009      SALK=0.0 1527
0010      SDP=0.0 1528
0011      SDE=0.0 1529
0012      SDX=0.0 1530
0013      DO 8 K=1,NR 1531
0014      P(K)=QA(K)/RA(K) 1532
0015      KK=5 1533
0016      PP=1.0 1534
0017      PRD(K)=XCON(5) 1535
0018      DO 19 JJ=1,4 1536
0019      PP=PP*P(K) 1537
0020      19 PRD(K)=PRD(K)+PP*XCON(KK-JJ) 1538
0021      AI=C1(J)*(1.0/RA(K)-1.0/RA(K)**0.4)+ARG(J)*(1.0/RA(K)-1.0) 1539
0022      AJ=A1*QA(K) 1540
0023      EI=PRD(K)+AI 1541
0024      BJ=C2(J)*(1.0/RA(K)-1.0/RA(K)**0.4)+D(J)*(1.0/RA(K)-1.0) 1542
0025      BI=B1*QA(K) 1543
0026      CI=F(J)*(1.0/RA(K)-1.0) 1544
0027      C1=C1*QA(K) 1545
0028      DI=BI+CI/COND(J) 1546
0029      PPMW=-PA(K)/QA(K) 1547
0030      ALK=(-PA(K)-EI)/DI 1548
0031      SALK=SALK+ALK 1549
0032      SDP=SDP-DI*PA(K) 1550
0033      SDE=SDE+DI*EI 1551
0034      SDX=SDX+DI**2.0 1552
0035      ES(K)=EI 1553
0036      8 DS(K)=DI 1554
0037      ALF=(SDP-SDE)/SDX 1555
0038      DO 50 I=1,NR 1556
0039      PA(I)=-PA(I) 1557
0040      50 PCL(I)=ES(I)+DS(I)*ALF 1558
0041      ANR=NR 1559
0042      ALFAV=SALK/ANR 1560
0043      PRINT 100,(TITLE(I),I=1,20),(I,QA(I),RA(I),P(I),PA(I),PCL(I), 1561
1 I=1,NR) 1562
0044      PRINT 101,ALF,ALFAV,(A(1),B(1),C1(1),C2(1),D(1),F(1),ARG(1), 1563
1 COND(1),I=1,JMAX) 1564
0045      6 CONTINUE 1565
0046      100 FORMAT(1H1/20A4/// ' REDUCED POWER PRIMARY POWER/ CORR. PRO 1566
1 PRD FROM'/' FLOW PT 'N FLOW FLOW [H ALPHA I 1567
2H'/(15,F9.2,F9.3,F9.1,F11.3,F11.3)) 1568
0047      101 FORMAT(//T8,'ALPHA = ',E12.6/T8,'AVE. ALPHA = ',E12.6// 1569
1T3,'DISCRPTION OF CONSTANTS'//T8,'THERMAL EXPANSION COEFFICIENT U 1570
2SED IN PRD'/' T3,'-E = DIA/R + B*ALPHA/R + C1/R**4 + C2*ALPHA/R** 1571
3-4 +'/' T8,'D*ALPHA + F*ALPHA/COND + ARG'//T8,'Q = REACTOR POWER', 1572
4 T38,'R = PRIMARY FLOW'/' T8,'A = ',E12.6,T38,'B = ',E12.6/ 1573
5 T8,'C1 = ',E12.6,T38,'C2 = ',E12.6/' T8,'D = ',E12.6,T38,'F = 1574
6 ',E12.6/T8,'ARG = ',E12.6,T38,'COND = ',E12.6) 1575
0048      RETURN 1576
0049      END 1577

```

SAMPLE PROBLEM INPUT

END OF 38A - PRD OF 9/25/69, REDUCED FLOW OF 9/27/69

4.45	14.	0	9/16/69
145.53	7.	1	9/16/69
138.58	12.	1	9/16/69
163.95	12.	1	9/16/69
139.94	12.	1	9/16/69
157.49	12.	1	9/16/69
131.46	10.	1	9/16/69
150.44	12.	1	9/16/69
119.37	12.	1	9/16/69
139.37	12.	1	9/16/69
128.90	12.	1	9/16/69
151.28	12.	1	9/16/69

2 .950 7 .985 0.12 0.

1.0	E+00	1.483	E+06	8	4	3
1940 .341	E-07	6.01		6.0	628.	-0.2
2048 .723	E-05	6.01		7.78	628.	0.3
2139 .143	E-04	6.01		9.15	629.	-0.24
2244 .209	E-04	6.01		10.58	630.	0.7
2356 .274	E-04	6.20		12.0	632.	0.5
0118 .342	E-04	7.03		12.0	634.	-0.6
0211 .381	E-04	7.66		12.0	636.	0.
0327 .426	E-04	8.39		12.0	638.	0.1

1 1 1.148 22823. 4687.

13446. 844. 0.055

END OF 38A - REDUCED FLOW DATA OF 9/27/69

1.005	712.	700.	5.92	.23	E-04	12.	2
.92	713.	700.1	6.212	.23	E-04	12.	2
.54	717.	699.9	6.57	.23	E-04	12.	2
.77	720.	699.8	6.99	.2311	E-04	12.	2

SAMPLE PROBLEM OUTPUT

ROD EXPANSION CORRECTION FOR POWER-REACTIVITY DECUREMENT

END OF 38A - PRD OF 9/25/69, REDUCED FLOW OF 9/27/69

POWER = 63.43
BANK POSITION = 12.00

PERCENT FLOW = 100.00
BANK CORR. = -18.019

ROD NO.	RJD PJS	DATE CAL.	WORTH (IH)	DL IN.	IH X	IH X-DL	CORR. (IH)
1	14.00	9/16/69	4.45	0.0	0.0	0.0	0.0
2	8.39	9/16/69	145.53	0.2008	46.69	49.27	-2.579
3	12.00	9/16/69	138.58	0.2177	8.54	10.03	-1.495
4	12.00	9/16/69	163.95	0.2177	10.08	11.88	-1.793
5	12.00	9/16/69	139.94	0.2177	8.62	10.13	-1.509
6	12.00	9/16/69	157.49	0.2177	9.69	11.41	-1.722
7	12.00	9/16/69	131.46	0.2177	8.10	9.52	-1.418
8	12.00	9/16/69	150.44	0.2177	9.25	10.90	-1.645
9	12.00	9/16/69	119.37	0.2177	7.35	8.64	-1.288
10	12.00	9/16/69	139.37	0.2177	8.57	10.10	-1.524
11	12.00	9/16/69	128.90	0.2177	7.94	9.33	-1.390
12	12.00	9/16/69	151.28	0.2177	9.30	10.96	-1.654

POWER MW	BANK CORR AT 12.00	PURE BANK CORR AT 11.00 *	BANK CORR TO 11.00
0.0	0.0	0.0	0.0
5.30	-1.420	-1.709	-0.289
10.00	-2.841	-3.418	-0.577
15.00	-4.261	-5.127	-0.866
20.00	-5.681	-6.836	-1.154
25.00	-7.102	-8.545	-1.443
30.00	-8.522	-10.254	-1.732
35.00	-9.942	-11.963	-2.020
40.00	-11.363	-13.672	-2.309
45.00	-12.783	-15.380	-2.597
50.00	-14.203	-17.089	-2.886
55.00	-15.624	-18.798	-3.175
60.00	-17.044	-20.507	-3.463
62.50	-17.754	-21.362	-3.608

* 11 CONTROL RODS AT 11.00

ROD NO. 2 CAL. 0.960
ROD NO. 7 CAL. 0.985

TIME HRS	POWER MW	ROD NO. 2 POS. (IN.)	ROD NO. 7 POS. (IN.)	TEMP CORR IH	BURN-UP CORR. IH	ROD BANK CORR. IH	EXCESS IH	PRD IH
1940	0.05	6.01	6.00	-0.20	0.0	-0.00	154.63	0.0
2048	10.77	6.01	7.78	0.30	0.0	-0.62	133.44	-21.2
2139	21.29	6.01	9.15	-0.24	0.12	-1.23	115.82	-38.8
2244	31.12	6.01	10.58	0.70	0.24	-1.80	101.91	-52.7
2356	40.80	6.20	12.00	0.50	0.48	-2.35	88.70	-65.9
118	50.92	7.03	12.00	-0.60	0.72	-2.94	75.22	-79.4
211	56.73	7.66	12.00	0.0	0.96	-3.27	67.30	-87.3
327	63.43	8.39	12.00	0.10	1.20	-3.66	56.95	-97.7

END OF 38A - PRD OF 9/25/69, REDUCED FLOW OF 9/27/69

CURVE FIT TO PRD DATA

TIME HRS	POWER MW	MEASURED PRD DATA (IH)	FIT PRD DATA * (IH)	MEAS. - FIT (IH)
1940	0.05	0.0	0.148	-0.1482
2048	10.77	-21.194	-21.217	0.0233
2139	21.29	-38.808	-38.704	-0.1035
2244	31.12	-52.724	-52.899	0.1748
2356	40.80	-65.954	-65.835	-0.0983
118	50.92	-79.415	-79.322	-0.0931
211	56.73	-87.335	-87.478	0.1432
327	63.43	-97.680	-97.635	-0.0450

* EQUATION FOR PRD

$$\text{PRD} = A \times X^4 + B \times X^3 + C \times X^2 + D \times X + E$$

$$A = -.2119120-06$$

$$B = -.1483130-03$$

$$C = 0.2060190-01$$

$$D = -.2199300 \text{ 01}$$

$$E = 0.2538580 \text{ 00}$$

POWER = 34.25
BANK POSITION = 12.00

PERCENT FLOW = 92.00
BANK CORR. = -10.431

ROD NO.	RJD POS	DATE CAL.	WORTH (IH)	DL IN.	IH X	IH X-DL	CORR. (IH)
1	14.00	9/16/69	4.45	0.0	0.0	0.0	0.0
2	6.21	9/16/69	145.53	0.1156	75.23	76.73	-1.503
3	12.00	9/16/69	138.58	0.1277	8.54	9.40	-0.864
4	12.00	9/16/69	163.95	0.1277	10.08	11.12	-1.037
5	12.00	9/16/69	139.94	0.1277	8.62	9.49	-0.873
6	12.00	9/16/69	157.49	0.1277	9.69	10.68	-0.996
7	12.00	9/16/69	131.46	0.1277	8.10	8.92	-0.820
8	12.00	9/16/69	150.44	0.1277	9.25	10.20	-0.951
9	12.00	9/16/69	119.37	0.1277	7.35	8.10	-0.744
10	12.00	9/16/69	139.37	0.1277	8.57	9.45	-0.881
11	12.00	9/16/69	128.90	0.1277	7.94	8.74	-0.804
12	12.00	9/16/69	151.28	0.1277	9.30	10.26	-0.957

POWER MW	BANK CORR AT 12.00	PURE BANK CORR AT 11.00 *	BANK CORR TO 11.00
0.0	0.0	0.0	0.0
5.00	-1.523	-1.840	-0.317
10.00	-3.046	-3.681	-0.635
15.00	-4.569	-5.521	-0.952
20.00	-6.092	-7.361	-1.270
25.00	-7.614	-9.201	-1.587
30.00	-9.137	-11.042	-1.904
35.00	-10.660	-12.882	-2.222
40.00	-12.183	-14.722	-2.539
45.00	-13.706	-16.563	-2.857
50.00	-15.229	-18.403	-3.174
55.00	-16.752	-20.243	-3.492
60.00	-18.275	-22.084	-3.809
62.50	-19.036	-23.004	-3.968

* 11 CONTROL RODS AT 11.00

POWER = 34.25
BANK POSITION =12.00

PERCENT FLOW = 54.00
BANK CORR. = -18.000

ROD NO.	RJD PJS	DATE CAL.	WORTH (IH)	DL IN.	IH X	IH X-DL	CORR. (IH)
1	14.00	9/16/69	4.45	0.0	0.0	0.0	0.0
2	8.57	9/16/69	145.53	0.2014	44.40	46.96	-2.563
3	12.00	9/16/69	138.58	0.2176	8.54	10.03	-1.494
4	12.00	9/16/69	163.95	0.2176	10.08	11.88	-1.793
5	12.00	9/16/69	139.94	0.2176	8.62	10.13	-1.509
6	12.00	9/16/69	157.49	0.2176	9.69	11.41	-1.722
7	12.00	9/16/69	131.46	0.2176	8.10	9.52	-1.418
8	12.00	9/16/69	150.44	0.2176	9.25	10.90	-1.645
9	12.00	9/16/69	119.37	0.2176	7.35	8.64	-1.287
10	12.00	9/16/69	139.37	0.2176	8.57	10.10	-1.524
11	12.00	9/16/69	128.90	0.2176	7.94	9.33	-1.390
12	12.00	9/16/69	151.28	0.2176	9.30	10.96	-1.654

POWER MW	BANK CORR AT 12.00	PURE BANK CORR AT 11.00 *	BANK CORR TO 11.00
0.0	0.0	0.0	0.0
5.00	-2.628	-3.165	-0.537
10.00	-5.256	-6.329	-1.074
15.00	-7.884	-9.494	-1.610
20.00	-10.512	-12.659	-2.147
25.00	-13.140	-15.823	-2.684
30.00	-15.768	-18.988	-3.221
35.00	-18.395	-22.153	-3.757
40.00	-21.023	-25.318	-4.294
45.00	-23.651	-28.482	-4.831
50.00	-26.279	-31.647	-5.368
55.00	-28.907	-34.812	-5.904
60.00	-31.535	-37.976	-6.441
62.50	-32.849	-39.559	-6.710

* 11 CONTROL RODS AT 11.00

POWER = 34.41
BANK POSITION =12.00

PERCENT FLOW = 77.00
BANK CORR. = -12.602

ROD NO.	RJD PJS	DATE CAL.	WORTH (IH)	DL IN.	IH X	IH X-DL	CORR. (IH)
1	14.00	9/16/69	4.45	0.0	0.0	0.0	0.0
2	6.99	9/16/69	145.53	0.1392	65.00	66.84	-1.838
3	12.00	9/16/69	138.58	0.1533	8.54	9.58	-1.042
4	12.00	9/16/69	163.95	0.1533	10.08	11.33	-1.250
5	12.00	9/16/69	139.94	0.1533	8.62	9.67	-1.052
6	12.00	9/16/69	157.49	0.1533	9.69	10.89	-1.201
7	12.00	9/16/69	131.46	0.1533	8.10	9.09	-0.988
8	12.00	9/16/69	150.44	0.1533	9.25	10.40	-1.147
9	12.00	9/16/69	119.37	0.1533	7.35	8.25	-0.898
10	12.00	9/16/69	139.37	0.1533	8.57	9.63	-1.063
11	12.00	9/16/69	128.90	0.1533	7.94	8.91	-0.969
12	12.00	9/16/69	151.28	0.1533	9.30	10.46	-1.153

POWER = 34.41
BANK POSITION = 12.00

PERCENT FLOW = 77.00
BANK CORR. = -12.602

POWER MW	BANK CORR AT 12.00	PURE BANK CORR AT 11.00 *	BANK CORR TO 11.00
0.0	0.0	0.0	0.0
5.00	-1.831	-2.205	-0.374
10.00	-3.662	-4.409	-0.747
15.00	-5.493	-6.614	-1.121
20.00	-7.324	-8.819	-1.495
25.00	-9.155	-11.023	-1.868
30.00	-10.986	-13.228	-2.242
35.00	-12.817	-15.433	-2.616
40.00	-14.648	-17.638	-2.989
45.00	-16.479	-19.842	-3.363
50.00	-18.310	-22.047	-3.736
55.00	-20.141	-24.252	-4.110
60.00	-21.973	-26.456	-4.484
62.50	-22.888	-27.559	-4.671

* 11 CONTROL RODS AT 11.00

REDUCED FLOW PT	POWER MW	PRIMARY FLOW	POWER/ FLOW	CORR. PRD IH	PRD FROM ALPHA IH
1	34.25	0.920	37.2	-60.884	-60.939
2	34.25	0.540	63.4	-95.240	-95.840
3	34.41	0.770	44.7	-72.070	-70.340

ALPHA = 0.190776D-05
AVE. ALPHA = 0.548378D-06

DISCRIPTION OF CONSTANTS

THERMAL EXPANSION COEFFICIENT USED IN PRD
-E = Q/A/R + B*ALPHA/R + C1/R**.4 + C2*ALPHA/R**.4 +
D*ALPHA + F*ALPHA/COND + ARG

Q = REACTOR POWER
A = 0.11480D 01
C1 = 0.0
D = 0.134460D 05
ARG = 0.0

R = PRIMARY FLOW
B = 0.228230D 05
C2 = 0.468700D 04
F = 0.844000D 03
COND = 0.550000D-01

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