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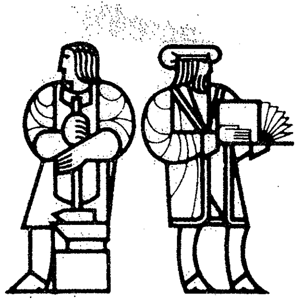

COBRA IIIc/MIT-2: A DIGITAL COMPUTER PROGRAM FOR STEADY STATE AND TRANSIENT THERMAL-HYDRAULIC ANALYSIS OF ROD BUNDLE NUCLEAR FUEL ELEMENTS

by

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REPORTS IN REACTOR THERMAL HYDRAULICS RELATED TO THE MIT ENERGY LABORATORY ELECTRIC POWER PROGRAM

A. Topical Reports (For availability check Energy Laboratory Headquarters, Headquarters, Room E19-439, MIT, Cambridge, Massachusetts, 02139)

A.1 General Applications
A.2 PWR Applications
A.3 BWR Applications
A.4 LMFBR Applications

A.1 J.E. Kelly, J. Loomis, L. Wolf, "LWR Core Thermal-Hydraulic Analysis--Assessment and Comparison of the Range of Applicability of the Codes COBRA-IIIC/MIT and COBRA-IV-1," MIT Energy Laboratory Report MIT-EL 78-026, September 1978.

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J.E. Kelly and M.S. Kazimi, "Development and Testing of the Three Dimensional, Two-Fluid Code THERMIT for LWR Core and Subchannel Applications," MIT Energy Laboratory Report MIT-El 79-046.

J.N. Loomis and W.D. Hinkle, "Reactor Core Thermal-Hydraulic Analysis--Improvement and Application of the Code COBRA-IIIC/MIT," MIT Energy Laboratory Report No. MIT-EL 80-027, September 1980.

D.P. Griggs, A.F. Henry and M.S. Kazimi, "Development of a Three-Dimensional Two-Fluid Code with Transient Neutronic Feedback for LWR Applications," MIT-EL-81-013, April 1981.

J.E. Kelly, S.P. Kao and M.S. Kazimi, "THERMIT-2: A Two-Fluid Model for Light Water Reactor Subchannel Transient Analysis," MIT-EL-81-014 April 1981.

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A.2 P. Moreno, C. Chiu, R. Bowring, E. Khan, J. Liu, and N. Todreas, "Methods for Steady-State Thermal/Hydraulic Analysis of PWR Cores," MIT Energy Laboratory Report No. MIT-EL 76-006, Rev. 1, July 1977 (Orig. 3/77).

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J. Liu, and N. Todreas, "The Comparison of Available Data on PWR Assembly Thermal Behavior with Analytic Predictions," MIT Energy Laboratory Report MIT-EL 77-009, Final, February 1979, (Draft, June 1977).

A.3 L. Guillebaud, A. Levin, W. Boyd, A. Faya, and L. Wolf, "WOSUB-A Subchannel Code for Steady-State and Transient Thermal-Hydraulic Analysis of Boiling Water Reactor Fuel Bundles," Vol. II, Users Manual, MIT-EL 78-024, July 1977.

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A. Faya, L. Wolf and N. Todreas, "Development of a Method for BWR Subchannel Analysis," MIT-EL-79-027, November 1979.

A. Faya, L. Wolf and N. Todreas, "CANAL User's Manual," MIT-EL-79-028, November 1979.

A.4 W.D. Hinkle, "Water Tests for Determining Post-Voiding Behavior in the LMFBR," MIT Energy Laboratory Report MIT-EL-76-005, June 1976.

W.D. Hinkle, Ed., "LMFBR Safety and Sodium Boiling - A State of the Art Report," Draft DOE Report, June 1978.

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A. Levin and P. Griffith, "Development of a Model to Predict Flow Oscillations in Low-Flow Sodium Boiling," MIT-EL-80-006, April 1980.

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G. Wilson and M. Kazimi, "Development of Models for the Sodium Version of the Two-Phase Three Dimensional Thermal Hydraulics Code THERMIT," MIT-EL-80-010, May 1980.

B. Papers

B.1 General Applications
B.2 PWR Applications
B.3 BWR Applications
B.4 LMFBR Application

B.1 J.E. Kelly and M.S. Kazimi, "Development of the Two-Fluid Multi-Dimensional Code THERMIT for LWR Analysis," Heat Transfer-Orlando 1980, AIChE Symposium Series 199, Vol. 76, August 1980.

J.E. Kelly and M.S. Kazimi, "THERMIT, A Three-Dimensional, Two-Fluid Code for LWR Transient Analysis," Transactions of American Nuclear Society, 34, p. 893, June 1980.

B.2 P. Moreno, J. Kiu, E. Khan, N. Todreas, "Steady State Thermal Analysis of PWR's by a Single Pass Procedure Using a Simplified Method," American Nuclear Society Transactions, Vol. 26.

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B.4 W.D. Hinkle, (MIT), P.M. Tschamper (GE), M.H. Fontana (ORNL), R.E. Henry (ANL), and A. Padilla (HEDL), for U.S. Department of Energy, "LMFBR Safety & Sodium Boiling," paper presented at the ENS/ANS International Topical Meeting on Nuclear Reactor Safety, October 16-19, 1978, Brussels, Belgium.

M.I. Autruffe, G.J. Wilson, B. Stewart and M. Kazimi, "A Proposed Momentum Exchange Coefficient for Two-Phase Modeling of Sodium Boiling," Proc. Int. Meeting Fast Reactor Safety Technology, Vol. 4, 2512-2521, Seattle, Washington, August 1979.

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PREFACE

This publication has been produced to reflect changes made to COBRA IIIc/MIT-1 since the manual was last updated (Ref. 1). The suffix "-1" is used to designate the original version of the code as reported in reference 1. The current version is denoted by the suffix "-2". When the generic nature of both versions is being referred to, the designation "COBRA IIIc/MIT" is used without any version number suffix. The major references in the production of this updated manual were the COBRA IIIc/MIT-1 manual, the original COBRA IIIc manual (BNWL-1695), and the various reports of modifications made over the years. The publications mentioned above are references 1 through 5 of the reference list. Many sections of this manual have been copied in full or in part from these sources, and the interested reader is refered to them for more detailed information concerning the origin, modifications, and testing of COBRA IIIc and COBRA IIIc/MIT. The reference from which the major portion of each section of was taken is indicated in the section heading.

The primary objective of this manual is to provide sufficient information to enable any student or engineer in the field of Thermal-Hydraulics to use COBRA IIIc/MIT-2 competently, and with confidence. Recognizing that errors are always possible in a publication of this size, the entire text of this manual has been stored on magnetic tape to facilitate correction. It is also hoped that this manual will be updated to include any future modifications to COBRA IIIc/MIT.

A source listing of the code, the data files used for the sample problems, and the printout results from the executions of the sample problems have also been stored on the same tape as the text of the manual. All corespondence concerning the contents of this tape, including corrections to the manual and requests for copies of the code should be addressed to:

Computer Code Librarian
Nuclear Engineering Department
Massachusetts Institute of Technology
Building NW-12 Room 230
138 Albany Street
Cambridge, Ma 02139
ATTN: Rachel Morton

COBRA IIIc/MIT-2: A DIGITAL COMPUTER PROGRAM FOR STEADY STATE AND TRANSIENT THERMAL-HYDRAULIC ANALYSIS OF ROD BUNDLE NUCLEAR FUEL ELEMENTS

INTRODUCTION

This report presents the COBRA IIIc/MIT-2 computer program for performing both steady-state and transient subchannel analysis of rod bundle nuclear fuel elements. COBRA IIIc/MIT-2 computes the flow and enthalpy in the subchannels of rod bundles during both boiling and nonboiling conditions by including the effects of crossflow mixing.

The subchannel analysis approach has become recognized as the standard method to analyze the steady-state thermal-hydraulic performance of nuclear fuel bundles. As a result, there has been considerable interest in using a similar analysis method for transients. Much of the safety analysis of nuclear reactors is related to the transient response of the reactor core and fuel following normal operating transients and potential accident situations. The analysis of these transients with one-dimensional analysis methods is not entirely complete. More sophisticated multi- dimensional analysis techniques provide a more detailed understanding of the thermal-hydraulic performance of nuclear fuel bundles during transients.

SUMMARY

The COBRA IIIc/MIT-2 computer program computes the flow and enthalpy in rod-bundle nuclear fuel element subchannels during both steady state and transient conditions. It uses a mathematical model which considers both turbulent and diversion crossflow mixing between adjacent subchannels. Each subchannel is assumed to contain one-dimensional, two-phase, separated, slip-flow. The two-phase flow structure is assumed to be fine enough to define the void fraction as a function of enthalpy, flow-rate, heat-flux, pressure, position and time. At the present time, steady-state two-phase flow correlations are assumed to apply to transients. The mathematical model neglects sonic velocity propagation; therefore, it is limited to transients where the transient times are greater than the time for a sonic wave to pass through the channel. The equations of the mathematical model are solved by using a semi-explicit finite difference scheme. This scheme also gives a boundary-value flow solution for both steady state and transients where the boundary conditions are the inlet enthalpy, inlet mass velocity, and exit pressure.

The features of COBRA IIIc/MIT-2 can be summarized as follows:

- It can consider transients of fast-to-intermediate speed. No sonic velocity propagation effects are considered.
- The numerical scheme performs a boundary value solution where the boundary conditions are the inlet flow, inlet crossflow, inlet enthalpy and exit pressure.
- The numerical solution has no stability limitation on space or time steps.
- The transverse momentum equation includes temporal and spatial acceleration of the diversion crossflow.
- Fuel pin model options allow calculation of fuel and cladding temperatures during transients by specifying power density.
- Forced flow mixing due to diverter vanes or wire wraps is included.
- The numerical procedures allow more complete analysis of bundles with partial flow blockages.

The inclusion of the temporal and spatial acceleration of the diversion crossflow provides a more complete physical model with only a small increase in the complexity of the numerical solution. The importance of these additional phenomena are governed by the parameters u*, C, and (s/l). These have only a small-to-moderate effect on subchannel flow solutions for most rod bundle analyses. The effect of these parameters should be evaluated and justified experimentally if they have important influence on the flow solutions.

The use of fuel rod heat transfer models coupled with the subchannel analysis method provides a more complete way of performing transient thermal-hydraulic analysis of rod bundle nuclear fuel elements. By selecting appropriate heat transfer correlations the fuel temperature response to selected transients can now be analyzed in much greater detail.

While the use of an inlet flow boundary condition may be entirely satisfactory for a wide range of problems, there are many analyses where the pressure at each end of the bundle could be defined with greater ease. Cases involving transient flow reversal, coolant expulsion or countercurrent subchannel flow would require the use of other computer codes.

I. FLUID TRANSPORT MATHEMATICAL MODEL

To develop a method for predicting the flow and enthalpy in selected regions of a rod bundle, a mathematical model is used that considers lateral mixing processes. In this model the cross section of the rod bundle is divided into discrete flow subchannels as shown in Figure 1. By making suitable assumptions concerning the flow and crossflow in these subchannels, the equations of continuity, energy and momentum can be derived. This set of equations can then be solved numerically by using a digital computer.

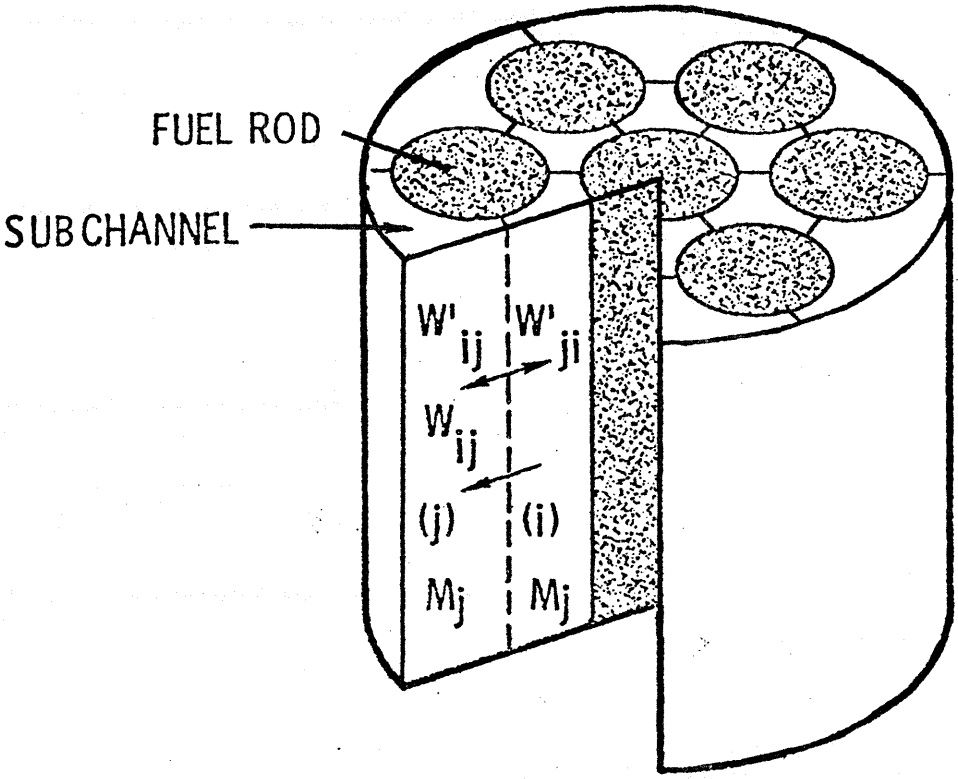

FIGURE 1. Method of Subchannel Selection

I.1 BASIC ASSUMPTIONS (from Reference 2)

- One-dimensional, two-phase, separated, slip-flow exists in each subchannel during boiling.
- The two-phase flow structure is fine enough to allow specification of void fraction as a function of enthalpy, pressure, flow rate, axial position and time.
- A turbulent crossflow exists between adjacent subchannels that causes no net flow redistribution.

- The turbulent crossflow may be superimposed upon a diversion crossflow between subchannels that results from flow redistribution. This may occur artificially from devices that force diversion crossflow.
- Sonic velocity propagation effects are ignored.
- The diversion crossflow velocity is small compared to the axial velocity within a subchannel.

The first four assumptions are those used in Meyer's (Ref. 8) two-phase flow model which is assumed to apply to rod bundle subchannels. The separated slip flow assumption is valid provided that in the regions they occupy the separated phases have uniform properties and mass fluxs. This is not always the case, especially for annular flow (Ref. 9) where the liquid at the wall is at significantly lower velocity than the entrained liquid drops. Although the separated flow assumption allows considerable simplification of the momentum and energy equations, the limitations of the assumption should be realized by users of the COBRA IIIc/MIT programs. The last two assumptions greatly simplify the mathematical model and the numerical solution. Neglecting sonic velocity propagation is justified for moderate speed transients. Meyer justifies this assumption for transients with times that are longer than the sonic propagation time through the channel.

The last assumption allows a transverse momentum equation to be derived by only preserving the vector direction between adjacent pairs of subchannels. In other words, the crossflow loses its sense of direction when it enters a subchannel. This assumption also allows the difference between transverse momentum fluxes normal to the gap to be neglected. This assumption is justified even for severe flow diversions.

I.2 EQUATIONS OF THE MATHEMATICAL MODEL (from Reference 2)

The equations of the mathematical model may be derived by using the previous assumptions and by applying the general equations of continuity, energy and momentum to a segment of an arbitrary subchannel, as shown in Appendix A. The derivations are similar to those presented earlier (Ref. 5,6,7) and are included here for completeness. For simplicity the equations are presented for an arbitrary Subchannel (i) which is connected to another Subchannel (j). The equations are generalized later to account for an arbitrary subchannel layout.

The right side of the continuity equation

$$A_i \frac{\partial p_i}{\partial t} + \frac{\partial m_i}{\partial x} = -w_{ij} \qquad (I.1)$$

gives the net rate of change of subchannel flow in terms of the diversion crossflow per unit length. By choice, the diversion crossflow is positive when flow is diverted out of Subchannel (i). The turbulent crossflow does not appear because it does not cause a net flow change. The time derivative of density gives the component of flow change caused by the fluid expansion or contraction.

The right side of the energy equation

$$\frac{1}{u''}\frac{\partial h_i}{\partial t} + \frac{\partial h_i}{\partial x} = \frac{q'_i}{m_i} - (h_i - h_j)\frac{w'_{ij}}{m_i} - (t_i - t_j)\frac{c_{ij}}{m_i} + (h_i - h^*)\frac{w_{ij}}{m_i} \qquad (I.2)$$

contains three terms for thermal energy transport in a rod bundle fuel element. The first term is the power-to-flow ration of a subchannel and gives the rate of enthalpy change if no thermal mixing occurs. The second term accounts for the turbulent enthalpy transport between all interconnected subchannels. The turbulent thermal mixing w' is analogous to eddy diffusion and is defined through empirical correlations.(Ref. 6) The third term accounts for the thermal conduction mixing. The fourth term accounts for thermal energy carried by the diversion crossflow. This is a convective term that requires a selection of the enthalpy h* to be carried by the diversion crossflow. The first term on the left side of Equation (I.2) gives the transient contribution to the spatial rate of enthalpy change. These are convective terms with a transport velocity u". Since u" represents the effective velocity for energy transport, the time duration of a transient is related to this velocity. Note that sonic velocity propagation effects are ignored by the absence of a $\partial\rho/\partial t$ term.

The right side of the axial momentum equation

$$\frac{1}{A_i}\frac{\partial m_i}{\partial t} - 2u_i\frac{\partial p_i}{\partial t} + \frac{\partial p_i}{\partial x} = \left(\frac{m_i}{A_i}\right)^2\left[\frac{v_i f_i \phi}{2D_i} + \frac{k_i}{2\Delta x} + A_i\frac{\partial(v'_i/A_i)}{\partial x}\right] \qquad (I.3)$$

$$\rho_i g\cos\theta - \frac{f_T}{A_i}(u_i - u_j)\, w'_{ij} + \frac{1}{A_i}(2u_i - u^*)\, w_{ij}$$

contains several terms that govern the axial pressure gradient in a subchannel. Without the crossflow terms, these are the frictional, spatial acceleration and elevation components of pressure gradient. The turbulent crossflow term tends to equalize the velocities of adjacent subchannels. This is analogous to turbulent stresses in turbulent flow. The factor f_T is included to help account for the imperfect analogy between the turbulent transport of enthalpy and momentum. The diversion crossflow term accounts for the momentum changes due to changes in subchannel velocity. The first two terms on the left side of Equation (I.3) are the transient components of the axial pressure gradient.

Appendix A presents a derivation of a more complete transverse momentum equation that more properly accounts for the crossflow momentum coupling. For two adjacent subchannels this equation can be written as

$$\frac{\partial w_{ij}}{\partial t} + \frac{(u^*_{ij} w_{ij})}{\partial x} + \left(\frac{s}{\ell}\right) C_{ij} w_{ij} = \left(\frac{s}{\ell}\right)(p_i - p_j) \qquad (I.4)$$

The first two terms represent the temporal and spatial acceleration (1) of the crossflow. The remaining two terms are the friction and pressure terms used in an earlier transverse momentum equation.(Ref. 5,6,7) The new parameter (s/1) represents the importance of friction and pressure terms versus the inertial terms. These inertial terms also represent the transport of the crossflow at axial velocity u^*_{ij} . These terms cause the crossflows to persist as they move down the channel. This is the "axial inertia" effect often included in crossflow resistence correlations.(Ref. 6,10) The friction term is a linearized representation of fluid friction; however, COBRA IIIc/MIT presently considers C_{ij} to be a nonlinear function that depends on the absolute value of the diversion crossflow.

The primary assumption used to derive Equation (I.4) is that the crossflow through a rod gap loses its sense of direction upon enering or leaving a subchannel and that the difference in lateral momentum flux is small. The direction of the crossflow is only considered between the two interconnecting subchannels of interest. This assmption is valid if the crossflow velocities are small compared to the axial velocities. This is usually the case for most computations in nuclear rod bundles.

An equation of state of the form

$$\rho_i = \rho(h_i, p^*, m_i, x, t) \qquad (I.5)$$

is used to define the two-phase fluid density. This equation can be obtained by using an appropriate correlation for void fraction. Selection of the appropriate correlation for the case being analyzed is left to the user. Several void fraction correlations are provided as options in the code.

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(1) A term analogous to $\partial(\rho v^2)/\partial y$ has been ignored in relation to a term analogous to $\partial(\rho uv)/\partial x$ by the assumption of small crossflow velocity. This can be justified by an order of magnitude analysis

For a large rod bundle the previous equations become unwieldy; therefore, a more compact form is very desirable. Reference 7 presents a vector form of the equations by using a matrix transformation [S] and its transpose $[S]^T$. Using the [S] transformation the previous equations may be written as follows:

Continuity

$$\left\{A\frac{\partial \rho}{\partial t}\right\} + \left\{\frac{\partial m}{\partial x}\right\} = -[S]^T\{w\} \tag{I.6}$$

Energy

$$\left\{\frac{m}{u''}\frac{\partial h}{\partial t}\right\} + \left\{m\frac{\partial h}{\partial x}\right\} = \{q'\} - [S]^T[\Delta h]\{w'\} - [S]^T[\Delta t]\{c\} + [h][S]^T\{w\} - [S]^T[h^*]\{w\} \tag{I.7}$$

Axial Momentum

$$\left\{\frac{1}{A}\frac{\partial m}{\partial t}\right\} - \left\{2u\frac{\partial \rho}{\partial t}\right\} + \left\{\frac{\partial \rho}{\partial x}\right\} = \{a'\} + [A]^{-1}\Big[[2u][S]^T - [S]^T[u^*]\Big]\{w\} \tag{I.8}$$

Transverse Momentum

$$\left\{\frac{\partial w}{\partial t}\right\} + \left\{\frac{\partial (u^* w)}{\partial x}\right\} + \left(\frac{s}{\ell}\right)\{cw\} + \left(\frac{s}{\ell}\right)[S]\{p\} \tag{I.9}$$

where

$$\{a'\} = \left\{\left(\frac{m}{A}\right)^2\left(\frac{vf\phi}{2D} + \frac{Kv'}{2\Delta x} + A\frac{\partial (v'/A)}{\partial x}\right) + \rho\cdot\cos\right\} - f_T[A]^{-1}[S]^T[\Delta u]\{w'\} \tag{I.10}$$

The elements of the matrix [S] are defined through two column vectors i(k) and j(k) where, for each pair of connected subchannels (i,j), a unique connection (or gap) number k is assigned. The connection numbers are assigned in ascending order by considering Subchannel (i) and then assigning a unique connection number for each successively connected Subchannel (j) where j is greater than i. By using this identification procedure the crossflows can be written as w_k where k implies the subchannel pair i(k), j(k). For $w_k > 0$ the crossflow is chosen to be from Subchannel (i) to Subchannel (j) where i is less than

j. The elements of the matrix [S] are defined as: $S_{ki}=0$; except, $S_{ki}=1$, if $i=i(k)$; and $S_{ki}=-1$, if $i=j(k)$.

I.3 METHOD OF SOLUTION

The previous equations are solved as a boundary-value problem by using a semiexplicit finite difference scheme. The boundary conditions selected for the problem are the inlet enthalpy, inlet flow, inlet crossflow, and exit pressure. Initial conditions for enthalpy, flow, and crossflow distribution are established from an initial steady-state calculation. No inlet condition for pressure is required as it is determined from the other boundary conditions and resulting solution. Solving the problem this way is an improvement over the initial-value solutions that are used in many subchannel analysis computer programs. While the use of the initial value solution can be justified as an approximation to the boundary-value solution if the crossflow resistance is small, it restricts the solutions to a limited class of problems.

Equations (I.6) through (I.9) are solved by using a finite difference procedure. Finite difference node interfaces are numbered starting at the inlet end of each node. The location at the end of the last node is N+1 where N is the number of nodes. Enthalpy, flow, pressure and crossflow are defined at the node interfaces. Boundary conditions for enthalpy, flow and crossflow are set at the channel inlet (J=1) and the exit pressure boundary condition set at the channel outlet (J=N+1). The distance x=0 corresponds to J=1 and x=L corresponds to J=N+1. The finite difference scheme is written for an interval J-1 to J corresponding to x_{j-1} and x_j respectively.

The finite difference analogs to Equations (I.6) through (I.9) are: (1)

Continuity

$$\left\{A_J \frac{\rho_J-\bar{\rho}_J}{\Delta t}\right\} + \left\{\frac{m_J - m_{J-1}}{\Delta x}\right\} = -[S]\left\{w_J\right\} \tag{I.11}$$

---

(1) The overscore bar ($^{-}$) indicates previous time.

Energy

$$\left\{\frac{1}{u''_j}\ \frac{h_j - \bar{h}_j}{\Delta t}\right\} + \left\{\frac{h_j - h_{j-1}}{\Delta x}\right\} = [m_{j-1}]^{-1} \Big\{ q_{j-1/2} - [S]^T [\Delta h_{j-1}]$$

$$\{w'_{j-1}\} - [S]^T [\, t_{j-1}] \{c_{j-1}\} + \Big[[h_{j-1}] [S]^T - [S]^T [h^*_{j-1}] \Big] \{w_{j-1}\} \Big\} \tag{I.12}$$

Axial Momentum

$$\left\{\frac{1}{A_j}\ \frac{m_j - \bar{m}_j}{\Delta t}\right\} - \left\{2u_j\ \frac{p_j - \bar{p}_j}{\Delta t}\right\} + \left\{\frac{p_j - p_{j-1}}{\Delta x}\right\} =$$

$$\left\{a'_j\right\} + [A_j]^{-1} \Big[[2u_j]\ [S]^T - [S]^T\ [u^*_j] \Big] \left\{w_j\right\} \tag{I.13}$$

Transverse Momentum

$$\left\{\frac{w_j - \bar{w}_j}{\Delta t}\right\} + \left\{\frac{u^*_j w_j - u^*_{j-1} w_{j-1}}{\Delta x}\right\} + \left(\frac{s}{\ell}\right) \left\{C_j\ w_j\right\} = \left(\frac{s}{\ell}\right)\ [S] \left\{p_{j-1}\right\} \tag{I.14}$$

Equations (I.11), (I.13) and (I.14) can be combined to eliminate $\{P_{j-1}\}$ and $\{m_j\}$. Let $\{a'_j\}$ in equation (I.13) be written as

$$\left\{a'_j\right\} = \left\{K_j m_j^{\ 2}\right\} - \left\{f_j\right\} \tag{I.15}$$

where K_j represents coefficient of the flow-squared terms and $\{f_j\}$ are the remaining terms of $\{a'_j\}$. Now let

$$\left\{m_j\right\} = \left\{m_{j-1} + \Delta m\right\} \tag{I.16}$$

where $\Delta m = -[S]^T \left\{w_j\right\} \Delta x - A_j (p_j - \bar{p}_j) \Delta x / \Delta t$ (I.17)

Squaring m_j gives

$$\left\{m_j^{\ 2}\right\} = \left\{m_{j-1}^{\ 2} + \left(2m_{j-1} + \Delta m\right) + \Delta m^2\right\} \tag{I.18}$$

Normally Δm^2 would be discarded as being small, however, for flow blockage analysis Δm can be as large as m. It can be retained by using the following form for Equation (I.18)

$$\left\{m_J^{\,2}\right\} = \left\{m_{J-1}^{2} + (2m_{J-1} + \Delta m)\,\Delta m\right\} \tag{I.18a}$$

and upon substituting Equation (I.16) it becomes

$$\left\{m_J^{\,2}\right\} = \left\{m_{J-1}^{2} + (m_{J-1} + \tilde{m}_J)\,\Delta m\right\} \tag{I.19}$$

The value of m_J on the right side is unknown but it can be initially estimated and updated through iteration. By using Equations (I.13), (I.15), and (I.19) the pressure at J-1 can be written as

$$\left\{P_{J-1}\right\} = \left\{P_J\right\} - \left\{F_J\right\}\Delta x - [R_J]\left\{w_J\right\}\Delta x \tag{I.20}$$

where

$$\begin{aligned}[R_J] = \; & [A_J]^{-1}\left[\left[2u_J + \frac{\Delta x}{\Delta t}\right][S]^T - [S]^T[u_J*]\right] \\ & \Delta x\,[K_J(m_{J-1} + m_J)]\,[S]^T\end{aligned} \tag{I.21}$$

and

$$\begin{aligned}\left\{F_J\right\} = & -\left\{K_J m^2_{J-1}\right\} - \left\{f_J\right\} + \left\{\frac{\bar{m}_J - m_{J-1}}{A_J\Delta t}\right\} \\ & + \left\{\left(\frac{\rho_J - \bar{\rho}_J}{\Delta t}\right)\left(2u_J + \frac{\Delta x}{\Delta t} + \Delta x K_J\, A_J\,(m_{J-1} + m_J)\right)\right\}\end{aligned} \tag{I.22}$$

The pressure difference between subchannels can now be written as

$$[S]\left\{p_{J-1}\right\} = [S]\left\{p_J\right\} - [S]\left\{F_J\right\}\Delta x - [S]\,[R_J]\left\{w_J\right\}\Delta x \tag{I.23}$$

Substituting this result into Equation (I.14) to eliminate $[S]\{P_{j-1}\}$ gives a set of simultaneous equations of the form

$$[M_J]\left\{w_J\right\} = \left\{b_J\right\} \tag{I.24}$$

where

$$[M_J] = \left[\frac{1}{\Delta t}\right] + \left[\frac{u_J^*}{\Delta x}\right] + \left(\frac{s}{\ell}\right) [C_J] + \left(\frac{s}{\ell}\right) [S] [R_J] \Delta x \qquad (I.25)$$

and

$$\left\{b_J\right\} = \left\{\frac{\bar{w}_J}{\Delta t}\right\} + \left\{\frac{(u^*w)_{J-1}}{\Delta x}\right\} + \left(\frac{s}{\ell}\right) [S] \left\{p_J\right\} - \left(\frac{s}{\ell}\right) [S] \left\{F_J\right\} \Delta x \qquad (I.26)$$

The first three items on the right side of Equation (I.25) are diagonal matrices. The first two of these come from the added temporal and spatial acceleration terms in the transverse momentum equation. They are also very important as they provide additional numerical stability. Reducing Δx and Δt adds more diagonal dominance and thus more stability to the numerical solution. However, beyond a certain value reducing the mesh size may begin to increase the number of iterations required to achieve convergence due to the marching solution proceedure. As in earlier difference schemes (Ref. 5,6,7) the last term on the right side of Equation (I.25) includes a matrix which is singular for any rod bundle problem with a lateral transverse flow loop. The additional terms in Equation (I.25) remove the singularity and thus allow a unique solution for the crossflow. Two additional terms are included in Equation (I.21), one is a term to account for the axial friction pressure loss at x_j. This is a very important term for flow blockage analysis because it allows the calculation to look downstream and account for a sudden large change in the friction pressure gradient. The other term Δx/Δt in Equation (I.21) accounts for rapid changes in the flow m_j.

The matrix [M] controls the distribution of crossflow; however, the vector (b) contains the crossflow forcing terms. The first two terms on the right side of Equation (I.26) try to maintain the crossflow that existed at previous time or space. If other forces did not exist, crossflow would tend to persist. The third term is the pressure difference affecting the crossflow. This is also the term that feeds downstream information into the crossflow solution. The fourth term provides the basic driving force for crossflow. If the pressure gradients due to friction, acceleration and gravity are unbalanced, crossflows occur in an attempt to equalize them.

I.4 DISCUSSION OF PARAMETERS (from Reference 2)

Solutions to the previous set of equations require a certain amount of empirical information. Because of the incomplete knowledge of steady state and transient two-phase flow in bundles some of this information must be supplied by assumption. For example, h* and u* are commonly assumed to be their respective values from the donor subchannels. Other selections of u* and h* may be made(Ref. 11) to account for the nonuniform enthalpy distribution in a subchannel. This usually requires information about the liquid-and-vapor-phase distribution. The factor f_T used to account for the imperfect analogy between eddy diffusivity of heat and momentum is also unknown but its effect is weak. For many problems f_T can be safely set equal to zero.(Ref. 5) The correlations required for calculating the pressure gradient are of major importance. This includes the correlations for friction factor, subcooled void fraction, bulk void fraction and two-phase friction multiplier. Fortunately, correlations of these effects developed for simple channels (Ref. 12-15) may be applied to rod bundle subchannels for steady state with reasonably good results (Ref. 16-18). Since their accuracy is questionable for high speed transients, additional experimental work is needed in this area. Turbulent mixing must also be specified from empirical correlations or data. At the present time a definitive correlation for mixing does not exist for all bundle geometries and all flow conditions. Some progress has been made to describe mixing for single (Ref. 19,20,21) and two-phase (Ref. 11,17,18) flow; however, very little is known about two-phase mixing processes during transients.

The transverse momentum equation and fuel heat transfer model add still more parameters to the subchannel analysis method. These parameters and their effect on typical rod bundle calculations are discussed in the succeeding sections.

I.5 TRANSVERSE MOMENTUM EQUATION PARAMETERS (from Reference 2)

The transverse momentum equation introduces the parameter (s/l) and also underscores importance of the terms u* and C. Some insight concerning the importance of these parameters can be found by inspecting the finite difference form of the combined transverse momentum equation, Equation (I.24). For discussion purposes, consider the matrix [M] for two interconnected subchannels of equal area. (1) The matrix has only one element given by

$$m = \frac{1}{\Delta t} + \frac{u^*}{\Delta x} + \left(\frac{s}{\ell}\right) C + \left(\frac{s}{\ell}\right) \frac{2u^*}{A} \Delta x \qquad \text{(I.27)}$$

---

(1) A similar equation for unequal areas shows that a sign change leading to instabilities can occur depending upon the subchannel velocities and flow areas. This is a source of computation failure of COBRA IIIc/MIT when subchannel areas are highly nonuniform.

where u* is the average of the two subchannel velocities. The relative importance of the terms can be controlled by arbitrarily selecting Δx. The second and fourth terms can be made comparable magnitude by selecting $s/l = 1/2$ and $\Delta x^2 = A$ which usually requires $\Delta x < 0.5$ inch for typical nuclear reactor rod bundle problems. A larger value of Δx is normally used as it reduces computation time for long bundles. In those cases the last term is the largest one. The smallest term is usually the transverse friction term, C. It contains the friction coefficient K_{ij} which could be expected to be on the order of unity or less. This friction coefficient does not include an "axial inertia" term contained in some previous crossflow resistance correlations. (Ref. 19,10) It is improper to use those correlations here because the "axial inertia" effect is contained in the transverse momentum term $u^*/\Delta x$. This can be seen by writing the pressure difference $P_i - P_j = u^* dw/dx$. If dw is approximated by w and if dx is approximated by an appropriate length, then, $P_i - P_j \propto (u^*/v)v^2$ and the resistance coefficient due to axial inertia is proportional to u^*/v. This ratio is large for small crossflow velocity. The same result is reported in a combined momentum and friction crossflow correlation by Khan (Ref. 10) at large values of u^*/v. At small values of u^*/v Khan's correlation reduces to $K_{ij} \approx 0.25$ which would presumably be an estimate of the friction coefficient for pure crossflow. This discussion points out the usual dominance of $u^*/\Delta x$ over $(s/l)C$. The values of C are therefore relatively unimportant for most problems. This conclusion may not be true, however, for very closely spaced rod bundles since C is believed to be nearly inversely proportional to the square of the gap spacing.

The (s/l) parameter appears in all but the transverse momentum terms; therefore, as long as $u^*/\Delta x$ and $1/\Delta t$ are small components of [M], (s/l) is a weak parameter. Since this is usually the case for the value of Δx used in rod bundle analysis (s/l) need not be specified to high accuracy. For core-wide analysis of pressurized water reactors this conclusion may not be valid because Δx^2 may be small compared to A.

The velocity u* appears in the transverse and axial momentum terms. Since these are usually the the largest components of [M], u* could have a stronger effect on crossflow solutions than the previously discussed parameters. The choice of u* must presently be made by assumption because of insuficient data to define it accurately. Fortunately, a variety of assumptions can be made that give comparable values of u*. This is because most bundles have rather uniform subchannel velocity distributions. The most serious errors in u* could ocur where large subchannel velocity differences occur. In those cases the effect of the u* assumption should be checked.

The previous comments concerning the usually small magnitude of $u^*/\Delta x$ and C does not mean that they can be dropped from the calculations. They play a vital role in the numerical stability. As discussed previously, part of the matrix [M] is a singular matrix for any problem where one or more transverse flow loops exist such as around a fuel rod. In those cases the crossflow around the loop is not unique. Including $u^*\Delta x$ and C removes the singularity by imposing the friction and momentum constraint that the sum of the pressure drop around a transverse loop is equal to zero. Mathematically these terms add diagonal dominance to [M], thus, improve the condition of [M]. The diagonal dominance can be improved by decreasing Δx.

I.6 THREE APPROACHES FOR COBRA IIIC/MIT-2 (from Reference 3) TRANSVERSE MOMENTUM MODELING

Weisman (Ref. 22) has suggested that the transverse momentum paramaters used in COBRA IIIc/MIT, s/l and K_{ij}, should be modified when the code is used for analysis cases involving interconnected regions of different size. This suggestion has also been made by Chiu (Ref. 23). COBRA IIIc/MIT-2 provides the option of using the Weisman and Chiu approaches in addition to the old COBRA approach for transverse momentum modeling.

I.6.a The COBRA IIIc/MIT-1 Approach

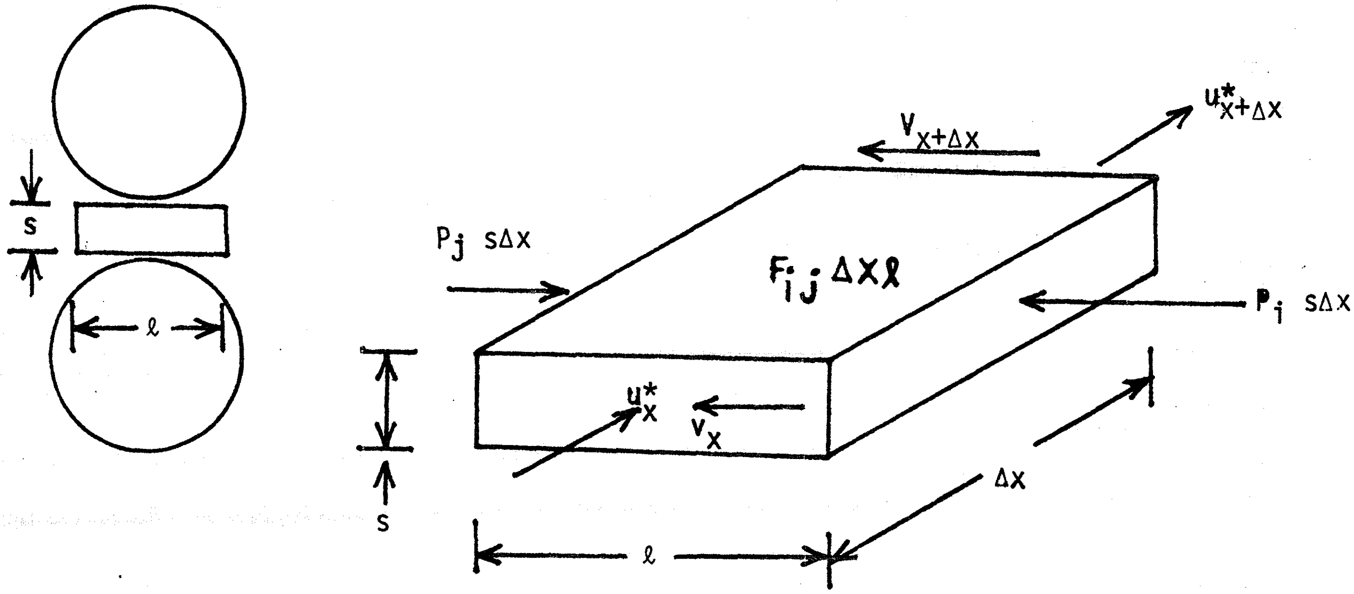


Figure 2: COBRA Transverse Momentum Control Volume

The old COBRA approach (Ref. 2) is based on conserving transverse momentum in a control volume for the gap between two subchannels as shown in Figure 2. By conservation of momentum, the following equation is obtained:

$$\frac{\partial}{\partial t}[W_{ij}] + \frac{\partial(u^* W_{ij})}{\partial x} = \frac{s}{\ell}(P_i - P_j) - F_{ij} \qquad (I.28)$$

where

$$F_{ij} = \frac{K|W_{ij}|W_{ij}}{2(S_{ij})^2\rho^*}\frac{s}{\ell} \qquad (I.29)$$

and

W_{ij} = diversion crossflow between subchannels i and j (lbm/hr ft)

u^* = effective velocity carried by diversion crossflow (ft/sec)

x= axial distance (ft)

s = width of gap between rods (ft)

l = effective length of connection between subchannels (ft)

P_i = pressure in channel i (lbf/ft^2)

P_j = pressure in channel j (lbf/ft^2)

K = crossflow coefficient (dimensionless)

S_{ij} = total gap width connecting channels i and j (S_{ij} = s for subchannel analysis) [ft]

ρ^* = density of the diversion crossflow (lbm/ft^3)

I.6.b The Weisman Approach (from Reference 3)

The Weisman approach (Ref. 22) casts the transverse momentum equation in a more general form, allowing interconnection of different-sized channels.

$$\frac{\partial}{\partial t}[W_{ij}] + \frac{\partial(u^* W_{ij})}{\partial x} = \left(\frac{S}{L}\right)_{ij}(P_i - P_j) - F_{ij} \qquad (I.30)$$

where

$$F_{ij} = \frac{K|W_{ij}|W_{ij}}{2(S_{ij})^2\rho^*} \left(\frac{S}{L}\right)_{ij}(N_r)_{ij} \qquad (I.31)$$

and

$$S_{ij} = (N_g)_{ij}s \qquad (I.32)$$

$$L_{ij} = (N_r)_{ij}\ell \qquad (I.33)$$

where

$(N_g)_{ij}$ = number of gaps through which flow between channels i and j takes place

(N_r) = number of rods between centers of channels i and j.

For subchannel or bundle-to-bundle analysis, $N_g = N_r$ for all flow region interconnections. Thus, the Weisman approach reduces to the old COBRA approach for such analyses. Figure 3 shows two interconnected regions of different size, a situation where the Weisman approach applies.

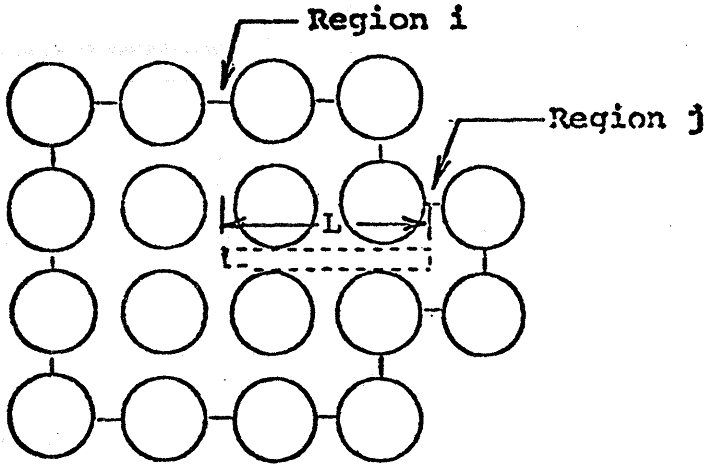


Figure 3: Transverse Momentum Control Volume for Weisman Approach

I.6.c The Chiu Approach (from Reference 3)

The Chiu approach (Ref. 23) differs from the Weisman approach in the control volume used. Chiu uses the interaction of the adjacent rows of subchannels of two regions to represent the interaction between two regions, as shown in Figure 4. This approach uses the following transverse momentum equation.

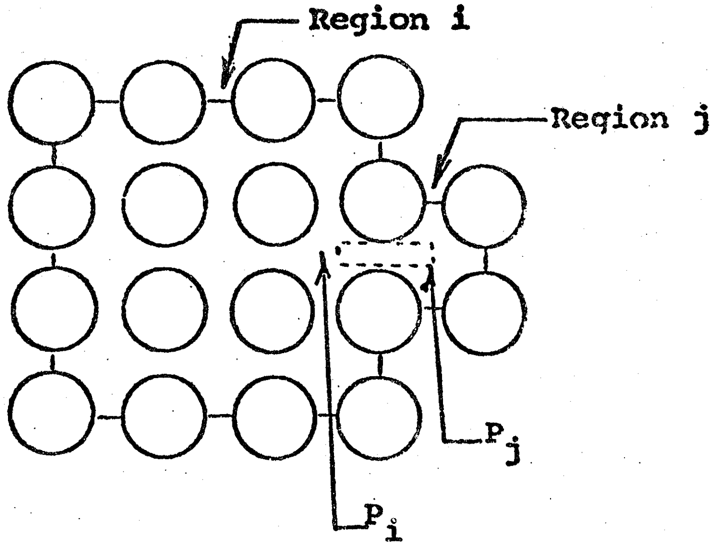


Figure 4: Transverse Momentum Control Volume for Chiu Approach

$$\frac{\partial}{\partial t}[W_{ij}] + \frac{\partial(u^*W_{ij})}{\partial x} = \frac{S_{ij}}{\ell}\,\frac{(P_i - P_j)}{(N_p)_{ij}} - F_{ij} \tag{I.34}$$

where

$$F_{ij} = \frac{K|W_{ij}|W_{ij}}{2(S_{ij})^2\rho^*}\,\frac{S_{ij}}{\ell} \tag{I.35}$$

and

$$(N_p)_{ij} = \frac{(P_i - P_j)}{(p_i - p_j)} \tag{I.36}$$

where

$(N_p)_{ij}$ = the pressure transport coefficient for subchannels adjacent to the boundary between subchannels i and j.

P_i = pressure in interacting subchannel(s) of channel i adjacent to gap interconnection ij (lbf/ft^2).

P_j = pressure in interacting subchannel(s) of channel j adjacent to gap interconnection if (lbf/ft^2).

During the development of the single-pass method (Ref. 24), use of the pressure transport coefficient was found to have little effect upon COBRA IIIc/MIT enthalpy predictions, especially in comparision to changes resulting from use of an enthalpy transport coefficient in COBRA's energy equation. Both pressure and enthalpy transport coefficients were found to be unnecessary for single-pass MDNBR analysis under conditions without strong crossflow.

I.6.d The Combined COBRA IIIc/MIT-2 Approach (new)

By noting the similarities between the three approaches, a combined set of equations was derived.

$$\frac{\partial}{\partial t}[W_{ij}] + \frac{\partial(u^*W_{ij})}{\partial x} = (f_{s\ell})_{ij}\,\frac{s}{\ell}(P_i - P_j) - F_{ij} \tag{I.37}$$

$$F_{ij} = \frac{K|W_{ij}|W_{ij}}{2(S_{ij})^2\rho^*}\,\frac{s}{\ell}(f_{s\ell k})_{ij} \tag{I.38}$$

By proper selection of the constants, $(f_{s\ell})_{ij}$ and $(f_{s\ell k})_{ij}$ any of the three models can be used,

For the Weisman approach,

$$(f_{s\ell})_{ij} = (\frac{N_g}{N_r})_{ij} \tag{I.39a}$$

$$(f_{s\ell k})_{ij} = (N_g)_{ij} \tag{I.39b}$$

For the Chiu approach,

$$(f_{s\ell})_{ij} = \frac{(N_g)_{ij}}{(N_p)_{ij}} \tag{I.40a}$$

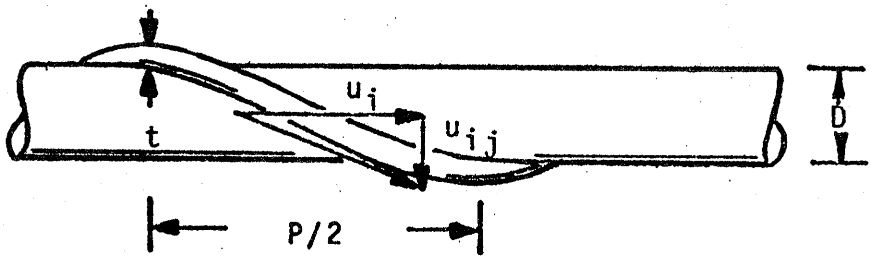
$$(f_{s\ell k})_{ij} = (N_g)_{ij} \tag{I.40b}$$

When a user does not select the new transverse momentum option, the $f_{s\ell}$ and $f_{s\ell k}$ factors are set to unity and the old COBRA approach will be used.

I.7 FORCED CROSS FLOW MIXING (from Reference 2)

The previous finite difference scheme allows forced diversion cross- flows to be specified. This feature allows the effects of forced flow diverter vanes and forced crossflow mixing from wire wrapped bundles to be considered.

COBRA IIIc/MIT includes a forced crossflow mixing model which was originally developed for the COBRA II program(Ref. 6) but not published. Initial calculations with COBRA II were not entirely satisfactory because the numerical solution was not a boundary-value flow solution. The absence of the boundary-value solution allowed crossflows to increase fictitiously around the periphery of a bundle as the bundle size was increased. The method of solution did not allow the forced flow diversions to redistribute flow axialy. The boundary-value solution used in COBRA IIIc/MIT allows these calculations to be included on a more realistic basis. The following model is the one contained in COBRA IIIc/MIT-2.



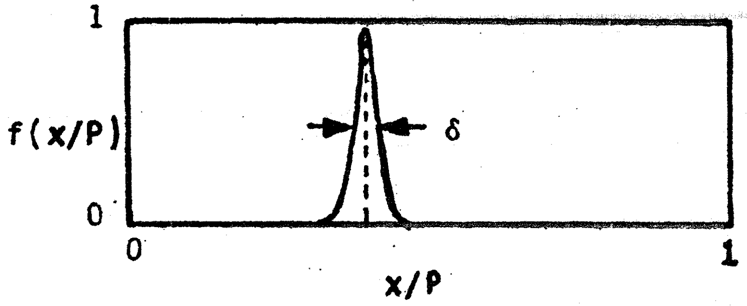
Consider the wire wrap as it passes from one subchannel to another as shown in the sketch. Where the wrap crosses the minimum part of the gap the slope of the wrap imposes a transverse velocity given by

$$u_{ij} = \pi \frac{D+t}{P} u_i \tag{I.41}$$

If this is multiplied by the fluid density and gap spacing the crossflow per unit length becomes

$$w_{ij} = \rho_i s_{ij} u_{ij} = \pi\left(\frac{D+t}{P}\right)\left(\frac{s_{ij}}{A_i}\right) m_i \qquad (I.42)$$

This equation applied at the gap only. When the wrap is sufficiently far away from the gap it probably has little or no effect on forcing flow through the gap in question. It is now postulated that there is some function f(x/P) that periodically defines the importance of Equation (I.42) for defining the forced crossflow through a chosen gap. This function may look something like the one in the following sketch.



The rise in the function represents the approach of the wire toward the gap. The function peaks at 1.0 according to Equation (I.42) and then decays as the wrap moves away from the gap. The area under the curve represents the fraction of flow diverted through the gap as compared to the total possible flow that could be carried by a wrap over an entire pitch length. Since the shape of this function is not known, the pulse is assumed to be a rectangular pulse with width δ. The forcing function is then f(x/p) = 0, except for

$$f(x/p) = 1 \; ; \; (x_c/P - \delta/2) \leq x \leq (x_c/P + \delta/2) \qquad (I.43)$$

For computations in COBRA IIIc/MIT it is presently assumed that the flow carried through a gap by a wrap occurs over one node length, Δx. The total flow diverted is; therefore,

$$w\delta p = \pi\left(\frac{D+t}{p}\right)\left(\frac{s_{ij}}{A_i}\right) m_i \delta P \qquad (I.44)$$

Dividing this by Δx gives the crossflow per unit length over one node length

$$w_{forced} = \frac{w\delta p}{\Delta x} = \pi\ (D+t) \left(\frac{s_{ij}}{A_i}\right) \left(\frac{\delta}{\Delta x}\right)\ m_i\ ;\ x-\Delta x<x_c<x \qquad (I.45)$$

This equation shows that a fraction of the subchannel flow m is diverted from one subchannel to another when a wrap crosses a gap at axial position x_c when $x-\Delta x \leq x_c < x$.

The calculations also correct the subchannel flow area and wetted perimeter for the number of wraps in a subchannel at each axial position.

The specified value of forced crossflow is included by simply modifying Equation (I.24). Suppose the crossflow in gap ℓ is to be specified. First the right side (b) must be modified. For each k = ℓ

$$b_{k_{mod}} = b_k - M_{k\ell}\ w_{\ell_{forced}} \qquad (I.46)$$

and for k = 1

$$b_{k_{mod}} = w_{\ell_{forced}} \qquad (I.47)$$

The matrix [M] is modified by setting row ℓ and column ℓ equal to zero except $M_{\ell\ell}$ = 1. As an example if $\ell = 3$ the matrix modification would be that shown in Figure 5. The same procedure applies if more than one crossflow is being forced.

Forced crossflow mixing due to diverter vanes is considered in much the same way. When subchannel grid spacer losses are specified for input to COBRA IIIc/MIT, a flow diversion fraction is specified where the fraction is defined by the ratio $w_{ij}\,\Delta x/m_i$ if $w_{ij} > 0$ and $w_{ij}\ \Delta x/m_j$ if $w_{ij} < 0$.

The previous method of considering forced crossflow should be considered tentative until experimental data are available to check the validity.

I.8 COMPUTATION PROCEDURE

Steady-state computations are performed first to obtain initial conditions for the transient. Since the previously presented finite difference equations are stable for large time steps, those same equations are used for the steady state calculations by setting Δt equal to some arbitrarily large value.

$$\begin{bmatrix} M_{11} & M_{12} & 0 & M_{14} & --- & M_{1n} \\ M_{21} & M_{22} & 0 & M_{24} & --- & M_{2n} \\ 0 & 0 & 1 & 0 & --- & 0 \\ M_{41} & M_{42} & 0 & M_{44} & --- & M_{4n} \\ - & - & 1 & - & & - \\ - & & 1 & - & & - \\ - & & 1 & - & & - \\ Mn1 & & & & & Mnn \end{bmatrix} \begin{Bmatrix} w_1 \\ w_2 \\ w_3 \\ w_4 \\ \\ \\ \\ wn \end{Bmatrix} = \begin{Bmatrix} b_1 - M_{13}\, w_{3_{forced}} \\ b_2 - M_{23}\, w_{3_{forced}} \\ w_{3_{forced}} \\ b_4 - M_{43} w_{3_{forced}} \\ - \\ - \\ - \\ b_n - M_{n3}\, w_{3_{forced}} \end{Bmatrix}$$

FIGURE 5: The Matrix [M] Modified for Forced Cross Flow Mixing with $\ell = 3$

An iteration is performed until convergence of the flow solution is obtained. Convergence is achieved when the change in any subchannel flow is less than a user selected fraction of the flow from the previous iteration.

For each iteration the computation sweeps from the inlet to the exit of the channel. With inlet boundary information on flow, crossflow and enthalpy given, the enthalpy can be advanced one space step by using Equation (I.11). For the first iteration the flow $\{m_j\}$ is set equal to $\{m_{j-1}\}$ otherwise the value from the previous iteration is used. The crossflow solution is performed by solving Equation (I.24) with the previous iterate value of the subchannel difference $[S]\{p_j\}$. After the crossflow $\{w_j\}$ is calculated, $\{m_j\}$ is calculated using equation (I.11), and $[S]\{p\}$ is calculated from Equation (I.23) and saved for use during the next iteration. Note that $[S]\{p_j\}$ is downstream of $[S]\{p_{j-1}\}$; therefore, iteration allows the downstream pressure differences to be felt at upstream locations. At the end of the channel the boundary condition is that the pressure difference between the channels is zero (i.e. $[S]\{p\} = 0$). In this way a boundary value solution is obtained. Only a few iterations are sufficient for convergence because the pressure difference $[S]\{p\}$ only propagates a few nodes for most problems.

The above equations do not require actual pressure since pressure difference is only used in the combined momentum equation. The calculation of pressure is, therefore, only a back calculation. It is calculated from Equation (I.13) in a forward direction. When the exit is reached the pressures are set equal to the exit pressure.

Transient calculations are performed in the same way but for a selected time step Δt. Boundary conditions and other forcing functions are set to their desired values at the new time; then, the calculation sweeps through the channel for the number of iterations required to achieve convergence on the crossflow. The converged solution is used for the new initial condition and the procedure continues for all time steps.

II. COMPUTER PROGRAM DESCRIPTION

COBRA IIIc/MIT-2 should be thought of as an automated solution to the basic set of differential equations of the mathematical model. To actually perform this solution, the user must provide input. This input not only includes the geometric parameters and operating conditions, but also the various required empirical or semiempirical correlations. Any set of correlations can give a solution, but some correlations will give better solutions. At the present time, guidelines have not been established for complete selection of these correlations; therefore, the COBRA IIIc/MIT-2 program does not contain a pre-selected set of input correlations. Several correlations are provided for examples, but the final selection must be made by the user. Considerable work is required to define correlations and flow modeling applicable to rod bundle transients. The applicability of the two-phase flow model should always be evaluated by the user. Users should also justify use of COBRA for any analysis outside the range of experimental verification. Experiments may be required in some cases to verify application of COBRA.

The following sections present the general features of the COBRA IIIc/MIT-2 program, an illustrated description of the program organization and a description of the program's subroutines.

II.1 GENERAL FEATURES (from Reference 2)

The significant features of COBRA IIIc/MIT include the following:

- It considers both steady-state and transient flow in rod bundle fuel elements.
- It performs a boundary-value flow solution that permits the influence of downstream flow disturbances to be felt upstream.
- It can consider both single- and two-phase flow.
- It considers the effects of turbulent and thermal conduction mixing throughout the bundle by using empirically determined mixing coefficients.
- It includes mixing which results from the convective transport of enthalpy by diversion crossflow.
- It includes the momentum transport between adjacent subchannels which results from both turbulent and diversion crossflow.
- It includes the effect of temporal and spatial acceleration in the transverse momentum equation.
- It includes the effect of transverse resistance to diversion crossflow.
- It can consider an arbitrary layout of fuel rods and flow subchannels for analysis of most any rod bundle

configuration. A single subchannel may interact with up to four adjacent subchannels, and a fuel rod may transfer heat to a maximum of six adjacent subchannels.
- It can include arbitrary heat flux distribution by specifying the axial flux distribution, relative rod power, and the fraction of rod power to each of the six adjacent subchannels. (The latter feature allows variation in circumferential rod heat flux.)
- It can consider time varying fuel rod temperatures.
- It can consider variable subchannel area and gap spacing.
- It can consider nonuniform hydraulic behavior by assigning different single-phase friction factors to selected subchannels.
- Its subroutines are designed to allow the user to set up empirical correlations of his choice and then select these correlations through input options.
- It includes options to select arbitrary subchannel inlet flow and enthalpy.
- It can consider forced crossflow mixing due to diverter vanes or wire wrap spacers.
- The numerical solution allows analysis of partial flow blockages in rod bundles.

II.2 COMPUTER PROGRAM CORRELATIONS AND MODELS

To carry out a solution, empirical and semiempirical correlations must be selected for input to the computer program.

II.2.a FRICTION FACTOR (from Reference 1)

The friction factor correlation is assumed to be of the form (Ref. 12)

$$f_i = a(R_{e_i})^b + c \qquad \text{(II.1)}$$

where a,b, and c are specified constants that depend upon the subchannel roughness and geometry. Since these constants can be influenced by different subchannel roughnesses and the pitch-to-diameter ratio,(Ref. 16) the program can accept up to four sets of constants that correspond to four subchannel types which may be assigned to the subchannels of the bundle. For example, subchannels next to a flow housing may be given a different friction factor from those subchannels within the bundle.

The friction factor is also corrected for wall viscosity by using the relationship (Ref. 16)

$$\frac{f}{f_{iso}} = 1 + \frac{P_h}{P_w}\left[\left(\frac{\mu_{wall}}{\mu_{bulk}}\right)^{.6} -1\right] \qquad (II.2)$$

where μ_{wall} is evaluated at the wall temperature which is calculated from

$$t_{wall} = t_{bulk} + \frac{q'}{P_h h} \qquad (II.3)$$

This correction is based on the assumption of the total perimeter consisting of two regions--one heated and the other unheated and also that the heated portion has uniform heat flux. The heat transfer coefficient is calculated from

$$\frac{hD}{k} = 0.023 \left(\frac{GD}{\mu}\right)^{0.8} \left(\frac{C_p\mu}{k}\right)^{0.4} \qquad (II.4)$$

where bulk fluid properties are used.

II.2.b TWO-PHASE FRICTION MULTIPLIER (from Reference 2)

Several correlations are available for the two-phase friction multiplier. Four are presently included in the program.

Homogeneous Model

$$\begin{aligned} \phi &= 1.0 && X < 0. \\ \phi &= \frac{\rho_f}{\rho} && X > 0. \end{aligned} \qquad (II.5)$$

Armand (Ref. 13)

$$\begin{aligned} \phi &= 1.0 && \alpha \le 0 \\ \phi &= \frac{(1-X)}{(1-\alpha)^{1.42}} && 0.39 < (1-\alpha) \le 1.0 \\ \phi &= 0.478\,\frac{(1-X)^2}{(1-\alpha)^{2.2}} && 0.1 < (1-\alpha) \le 0.39 \\ \phi &= 1.730\,\frac{(1-X)^2}{(1-\alpha)^{1.64}} && 0. < (1-\alpha) \le 0.1 \end{aligned} \qquad (II.6)$$

Baroczy

$$\Phi = \Phi^2_{fo} \quad \Omega \tag{II.7}$$

where $\Phi^2_{f\rho}$ is read from Figure 6, and Ω is read from Figure 7. These figures have been tabulated into data arrays in subroutine BAROC and values between those in the table are found by linear interpolation.

Polynomial Function

$$\begin{aligned} \phi &= 1.0 & X &< 0 \\ \phi &= a_0 + a_1 X + a_2 X^2 + \ldots a_n X^n & X &> 0 \end{aligned} \tag{II.8}$$

where the coefficients are supplied as input.

II.2.c SPACER LOSS COEFFICIENT (from Reference 2)

The pressure drop from spacers is lumped into an effective loss coefficient which may be defined (Ref. 16) in terms of all liquid flow as

$$\Delta P = \frac{K}{2\rho} \left(\frac{m}{A}\right)^2 \tag{II.9}$$

For two-phase flow, the same coefficient is used but it is modified by the two-phase specific volume for momentum. This pressure drop loss coefficient is converted to a pressure gradient loss coefficient at the location of the spacer by dividing by the calculation increment Δx; therefore,

$$K_i = \frac{K}{\Delta x} \tag{II.10}$$

This is the coefficient used in Equation (A.12).

II.2.d VOID FRACTION (from Reference 2)

Four methods are available for calculating the void fraction.

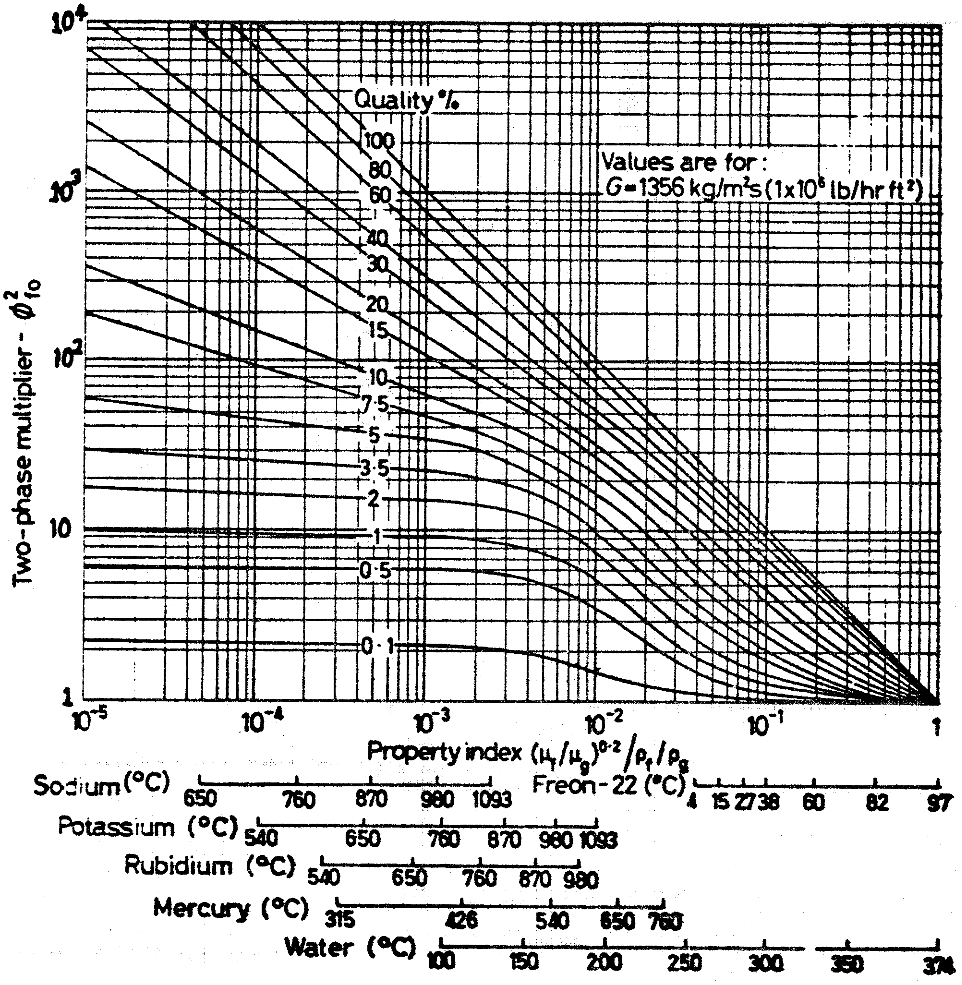


Figure 6: The Φ^2_{fo} Factor in the Baroczy Two-Phase Friction Multiplier Correlation (Eqn. II.7)

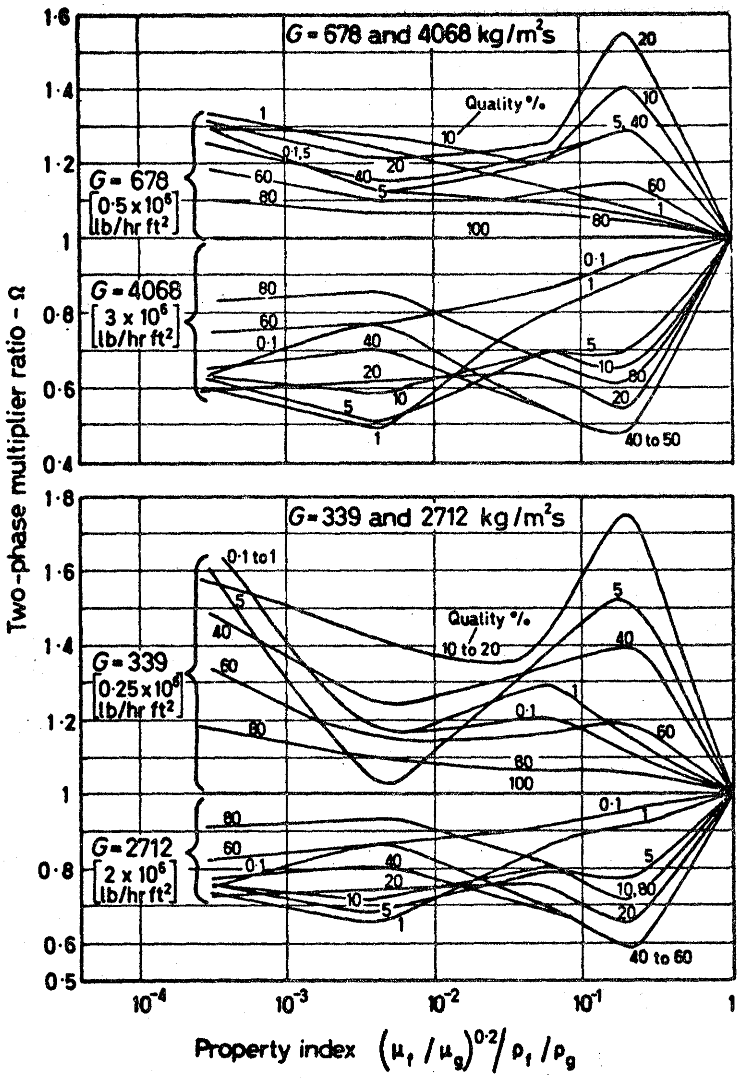


Figure 7: The Ω Factor in the Baroczy Two-Phase Friction Multiplier correlation (Eqn. II.7)

Homogeneous/Slip model

$$\alpha = 0. \qquad X \leq 0.$$

$$\alpha = \frac{Xv_g}{(1-X)v_f\gamma + Xv_g} \qquad X > 0. \tag{II.11}$$

where γ is the slip ratio. When the homogeneous model is selected, the slip ratio is set equal to 1.0. When the Slip Model is used the slip ratio can either be supplied as input, or calculated from the Smith Slip Ratio correlation

$$\gamma = 0.4 + 0.6 \left\{\frac{0.4 + x\,(\rho f/\rho g - 0.4)}{0.4 + 0.6x}\right\}^{1/2} \tag{II.12}$$

Modified Armand (Ref. 14)

$$\alpha = 0. \qquad X \leq 0$$

$$\alpha = \frac{(0.833+0.167X)Xv_g}{(1-X)v_f + Xv_g} + \qquad X > 0. \tag{II.13}$$

Polynomial Function

$$\alpha = 0. \qquad X < 0.$$

$$\alpha = a_o + a_1X + a_2X^2 + \ldots a_nX_x \qquad X > 0. \tag{II.14}$$

The maximum number of terms in the polynomial is limited to 7.

To specify a user supplied slip ratio, only one term in the polynomial is used and the slip ratio is set equal to that term.

II.2.e SUBCOOLED VOID FRACTION (from Reference 2)

Two options are presently included. Subcooled void formation may be ignored or it may be included by using Levy's subcooled void model.(Ref. 15) Levy's model calculates the true quality in terms of the equilibrium quality and the quality at which bubble departure starts. It is given by

$$X = 0. \qquad X_e < X_d$$

$$X = X_e - X_d\exp\left(\frac{X_e}{X_d} - 1\right) \qquad X_e/X_d < 1 \tag{II.15}$$

where X_e is the equilibrium quality and

$$X_d = -\frac{C_p \Delta T}{h_{fg}} \qquad \text{(II.16)}$$

$$\begin{aligned}
\Delta T &= \frac{q'}{P_h h} - QP_r Y_B && 0 < Y_B \leq 5 \\
\Delta T &= \frac{q'}{P_h h} - 5Q(P_r + \log(1 + P_r(\frac{Y_B}{5} - 1))) && 5 < Y_B \leq 30 \qquad \text{(II.17)} \\
\Delta T &= \frac{q'}{P_h h} - 5Q(P_r + \log(1 + 5P_r) + \frac{1}{2}\log(\frac{Y_B}{30})) && 30 < Y_B
\end{aligned}$$

$$Q = \frac{q'v}{P_h c_p} \frac{1}{\sqrt{\tau_w v'}} \qquad \text{(II.18)}$$

$$\tau_w = \frac{fv}{8}\left(\frac{m}{A}\right)^2 \qquad \text{(II.19)}$$

$$Y_B = \frac{0.015}{\mu}\sqrt{\frac{\sigma D}{v}} \qquad \text{(II.20)}$$

The heat transfer coefficient h is calculated from Equation (II.4). The use of Levy's model may not apply universally since the use of a single phase heat transfer coefficient is not always compatible with experimental measurements. (Ref. 25)

Experience has shown that the Levy subcooled void model makes convergence difficult if not impossible for some calculations. This effect results from the relatively large void fraction changes which can result from small changes in other flow parameters. The resulting oscillations in the thermal-hydraulic calculations are most severe for cases very close to saturated conditions.

II.2.f SINGLE PHASE TURBULENT MIXING (from Reference 2)

Several forms of equations for specifying the turbulent crossflow are included. The presently available forms in COBRA

IIIc/MIT for calculating w' include:

$$w'_k = \beta s_k G \tag{II.21}$$

$$w'_k = a \, Re^b s_k \, G \tag{II.22}$$

$$w'_k = a \, Re^b \, \bar{D} \, \bar{G} \tag{II.23}$$

$$w'_k = a \, Re^b \frac{s_k}{z_k} \bar{D} \, \bar{G} \tag{II.24}$$

where $Re = \dfrac{\bar{G} \, \bar{D}}{\bar{\mu}}$ (II.25)

$$\bar{D} = 4 \, (A_{i(k)} + A_{j(k)})/(Pw_{i(k)} + Pw_{j(k)}) \tag{II.26}$$

$$\bar{G} = (m_{i(k)} + m_{j(k)})/(A_{i(k)} + A_{j(k)}) \tag{II.27}$$

$$\bar{\mu} = \frac{1}{2} \, (\mu_{i(k)} + \mu_{j(k)}) \tag{II.28}$$

and a and b are input constants. Since a definitive mixing correlation does not exist and other forms are available, (Ref. 19,20,21) the user should set up correlations of his choice.

Also available, is the option to include thermal conduction in the subcooled mixing. When thermal conduction is included, the conduction coefficient is given by

$$c_k = \left(\frac{k_{i(k)} + k_{j(k)}}{2} \right) \frac{s_k}{z_k} K_g \tag{II.29}$$

where K_g is a geometric correction factor. Note that the distance z_k is used in both Equations (II.24) and (II.29). This is the centroid-to- centroid distance between subchannels. Care should be taken to select this value for its intended use. For example, z_k could be selected as the effective mixing distance.

II.2.g TWO-PHASE TURBULENT MIXING (new)

Complete information concerning mixing during boiling is not available. It is known, however, that mixing is strongly dependent on quality; therefore, COBRA IIIc/MIT is set up to allow two options for calculating the turbulent two phase mixing. The first is the Beus Quality Dependent Mixing model.

II.2.g.1 Beus Mixing Model (from Reference 3)

The Beus quality dependent mixing model (Ref. 26) offers improved prediction of turbulent mixing for two-phase flow in rod bundles. The model assumes the existence of two mixing regions, corresponding to the bubbly-slug and annular flow regimes. The data used to develop the model was taken between the following limits.

System Pressure (psia)	$50 \leq P \leq 775$
Mass Velocity (lb/hr-ft)	$7.3\text{x}10 \leq G \leq 3\text{x}10$
Quality	$0 \leq x \leq .80$
Gap Width (in.)	$.02 \leq s \leq .10$

The Beus model considers two regions on a plot of mixing rate versus quality as shown in Figure 8. The low quality region is referred to as the churn mixing region and corresponds to the bubbly slug flow regime. The high quality region is referred to as the transition mixing region and corresponds to the annular flow regime. The two regimes are divided by a location of peak mixing at which quality, x, equals x_c.

In the churn mixing region, the mixing model is based on a physical model which assumes that mixing is due to displacements of fluid between subchannels caused by movement of vapor slugs with respect to currently flowing liquid. In this region, the experimental data studied by Beus indicates that the mixing rate increases steadily with quality and is given by the following equation:

$$W' = W_L + \beta_1 \left[\frac{AG}{D_h}\right] \frac{\rho_\ell}{\rho_g} \left[\frac{\gamma - 1}{\gamma}\right] x \qquad \text{(II.30)}$$

where the slip ratio, γ ,is obtained from the Smith correlation (Ref. 27). W_L and β_1 are calculated using the following equations:

$$W_L = 0.0035 \mu_\ell \mathrm{Re}_\ell^{.9} \qquad \text{(II.31)}$$

$$\beta_1 = 0.04\{s/D_h]^\lambda, \qquad \text{with} \quad \lambda = 1.5 \qquad \text{(II.32)}$$

The quality at which peak mixing occurs, and where transition

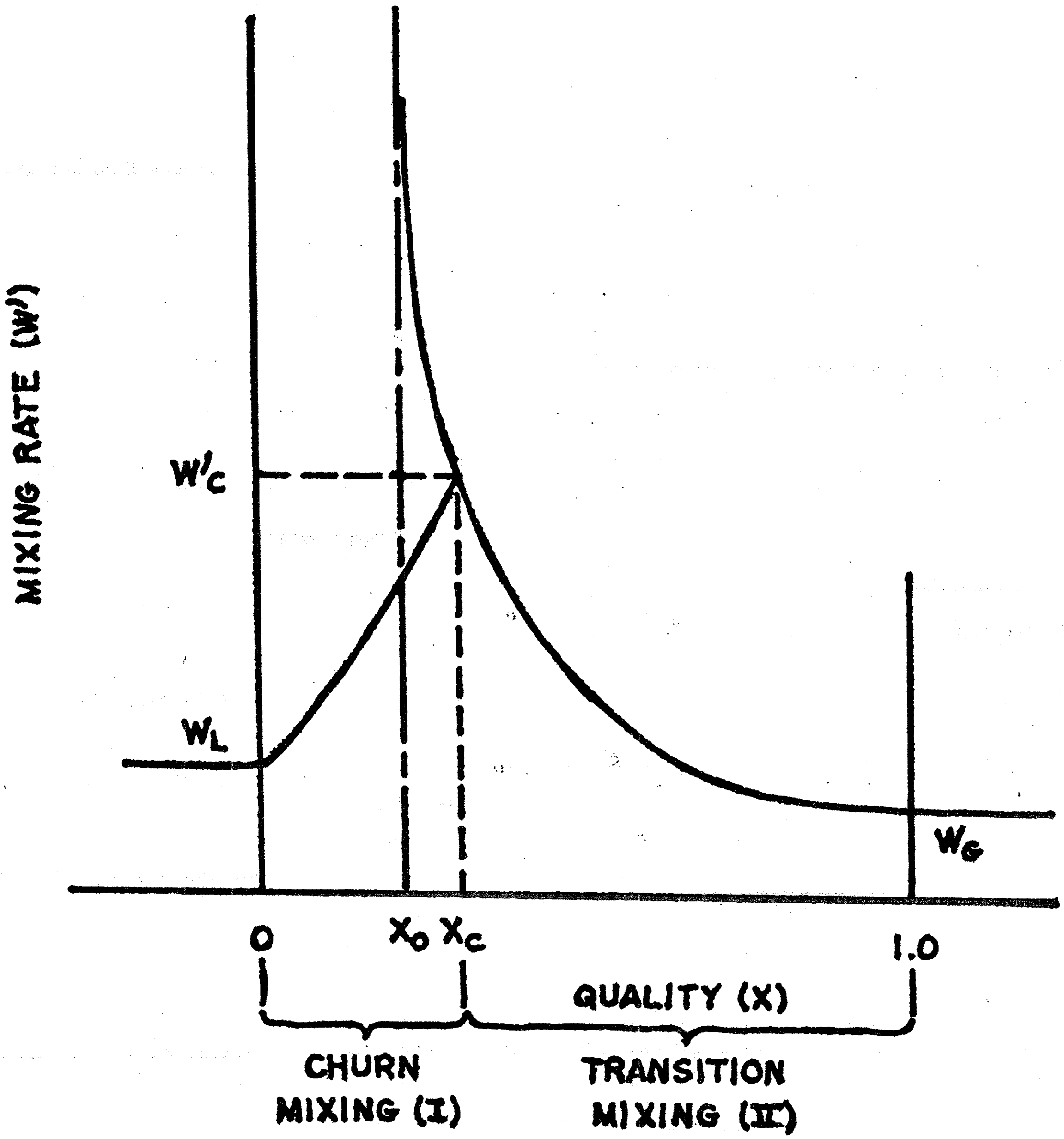


FIGURE 8: (Fig. 4 of Ref. 26) Plot of Mixing Model Showing Variation with Quality

mixing begins, x_c is determined by the following equation:

$$x_c = \frac{\frac{A_1}{G}\left[g\rho_\ell D_h(\rho_\ell-\rho_g)\right]^{1/2}}{\left[\frac{\rho_\ell}{\rho_g}\right]^{1/2} + A_2} \tag{II.33}$$

where $A_1 = 0.4$

$A_1 = 0.6$

In the transition mixing region, the data studied by Beus indicated a smooth decline of mixing rate from the peak value to a constant value at high quality, W_G, as shown in Figure 8. The Beus model constructs a hyperbolic curve to approximate this smooth decline of mixing in the transition region using the equation:

$$W'_{II} = W_G + [W'_c - W_G]\left[\frac{1-\frac{x_o}{x_c}}{\frac{x}{x_c}-\frac{x_o}{x_c}}\right] \tag{II.34}$$

where

$$W'_c = W'_I[x_c] \tag{II.35}$$

$$W_G = .0035\mu_g Re_g^{.9} \tag{II.36}$$

and

$$\frac{x_o}{x_c} = .57Re^{.0417} \tag{II.37}$$

The values of β_1, x_o/x_c, W_L and W_G were obtained by least square fits to the studied data.

Nomenclature

A = subchannel flow area (ft^2)
D_h = hydraulic diameter (ft)
G = mass flux ($lbm/hr\text{-}ft^2$)
L = channel length (ft)

T = temperature (F)
W = mixing rate (lbm/hr-ft)
= viscosity (lbm/hr-ft)

II.2.g.2 Tabular Data Input

The other option is to input as a tabular function of quality. With this option, the crossflow mixing between channels will be determined by interpolation between points in the table. When the quality of two adjacent subchannels is different, the calculations use a quality calculated from the mean mixed enthalpy of the two subchannels.

II.2.h FUEL ROD HEAT TRANSPORT

II.2.h.1 The COBRA IIIc/MIT-1 Model (from reference 2)

The old fuel heat transfer model included in COBRA IIIc/MIT considers radial conduction within the fuel by dividing the fuel into equally spaced concentric rings as shown in Figure 9. Axial and circumferential heat conduction are ignored. Axial heat conduction can be ignored because axial temperature gradients are usually small. Circumferential heat conduction is ignored to maintain a reasonable limit on the number of fuel nodes. This assumption can be justified if the heat transfer coefficients and fluid temperatures are rather uniform around a fuel rod. For boiling flow the fluid temperature is usually quite uniform. The validity of assuming a uniform heat transfer coefficient must be evaluated for each problem.

Figure 9 shows the node layout used to construct the conduction model. The fuel is divided into equal radial nodes plus a node for the cladding. For N nodes this gives N+1 temperatures where the temperature at $i = N+1$ is at the outer surface of the cladding. An effective gap conductance coefficient is used at the fuel-clad interface to combine the conductance of the cladding and the gap. The surface heat transfer coefficient is arbitrarily specified through heat transfer correlations. An average heat transfer coefficient is determined from a circumferentially weighted average of the heat transfer coefficients in the subchannels surrounding a fuel rod. A similar calculation is performed to obtain an average fluid temperature.

The numerical solution developed in Appendix D uses an implicit finite difference scheme (Ref. 28,29) that is stable for all time steps. The equations used for the numerical solution are as follows:

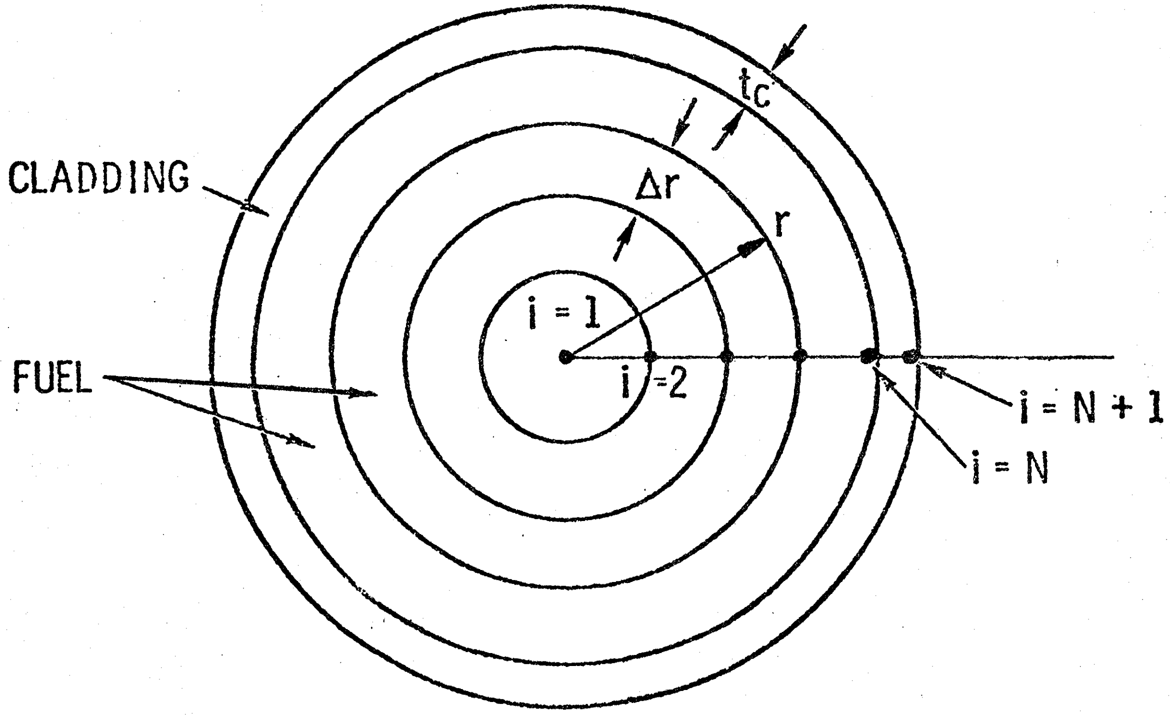


FIGURE 9: Fuel Model Node Designation

i = 1, temperature at fuel center

$$\left(\frac{\rho c}{\Delta t} + \frac{4k}{\Delta r^2}\right) T_1 - \frac{4k}{\Delta r^2} T_2 = q_1''' + \frac{\rho c \bar{T}_1}{\Delta t} \qquad \text{(II.38)}$$

1 < i ≤ N-1, temperature in fuel region

$$\left(-\frac{k}{\Delta r^2} + \frac{k}{2(i-1)\Delta r^2}\right) T_{i-1} + \left(\frac{\rho c}{\Delta t} + \frac{2k}{\Delta r^2}\right) T_i + \left(-\frac{k}{\Delta r^2} - \frac{k}{2(i-1)\Delta r^2}\right) T_{i+1} = q_i''' + \frac{\rho c \bar{T}_i}{\Delta t} \qquad \text{(II.39)}$$

i = N, fuel temperature at fuel-clad interface

$$\left(-\frac{2k}{\Delta r^2}\right) T_{N-1} + \left(-\frac{\rho c}{\Delta t} + \frac{2k}{\Delta r^2} + \frac{2h_{gap}}{\Delta r} + \frac{h_{gap}}{(i-1)\Delta r}\right) T_N + \left(-\frac{2h_{gap}}{r} - \frac{h_{gap}}{(i-1)\,\Delta r}\right) T_{N+1} \tag{II.40}$$

$$= q_N''' + \frac{\rho c \bar{T}_N}{\Delta t}$$

i = N+1, cladding temperature

$$-\left(\frac{h_{gap}}{t_c}\frac{r_N}{r_{N+1}}\right) T_N + \left(\frac{\rho c}{\Delta t} + \frac{h_{gap}}{t_c}\frac{r_N}{r_{N+1}} + \frac{h_{surf}}{t_c}\right) T_{N+1} = q_{N+1}''' + \frac{\rho c \bar{T}_{N+1}}{\Delta t} + \frac{h_{surf}}{t_c} T_c \tag{II.41}$$

These equations are arranged as a set of simultaneous equations where the temperature coefficient matrix is tridiagonal. This system of equations is solved by using a compact Gaussian elimination routine for tridiagonal matrices.

The fuel heat transfer model is used only once per time step to calculate the fuel rod heat flux. By using data at time t the fuel temperature is advanced to t + Δt during the first flow solution iteration. That temperature and resulting heat flux calculation is held constant during the flow solution iteration.

II.2.h.2 The MATPRO Fuel Rod Model (from Reference 3)

II.2.h.2.1 Fuel and Cladding Material Properties

The original MATPRO model contains good fits to experimental data for fuel and clad material properties. Some of the fits, however, were formulated in terms which, although physically derived, were time consuming to compute. The version of the MATPRO fuel rod model installed in COBRA IIIc/MIT-2 uses cubic polynomials to fit the temperature dependence of fuel ρc_p within 2 percent over temperatures from 300° K to 3000° K. The thermal conductivity of fuel was fit by a quadratic polynomial within 10 percent over the range 400°K to 2500°K. In each case there are separate, slightly different fits for uranium oxide and mixed oxide fuels.

Temperature-dependent clad material properties are also given by simple expressions. The MATPRO model for thermal conductivity of Zircaloy is already a simple polynomial fit, and was taken over unchanged. The value of ρc_p has been approximated by a linear fit over the range 300°K to 1190°K; this fit is within 5 percent of the data given in Ref. 30. Clad temperatures would normally be far below 1190 K At 1190°K Zircaloy undergoes a transition fitted into the new model by two linear fits making a sharp, inverted vee corresponding to data in Ref. 30; above 1254°K, where the transition ends, little data is available, and a constant value is assumed as is recommended in Ref. 30.

II.2.h.2.2 Fuel-to-Clad Gap Heat Transfer Coefficient

The new fuel rod model calculates time-space behavior of gap conductance, hgap, using the MATPRO cracked-pellet model. This model calculates

$$H_{gap} = h_{cond} + h_{contact} + h_{rad} + h_{press}$$

where the four components on the right hand side represent, respectively, the effects of: thermal conductivity of the gas mixture in the gap; partial fuel-clad contact supposed to change with burnup due to fuel pellet cracking and relocation; radiation heat transfer across the gap; and fuel pressing against clad if the gap is closed due to excessive fuel expansion. The gap heat transfer model in COBRA IIIc/MIT-2 is contained in Subroutine MPG.

The four components of gap conductance will be briefly discussed. The first, gap gas conductivity, is computed in subroutine MPG by calculating a theoretical mixture conductivity for a mixture of four noble gases, helium, argon, krypton, and zenon. The presence of air and water vapor is neglected. The conductivity of helium is modified to represent the effect of a small gap on the statistical thermodynamic assumptions involved. The partial fuel-clad contact contribution is from the cracked-pellet model developed at INEL (Ref. 30); it involves a function of fuel burnup calculated once on the basis of input to MPG at the beginning of COBRA IIIc/MIT-2 calculations. The radiation heat transfer is based on standard formulas depending on the fuel and clad emissivities. The closed gap component is added on when the user-input gap width is less than the mean fuel-clad surface roughness; it takes the form $h_{press} = CP_f^n$, where C, P_f (the fuel contact pressure against the clad), and the exponent n are user- specified input. The user-input dimensions are hot dimensions and are not recalculated to account for thermal expansion.

II.2.i BEEST HEAT TRANSFER MODEL (from Reference 3)

The BEEST heat transfer model is based on the BEEST package described in Reference 31. The model can construct a complete boiling curve, such as the one shown in Figure 10, for each space and time step. The boiling curve shown has positive slope up to point A, where critical heat flux occurs. Between points A and B

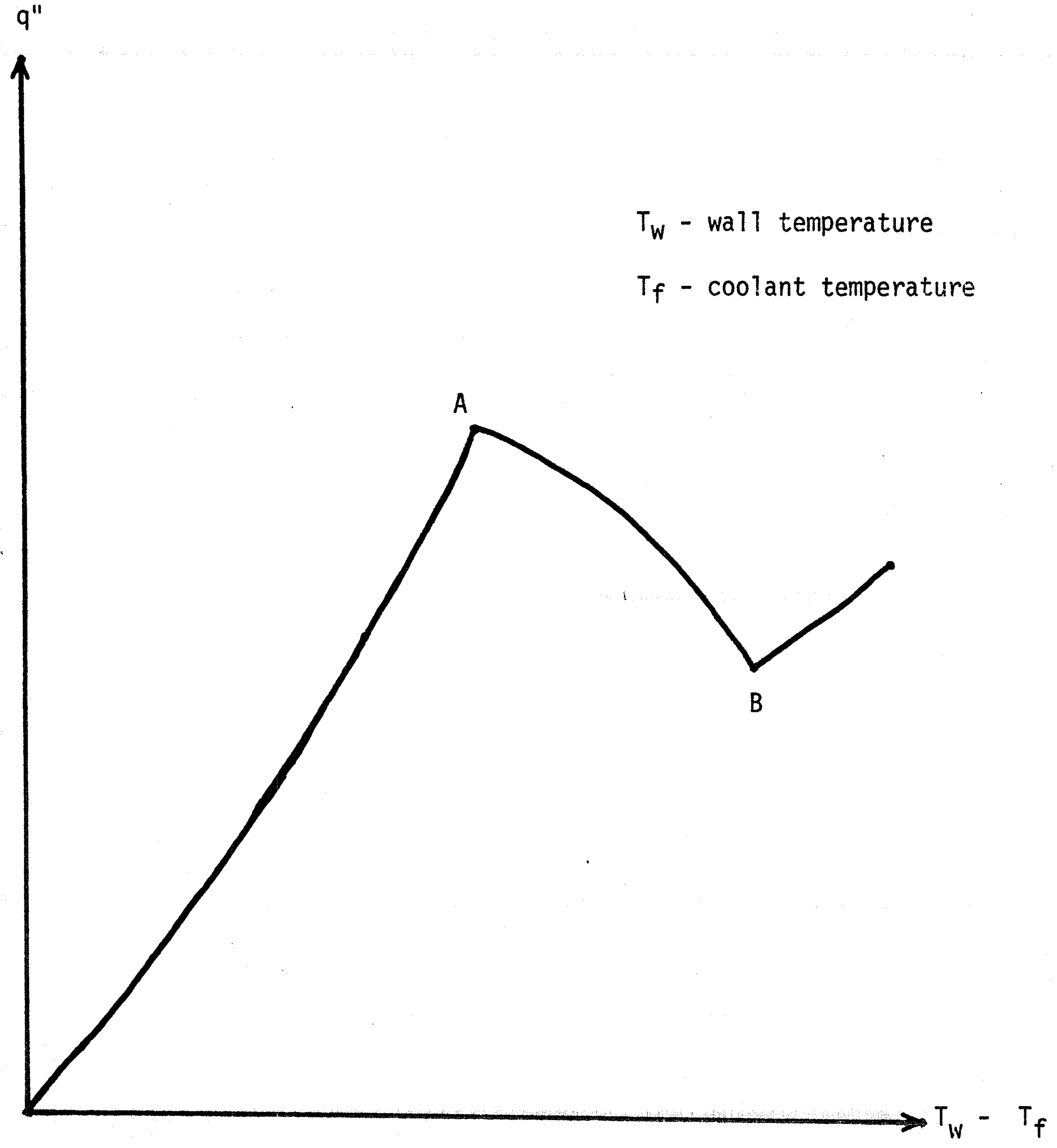


FIGURE 10: A Typical Boiling Curve of Beest Heat Transfer Model

is a transition boiling region. Point B is at the metastable film boiling temperature. The curve continues to the right from B in the film boiling region. The BEEST model in COBRA IIIc/MIT-2 constructs portions of the curve only as they are needed in order to avoid unnecessary computation.

To consider post-CHF heat transfer, the BEEST model requires a critical heat flux calculation. The original BEEST model used the Biasi/Void-CHF correlation. The BEEST model operational in COBRA IIIc/MIT-2 has been modified to permit the use of any of the other correlations included in the code.

The BEEST model calculates the rod-to-coolant heat transfer coefficient in subroutine HTRAN which is called by subroutine HEAT. HTRAN calculates the heat transfer coefficient in two steps. First, it determines the heat transfer regime. Then, the correlation appropriate to the regime is used to calculate a heat transfer coefficient. The input to HTRAN is clad outer surface temperature and coolant temperature, pressure, velocity and void fraction. The heat transfer logic is given in Figure 11. Correlations used by the BEEST model are listed in Table 1. The variable "IHTR" is a heat transfer regime indicator.

Subroutine HTRAN computes fuel-to-fluid heat transfer coefficient using input from the following subroutines:

STATE - calculates fluid properties as a function of temperature and pressures
FILM - film boiling heat transfer coefficient
CHF3 - determines critical heat flux
MPC - thermal conductivity of cladding
SURTEN - surface tension of liquid water

II.2.j CHFR AND CPR CORRELATIONS (1)

Five correlations are currently available for calculating CPR and CHFR values. These are contained in Functions CHF1 through CHF4 and in Subroutine CHF5. The five correlations are briefly discussed in the following sections. Appendix C provides a complete summary of the correlations including references, equations and range of data base information.

II.2.j.1 The W-3 and B&W-2 CHFR Correlations (from Reference 2)

Reference 32 summarizes the details of The W-3 and B&W-2 correlations as they are implimented in COBRA IIIc/MIT. A

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(1) See Appendix C for the definitions of nomenclature used in this section.

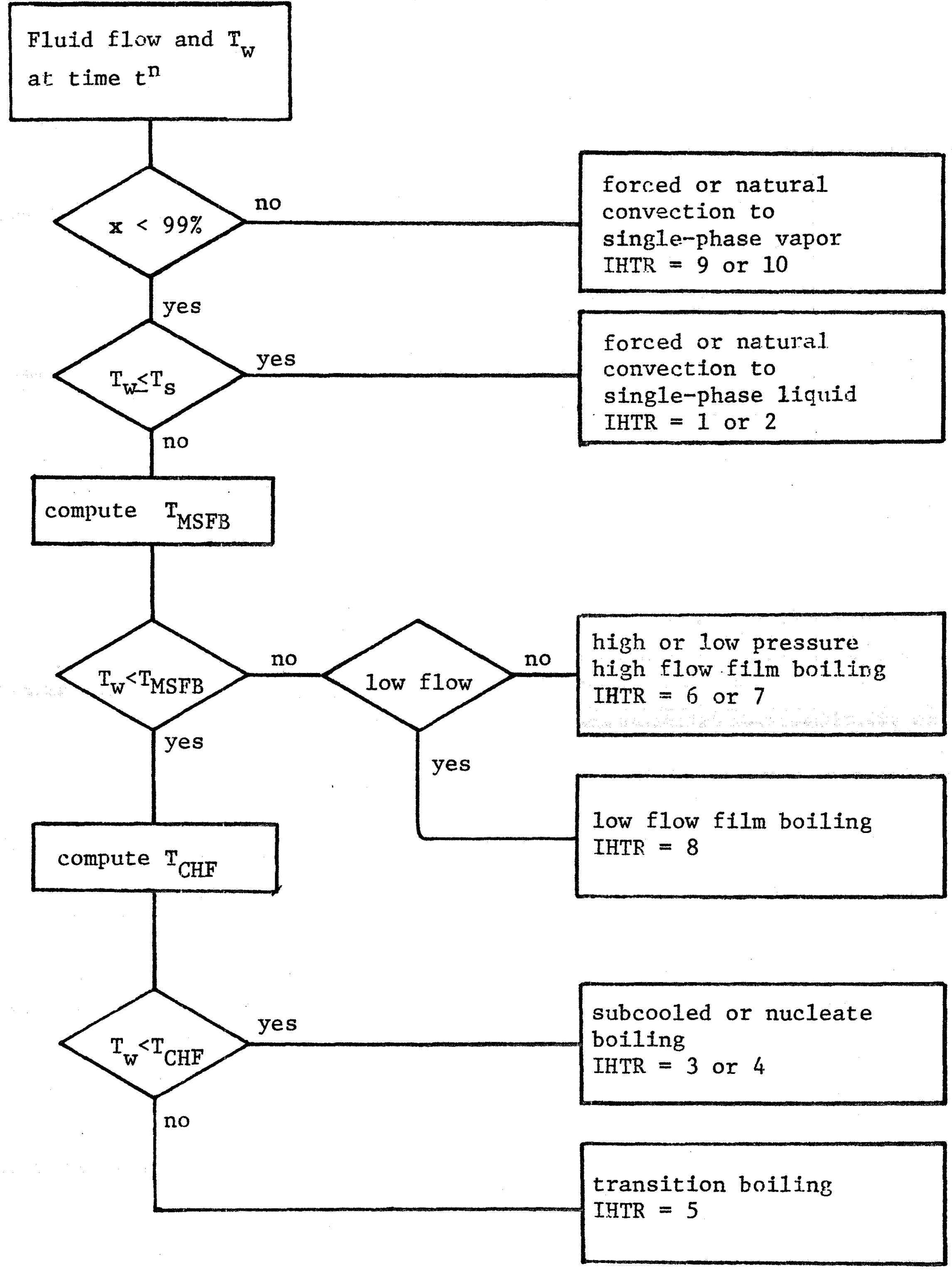


FIGURE 11: Logic Flowchart for BEEST Heat Transfer Model. (IHTR is the heat transfer regime indicator, see Table 1.)

Table 1: Heat Transfer Summary

ithr	Regime	Correlation
1	forced convection to single-phase liquid	Sieder-Tate
2	natural convection to single-phase liquid	McAdams
3	subcooled boiling	Chen
4	nucleate boiling	Chen
5	transition	interpolation between q_{CHF} and q_{MSFB}
6	high P, high G film boiling	Groeneveld
7	low P, high G film boiling	Modified Dittus-Boelter
8	low 5 film boiling	Modified Bromley plus either MdAdams vapor or high flow film boiling
9	forced convection to single-phase vapor	Sieder-Tate
10	natural convection to single-phase vapor	McAdams

summary is also provided in APPENDIX C. The interested user is refered to these sources for backgroung on the W-3 and B&W-2 correlations. This section will discuss only the implimentation of the Nonuniform Axial Flux Factor in these correlations.

To implement the nonuniform axial flux factor into COBRA a finite increment integration scheme is used. The axial flux factor at location x_j is of the form

$$F = \frac{C}{q'(X_j)(1-e^{-CX_j})} \int_{X_0}^{X_j} q''(X) e^{-(X_j - X)} dX \tag{II.42}$$

where C is a constant. Consider the integral to be a summation of finite integrals, each taken over the calculation increment ΔX. Over each ΔX assume a constant value of the heat flux $q''(X)$. The integral from $X - \Delta X$ to X is

$$q'(X) \int_{X-\Delta X}^{X} e^{-C(X_j - X)} dX = \frac{q''(X)}{C} e^{-CX_j} \left[e^{CX} - e^{C(X-\Delta X)} \right] \tag{II.43}$$

and the entire integral taken as a summation over the increments of ΔX from X_o to X_j is

$$F = \frac{e^{-CX_j} \sum_{j=J_0+1}^{J} q''(X_j)(e^{CX_j} - e^{CX_{j-1}})}{q''(X_j)[1 - e^{-C(X_j - X_{J_0})}]} \tag{II.44}$$

where $X_{J_o} = 0$ is the axial location of the start of integration. For the B&W-2 correlation, the start of integration is the channel inlet and for the W-3 correlation it is the start of local boiling defined by the Jens-Lottes correlation. (Ref. 32)

II.2.j.2 CISE-4 CPR Correlation (from Reference 3)

CISE-4 is a modified version of the earlier CISE-3 correlation (Ref. 33,34). The modification extends the range of the correlation's applicability to lower flow rates. The CISE-4 correlation is intended for analysis using rod-centered subchannels, rather than coolant centered subchannels such as COBRA uses. The use of CISE-4 correlations for coolant-centered subchannels is thought to be permissable however, for analysis of central bundle subchannels.

The general functional form of the correlation is:

$$\langle x_e \rangle_c = \frac{D_h}{D_e} \frac{a(P,G) L_{B_c}}{[L_{B_c} + b(P,G,D_e)]} \tag{II.45}$$

In COBRA IIIc/MIT-2, the critical power ratio (CPR) prediction is based on a heat balance, which yields the following equation:

$$\text{CPR} \approx 1 + \frac{\langle x_e(L_{B_c}) \rangle_c - \langle x_e(L_{B_c}) \rangle}{\langle x_e(L_{B_c}) \rangle + \frac{h_f - h_{in}}{h_{fg}}} \tag{II.46}$$

Eqn. (II.46) is approximate in that it assumes that the distribution of coolant flow among channels does not change with power level. This assumption is fairly accurate in the general vicinity of critical power. The accuracy is sufficient for iteration on power until CPR=1.

II.2.j.3 Hench-Levy CHFR Correlation (from Reference 3)

The Hench-Levy correlation (Ref. 35) uses limit lines to define a lower envelope to the CHF data. Hench-Levy limit lines are shown in Figure 12.

The limit line approach is conservative in that it predicts CHF at a power level below the power level at which the experimental data indicates it would actually occur. Because it does not account for non-uniform axial heat flux effects, however, it does not accurately predict the axial CHF location. Also, under some conditions, it can conservatively predict the power levels at which CHF occurs while non-conservatively predicting the local CHF at the critical power. An example of this paradox is given in Figure 13.

II.2.j.4 Biasi/Void-CHF Correlation (from Reference 3)

The Biasi/Void-CHF correlation is actually a combination of the Biasi (Ref. 36) and Void-CHF (Ref. 37) correlations. The combination was developed for calculation of local CHF during transients. Simplicity and applicability to a wide range of coolant conditions were high priorities. CHF prediction accuracy was a lesser priority.

The form of the Biasi/Void-CHF correlation is:

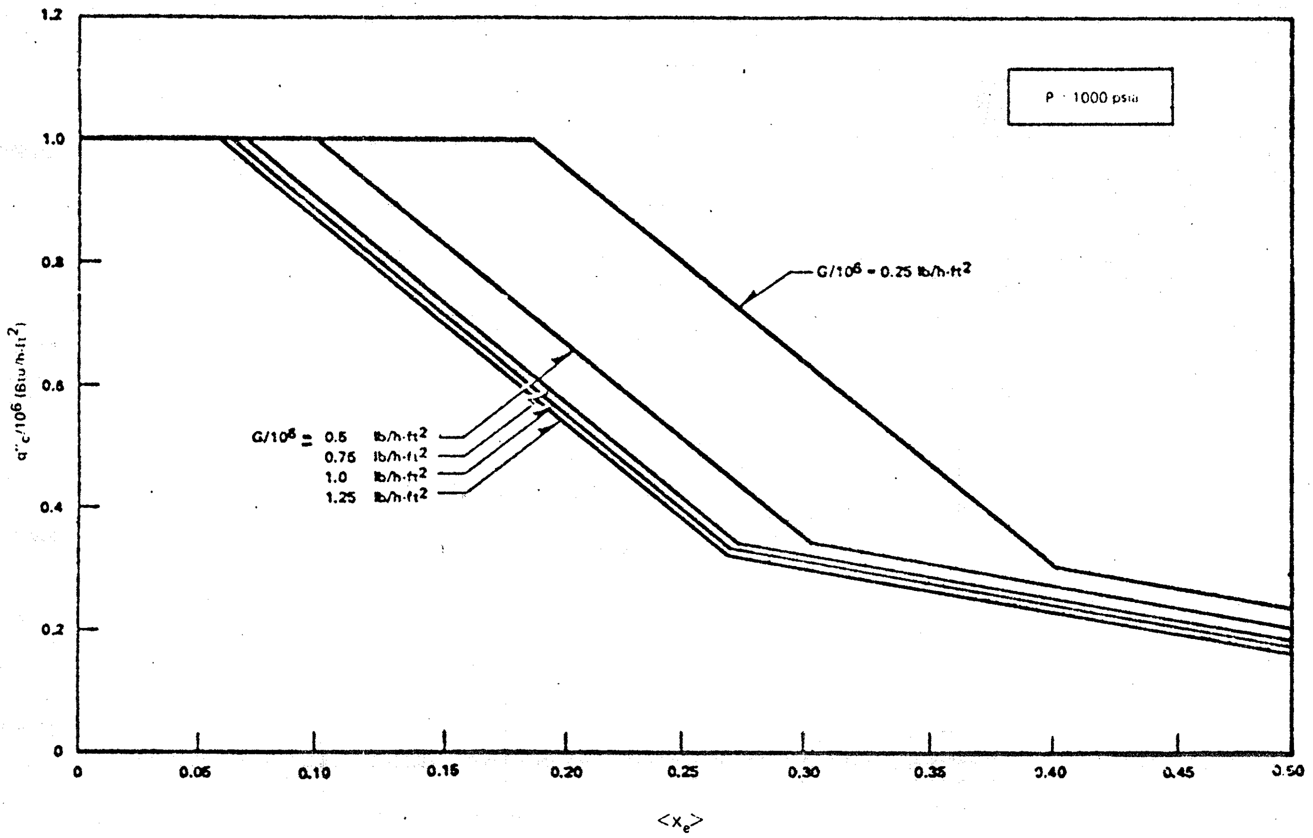


FIGURE 12: Hench-Levy Limit Lines

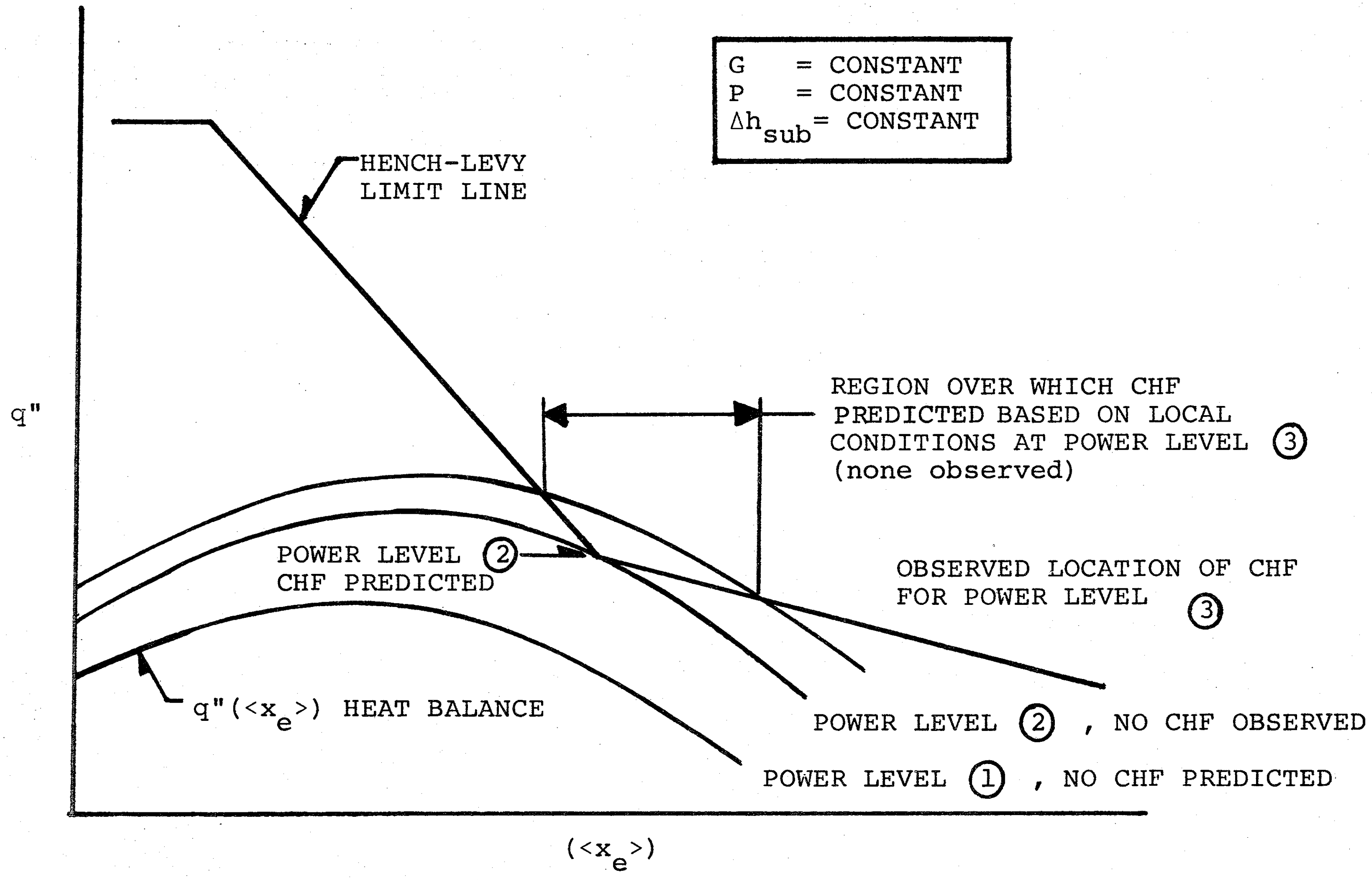


FIGURE 13: Experimentally Observed Trend in CHF Data Compared to the Hench-Levy Limit Line.

$$(q''_{CHF})_{Biasi} = f(D_e, G, P, x) \qquad \text{(II.47a)}$$

$$(q_{CHF})_{Void-CHF} = f(\alpha, \sigma, \rho_f, \rho_g, H_{fg}) \qquad \text{(II.47b)}$$

where,

Eqn. (II.47a) is used for $G > G_1$

A linear interpolation between Eqn. (II.47a) and (II.47b) is used for $G_0 < G < G_1$

Eqn. (II.47b) is used for $G < G_0$
See Appendix C for a more detailed description of the correlation, including information concerning its range of applicability

II.3 PROGRAM ORGANIZATION (from Reference 2)

The organization of the main COBRA IIIc/MIT-2 program can best be described by following the flow chart of Figure 14. The first function of the program is to read in the input data. This is accomplished using any of the three input methods described in later sections. New cases, after the first, require input of only the card groups that will change the input of the previous case. The new input data for each case may be printed out prior to starting the calculations. The user can also omit this or can print out the entire set of input for each case, depending on the options selected.

Boundary conditions are established for the steady-state solution by recalling previously stored values of inlet flow rate and enthalpy established from the input data. Subroutine SPLIT is used to calculate subchannel flows to give equal subchannel pressure gradients, if it is requested by an input option. All crossflows and the matrix [S] {p} are set equal to zero to establish the inlet crossflow and exit pressure boundary condition and to provide an initial estimate for starting the iteration procedure.

An iteration loop is now entered which sweeps the calculation through the bundle. Within this loop is a call to Subroutine SCHEME that carries the solution through the bundle at steps Δx. The iteration continues until the flow converges to within a selected tolerance.

The transient calculation is performed in much the same way as the steady state solution. A time loop is entered that carries

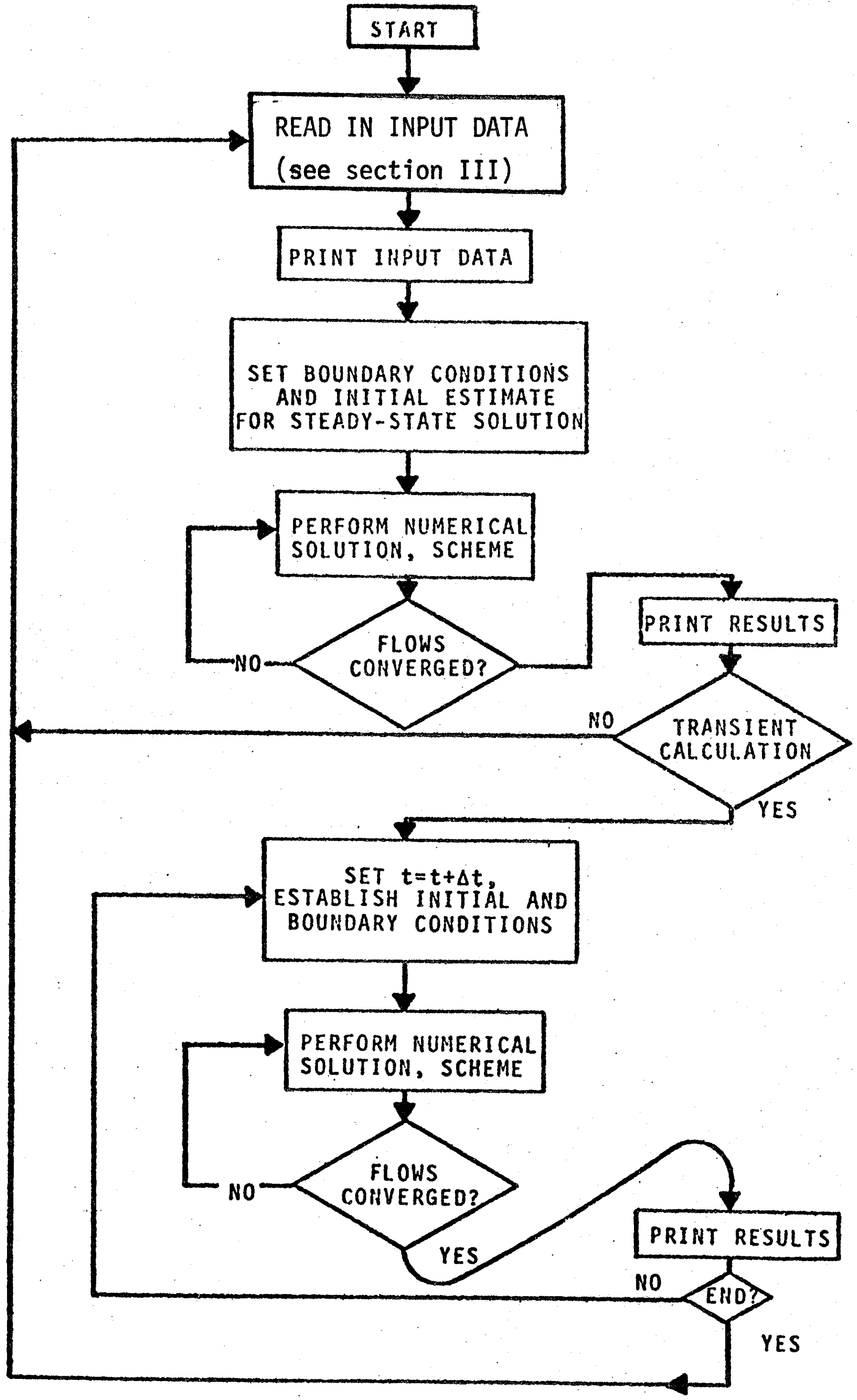


FIGURE 14: MAIN COBRA IIIC-2 PROGRAM FLOW CHART

the solution through successive time steps of Δt. At the beginning of each time step, the channel boundary conditions and forcing functions are set at $t + \Delta t$. During each time step iteration is performed as described above to obtain a converged flow solution. This calculation procedure repeats for each time step until the end of the transient is reached. The calculation then moves on to a new case if there is one.

II.4 SUBROUTINES (from Reference 2)

The organization of the COBRA IIIc/MIT programs puts most of the calculational effort into subroutines. The more important ones are discussed here to describe their use.

II.4.a Subroutine AREA

This subroutine calculates subchannel area and gap spacings by using a tabular list of area and gap variations supplied as input. A linear interpolation is used to select values from these tables. When wire wrap mixing is included AREA corrects the subchannel flow area and hydraulic diameter according to the wire wrap inventory provided by subroutine FORCE.

II.4.b Subroutine CHF (JSTART, JEND)

At the completion of the subchannel flow and enthalpy calculation an optional call to subroutine CHF is provided to calculate critical heat flux ratios over the portion of the channel denoted by J = JSTART through J = JEND. The critical heat flux ratio CHFR(N,J) and critical chanel CCHANL(N<J) are calculated for each rod N at position J. CHFR(N<J) is also searched to determine the minimum critical heat flux ratio MCHFR(J), critical rod MCHFRR(J) and critical chanel MCHFRC(J) at each axial location J. The data is printed as part of the fuel temperature and heat flux output.

II.4.c Subroutine DIFFER (IPART,J)

Subroutine DIFFER is divided into four parts as indicated by the variable IPART.

Part 1 calculates the right hand side of Equation (I.12) which is designated DHDX(I). This quantity is the steady state value of the enthalpy gradient {dh/dx}. Part 1 contains the calculation of the enthalpy carried by the crossflow h* which is presently assumed to be the enthalpy of the donor subchannel.

Part 2 calculates the right hand side of Equation (I.11) which is designated DFDX(I). This is the steady-state value of the flow gradient {dm/dx}.

Part 3 calculates the pressure gradient coefficient $\{K_i\}$ used in Equation (I.15) and designates it DPK(I). It also calculates the other components of the pressure gradient $\{F_i\}$ without the diversion crossflow terms as defined by Equation (I.22) and designates it as DPDX(I).

Part 4 calculates the complete pressure gradient {dp/dx} including the crossflow terms and designates it DPDX(I).

II.4.d Subroutine DIVERT

This subroutine calculates the diversion crossflows $\{W_x\}$ by setting up and solving the set of simultaneous Equations (I.24). The matrix [M] is designated by AAA(K,L) and the vector {b} by B(K) in DIVERT. The simultaneous solution is performed by a call to DECOMP and SOLVE. The value of the axial velocity u* carried by the crossflow is calculated in DIVERT. Presently, u* is assumed to be the average velocity of the two adjacent subchannels or

$$u^*_k = \frac{1}{2}\left(u_{i(k)} + u_{j(k)}\right) \qquad \text{(II.49)}$$

If forced flow diversion between subchannel is specified by FORCE, the simultaneous equations are modified prior to solving for {w(x)}.

II.4.e Subroutine FORCE

Subroutine FORCE is provided to specify forced diversion crossflow at selected gaps and at selected axial positions. If a forced crossflow is specified, the logical variable FDIV = .TRUE.; otherwise, FDIV = .FALSE. Subroutine FORCE includes two options for forced crossflow mixing in COBRA IIIc/MIT. One option is the wire wrap mixing model described previously. FORCE identifies when a wire wrap crosses a gap, computes the forced crossflow and corrects the wire wrap inventory for the adjacent subchannels. The other option is for a specified flow fraction diverted from one subchannel to an adjacent subchannel by spacers, mixing vanes or any other flow diverters.

II.4.f Subroutine HEAT (from Reference 3)

Subroutine HEAT calculates the heat addition per unit length q'(I,J) for coolant nodes at axial position J of all channels I, from 1 to NCHANL. HEAT is called once for each axial level during the axial iteration scheme of COBRA IIIc/MIT-2.HEAT may be used with or without a fuel rod model. When HEAT is used without a fuel rod model, the effect of heat capacity is ignored.

When a fuel rod model is used, the sequence of operations is as shown in Figure 15. HEAT calculates fuel rod temperatures by first calling subroutine HTRAN to calculate a rod-to-coolant heat transfer coefficient. Then HEAT calls either subroutine TEMP (old fuel rod model) or subroutine TEMFR (MATPRO fuel rod model) to solve for the fuel rod temperature distribution. The calculation of rod-to-coolant heat transfer coefficient and the calculation of fuel rod temperatures have several options, as shown in Table 2

Subroutine HEAT has an inner iteration scheme to determine steady state temperature distributions. This scheme is used at each axial level and for each pass through the reactor when either the temperature dependent property option or the MATPRO model is used. The iteration is done either 50 times or until the centerline fuel temperature changes by lss than a fraction EPSF, which is user specified. If convergence is not reached in 50 iterations, the COBRA calculations are stopped and an error message is given.

II.4.g Subroutine MIX

Subroutine MIX calculates the thermal mixing parameters w' and c which are designated by WP(k) and COND(K), respectively. Since completely general correlations for mixing have not been developed for single and two phase mixing, this subroutine is set up so that improved correlation functions can be included when they become available. The approach used for now is to separate the mixing into boiling and nonboiling regions. For nonboiling conditions, several correlation forms are included as discussed earlier. For two-phase flow, three options are available. The first is to assume that the single phase correlations apply in the two-phase region. The second is to use the Beus Quality Dependant Mixing Model descriped in section The last option (available only when using the old COBRA input method) is to read mixing rate vs. quality data into a table and then interpolate between data points to find the mixing rate as a function of quality.

The thermal conducion coefficient is assumed to be a function of the subchannel geometry and the average fluid thermal conductivity.

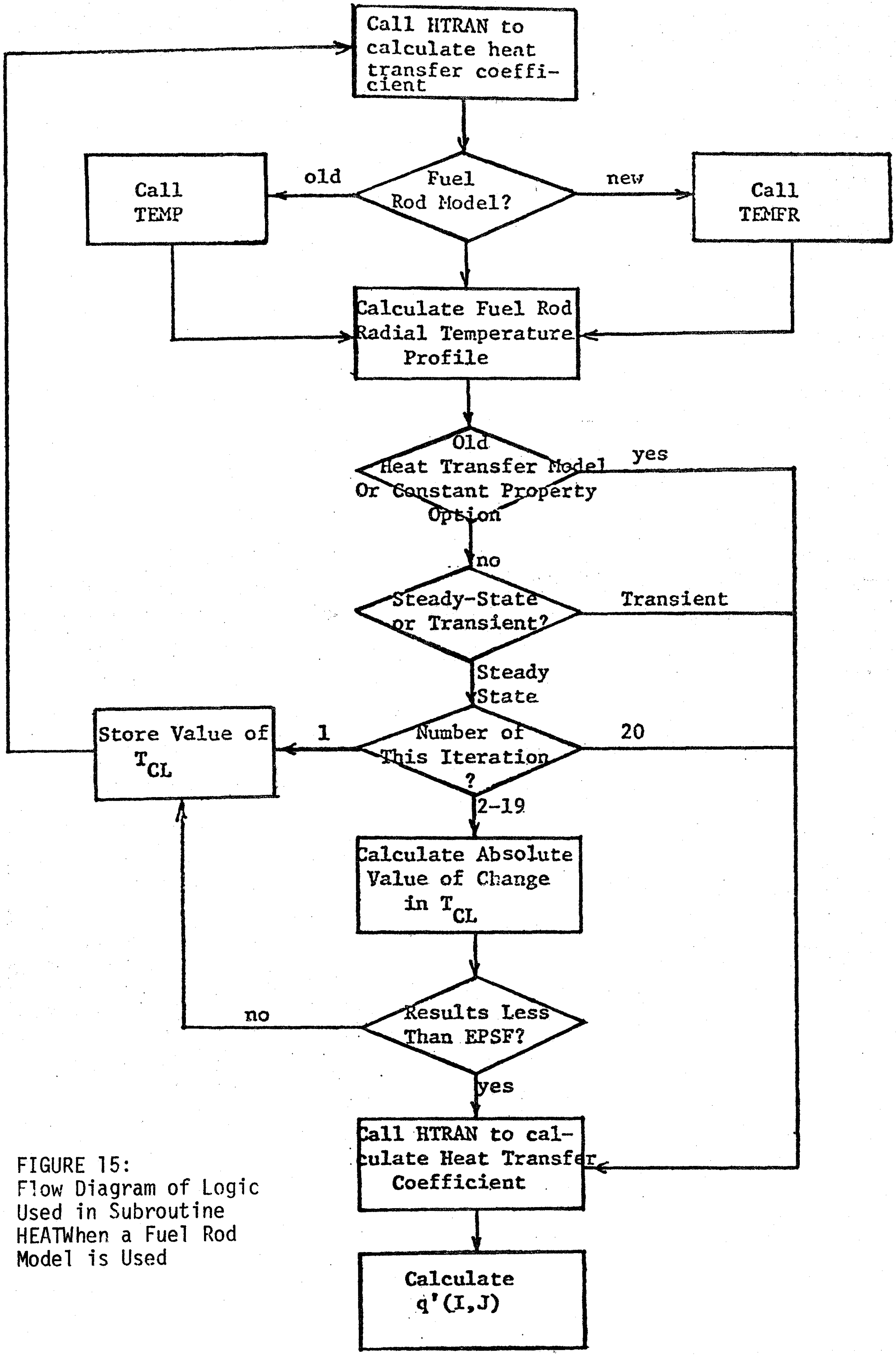


FIGURE 15:
Flow Diagram of Logic
Used in Subroutine
HEATWhen a Fuel Rod
Model is Used

Table 2:

Available Options for Calculation of Heat Transfer Coefficient and Fuel Rod Temperatures

Option Indicator		Calculational Model Used	
IFRM	IPROP	Fuel Rod Model	Property Option
0	0	Old	Constant properties, user input values of fuel and cladding properties and h_{gap}.
1	0	New	Constant properties, user input values of fuel and cladding properties and h_{gap}.
1	1	New	Fuel and cladding properties calculated, user input value of h_{gap}.
1	2	New	Fuel and cladding properties and h_{gap} calculated

IHTM	Heat Transfer Model
0	Old
1	New, pre-CHF only
2	New,pre and post CHF

Note

Inner iteration on fuel rod temperature is used for all options except those which involve use of the constant property option (IPROP = 0) and the old heat transfer model (IHTM = 0).

II.4.h Subroutine PROP (IPART)

This subroutine consists of two parts. The first part calculates the saturated fluid properties as a function of the system reference pressure. The second part calculates all the liquid fluid properties as a function of temperature and limits these to saturated values during boiling. The second part also calculates the convection heat transfer coefficient used in Levy's subcooled void model.

II.4.i Subroutine SCHEME (JUMP)

This subroutine performs the previously outlined numerical solution. Given a set of boundary and initial conditions it carries the calculations once through the bundle in a stepwise manner. Upon completion of calculation it returns to the main program with an indication of whether or not convergence has been reached. If JUMP = 1, the calculations have not yet converged. If JUMP = 2, the calculations have converged. Special provision is included in SCHEME to preserve the flow and crossflow solution for succeeding cases. After convergence of the first case an option is provided to set JUMP = 3. This flag bypasses the tedious crossflow solution and instead uses the crossflow solution residing in core. (1)

The flow chart shown in Figure 16 outlines the calculation procedure in SCHEME. The calculations start by checking the value of JUMP to determine if the previous crossflow solution is to be used.

Subchannel flow and heat transfer parameters are calculated at the beginning of the channel to start the calculations. A loop is now entered to take the calculation through the channel.

First, the enthalpy $\{h(x)\}$ is calculated and an estimate is made for $\{m(x)\}$ for the first iteration only. If JUMP $\neq$ 3, the crossflow $\{x(x)\}$ is calculated. The flows are calculated next followed by the pressures $\{p(x)\}$ and pressure difference $[S]\{p(x)\}$ provided JUMP $\neq$ 3. Any value of flow not converged to within a selected tolerance is sufficient to set JUMP = 1 which is the nonconvergence signal. The calculation continues until the end of the channel is reached and then returns to the calling program.

II.4.j Subroutine TEMP

---

(1) The code also includes an option to read from tape a previously written crossflow solution.

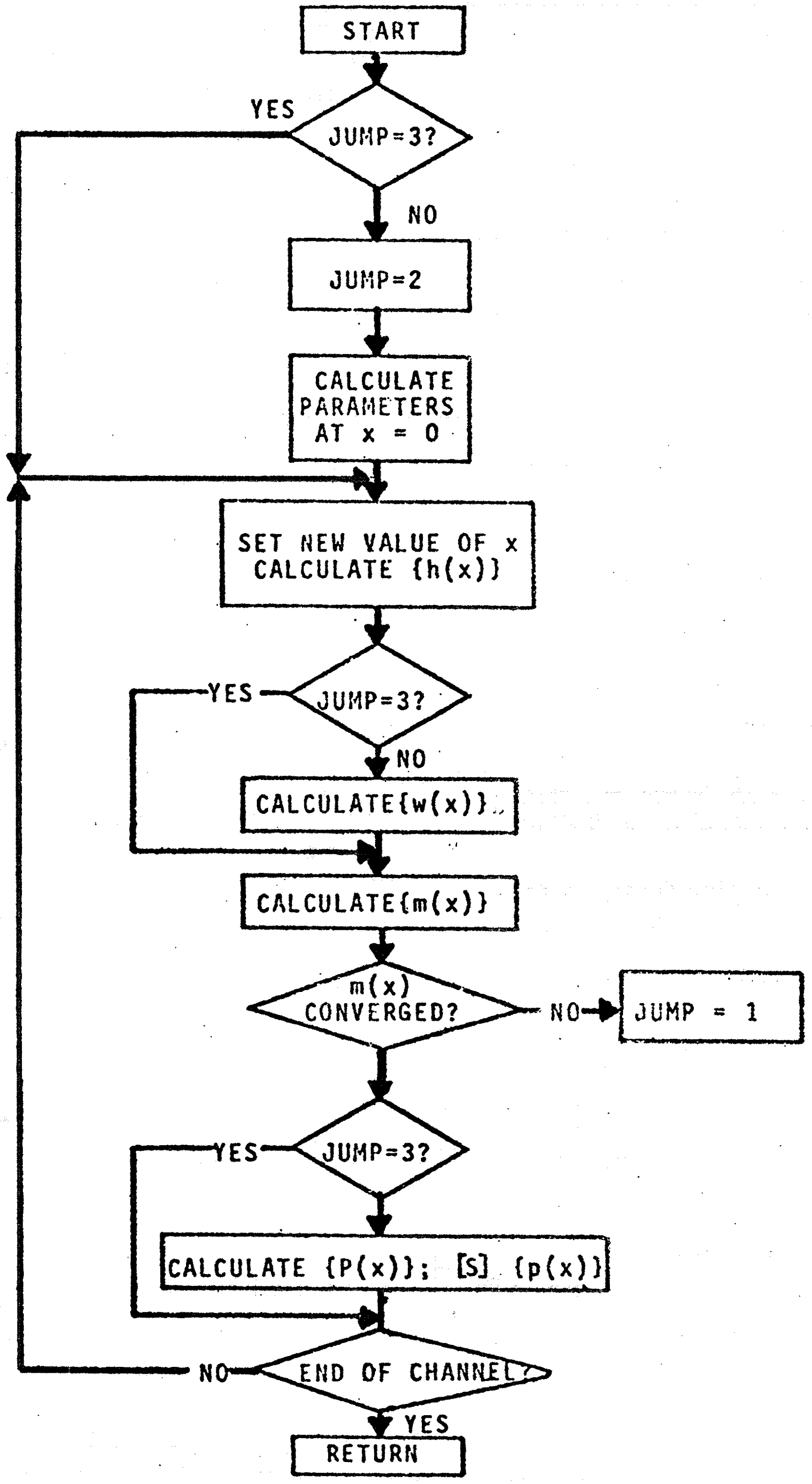


FIGURE 16: Flow Chart of the Calculation Procedure in SCHEME

This subroutine calculates the fuel temperatures by using the previously described heat transfer model. Both cylinderical and plate type fuel can be considered. The plate fuel option can be used to account for heat transfer to a flow housing. TEMP obtains heat transfer correlations from Function HCOOL. The tri-diagonal system of equations used in Subroutine TEMP is solved using gaussian elimination.

II.4.k Subroutine VOID

Subroutine VOID calculates the subcooled void fraction, bulk void fraction, density, effective specific volume for momentum, two-phase friction gradient multiplier velocity and energy transport velocity. Several correlations are included in this subroutine that the user can select as options. These are provided as an example with the thought that the users will set up correlations that are most applicable to their particular problem.

II.4.1 Other Subroutines

Several other subroutines are required for operation of the COBRA IIIc/MIT programs. Subroutine CURVE performs a linear interpolation of tabulated data. Subroutine DECOMP and SOLVE perform the solution to the simultaneous equations. Subroutine SPLIT divides the subchannel flow rates at the inlet of the bundle to give equal pressure gradients by assuming that there is no spatial acceleration component of pressure drop.

II.5 FUNCTIONS

II.5.a Function HCOOL

This function computes the surface heat transfer coefficient designated by HCOOL (N,I,J) where N is the rod number, I is the adjacent subchannel and J is the axial position. Users are expected to select and program correlations applicable to the problem being analyzed. The model currently coded is the Thom/Jens/Lottes subcooled boiling heat transfer correlation.

II.5.b Function S(K,I)

This function subprogram calculates the elements of [S] according to the subchannel connection logic described in Appendix B. This calculation first assumes that

$S(K,I) = 0$

and then checks to see if I corresponds to either channel of the subchannel pair that defines boundary K. If I corresponds to Subchannel i of the subchannel pair, i-j where $i < j$ then

$S(K,I) = 1.$

If I corresponds to Subchannel j of the subchannel pair i-j then

$S(K,I) = -1$

On some cases the [S] transformation is performed directly without using this function by noting that the kth element of [S]{p} is just

$P_{i(k)} - P_{j(k)}$.

II.6 USE OF COBRA IIIc/MIT-2

This section presents some general comments on the use of COBRA IIIc/MIT-2.

Complete input instructions are given in the following section. The input is set up with options by which the user may select correlations for input to a problem. This has been done to make it clear that the user should treat these correlations as input since none of these correlations have universal validity. By forcing the user to make this selection, the correlations are given the status of input. In particular, the user must select or provide for:

- Friction factor correlation
- Subcooled void fraction correlation
- Two-phase friction multiplier correlation
- Two-phase void fraction correlation
- Single-phase mixing correlation
- Two-phase mixing correlation
- Pressure loss coefficients for spacers
- Flow diversion from spacing devices
- Diversion crossflow resistance factor
- Crossflow momentum factors
- Heat transfer correlations

COBRA IIIc/MIT-2 uses steady-state correlations for transients. This approximation must be evaluated for applicability to any transient analysis.

II.7 NOMENCLATURE* (1)

Equations	Computer Program	
a	DPDX	Single channel pressure gradient, (F/L^3)
a'	DPDX	Pressure gradient without crossflow in Equation (I.8), (F/L^3)
A	A	Cross-sectional area, (L^2)
[B]	B	Column vector defined by Equation (I.26)
c	COND	Thermal conduction coefficient $(H/T\theta L)$
C	CIJ	Loss function for transverse crossflow in Equation (I.4), (FT/ML)
C_p	CP	Specific heat $(H/M\theta)$
dh/dx	DHDX	Enthalpy derivative, (H/TL)
dm/dx	DFDX	Flow rate derivative, (M/TL)
dp/dx	DPDX	Pressure gradient, (F/L^3)
D	DHYD	Hydraulic diameter, 4A/Pw, (L)
D_r	D	Rod Diameter (L)
f	FSP	Friction factor based on all-liquid flow, (Dimensionless)
f_A	AXIAL	Local-to-average axial power distribution
f_c	PWRF	Fraction of rod power transferred to an adjacent subchannel (Dimensionless)
f_R	RADIAL	Relative rod power distribution (Dimensionless)
f_T	FTM	Turbulent momentum factor (Dimensionless)
F		Force(F)
g_c	GC	Gravitational constant, (ML/FT^2)
G		Mass velocity, (M/TL^2)
h	HFILM	Heat transfer coefficient, $(H/TL^2\theta)$
h	H	Enthalpy, Xhg + (1-X)hf, (H/M)
h*	HSTAR	Enthalpy carried by diversion crossflow, (H/M)
hg,hf	HG,HF	Saturated vapor and liquid enthalpy (H/M)
[Δh]		Enthalpy matrix (H/M)
k	CON	Thermal conductivity, $(H/TL\theta)$
v	V	Liquid specific volume, $1/\rho$, (L^3/M)
v'	VP	Effective specific volume for momentum, $(1-X)^2/\rho_f(1-\alpha) + X^2/\rho_g\alpha$, (L^3/M)
w	W	Diversion crossflow between adjacent subchannels (M/TL)
w'	WP	Turbulent (fluctuating) crossflow between adjacent subchannels, (M/TL)
x	X	Distance (L)
X	QUAL	Quality, $M_g/(M_g + m_f)$, (Dimensionless)

---

(1) *Dimensions are denoted by: L = length, T = time, M = mass, θ = temperature, $F = ML/T^2$ = force and $H = ML^2/T^2$ = energy

X_d	XD	Parameter given by Equation (II.16)
z_{ij}	LENGTH	Effective centroid distance (L)
α	ALPHA	Void fraction, $A_g/A_g + A_f)$, (Dimensionless)
β		Turbulent mixing parameter, (Dimensionless)
γ	AV(1)	Slip Ratio, u_g/ u_f, (Dimensionless)
Θ	THETA	Orientation of channel with respect to vertical, (radians)
ρ	RHO	Two-phase density, $\rho_g \alpha + \rho_f (1-\alpha)$, (M/L^3)
ρ		Effective density for enthalpy transport, $(\rho_g h_g \alpha + \rho_f h_f(1-\alpha)/h$, (M/L^3)
ρ_g, ρ_f	RHOG,RHOF	Saturated vapor and liquid density, (M/L^3)
σ	SIGMA	Surface tension, (F/L)
τ_w	TAUW	Wall shear stress (F/L^2)
ϕ	PHI,FMULT	Two-phase friction multiplier, (Dimensionless)
μ	VISC	Viscosity, (F/LT)
μ_w	VISCW	Wall viscosity, F/LT)
Ψ		Slip correlation function for energy transport, $\rho_f X(1-\alpha) - \rho_g \alpha(1-X)$, (M/L^3)

Subscripts

f,g		Saturated conditions for liquid and vapor, respectively
i	I	Fuel node number
i,j	I,J	Subchannel identification number
ij,ji		Double subscripts imply subchannel connection i to j and j to i, respectively
i(k),J(k)	IK,JK	Subchannel pair for connection number (k)
k	K,L	Subchannel connection number
J	J	Axial node number

III. INPUT DESCRIPTION

III.1 INTRODUCTION

In the various states of development of the current COBRA IIIc/MIT code, three input methods have been devised and included. Each of the later methods was a revision of the prior method.

The first input method is based on that of the original COBRA IIIc. The second method simplifies the input for assembly to assembly, or subchannel analysis of LWR's but is otherwise the same as the first. The third method departs from the original input format and achieves a higher degree of flexibility. This flexibility is most useful when using COBRA IIIc/MIT for single-pass LWR analysis although it further simplifies the input for assembly-to-assembly and subchannel analysis. The third method also offers a number of new modeling options that are not all available in the older method. Because of its greater flexibility and additional modeling options, the third input method is the recommended method for all LWR analysis.

Card Type I1	Problem Array Size
Required:	Always
FORTRAN READ List:	MC, MG, MN, MR, MX
FORTRAN FORMAT:	10I5
Read from Subroutine:	INDAT

Variable	Columns	Format	Description
MC	1-5	I5	≥No. of channels (NCHAN) in problem. NCHAN is set from NTHBOX on cards 1-CNS through 2-CNS, or in the original COBRA format, in Card Group 4.
MG	6-10	I5	≥ No. of gap interconnections (NK) for crossflow mixing between channels in problem. If this is not known, MG = 2*MC is usually adequate but should be checked later. For a BWR (IPILE = 2), MG may be given as zero, since there are no crossflows. If MG is given as zero, it is reset to 1 in subroutine CORE.
MN	11-15	I5	≥ No. of radial fuel nodes in problem. This should be set equal to NODESF + 1 (card 8-CD). If the fuel pin temperature distribution will not be calculated, set mn equal to zero. If MN is given as zero, it is reset to 1 in subroutine CORE.
MR	16-20	I5	≥ No. of rods (NROD) in problem. For PWR and BWR, NROD = NCHAN, hence MR may be given = MC.
MX	21-25	I5	≥ No. of axial stations in problem. It may be given as NDX (Card 7-MD) since it is increased by 1 immediately after reading in.

Notes

(1) Card I1 must be used regardless of which input method is chosen

(2) MC to MX are used to set the array sizes in the dynamic storage, hence they should be set too big rather than too small.

(3) The maximum problem size is limited to 80,000 words by the dimension of the DATA array given in the MAIN program and the value

of KMAX given in the CORE subroutine. Users can alter this limit with appropriate changes in their source programs.

(4) Although there is currently no limit to the number of axial mesh points that may be specified, it has been found that an axial mesh spacing between 2 inches and 1 foot is usually adaquate for most problems. Decreasing the mesh size poses a trade off in terms of achieving convergance and increasing run time. Not only does a finer mesh size imply longer run time. but due to the numerical techniques used in COBRA IIIc/MIT it may actually require more iterations to achieve convergence.

(5) Note that MC to MX are given in alphabetical order.

Card Type I2	Maximum Running Time
Required:	Always
FORTRAN READ List:	MAXT
FORTRAN FORMAT:	I5, 6E12.6
Read from Subroutine:	INDAT

Variable	Columns	Format	Description
MAXT	1-5	I5	Maximum Running Time, Nominal value is 2000.

notes

(1) Card I2 must be used regardless of which input method is chosen

(2) Using MAXT to set the maximum run time works only when there is a routine available to the user which can provide cpu time in one hundredths of a second as an integer. A dummy subroutine has been provided which always returns a zero value for cpu time, and thus disables the maximum run time checks. For systems where the required cpu time value is available, the appropriate commands should be coded into subroutine TIMING

(3) The use of this card is mandatory even if the timing option is not available on the user's system.

(4) Note that MAXT includes the central processing unit time (the CPU time), the printing time, and the amount of time spent in the buffer and in the central processing unit is no more than a few seconds for most problems.

Card Type	I3	Case Control Card
Required:		Always
FORTRAN READ List:		IPILE, KASE, J1, TEXT
FORTRAN FORMAT:		I1, I4, I5, 17A4
Read from Subroutine:		INDAT

Variable	Columns	Format	Description
IPILE	1	I1	IPILE = 0 for simplified method IPILE = 1 for PWR, with interconnected channels. IPILE = 2 for BWR, with separated channels. The value is unimportant if Card Group 20 is selected since it is overwritten on Card 8-CD.
KASE	2-5	I4	Run Identification Number If KASE > 0, calculation continues; if KASE ≤, calculation stops.
J1	6-10	I5	Printing option for standard COBRA output J1 = 0 print only new input J1 = 1 print entire input J1 = 2 print only operating conditions This option is only effective if NOPRIN = 0, i.e., N1 = 0 on card GCC20
TEXT	11-78	17A4	Alphanumeric information to identify Case.

notes

(1) Card I3 must be used regardless of which input method is chosen

(2) The value of KASE will be printed at the top of the output headings as a method of identification for the user. No importance is attached to the value of KASE other than the indication it provides of wether or not another case follows.

III.2

CARD GROUP 20 - THE RECOMMENDED INPUT METHOD

Card Group 20 is the consolidation of all input into one card group. Although some options are not available in this method that are available in the older methods, and it is not possible to input only those parts of the data which change from case to case with this method, this method is recommended. The advantages of this method include simplicity, and a greater selection of input options.

The Card Numbering System in this card group is designed to give both the sequential order of the cards and the general data type being input on the card. The channel numbers taske the following form;

<position of card in the group>-<general data type>

The data type indications used are the following;

CNS = Channel Numbering System
HF = Heat Flux data
MD = Miscellaneous Data
CD = Channel Data
RD = Rod Data
FD = Fuel Data
GB = Gaps and Boundary data
HM = Hydraulic Model input
OC = Operating Conditions
T = Transient data
OO = Output Options
NP = Nodal Power data
DB = DeBug printing selection

As an example, Card 23-HM would be the twenty-third card in this card group and would be used for inputing the Hydraulic Models.

Card Type	GCC20	Select Card Group 20
Required:		Always
FORTRAN READ List:		NGROUP, N1, N2, N3, N4, N5, N6
FORTRAN FORMAT:		7I5
Read from Subroutine:		INDAT

Variable	Columns	Format	Description
NGROUP	1-5	I5	NGROUP = 20 (to select Card Group 20)
N1 (NOPRIN)	6-10	I5	Printing trigger, NOPRIN, set to N1. N1 = 0, standard COBRA IIIC printing obtained as well as "new" printout. N1 = 1, standard COBRA printing suppressed.
N2-N6	11-35	I5	Leave blank

Notes

(1) If NGROUP = 0, this acts as a trigger to stop reading Input Data and to start the hydraulic calculation (e.g., after card 47-OP).

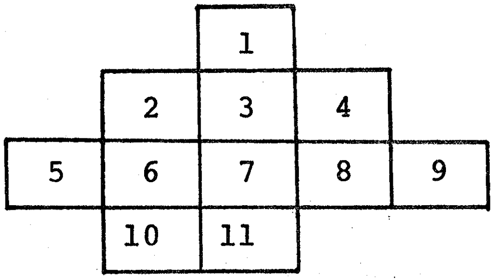
(2) In the older input methods, the remaining input data was divided into as many as 12 groups and a group control card, card type GCC, was provided at the start of each data group. These older methods will be taken up again on page . In the latest method, all of the data has been consolidated into one card group. To select this recommended input method, the value of "NGROUP" on the group control card is set to 20 and thus this card group is called Card Group 20.

Card Type	1-CNS	Channel Map parameter
Required:		Whenever Card Group 20 is used
FORTRAN READ List:		IMAP, ND1X, ND2X
FORTRAN FORMAT:		14I5
Read from Subroutine:		Card20

Variable	Columns	Format	Description
IMAP	1-5	I5	Selects method for reading channel map into array NTHBOX (ND1X, ND2X). IMAP = 1, 2 or 3
ND1X	6-10	I5	The number of channels across the longest row of the channel numbering map. (Maximun = 25)
ND2X	11-15	I5	The number of rows in the channel numbering map.

notes

(1) In COBRA IIIc/MIT, the channel numbering system is contained in the array NTHBOX(ND1X, ND2X) with a zero for each non-channel. This array is later used to define the interaction between adjacent channels. Thus a channel map:

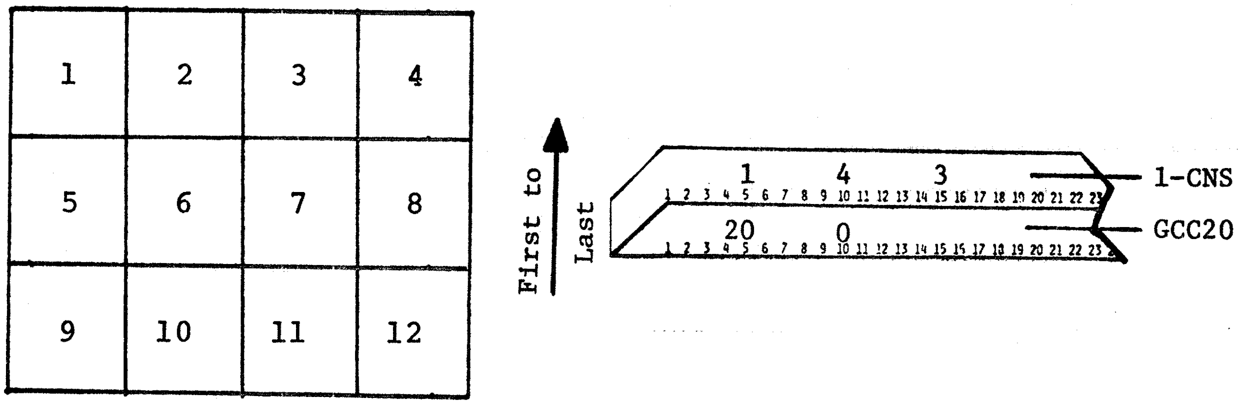


would be represented in NTHBOX (5,4) as

$$\begin{matrix} 0 & 0 & 1 & 0 & 0 \\ 0 & 2 & 3 & 4 & 0 \\ 5 & 6 & 7 & 8 & 9 \\ 0 & 10 & 11 & 0 & 0 \end{matrix}$$

The method of inputting the channel map into NTHBOX and the dimensions for NTHBOX are provided on card 1-CNS. IMAP = 1, 2 or 3 indicates the input method while ND1X and ND2X carry the apropriate dimensions.

If IMAP = 1, there are assmed to be ND1X*ND2X channels numbered sequentialy along each row, and column by colum, to give a rectangular matrix. Thus, if cards GCC and 1-CNS are given as in Figure 17(b) with IMAP = 1, ND1X = 4, and ND2X = 3, the resulting channel map would be, that shown in Figure 17(a)



(a) (b)

Figure 17: Channel map and required cards using IMAP = 1.

(2) If IMAP = 1, go to card 4-HF
If IMAP = 2, go to card 2-CNS
If IMAP = 3, go to card 3-CNS

Card Type	2-CNS	Channel Map
Required:		If IMAP = 2 while using Card Group 20
FORTRAN READ List:		ISTART, IFIN
FORTRAN FORMAT:		14I5
Read from Subroutine:		CARD20

Variable	Columns	Format	Description
ISTART	1-5	I5	Position in row where sequential channel numbering is to begin.
IFIN	6-10	I5	Position in row where sequential channel numbering ends.

notes

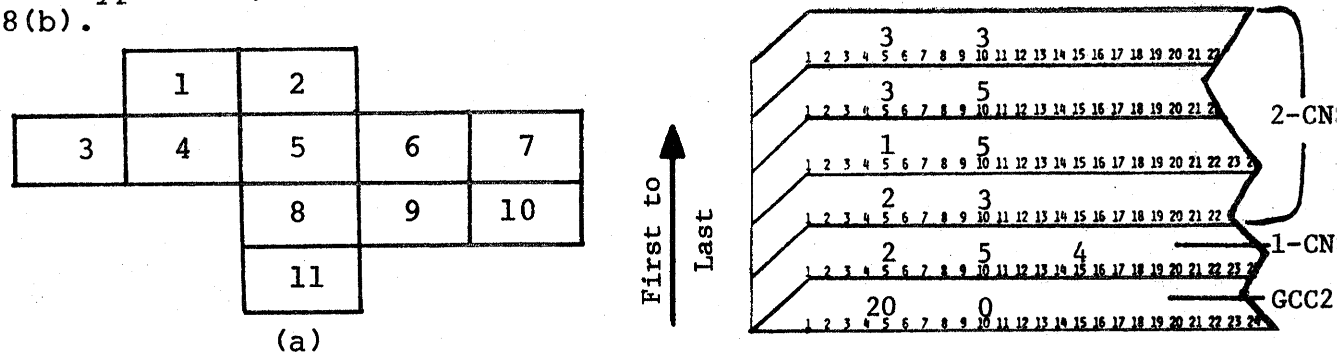
(1) A total of ND2X cards of this type are read sequentialy, one for each row of the channel map. Each card gives the column numbers in the row where channel numbering should begin and end. Channel Identification Numbers are then placed sequentially in each column from the first position (ISTART) to the last (IFIN) inclusively.

For example, ISTART = 3, IFIN = 6 would imply a row;

0 0 (N + 1) (N + 2) (N + 3) (N + 4) 0 0 etc.

where channel N was the last channel in the previous row, and ND1X = 8.

To input the channel map shown in Figure 18(a) using IMAP = 2, card types GCC, 1-CNS and 2-CNS would be given as shown in Figure 18(b).



(a)

Figure 18: channel map and required cards using IMAP = 2. (b)

Card Type 3-CNS	Channel Map
Required:	If IMAP = 3 while using Card Group 20
FORTRAN READ List:	((NTHBOX (ND1, ND2), ND1 = 1, ND1X), ND2 = 1, ND2X)
FORTRAN FORMAT:	14I5
Read from Subroutine:	CARD20

Variable	Columns	Format	Description
NTHBOX	1-70	14I5	Channel Identification Number for every channel apearing on this row of the channel numbering map. Channels are specified from left to right across the row.

notes

(1) One card of type 2-CNS must be given for each of the ND2X rows in the channel numbering map. Each row of NTHBOX must start on a new card.

(2) If ND1X > 14, the remaining channel numbers for each row (i.e., 15-ND1X) are read on a continuation card. Note ND1X must not exceed 25.

(3) All ND1X columns in the row must be given a Channel Identification Number. A zero (or blanks) may be given for columns which do not represent a channel.

(4) The IMAP = 3 option allows the user to directly specify the values of the array "NTHBOX". This flexibility permits the user to create and use channel maps which are not necessarily sequential.

To input the channel map of Figure 18(a) using IMAP = 3 instead of MAP = 2 requires the cards illustrated in Figure 19.

IMAP = 3 could be used, either to specify a particular numbering system or when there are two channels in the same row separated by a "zero" or "non-channel".

In the simplified method, (i.e. IPILE = 0) channel maps such as the one shown in Figure 20(a) may be required. Only IMAP = 3 is adaquate for inputing this kind of array. The cards needed are illustrated in Figure 20(b).

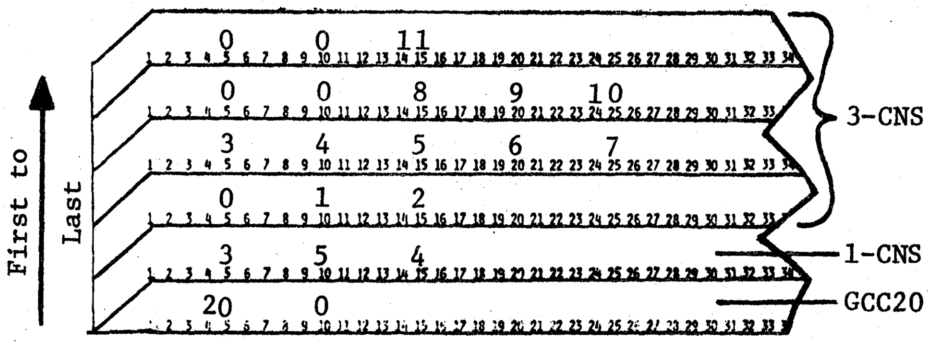


FIGURE 19: Cards Required to Input Channel Map of Figure 18 Using IMAP = 3 Instead of 2

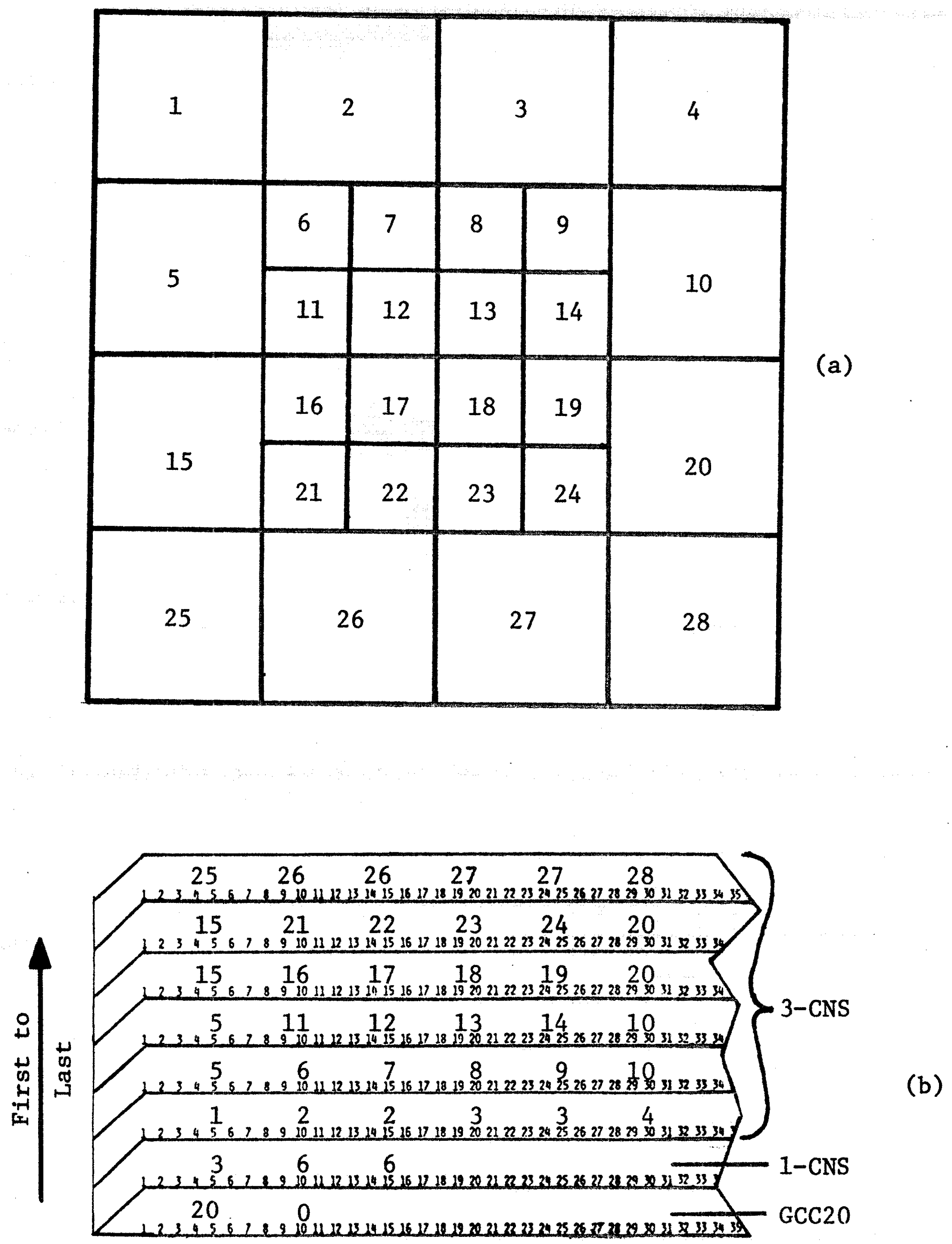


FIGURE 20: a) Channel Map for Which Only the IMAP = 3 Option Will Work
b) Resulting Input Deck

Card Type	4-HF	Heat Flux Specification
Required:		Always when NGROUP = 20
FORTRAN READ List:		N1, AFLUX
FORTRAN FORMAT:		I5, 13E5.0
Read from Subroutine:		CARD20

Variable	Columns	Format	Description
N1	1-5	I5	N1 = 0; trigger to read average nodal fuel powers after rest of data (Cards 48-NP through 49-NP). NAX set to 0, IQP3 set to 0. N1 = 1; trigger to read average nodal fuel and coolant powers after rest of data (Cards 48-NP through 50-NP). NAX set to 0, IQP3 set to 1. N1 $\geq$ 2; number of axial points at which heat flux profile will be given on following card 5-HF. Maximum value of N1 = 30. NAX set to N1, IQP3 set to 2.
AFLUX	6-10	E5.0	Reactor average heat flux (Mbtu/sqft-hr). If N1 = 0 or 1, the value of AFLUX is irrelevant and may be given as zero.

notes

(1) If the value of N1 is set at 0 or 1, the input of the nodal power factors is post-poned and the remainder of the card may be blank.

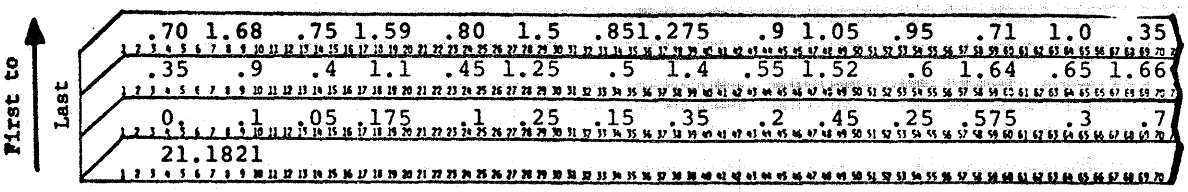
Card Type	5-HF	Heat Flux Profile
Required:		If N1 ≥ 2 (Card 4-HF) when NGROUP = 20
FORTRAN READ List:		Y(I), AXIAL (I), I = 1, N1
FORTRAN FORMAT:		14E5.0
Read from Subroutine:		READIN/CARD20

Variable	Columns	Format	Description
Y	1-70	E5.0	Normalised axial position along channel (x/L); $0 \leq Y \leq 1.0$
AXIAL	1-70	E5.0	Relative heat flux (local/average) corresponding to Y.

notes

(1) Note that both the position and the heat flux are specified as relative values with the average heat flux being supplied on card 4-HF.

(2) To input the relative axial heat flux profile illustrated in Table 3 and Figure 22: card types 4-HF and 5-HF are provided as illustrated in Figure 21.



```
 .70 1.68  .75 1.59  .80  1.5  .851.275   .9 1.05  .95   .71  1.0  .35
 .35   .9   .4  1.1  .45 1.25   .5  1.4  .55 1.52   .6 1.64  .65 1.66
  0.   .1  .05 .175   .1  .25  .15  .35   .2  .45  .25 .575   .3   .7
 21.1821
```

FIGURE 21: Cards of Type 5-HF to Input the Data of Table 3 and Figure 22

RELATIVE AXIAL HEAT FLUX			
x/L	$q''_x/\overline{q''}$	x/L	$q''_x/\overline{q''}$
0.0	0.100	0.55	1.520
0.05	0.175	0.60	1.640
0.10	0.250	0.65	1.660
0.15	0.350	0.70	1.680
0.20	0.450	0.75	1.590
0.25	0.575	0.80	1.500
0.30	0.700	0.85	1.275
0.35	0.900	0.90	1.050
0.40	1.100	0.95	0.710
0.45	1.250	1.00	0.350
0.50	1.400		

TABLE 3: Data for Figures 21 and 22

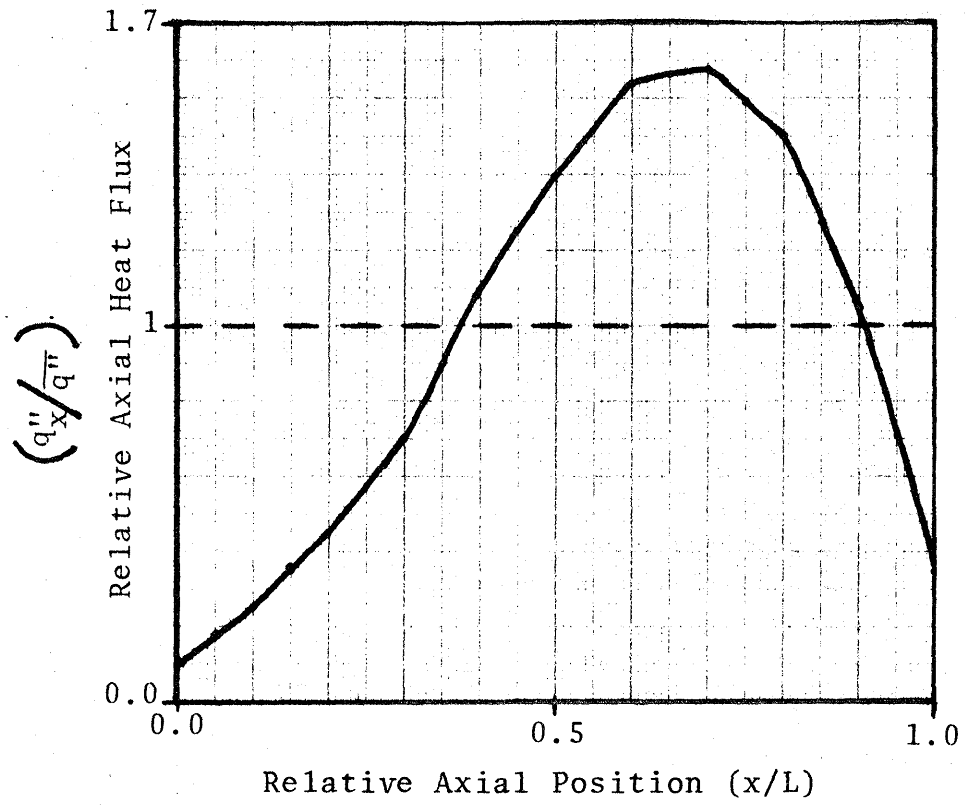


FIGURE 22: Axial Heat Flux Profile

Card Type	6-HF	Rod Power Factors
Required:		If N1 ≥ 2 (Card 4-HF) and NGROUP = 20
FORTRAN READ List:		RADIAL(I), I = 1, NCHAN
FORTRAN FORMAT:		14E5
Read from Subroutine:		READIN/CARD20

Variable	Columns	Format	Description
RADIAL	1-70	14E5.0	Relative Rod Power (local average)

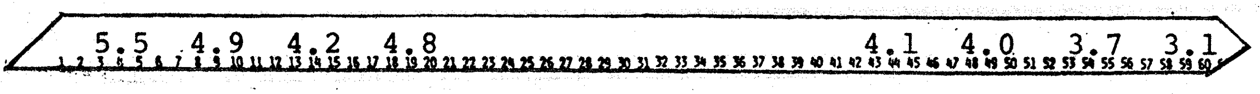
notes

(1) NCHAN = No. of channels in problem (NCHAN ≤ MC in Card I1). It is set to the highest value of the channel map array NTHBOX -- see cards 1-CNS through 3-CNS --

(2) In the simplified method (IPILE = 0) some subchannels are lumped together to create one channel, while others are treated as individual subchannels. (See Figure 23) Each composite channel can be visualized as having only one rod which generates the entire power input into that channel. In order to reduce the input data the power given to such a channel for its rod is specified here, while rods that share their power with several channels, will be described on Card 14-RD.

This system of entering the Data, reduces the cards required in the presentation and only introduces the restriction that the lumped channel needs to have the same identification number as its rod.

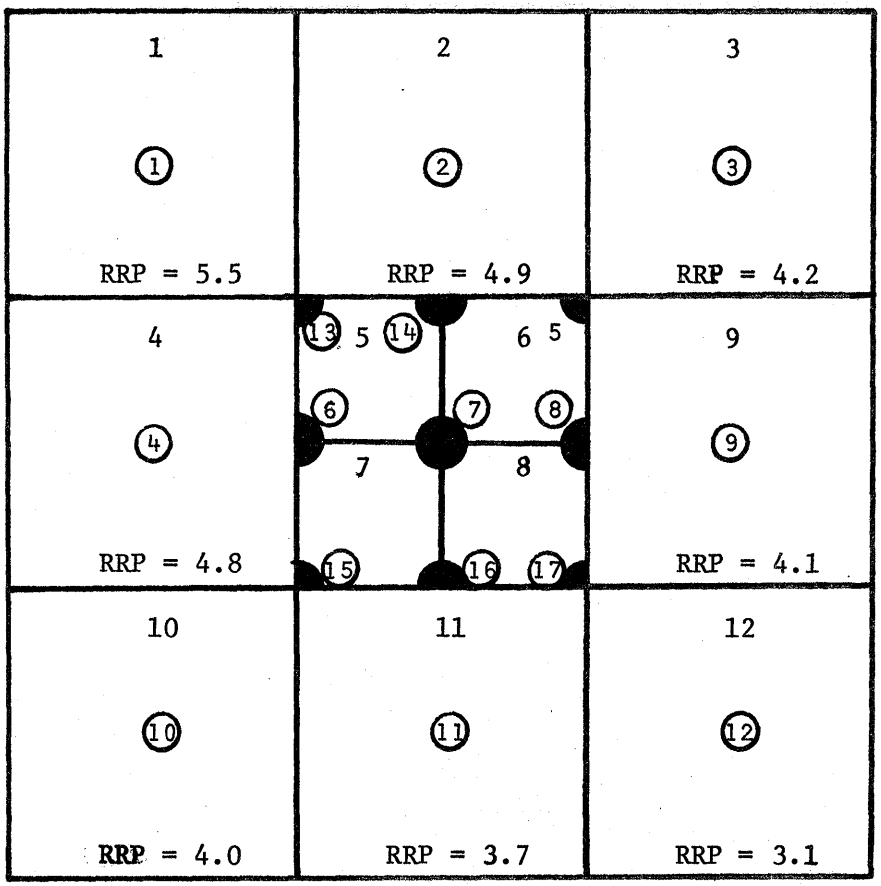
To input the Relative Rod Power (RRP) for the configuration shown in Figure 23, card 6-HF should have the actual relative rod power for channels 1-4, zero for channels 5-8 and the actual values for channels 9-12, as shown below.



(3) The Relative Rod Power is calculated as the total energy added to the channel from all rods devided by the average heat flux value, AFLUX (card 4-HF), and the product of the channel geometry fraction, FRAC, and the number of heated rods, HNR, (card 10-CD). In equation form;

RRP = TOTAL POWER TO CHANNEL/(AFLUX*FRAC*HNR)

(4) The power given to channels 5, 6, 7 and 8 from rods 5-8 and 13-17 will be specifid later in card 15-RD.



RRP = Relative Rod Power CHANNEL No. = 5 ROD No. = ⑤

Figure 23: Channel Map using lumped channel configuration and Relative Rod Powers (RRP). Note: it is assumed that the RRP calculation has accounted for the values of FRAC and HNR (number of heated rods)

Card Type 7-MD	Miscellaneous data
Required:	Whenever NGROUP = 20
FORTRAN READ List:	Z, NDX, NDT, TTIME
FORTRAN FORMAT:	E5.0, 2I5, 10E5.0
Read from Subroutine:	CARD20

Variable	Columns	Format	Description
Z	1-5	E5.0	Channel length (in.)
NDX	6-10	I5	Number of axial intervals
NDT	11-15	I5	Number of time steps NDT = 0; steady state only NDT > 0; steady state + transient
TTIME	16-20	E5.0	Total duration of transient (sec) The length of each time step is set to TTIME/NDT.

Card Type 8-CD	Channel Indicators
Required:	Whenever Card Group 20 is used
FORTRAN READ List:	PILE. NCTYP. NGRID, NGRIDT, NODESF, NFXF, IFRM, IHTM, IPROP
FORTRAN FORMAT:	14I5
Read from Subroutine:	CHAN

Variable	Columns	Format	Description
IPILE	1-5	I5	IPILE = 0 for simplified method IPILE = 1 for PWR's with interchannel connections. IPILE = 2 for BWR's with no interchannel connections or crossflow.
NCTYP	6-10	I5	No. of channel types to be read in; controls reading of cards 10-CD through 12-CD.
NGRID	11-15	I5	No. of grid positions (maximum = 10)
NGRIDT	16-20	I5	No. of grid types for each channel (Maximum = 5)
NODESF	21-25	I5	No. of fuel nodes
NFXF	26-30	I5	No. of "forced flow" types. If not in use; leave blank
IFRM	31-35	I5	Indicator for fuel rod model If IFRM = 0, old model is used If IFRM = 1, new model is used
IHTM	36-40	I5	Indicator for rod-to-coolant heat transfer model. IHTM = 0, old model is used. IHTM = 1, new model for pre-CHF conditions is used. IHTM = 2, new model for pre-and post-CHF conditions is used.
IPROP	41-45	I5	Indicator for new fuel rod properties (used only when IFRM = 1). IPROP = 0, constant fuel and clad properties, hgap (gap conductance) constant. IPROP = 1, temp-dep. fuel and clad, properties, hgap constant. IPROP = 2, temp-dep. fuel and clad, hgap calculated

Card Type 9-CD	
Required:	When NODESF > 0 and either IFRM = 1 or IGTM > 0 while using NGROUP = 20
FORTRAN READ List:	EPSF
FORTRAN FORMAT:	E8.0
Read from Subroutine:	CHAN

Variable	Columns	Format	Description
EPSF	1-8	E8.0	Fuel rod temperature convergence criterion. If EPSF is given as zero, it is set to the default value 0.01

Card Type	10-CD	Channel Data for Type I
Required:		When NGROUP = 20
FORTRAN READ List:		N. J, FRAC, GAP, HNR, DR, A, B, C, D
FORTRAN FORMAT:		2I5, 8E5.0
Read from Subroutine:		CHAN

Variable	Columns	Format	Description
N	1-5	I5	Friction Indicator to select friction factor for channel (card 25-HM) Nominal value = 1, maximum = 4.
J	6-10	I5	Indicator to define A, B, C, D below. For J = 1 the area and perimeters are user supplied. For J = 2 the area and perimeters are calculated from the user supplied dimensions.
FRAC	11-15	E5.0	Amount by which channel area, wetted and heated perimeters and number of heated rods are to be multiplied (see below). If FRAC > 1.0, relative rod powers will also be multiplied
GAP	16-20	E5.0	Effective rod gap for interconnection between channels (in.). If IPILE = 0 this may be given as zero since the individual gap sizes will be read in later.
HNR	21-25	E5.0	No. of heated rods in fuel assembly
DR	26-30	E5.0	Diameter of heated rods (in.)
A	31-35	E5.0	***** If J = 1: ***** A = Channel Flow Area (sq-in) B = Channel Wetted perimeter (in.) C = Channel heated perimeter (in,) D = Not used--leave blank ***** If j = 2: ***** A = No. of unheated (e.g., control) rods B = Diameter of unheated rods (in.) C = Width of square assembly (in.) D = Radius of channel corners (in.)
B	36-40	E5.0	
C	41-45	E5.0	
D	46-50	E5.0	

notes

(1) The values for channel area, heated and wetted perimeters,

and the number of heated rods are multiplied by FRAC. Thus, if a line of symmetry divides a channel so that it is a half-channel, the data for a whole channel may be given and FRAC set to 0.5. Alternatively, data for a single channel may be given and FRAC set to (say) 4.0 to obtain the parameters for a smeared group of 4 channels. If FRAC is given as zero, it is reset to 1.0.

(2) GAP is the "effective" gap between assemblies. For no internal resistance to mixing within an assembly, GAP could be considered to be the gap between individual rods * the number of gaps. This would be reduced according to the internal resistance model used.

(3) The recommended input method, or "Card Group 20", achieves considerable simplification of the input data by allowing the information for similar channels to be input only once. Two channels are of the same type if the data called for on cards 10-CD and 11-CD for both channels is identical.

The value of NCTYP on card 8-CD indicates the number of channel types in the problem. One group of cards 10-CD and 11-CD must be provided for the first channel type and one group of cards 10-CD through 12-CD must be present for each of the remaining channel types. The data for each channel type will then be read sequentially by type number (I = 1, NCTYP).

Cards 10-CD and 11-CD describe the geometry and grid locations for channel type i while card 12-CD specifies which channels are of this type. Since any channels which do not have their type declared specifically on a 12-CD card are assumed to be of type 1, no 12-CD card should be given for the first channel type. The best economy is also achieved if type 1 is defined as that type which contains the majority of channels.

As an example, if the value of NCTYP = 3 on card 8-CD, the cards needed to input data for these 3 channel types are illustrated in Figure 24

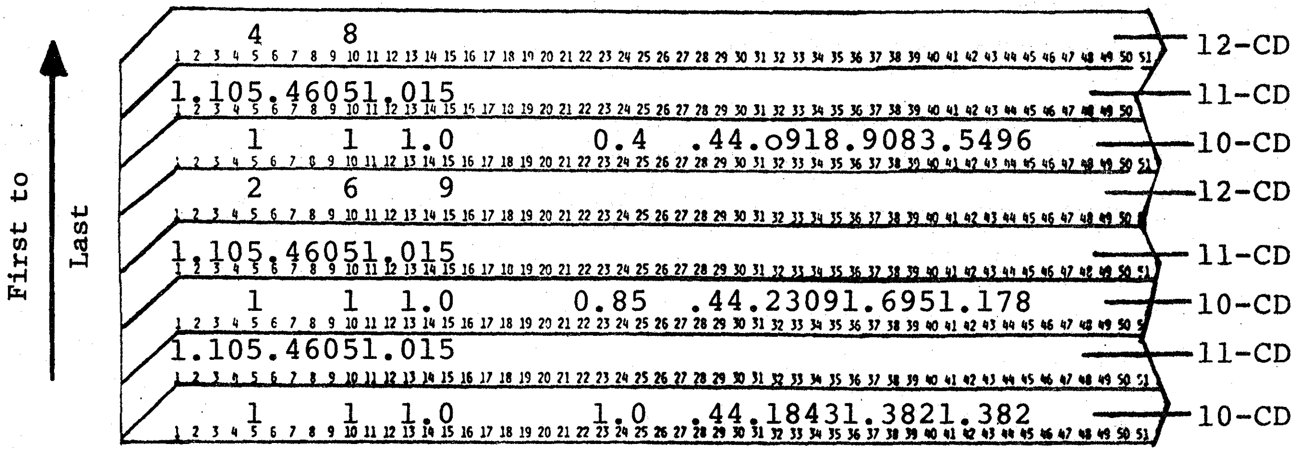


Figure 24: The arrangement of cards 10-CD through 12-CD to input channel data for three different channel types.

Card Type	11-CD	Grid Data for Channel Type I
Required:		If NGRID > 0 with NGROUP = 20
FORTRAN READ List:		CDG(L), L = 1, NGRIDT
FORTRAN FORMAT:		14E5.0
Read from Subroutine:		CHAN

Variable	Columns	Format	Description
CDG	1-70	15E5.0	Single phase grid coefficient for each grid type.

Card Type	12-CD	Channels making up Type I
Required:		If NCTYP > 1 and for channels of type I where $2 \leq I \leq$ NCTYPE
FORTRAN READ List:		JB(L), L = 1, NGRIDT
FORTRAN FORMAT:		14E5.0
Read from Subroutine:		CHAN

Variable	Columns	Format	Description
JB	1-70	I5	Channel Identification Numbers for channels of type i.

Notes

(1) The channels of Type I are listed on one or more cards. A complete card is read and the numbers up to the first zero are taken as the relevant channels. The zero (or blank) must be given since it acts as a trigger, hence if the last channel number is at the end of a card, a blank card must follow to supply the terminating zero.

(2) Next card read is: Card 13-CD if i = NCTYP
Card 10-CD if i < NCTYP

Card Type	13-CD	Grid Positions
Required:		If NGRID > 0
FORTRAN READ List:		GRIDXL (I), IGRID (I), I = 1,NGRID
FORTRAN FORMAT:		7(E5.0, I5)
Read from Subroutine:		CHAN

Variable	Columns	Format	Description
GRIDXL	1-70	E5.0	Fractional distance up channel (x/L) at which each grid is situated, i.e., $0 \le GRIDXL \le 1.0$
IGRID	1-70	I5	Grid Type; the coefficients for each type of grid were read in on card 11-CD.

Notes

(1) If NGRID > 0 a list of the grids, their position and types is required. If NGRID > 7, the remaining values are given on a continuation card.

Card Type	14-RD	Indicators
Required:		If IPILE = 0
FORTRAN READ List:		NN11, NN22, NN33, NN44, ITMP
FORTRAN FORMAT:		4I5
Read from Subroutine:		CHAN

Variable	Columns	Format	Description
NN11	1-5	I5	Number of cards of rod layout data to be read.
NN22	5-10	I5	Total number of rods
NN33	10-15	I5	Number of radial fuel nodes including the cladding
NN44	15-20	I5	Fuel type specification: NN44 = 1; cylindrical fuel only, NN44 = 2; plate fuel or combination of plate and cylindrical fuel.
ITMP	21-25	I5	Transverse momentum coupling parameter indicator; ITMP = 0; FACSL and FACSLK set to 1.0 for all gaps. ITMP = 1; FACSL and FACSLK read in on card 21-GB for each gap.

Note

(1) In the simplified method (IPILE = 0) the power addition to each channel from every rod must be specified for any channel which was not done as a lumped channel on card 6-HF. Cards 14-RD and 15-RD are used to input the necessary rod data starts the read in of this data.

(2) NN44 should equal 1 if IRFM = 1 (card 8-CD) because the new fuel rod model only considers cylindrical geometry.

(3) A description of the Transverse Momentum Models available in COBRA IIIc/MIT is given in section I.6.

Card Type 15-RD	Rod layout information
Required:	If IPILE = 0 and NN11 > 0 with NGROUP = 20
FORTRAN READ List:	N, I, DR(I), RADIA(I), (LR(I,L), PHI(I,L), L = 1,6)
FORTRAN FORMAT:	I1, I4, 2E5.0, 6(I3, E7.0), E5.0, E10.0
Read from Subroutine:	CHAN

Variable	Columns	Format	Description
N	1	I1	Fuel rod type (see note 1)
I	2-5	I4	Identification number of the rod
DR(I)	6-10	E5.0	Rod diameter
RADIA(I)	11-15	E5.0	Relative rod power (rod power/average rod power)
LR(I,L)		I3	Adjacent channel number
PHI(I,L)		E7.0	Fraction of the rod power to that channel

notes

(1) N = 1 indicates rod fuel
    N = 2 indicates plate fuel

(2) This block is repreated 6 times (L = 1,6)

(3) If NN11 on card 14-RD is greater than zero, a total of NN11 cards of type 15-RD must be provided. Each card gives rod type, identification number, diameter, relative power and adjacent channel numbers with fraction of rod power going to that channel for one rod. One card for every rod considered is required.

Card Type 16-FD	Fuel Temperature Data
Required:	If NODESF > 0
FORTRAN READ List:	KF(I), CF(I), RF(I), DF(I), KC(I), CC(I), RC(I), TC(I), HG(I), I =1,NN44
FORTRAN FORMAT:	14E5.0
Read from Subroutine:	CHAN

Variable	Columns	Format	Description
KF	1-5	E5.0	Fuel thermal conductivity (Btu/hr ft°F)
CF	6-10	E5.0	Fuel specific heat (Btu/lb°F)
RF	11-15	E5.0	Fuel density (lb/ft^3)
DF	16-20	E5.0	Pellet diameter (inch)
KC	21-25	E5.0	Clad thermal conductivity (Btu/hr ft°F)
CC	26-30	E5.0	Clad specific heat (Btu/lb°F)
RC	31-35	E5.0	Clad density (lb/ft^3)
TC	36-40	E5.0	Clad thickness (inch)
HG	41-45	E5.0	Fuel to-clad heat transfer coefficient (Btu/ft^2 hr°F)

Note

(1) Fuel temperature data must be given even when IPROP > 0 (Card 8-MD)

(2) Card type 16-FD gives the thermal properties of the fuel and clad. Whenever NODESF > 0 a total of NN44 cards (card 14-RD) of type 16-FD are required. If NN44 = 2, the first card gives data for the cylindrical fuel and can be blank if no cylindrical fuel is used. The second card gives data for the plate fuel only.

(3) All user supplied dimensions should be "hot" dimensions since no adjustment is made for thermal expansion.

Card Type 17-FD	
Required:	When NODESF > 0 and IFRM = 1
FORTRAN READ List:	NCF, NCC, THG
FORTRAN FORMAT:	2I5, 8E5.0
Read from Subroutine:	CHAN

Variable	Columns	Format	Description
NCF	1-5	I5	Number of radial clad cells
NCC	6-10	I5	Number of radial fuel cells
THG	11-15	I5	Gap thickness (in)

notes

(1) All user supplied dimensions should be "hot" dimensions since no adjustment is made for thermal expansion.

Card Type 18-FD	
Required:	When NODESF > 0 and IFRM = 1 and IPROP > 0
FORTRAN READ List:	FTD, EPUO2
FORTRAN FORMAT:	14E5.0
Read from Subroutine:	CHAN

Variable	Columns	Format	Description
FTD	1-5	E5.0	Fraction of theoretical density of fuel
EPUO2	6-10	E5.0	PUO2 content, volume fraction

Card Type 19-FD	
Required:	When NODESF > 0, IFRM = 1, and IPROP = 2
FORTRAN READ List:	BURN, CPR, EXPR, FPRESS, GRGH, GMIX, PGAS
FORTRAN FORMAT:	14E5.0
Read from Subroutine:	CHAN

Variable	Columns	Format	Description
BURN	1-5	E5.0	Burnup, (MWD/MTU)
CPR	6-10	E5.0	Coefficient of fuel pressure on clad for gap conductance model
EXPR	11-15	E5.0	Exponent for fuel pressure on clad
FPRESS	16-20	E5.0	Fuel pressure on clad for gap conductance model (psia)
GRGH	21-25	E5.0	RMS of fuel and clad roughness (in) GRGH set equal to 1.6×10^{-5} . if GRGH given as 0.
GMIX(1)	26-30	E5.0	Mole fraction of helium
GMIX(2)	31-35	E5.0	Mole fraction of argon
GMIX(3)	36-40	E5.0	Mole fraction of krypton
GMIX(4)	41-45	E5.0	Mole fraction of zenon
PGAS	46-50	E5.0	Pressure of gas mixture in gap (psia)

Note

(1) The four elements of GMIX must sum to 1.0.

Card Type	20-GB	Effective rod gap for interconnection between channels (in)
Required:		If IPILE = 0
FORTRAN READ List:		(GAPREC(I), I = 1, NK) where NK is the total number of gap interconnections
FORTRAN FORMAT:		14E5.0
Read from Subroutine:		CHAN

Variable	Columns	Format	Description
GAPREC	1-70	E5.0	Effective rod gap for interconnection between channels (in)

notes

(1) In order to give to each boundary its gap these gaps should be inputted in the same order as the boundaries are established In general the boundaries are established by going from left to right in each row and from top to bottom between two consecutive rows. As an example, consider the channel map of Figure 25 and the resulting channel pair - boundary number combinations of Table 4.

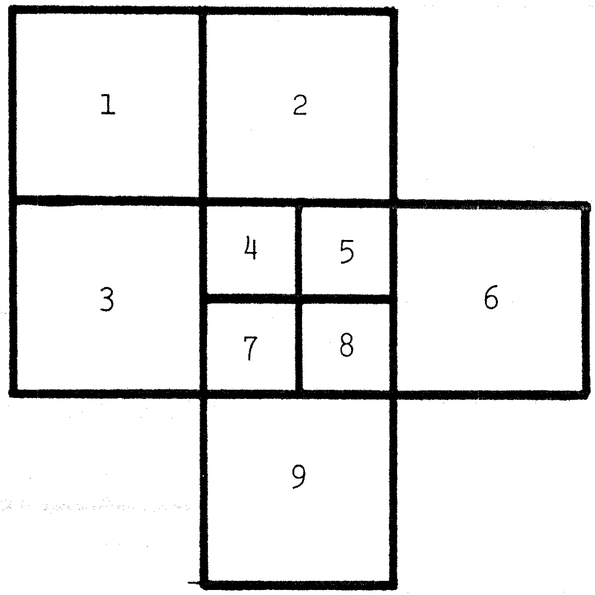


FIGURE 25: The Channel map from which the combinations of channel pairs and boundary numbers in table 4 were taken

CHANNEL PAIR MAKING UP BOUNDARY													
1-2	1-3	2-4	2-5	3-4	4-5	5-6	4-7	5-8	3-7	7-8	8-6	7-9	8-9
1	2	3	4	5	6	7	8	9	10	11	12	13	14
BOUNDARY NUMBER													

Table 4: The Channel pair — boundary number combinations resulting from the channel map of Figure 25

Card Type 21-GB	Transverse Momentum Coupling Parameters
Required:	When IPILE = 0 and ITMP = 1 (card 14-RD)
FORTRAN READ List:	FACSL(I), FACSLK(I), I = 1, NK
FORTRAN FORMAT:	14E5.0
Read from subroutine:	CHAN

Variable	Columns	Format	Description
FACSL(I)		E5.0	Coupling parameter for gap I. May be set equal to the ratio of the number of inter-rod gaps at the boundary between the two regions separated by gap I, divided by the number of rows of rods separating the centroids of the two inter-connected regions.
FACSLK(I)		E5.0	Second type of coupling parameter. May be set equal to the number of inter-rod gaps at the boundary of the two regions separated by gap I.

Note

(1) If IPILE = 0 and ITMP = 1 (card 14-RD) cards of type 21-GB are required containing the transverse momentum coupling parameter for each boundary. These parameters should appear in the same order as the boundaries are established.

(2) The suggestions given in the above descriptions are for use of the Weisman aproach for transverse momentum modeling. Alternatively, the Chiu approach could be used. See section I.6 for a description of both methods. FACSL corresponds to $(Ng/Nr)_{ij}$ and FACSLK corresponds to $(Nr)_{ij}$.

Card Type	22-GB	PWR Half-Boundaries
Required:		If IPILE = 1
FORTRAN READ List:		(II(L), JJ(L), L = 1, N) where II(N) = 0
FORTRAN FORMAT:		14I5
Read from Subroutine:		CHAN

Variable	Columns	Format	Description
II	1-70	I5	II(L), JJ(L) are the channel identification numbers which define the lth "half-boundary."
JJ	1-70	I5	

Notes

(1) Card 22-GB should be used whenever IPILE = 1. This card contains the channel pairs which define "half boundaries". A half boundary is any channel boundary cut by a line of symmetry. Figure 26 shows a channel map in which half boundaries are specified by the channel pairs 1 and 5, 5 and 8, 8 and 10. (Note that only half of the channel map is numbered since only half will be analyzed by the code). If there are no half boundaries in the problem, a blank card is still required.

(2) The list of "half-boundaries" is terminated by a zero. If the list finishes at the end of a card, a blank card should follow to provide the zero-trigger.

(3) If (IPILE = 0) the true rod spacing should have been set using cards 20-GB.

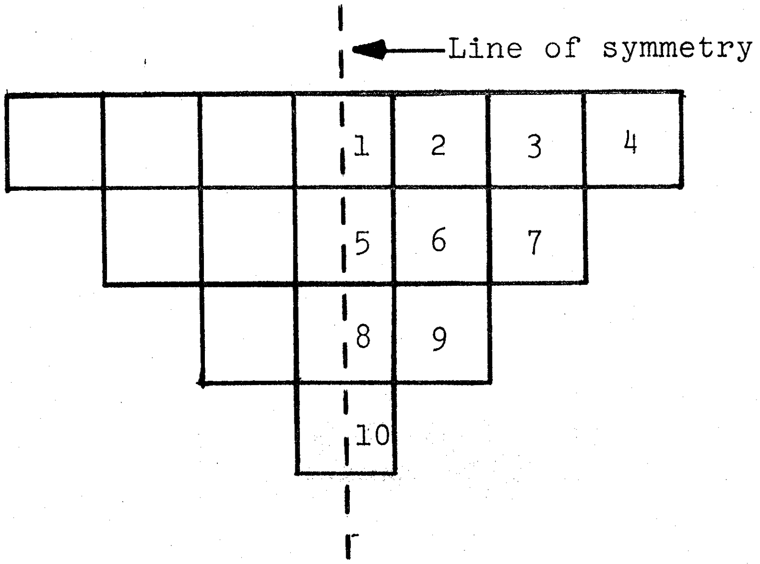


Figure 26: The Channel map with "Half-Boundaries" defined by channel pairs; 1 and 5, 5 and 8, 8 and 10

Card Type	23-HM	Hydraulic Model Indicators
Required:		Always
FORTRAN READ List:		N1 N2 N3 N4 N5 N6 N7 N8 N9
FORTRAN FORMAT:		14I5
Read from Subroutine:		MODEL

Variable	Columns	Format	Description
N1	1-5	I5	Mixing Indicator: N = 0; B = W/(G*S) = 0.02 N = 1; B = W/(G*S) = ABETA*(RE**BBETA) N = 2; B = W/(G*D) = ABETA*(RE**BBETA) N = 3; The new mixing model is used.
N2	6-10	I5	Single Phase Friction Indicator
N3	11-15	I5	Two Phase Friction Indicator
N4	16-20	I5	Void Indicator
N5	21-25	I5	Inlet Flow Indicator
N6	26-30	I5	Parameter Indicator
N7	31-35	I5	Iteration Indicator
N8	36-40	I5	Physical Property Indicator
N9	41-45	I5	Coupling parameter in the mixing term of the energy equation

Notes

(1) COBRA IIIc/MIT-2 contains a preset hydraulic model with many optional variations. Card 23-HM contains the indicators which select the various options. If all variables, N1-N9, are zero (ie. a blank card) the preset model is used unchanged and the next card read will be Card 36-OC.

(2) The parameters, N2-N9 are merely "Yes-No" triggers for the hydraulic model options. Any value given which is greater than zero indicates that a particular option wll be used and that the appropriate cards of input will be provided. Since no other significance is attached to the values of N2-N9, only the values of 0 and 1 should be used to avoid confusion.

(3) The Beus Mixing Model is described in section II.2.g.1

(4) The preset model is defined in the following card descriptions .

(5) N9 = 0 means that no coupling parameter will be used.

Card Type	24-HM	Mixing Model
Required:		If N1 = 1 or 2 (card 23-HM)
FORTRAN READ List:		ABETA BBETA
FORTRAN FORMAT:		14E5.0
Read from Subroutine:		MODEL

Variable	Columns	Format	Description
ABETA	1-5	E5.0	
BBETA	6-10	E5.0	

Notes

(1) If N1 = 0, then ABETA = 0.02, BBETA = 0.0, and
W/(G*S) = ABETA*(RE**BBETA)

(2) Thermal conduction between channels is suppressed for all N1.

(3) W is the mixing rate
RE is an average Reynolds number for the gap
S is the gap width
D is an average hydraulic diameter
G is the mass flux

Card Type	25-HM	Single Phase Friction Model
Required:		If N2 > 0 (card 23-HM)
FORTRAN READ List:		NVISCW, ((AA(N), BB(N), CC(N), N = 1, 4)
FORTRAN FORMAT:		I5, 13E5.0
Read from Subroutine:		MODEL

Variable	Columns	Format	Description
NVISCW	1-5	I5	NVISCW=1, if the wall viscosity correction to the single phase friction factor is required. If not required, NVISCW=0.
AA	6-65	E5.0	The single phase friction factor is calculated as AA*(RE**BB)*CC, where RE = Reynolds Number.
BB	6-65	E5.0	
CC	6-65	E5.0	

Notes

(1) Up to four sets of constants may be specified, one for each friction type specified.

(2) The friction factor defined by AA(N), BB(N), CC(N) is applied to those channels with that value of N on card 11-CD. If all channels have the same friction factor, N is given as 1 on card 10-CD for all channel types and only AA(1), BB(1), CC(1) are given.

(3) If N2 = 0, NVISCW is set to 0 and the smooth tube friction factor is used, i.e., AA = 0.184, BB = 0.2 and CC = 0.0 for all N = 1,4.

Card Type	26-HM	Two Phase Friction Model
Required:		If N3 > 0 (card 23-HM)
FORTRAN READ List:		J4
FORTRAN FORMAT:		14I5
Read from Subroutine:		MODEL

Variable	Columns	Format	Description
J4	1-5	I5	Two phase friction correlation trigger J4 = 0 Homogeneous Theory J4 = 1 Armand J4 = 2 Baroczy J4 = 3,4 Not in use J4 = 5 Polynomial inequality

Note

(1) If N3 = 0, J4 is set to 0.

Card Type	27-HM	Two phase friction polynomial
Required:		If J4 = 5 (card 26-HM)
FORTRAN READ List:		NF, AF(L), L = 1, NF
FORTRAN FORMAT:		I5, 13E5.0
Read from Subroutine:		MODEL

Variable	Columns	Format	Description
NF	1-5	I5	No. of terms in polynomial (max = 7)
AF	6-40	E5.0	Polynomial coefficients

Notes

(1) If the J4 = 5 option is selected (card 26-HM), the two phase friction multiplier will be calculated as,

$$\sum_{K=1}^{K=NF} (AF(K)*X**(K-1))$$

where X = quality ($0 \leq X \leq 1$).

Card Type	28-HM	Void Fraction Model
Required:		If N4 > 0 (card 23-HM)
FORTRAN READ List:		J2 J3
FORTRAN FORMAT:		14I5
Read from Subroutine:		MODEL

Variable	Columns	Format	Description
J2	1-5	I5	Subcooled Void Indicator J2 = 0 no subcooled void J2 = 1 Levy subcooled void correlation
J3	6-10	I5	Slip Ratio Indicator J3 = 0 Slip Ratio = 1 J3 = 1 Armand Slip Ratio Correlation J3 = 2 Smith Slip Ratio Correlation J3 = 3,4 Not in use J3 = 5 Slip ratio given (29-HM) J3 = 6 Void fraction as a polynomial in quality, coefficients given on card 29-HM.

Note

If N4 = 0, J2 and J3 are both set to 0.

Card Type	29-HM	Void Fraction Polynomial coefficients or Slip Ratio Specification
Required:		If J3 = 5 or 6 (card 28-HM)
FORTRAN READ List:		NV, (AV(L), L = 1, NV)
FORTRAN FORMAT:		I5, 13E5.0
Read from Subroutine:		MODEL

Variable	Columns	Format	Descriptiion
NV	1-5	I5	No. of terms in polynomial (NV $\leq$ 7)
AV	6-40	E5.0	Polynomial coefficients

notes

(1) For J3 = 5, NV should be set to 1 and only one value of AV read in. The slip ratio is taken as AV(1).

(2) For J3=6, up to 7 values of AV may be read in and the void fraction is calculated as a polynomial in X, namely:

$$\sum_{v=1}^{v=NV} (AV(v)*x**(v-1))$$

where x = quality, 0 < x < 1.0

Card Type 30-HM	Inlet Flow Model
Required:	If N5 > 0 (card 23-HM)
FORTRAN READ List:	IG
FORTRAN FORMAT:	14I5
Read from Subroutine:	MODEL

Variable	Columns	Format	Description
IG	1-5	I5	Inlet Flow Indicator IG = 0 Same inlet mass velocity for all channels IG = 1 Inlet mass velocities for channels calculated to give same inlet pressure gradient. IG = 2 Inlet mass velocities given on cards of type 31-HM.

Note

(1) If N5 = 0, IG set to 0.

Card Type 31-HM	Inlet Flow Distribution
Required:	If IG = 2 (card 30-HM)
FORTRAN READ List:	GR(I), I = 1, NCHAN
FORTRAN FORMAT:	14E5.0
Read from Subroutine:	READIN/MODEL

Variable	Columns	Format	Description
GR	1-70	E5.0	Inlet Mass Velocity Ratio for each channel (local/average). One value is required for every channel, given in the same order as the channels are numbered.

Card Type	32-HM	Parameters
Required:		If N6 > 0 (card 23-HM)
FORTRAN READ List:		NCHF KIF FTM SL THETA
FORTRAN FORMAT:		I5, 13E5.0
Read from Subroutine:		MODEL

Variable	Columns	Format	Description
NCHF	1-5	I5	Critical Heat Flux Correlation Indicator NCHF = 0 No CHF calculations done. NCHF = 1 BAW-2 correlation used. NCHF = 2 W-3 correlation used. NCHF = 3 Hench-Levy correlation used. NCHF = 4 CISE-4 correlation used. NCHF = 5 Biasi/Void -CHF correlation used.
KIJ	6-10	E5.0	Cross-Flow Resistance Coefficient, k.
FTM	11-15	E5.0	Turbulent Momentum Factor, f_t.
SL	16-20	E5.0	Transverse Momentum Factor, S/L
THETA	21-25	E5.0	Inclination of channel to vertical (degrees).

Note

(1) If N6 = 0; NCHF set to 0, KIJ to 0.5, FTM to 0.0, SL to 0.5 and THETA to 0.0 (i.e. vertical).

(2) If NCFH = 5 then IHTM must equal 2 on card 8-CD.

Card Type	33-HM	Convergence Criteria
Required:		If N7 > 0 (card 23-HM)
FORTRAN READ List:		NTRIES FERROR
FORTRAN FORMAT:		I5, 13E5.0
Read from Subroutine:		MODEL

Variable	Columns	Format	Description
NTRIES	1-5	I5	Maximum permissable number of hydraulic iterations.
FERROR	6-10	E5.0	Flow convergence criterion

Note

(1) If N7 = 0, NTRIES set to 20 and FERROR to 0.01

Card Type	34-HM	Physical Properties
Required:		If N8 > 0 (card 23-HM)
FORTRAN READ List:		NPROP N PH P2
FORTRAN FORMAT:		2I5, 2E5.0
Read from Subroutine:		MODEL

Variable	Columns	Format	Description
NPROP	1-5	I5	No. of pressure points in physical property table for interpolating between (Minimum = 2, Maximum = 30).
N	6-10	I5	N = 1 or 2 (see PH below)
PH	11-15	E5.0	N = 1, PH = lowest pressure (psia) in problem. N = 2, PH = lowest enthalpy (Btu/lb) in problem, from which the lowest pressure will be calculated (see below).
P2	16-20	E5.0	Highest pressure in problem (psia)

notes

(1) From this card, a table containing NPROP equi-spaced values of pressure from P1 to P2 is constructed giving relevant physical properties-- calculated from polynomial expressions--at each pressure. Physical properties at intermediate pressures are found by linear interpolation.

(2) It is important that the table spans the physical property range of the problem. The lowest pressure encountered in the problem is defined as that at which the lowest enthalpy would be the saturation value. For example, at 1000 psia the saturation enthalpy is 543 Btu/lb. At an inlet subcooling of 100 Btu/lb, the enthalpy would be 443 Btu/lb and this would be the saturation value at a pressure of about 470 psia. Thus, one would require physical property data over the range 470 psia (or less) to 1000 psia in order to include data which covered the enthalpy range.

(3) To avoid translating the lowest enthapy to pressure, the option of giving the enthalpy is included. The program translates this value to a pressure which is safely below that required using the expression

$$p = 6h \quad (h - 1.35) / (h - 0.35)$$

where p = calculated pressure (psia),
$h = 0.01H$,
H = enthalpy (Btu/lb).

(4) The option to use a user supplied property table is available using Card Group 1 of the old COBRA input method. This option is especially useful for coolants other than water.

Card Type	35-HM	Coupling parameters
Required:		If N9 > 0 (card 23-HM)
FORTRAN READ List:		(ENEH(K), K = 1,NK) where NK = total number of boundaries
FORTRAN FORMAT:		14E5.0
Read from Subroutine:		MODEL

Variable	Columns	Format	Description
ENEH	1-70	E5.0	Coupling parameter introduced in the mixing term of the energy conservation equation.

Note

(1) The coupling parameters should be entered in the same order as the inter-channel gaps are numbered. The numbering order is described on card 20-GB.

Card Type	36-OC	Steady State Operating Conditions
Required:		Always
FORTRAN READ List:		IH HIN GIN PEXIT
FORTRAN FORMAT:		I5, 13E5.0
Read from Subroutine:		OPERA

Variable	Columns	Format	Description
IH	1-5	I5	Inlet Enthalpy Indicator
HIN	6-10	E5.0	IH = 0: Inlet Enthalpy (Btu/lb) IH = 1; Inlet Temperature (°F) IH = 2,3* Inlet enthalpies or temperatures for each channel given on cards of type 37-OC. HIN not used, set to zero.
GIN	11-15	E5.0	Average Inlet Mass Velocity (Mlb/ft^2 hr)
PEXIT	16-20	E5.0	System pressure (psia)

Card Type	37-OC	Inlet Enthalpy Distribution
Required:		If IH = 2 or 3 on card 36-OC
FORTRAN READ List:		A(I), I = 1, NCHAN
FORTRAN FORMAT:		14E5.0
Read from Subroutine:		READIN/OPERA

Variable	Columns	Format	Description
A	1-70	E5.0	IH = 2: Inlet enthalpies for each channel (Btu/lb) IH = 3: Inlet temperatures for each channel (°F)

Card Type	38-T	Transient Indicators
Required:		Always
FORTRAN READ List:		NP NH NG NQ
FORTRAN FORMAT:		14I5
Read from Subroutine:		OPERA

Variable	Columns	Format	Description
NP	1-5	I5	No. of points at which pressure transient forcing function data points will be given (cards 10-CD) Maximum = 30
NH	6-10	I5	No. of points at which inlet enthalpy forcing function data pairs will be given (cards 11-CD) Maximum = 30
NG	11-15	I5	No. of points at which inlet flow transient forcing function data pairs will be given (cards 12-CD) Maximum = 30
NQ	16-20	I5	No. of points at which channel power transient forcing function data pairs will be given.(cards 13-CD) Maximum = 30

Notes

(1) If only steady state calculations are required, card 38-T is given as a blank card and cards 39-T through 42-T are omitted.

(2) COBRA IIIc/MIT handles transient analysis through the use of transient forcing functions. These forcing functions simulate transient behavior by allowing the user to specify up to thirty (30) parameter relative value and transient time data pairs for the parameters of pressure, inlet enthalpy, inlet flow, and channel power. Parameter values between two specified time points are then found by linear interpolation.

If any parameter is being held constant, the appropriate indicator should be left blank and the respective transient forcing function cards omitted.

Cards 39-T through 42-T are all of the same format and carry the data time specification (seconds from the start of the analysis), and the ratio of transient value to steady state value for the parameter in question at that time. Each card carries a maximum of seven (7) data pairs and sufficient cards must be provided to supply all the data pairs called by the value of the indicators above. Since all transients must start at time 0 and the full steady state value of all parameters, the first data pair must be time = 0 and relative value = 1.

Card Type	39-T	Pressure Transient Forcing Function
Required:		If NP > 1 (card 38-T)
FORTRAN READ List:		YP(I), FP(I), I = 1, NP
FORTRAN FORMAT:		14E5.0
Read from Subroutine:		READIN/OPERA

Variable	Columns	Format	Description
YP	1-80	E5.0	Time (seconds)
FP	1-70	E5.0	Ratio of transient to steady state pressure at time YP.

Notes

(1) YP(1), F(1) should be given as 0.0 and 1.0 respectively.

(2) The value of FP at a time intermediate between two values of YP is found by linear interpolation.

Card Type	40-T	Inlet Enthalpy Transient Forcing Function
Required:		If NH > 1 (38-T)
FORTRAN READ List:		YH(I), FH(I), I = 1, NH
FORTRAN FORMAT:		14E5.0
Read from Subroutine:		READIN/OPERA

Variable	Columns	Format	Description
YH	1-70	E5.0	Time (seconds)
FH	1-70	E5.0	Ratio of transient to steady state enthalpy or temperature (depending on the value of IH on card 36-OC) at time YH

Notes

(1) YH(1) and FH(1) should be given as 0.0 and 1.0 respectively.

(2) The value of FH at a time intermediate between two values of YH is found by linar interpolation.

Card Type	41-T	Inlet Flow Transient Forcing Function
Required:		If NG > 1 (38-T)
FORTRAN READ List:		YG(I), FG(I), I = 1, NG
FORTRAN FORMAT:		14E5.0
Read from Subroutine:		READIN/OPERA

Variable	Columns	Format	Description
YG	1-70	E5.0	Time (seconds)
FG	1-70	E5.0	Ratio of transient to steady state average mass velocity at time YG

Notes

(1) YG(1) and FG(1) should be given as 0.0 and 1.0 respectively.

(2) The value of FG at a time inermediate between two values of YG is found by linear interpolation

Card Type	42-T	Inlet Power Transient Forcing Function
Required:		If NQ > 1 (38-T) and IQP3 = 2 (4-HF)
FORTRAN READ List:		YQ(I), FQ(I), I = 1,NQ
FORTRAN FORMAT:		14E5.0
Read from Subroutine:		READIN/OPERA

Variable	Columns	Format	Description
YQ	1-70	E5.0	Time (seconds)
FQ	1-70	E5.0	Ratio of transient to steady state channel power at time YQ.

Notes

(1) YQ(1) and FQ(1) should be given as 0.0 and 1.0 respectively.

(2) The value of FQ at a time intermediate between two values of YQ is found by linear interpolation.

Card Type 43-DB "Debug" Option
Required: Always
FORTRAN READ List: KDEBUG
FORTRAN FORMAT: 14I5
Read from Subroutine: TABLES

Variable	Columns	Format	Description
KDEBUG	1-5	I5	"Debug" option KDEBUG = 0: normal--no test printing KDEBUG = 1: "debug"--with test printing

note

(1) The "debug" option can generate massive amounts of output and should be used only when necessary.

Card Type 44-00	Output Printing				
Required:	Always				
FORTRAN READ List:	NSKIPX	NSKIPT	NOUT	NPCHAN	NPROD
	NPNODE				
FORTRAN FORMAT:	14I5				
Read from Subroutine:	TABLES				

Variable	Columns	Format	Description
NSKIPX	1-5	I5	Axial print option: For NSKIPX = N, every N'th axial step will be printed. If N = 0 or 1, every step will be printed.
NSKIPT	6-10	I5	Time step option; Same as for NSKIPX but time (not axial) steps skipped.
NOUT	11-15	I5	NOUT = 0: print channel results only NOUT = 1: channel + cross flow tables printed. NOUT = 2: channel + fuel temperature tables printed. NOUT = 3: channel, cross flow, and fuel temperature tables printed.
NPCHAN	16-20	I5	NPCHAN = 0: Results for all channels printed. If NPCHAN = N, (N $\geq$ 1) then N channel numbers will be read in on cards of type 45-00, and results will be printed for those channels.
NPROD	21-25	I5	Same as for NPCHAN but for rod results instead of channels.
NPNODE	26-30	I5	Same as for NPCHAN but radial fuel node results instead of channels.

notes

(1) Radial fuel nodes are numbered such that rod center = 1 and the rod outer surface = NODESF + 1.

Card Type	45-00	Channels to be printed
Required:		If NPCHAN $\geq$ 1 (card 44-00)
FORTRAN READ List:		PRINTC(I), I = 1, NPCHAN
FORTRAN FORMAT:		14I5
Read from Subroutine:		TABLES

Variable	Columns	Format	Description
PRINTC	1-70	I5	Identification Number of channels to be printed.

Card Type	46-00	Rods to be printed
Required:		If NPROD $\geq$ 1 (card 44-00)
FORTRAN READ List:		PRINTR(I), I = 1, NPROD
FORTRAN FORMAT:		14I5
Read from Subroutine:		TABLES

Variable	Columns	Format	Description
PRINTR	1-70	I5	Identification Number of rods to be printed.

Card Type	47-00	Fuel nodes to be printed
Required:		If NPNODE $\geq$ 1 (card 44-00)
FORTRAN READ List:		PRINT(I), I = 1, NPNODE
FORTRAN FORMAT:		14I5
Read from Subroutine:		TABLES

Variable	Columns	Format	Description
PRINTN	1-70	I5	Radial fuel nodes to be printed 1 = rod center, (NODESF + 1) = outer clad surface.

Card Type	GCC	End Input Data, start calculation
Required:		Always
FORTRAN READ List:		BLANK CARD
FORTRAN FORMAT:		
Read from Subroutine:		INDAT

Variable	Columns	Format	Description

Note

(1) At this point in the calculation, control returns to reading Card GCC. If NGROUP = 1-12, more Input Data are read in the original COBRA format, these later data overwriting what has already been read in. If NGROUP = 0, calculation starts.

(2) If N1 = 0 or 1 on card 4-HF, then additional nodal power data must be provided here. This additional data is read in after the start of calculations from subroutine QPR3.

Card Type	48-NP	Nodal Power Multiplier
Required:		If IQP3 = 0 or 1 (card 4-HF)
FORTRAN READ List:		ZM
FORTRAN FORMAT:		8E10.0
Read from Subroutine:		QPR3

Variable	Columns	Format	Description
ZM	1-10	E10.0	Nodal Power Multiplier

notes

(1) ZM = -2.0: Reset to 1000.0/3.6 (MBtu/hr to Btu/s)
ZM = -1.0: Reset to 3413.0/3.6 (MW to Btu/s)
ZM ≥ 0.0: ZM unchanged

(2) ZM is a Nodal Power Multiplier by which the nodal powers given on cards 49-NP and 50-NP are all multiplied. ZM can thus be a units conversion factor or an uniform power multiplier to uniformly raise or lower the power to all channels at all times.

(3) As an example, consider the case where the data which follows on card types 49-NP and 50-NP is given in units of megawatts. To convert the units of Btu/sec which are used in the code, the user could either use ZM = -1 and let the computer provide the conversion factor, or the user could give ZM = 948.06 (3413.0/3.6 = 948.06) and provide the conversion factor himself.

Card Type 49-NP	Fuel Nodal Powers
Required:	If IQP3 = 0 or 1 (card 4-HF)
FORTRAN READ List:	(QF(I.J), J = 1, NDX), I = 1, NCHAN
FORTRAN FORMAT:	8E10.0
Read from Subroutine:	QPR3

Variable	Columns	Format	Description
QF	1-80	8E10.0	Average Fuel Nodal Power for Channel I, axial interval J to (J + 1).

notes

(1) The fuel nodal powers are read in sequentially from the first node to the last for each channel. Each set of nodal powers for a channel starts on a new card, and continues onto the next if NDX, the number of nodes, is greater than 8. The data for the channels is inputed in the same order as the channels are numbered

(2) The units of QF in the calculation are Btu/sec. They may be read in those units (when ZM = 1.0 on 48-NP) or converted using ZM. NDX is read on card 7-MD.

(3) If NDT > 0 on card 7-MD, a total of NDT data groups giving fuel nodal powers and, if N1 = 1, coolant nodal powers must be provided, one for each time step. Each data group is organized in the same manner as that described above for time zero of the transient.

Card Type	50-NP	Coolant Nodal Powers
Required:		If IQP = 1 (card 4-HF)
FORTRAN READ List:		(QC(I,J), J = 1, NDX), I = 1, NCHAN
FORTRAN FORMAT:		8E10.0
Read from Subroutine:		QPR3

Variable	Columns	Format	Description
QC(I,J)	1-80	8E10.0	Average Nodal Power deposited in Coolant for channel I, axial interval J to J + 1.

notes

(1) The fuel nodal powers are read in sequentially from the first node to the last for each channel. Each set of nodal powers for a channel starts on a new card, and continues onto the next if NDX, the number of nodes, is greater than 8. The data for the channels is inputed in the same order as the channels are numbered

(2) The units of QF in the calculation are Btu/sec. They may be read in those units (when ZM = 1.0 on 48-NP) or converted using ZM. NDX is read on card 7-MD.

(3) If NDT > 0 on card 7-MD, a total of NDT data groups giving fuel nodal powers and, if N1 = 1, coolant nodal powers must be provided, one for each time step. Each data group is organized in the same manner as that described above for time zero of the transient.

Card Type I3	ADDITIONAL CASES, Case Control Card
Required:	Always
FORTRAN READ List:	IPILE, KASE, J1, TEXT
FORTRAN FORMAT:	I1, I4, I5, 17A4
Read from Subroutine:	INDAT

Variable	Columns	Format	Description
IPILE	1	I1	
KASE	2-5	I4	
J1	6-10	I5	

notes

(1) At this point in the card deck, the data for additional cases may be given. At the end of calculation on each case, control returns to card I3. If Kase > 0 data for the next case is read in and the calculations performed. If Kase = 0 (e.g. a blank card) calculation stops and the job is terminated.

III.3

ORIGINAL INPUT METHODS

As previously explained, the data following the three introductory cards (I1-I3) is broken into card groups in the original COBRA IIIc input format.

Card Group 1 contains the data for the physical properties in the problem. Card Group 2 controls the flow correlation options. Group 3 inputs the axial heat flux table. If IPILE equals 1 or 2 (card I3) Card Group 4 inputs all the channel data including channel layout and dimensions, rod layout dimensions and power factors, and the spacer data. If IPILE = 0, card group 4 inputs only the channel layout and dimensions and the other data is left for Card Groups 7 and 8. Card Group 5 inputs a subchannel area variation table. Group 6 inputs the gap spacing variation table. Card Groups 7 and 8 which are used only when IPILE = 0 contain the spacer data and rod layout, dimensions and power factors. Card Group 9 inputs the calculation variables. Group 10 selects the turbulent mixing correlations. Group 11 sets the operating conditions and the last group, group 12 selects the output options.

The first card in every card group is a group control card designated as GCCi where i is the group number. The Group Control Card reads in the value of NGROUP (NGROUP = i, the card group number), and the integer constants N1, N2, etc. The variable in paranthesis after each of the integer constants is the variable which will be set equal to the value of the integer.

The card numbering system is of the form;

<Card Group Number>-<card position within the group>

Thus, card G3-1 is the first card after the group control card in Card Group 3.

Card Type	GCC1	Group Control Card for Card Group 1
Required:		Always
FORTRAN READ List:		NGROUP N1
FORTRAN FORMAT:		2I5
Read from Subroutine:		INDAT

Variable	Columns	Format	Description
NGROUP	1-5	I5	NGROUP = 1 (to select Card Group 1)
N1 (NPROP)	6-10	I5	N1 $\leq$ 0: Calculate physical properties from polynomials. N1 > 1: The physical properties are given in the next N1 Cards as in the original COBRA.

Card Type	G1-1	Physical Properties
Required:		When N1 $\leq$ 0 (Card GCC1)
FORTRAN READ List:		N PH P2 N1
FORTRAN FORMAT:		I5, F10.3, F10.3, I5
Read from Subroutine:		CARDS1

Variable	Columns	Format	Description
N	1-5	I5	N = 1: PH defined as lowest pressure encountered in problem. N = 2: PH defined as lowest enthalpy encountered in problem.
PH	6-15	F10.3	If N1 = 1: Lowest pressure (psia) If N1 = 2: lowest enthalpy (Btu/lb)
P2	16-25	F10.3	Highest pressure (psia) encountered in problem
N1	26-30	I5	Number of pressure steps generated by polynomial (minimum = 2; maximum = 30)

notes

(1) The function of this card is identical to that of card 34-HM in the Card Group 20 input method. A detailed description is provided following card 34-HM.

Card Type G1-2	Physical Properties
Required:	N1 $\geq$ 1 (card GCC1)
FORTRAN READ List:	PP TT VVF VVG HHF HHG UUF KKF SSIGMA
FORTRAN FORMAT	E5.2, F5.1, 7F10.0
Read from subroutine:	CARDS1

Variable	Columns	Format	Description
PP(I)	1-5	E5.2	Saturation Pressure (psia)
TT(I)	6-10	F5.1	Temperature (°F)
VVF(I)	11-20	F10.0	Liquid Specific Volume (ft^3/lbm)
VVG(I)	21-30	F10.0	Vapor Specific Volume (ft^3/lbm)
HHF(I)	31-40	F10.0	Liquid Enthalpy (Btu/lbm)
HHG(I)	41-50	F10.0	Vapor Enthalpy (Btu/lbm)
UUF(I)	51-60	F10.0	Liquid Viscosity (lbf/ft-hr)
KKF(I)	61-70	F10.0	Liquid Thermal Conductivity (Btu/hr-ft- °F)
SSIGMA(I)	71-80	F10.0	Surface Tenssion (lbf/ft)

Notes

(1) This property table must have pressure higher than operating pressure, and liquid enthalpy lower than the bundle inlet enthalpy. For additional details see the discussion following card 34-HM.

(2) A total of N1 (card GCC1) cards of physical properties must be present. Each card represents a line from the property tables for the coolant (ie. the steam tables), with all properties being those at the saturated state.

(3) The option to use a user supplied property table is not available in the Card Group 20 input method.

Card Type	GCC2	Group Control Card for Card Group 2, Flow Correlations
Required:		Always
FORTRAN READ List:		Ngroup, N1, N2, N3, N4
FORTRAN FORMAT:		5I5
Read from Subroutine:		INDAT

Variable	Columns	Format	Description
NGROUP	1-5	I5	NGROUP = 2 (to select Card Group 2)
N1 (J2)	5-10	I5	Subcooled Void Option N1 = 0 No subcooled voids N2 = 1 Levy Subcooled Void Correlation
N2 (J3)	11-15	I5	Bulk Void Correlation N2 = 0 Homogeneous Model N2 = 1 Modified Armand Model N2 = 5 Read in slip ratio (G2-2) N2 = 6 Polynomial in Quality, coefficients on card G2-2.
N3 (J4)	16-20	I5	Two-Phase Friction Multiplier N3 = 0 Homogeneous Model N3 = 1 Armand Model N3 = 5 Polynomial in Quality, coefficients on card G2-3.
N4 (NVISCW)	21-25	I5	Wall Viscosity Correlation Option N4 = 0 Wall viscosity not included N4 = 1 Wall viscosity included

notes

(1) The Card Group 20 input method provides additional correlations including the Smith Slip Ratio Correlation, and the Baroczy Two Phase Friction Multiplier Correlation.

Card Type	G2-1	Friction Factor Correlation Constants
Required:		Always
FORTRAN READ List:		AA(L), BB(L), CC(L), L = 1,4
FORTRAN FORMAT:		12F5.3
Read from Subroutine:		INDAT

Variable	Columns	Format	Description
AA	1-5	F5.3	Sets of three (AA, BB, & CC) repeated up to four times.
BB	6-10	F5.3	
CC	11-20	F5.3	

Notes

(1) The Friction Factor is calculated as AA * (RE ** BB) + CC where RE is the Reynolds number for the channel.

(2) the sets of constants are numbered sequentialy and associated with the channel type of the same number. The first three values on card G2-1 are thus called set one and are applied to channels of type 1, similarly for the second, third and fourth sets of constants. The user should check that the specified constants are in the appropriate columns for the channel type they apply to.

Card Type	G2-2	Void Fraction Polynomial Cofficients or Slip Ratio Specifiction
Required:		When N2 = 5 or 6 (card GCC2)
FORTRAN READ List:		NV,AV
FORTRAN FORMAT:		5X, E10.5
Read from Subroutine:		INDAT

Variable	Columns	Format	Description
NV	1-5	I5	If N2 = 5; not used, leave blank If N2 = 6; No. of terms in polynomial (max = 7)
AV	6-15	E10.0	If N2 = 5; The desired slip ratio If N2 = 6; Polynomial coefficients

Notes

(1) The polynomial is calculated as

$$\sum_{v=1}^{v=NV} (AV(v)*x**(v-1))$$

where X = Quality (0 > X > 1)

Card Type	G2-3	Two-Phase Friction Multiplier polynomial in quality
Required:		If N3 = 5 (card GCC2)
FORTRAN READ List:		NF, (AF(I), I =1,7)
FORTRAN FORMAT:		I5, 7E10.0
Read from Subroutine:		INDAT

Variable	Columns	Format	Description
NF	1-5	I5	No. of terms in polynomial (max = 7)
AF	6-10	E10.0	Polynomial coefficients

Notes
(1) The Polynomial is calculated as

$$\sum_{k=1}^{k=NF}(AF(k)*x**(k-1))$$

where X is Quality (0 > X > 1)

Card Type	GCC3	Axial Heat Flux Group Control Card
Required:		Whenever Card Group 3 is used
FORTRAN READ List:		NGROUP, N1
FORTRAN FORMAT:		2I5
Read from Subroutine:		INDAT

Variable	Columns	Format	Description
NGROUP	1-5	I5	NGROUP = 3 (to select Card Group 3)
N1	6-10	I5	No. of positions at which the relative axial heat flux will be specified. (maximum = 30; minimum = 2)

notes

(1) If N1 $\leq$ 1; IQP3 is set equal to N1
If N1 > 1; NAX is set equal to N1

Card Type	G3-1	Axial Heat Flux Data
Required:		If N1 > 1 (card GCC3)
FORTRAN READ List:		Y(I), AXIAL(I), I=1,N1
FORTRAN FORMAT		12F5.3
Read from Subroutine:		INDAT

Variable	Columns	Format	Description
Y(I)	1-5	F5.3	Relative axial position (X/L)
AXIAL(I)	6-10	F5.3	Relative heat flux (local/average)

Notes

(1) The above data pair format is repeated six (6) times per card, sufficient cards are required to pass N1 (card GCC3) data pairs.

(2) The Relative Axial Heat Flux between the points given above is found using linear interpolation.

Card Type	GCC4a	Group Control Card for Card Group 4a
Required:		When using Card Group 4 with IPILE = 0
FORTRAN READ List:		NGROUP, N1, N2
FORTRAN FORMAT:		3I5
Read from Subroutine:		INDAT

Variable	Columns	Format	Description
NGROUP	1-5	I5	NGROUP = 4 (to select Card Group 4)
N1	6-10	I5	No. of cards of type G4a-1 containing subchannel data.
N2	11-15	I5	Total number of subchannels

Card Type G4a-1	Subchannel Data
Required:	When using Card Group 4 with IPILE = 0
FORTRAN READ List:	N, I, AC, PW, PH, LC, GAPS, DIST
FORTRAN FORMAT	I1, I4, 3E5.2, 4(I5, 2E5.2)
Read from Subroutine:	INDAT

Variable	Columns	Format	Description
N	1	I1	Subchannel Type Number (if blank it is assumed type 1)
I	2-5	I4	Subchannel Identification Number
AC	6-10	E5.2	Nominal Flow Area (sq-in)
PW	11-15	E5.2	Wetted Perimeter (in)
PH	16-20	E5.2	Heated Perimeter (in)
GAPS	21-25	I5	Adjacent Subchannel Number (1)
DIST	26-30	E5.2	Nominal Gap Spacing (in)
	31-35	E5.2	Channel Centroid-to-Centroid (4) Distance (in)

Notes

(1) If a line of symmetry splits a gap at the boundary the Adjacent Subchannel Number is given as negative by the user.

(2) Up to four sets of Subchannel Connecting Information may be given.

(3) If subchannels are input in asending order, then only higher number subchannels need to be identified as connecting.

(4) Centroid-to-Centroid distances are not required if they are not used in the mixing correlations.

(5) No channel map is necessary for IPILE = 0, since the subchannel inter-connections are user supplied.

Card Type	GCC4b	Group Control Card for Card Group 4b
Required:		When IPILE = 1 or 2
FORTRAN READ List:		NGROUP
FORTRAN FORMAT:		I5
Read from Subroutine:		INDAT

Variable	Columns	Format	Description
NGROUP	1-5	I5	NGROUP = 4 (to select Card Group 4)

Note

(1) Once this card is read, the new subroutine CARDS4 is entered for the remaining Read statements and Data processing of this Card Group.

Card Type	G4b-1	Problem Specification Data
Required:		When NGROUP = 4 and IPILE = 1 or 2
FORTRAN READ List:		N1, N2, NGRID< NGRIDT. NODESF, NFUELT. NCHF, IMAP, ITEXT
FORTRAN FORMAT:		9I4
Read from Subroutine:		CARDS4

Variable	Columns	Format	Description
N1	1-4	I4	Number of channel types (max 15 - see below)
N2	5-8	I4	Total number of channels in problem (See note 2)
NGRID	9-12	I4	Number of grid positions
NGRIDT	13-16	I4	Number of types of grid
NODESF	17-20	I4	Number of radial nodes on the fuel for center temperature calculation
NFUELT	21-24	I4	Number of fuel types
NCHF	25-28	I4	NCHF = 0 for no CHF calculations NCHF = 1 for B&W2 CHF correlation NCHF = 2 for W-3 correlation NCHF = 3 for Hench-Levy correlation NCHF = 4 for CISE-4 correlation
IMAP	29-32	I4	IMAP = 1 to 4 to indicate method of presenting gap interconnection data (see cards G4b-8 to G4b-11)
ITEXT	33-36	I4	Number of cards to be read in next which will be printed out as a message. If ITEXT = 0, no message cards are read in.

Note

(1) Channels are defined as being all of the same type if they have the same geometry, rod dimensions and grids and only differ in their power. More precisely, Cards G4b-3 and G4b-4 given later which define the geometry and grids must apply to all channels of the same type. In, for example, 1/4-core symmetry data, 1/4, 1/2 and whole channels would be different types.

(2) NROD (the number of rods) and NCHAN (the number of channels) are both set to the value of N2.

(3) For BWR's (IPILE = 2) the channels are not connected and no channel map is required.

Card Type	G4b-2	Alphanumeric Data for Problem Identification
Required		When ITEXT > 0
FORTRAN READ List:		TEXT(20)
FORTRAN FORMAT:		20A4
Read From Subroutine		CARDS4

Variable	Columns	Format	Description
TEXT	1-80	20A4	The array TEXT (20) is read and immediately printed in a do loop from 1 to ITEXT. It is envisioned that a map of the channel numbering system could be printed as a memory aide in a large problem.

Card Type G4b-3	Hydraulic Data
Required:	Always (being NGROUP = 4)
FORTRAN READ List:	N, I, FRAC, AC(I), PW(I), PH(I), GAPS(I,1), DIST(i,1), DR(I), PHI(I.1), M
FORTRAN FORMAT:	I1, I4, 8E9.3, I2
READ from subroutine:	CARDS4

Variable	Columns	Format	Description
N	1	I1	Selector for friction factor expression. If N = 0 reset to 1.
I	2-5	I4	Any channel number, preferably the first of the channel type being described.
FRAC	6-14	E9.3	Factor by which AC, PW, PH should be multiplied. Thus for 1/4 channel, one may give FRAC = 0.25 and AC, PW, PH the same as for a whole channel.
AC	15-23	E9.3	Channel flow area (sq-in)
PW	24-32	E9.3	Channel wetted perimeter (in)
PH	33-41	E9.3	Channel heated perimeter (in)
GAPS	42-50	E9.3	Effective rod gap boundary gap dimensions (in)
DIST	51-59	E9.3	Centroid-to-Centroid channel distance (in). This is only required for a particular mixing correlation and may normally be given as zero.
DR	60-68	E9.3	Rod diameter (in)
PHI	69-77	E9.3	Number of rods in channel
M	78-79	I2	Fuel type: M = 1 for rod fuel, M = 2 for plate fuel, Reset to 1 if M = 0

notes

(1) The variable FRAC is used to multiply the values for AC, PW, PH, and PHI. The multiplication of PHI poses a potential input error if the value for RADIA on card G4b-5 is not adjusted to account for this factor.

(2) The variable "GAP" inputs the effective rod gap for interconnections between channels. The value of GAP need not be the actual physical dimensions of the gap depending upon the resistance model used. For assembly to assembly analysis, GAP is the effective rod gap multiplied by the number of gaps in the assembly.

(3) "M" indicates which fuel type is being used. M = 1 indicates rod fuel only; M = 2 indicates plate fuel or a combination of rod and plate fue. If M = 2 data must be given for rod fuel, giving zeroes or blanks if rod fuel is not used.

Card Type	G4b-4	Spacer Data
Required:		If NGRID > 0
FORTRAN READ List:		CD (I.L), L = 1, NGRIDT), (FXF(L), L = 1, NGRIDT
FORTRAN FORMAT:		16E5.3
Read from Subroutine:		CARDS4

Variable	Columns	Descriptions
CD	1-NGRIDT*5	Spacer loss coefficients
FXF	NGRIDT*5-2*NGRIDT*5	Fraction of axial flow forced across each boundary. It is not expected that this would be used in reactor problems hence nominal value = 0.0

notes

(1) The spacer loss coefficients are provided first, giving one coefficient for each of the NGRIDT grid types (card G4b-1). Following the loss coefficients. a total of NGRIDT Diversion Flow Fraction specifications must be provided.

(2) Note that the same Diversion Flow Fraction is used for all boundaries of the channel at that spacer location.

(3) Enough cards of type G4b-4 must be present to provide 2 * NGRIDT values even if those values are zero or blank.

(4) A total of N1 pairs of cards G4b-3 and G4b-4 must be provided. Each card pair gives the hydraulic and spacer data for one of the N1 channel types.

Card Type	G4b-5	Radial Power Factors
Required:		Always
FORTRAN READ List:		Radial (I), I = 1, NROD
FORTRAN FORMAT:		16E5.3
Read from Subroutine		CARDS4

Variable	Columns	Format	Description
RADIAL	1-70	16E5.3	Radial power factor for rod I which is located in channel I. This is defined as the ratio of the rod power to that of the reactor average rod power.

Notes

(1) NROD is the total number of rods, having set to NCHAN (total number of channels) which was itself set to N2 (Card G4b-1).

(2) One rod exists for each channel and the smeared channels must also have smeared rods. The radial power factor for such smeared rods should be the sum of the factors for each of the unsmeared rods devided by the product of FRAC and PHI (card G4b-3).

(3) If all rods have the same power, RADIAL(1) alone may be given and is set negative. This triggers setting (RADIAL (I); I = 1, NROD) equal to 1.0. No importance is attached to the magnitude of RADIAL(1) so long as RADIAL(1) < 0. In all other cases, a total of NROD factors must be given.

Card Type	G4b-6	Grid Data
Required:		If NGRID > 0
FORTRAN READ List:		GRIDXL(L), IGRID(I), (I = 1, NGRID
FORTRAN FORMAT:		8(E5.3, I5)
Read from Subroutine:		CARDS4

Variable	Columns	Format	description
GRIDXL	1-5	E5.3	Relative location (X/L) where grids are located.
IGRID	5-10	E5.3	Type of grid at GRIDXL

Notes

(1) A total of NGRID pairs of Data must be provided giving 8 pairs per card.

Card Type	G4b-7	Channel Lists by Type
Required:		If Nl > 1 (card G4b-1)
FORTRAN READ List:		JB(I)
FORTRAN FORMAT:		20I4
Read from Subroutine:		CARDS4

Variable	Column	Format	Description
JB	1-80	I4	List of channels of Type I (I>1)

Notes

(1) The first set given is the list of channel numbers for the channels of Type 2. The list is terminated by reading in a zero (or a blank space). Hence, if the last channel number comes at the end of a card, a blank card must follow in order to give the terminating zero. It is safer to make a habit of punching a final zero. Following Type 2, card(s) are read in for those channels in Type 3, then Type 4 etc. up to Nl Types.

(2) Note that since the channel numbers for Type 1 are not read in, it is more economical to select Type 1 as that with the majority of channels.

(3) An internal consistency check is made when reading in JB(I). If a set includes the channel number (I in Card G4b-3) for Type 1 or does not include that given for its own type in Card G4b-3, an appropriate message is printed and the run terminated.

(4) If Nl = 1, This card is not used.

Card Type	G4b-8	Array Size Specifications
Required:		If IPILE = 1 and IMAP = 1 (cards I3 and G4b-1)
FORTRAN READ List:		ICROSS, IDOWN
FORTRAN FORMAT		2I4
Read from Subroutine		CARDS4

Variable	Columns	Format	Description
ICROS	1-4	I4	The number of channels across the rectangular channel map.
IDOWN	5-8	I4	The number of channels down the side of the rectangular channel map.

Notes

(1) For BWR's (IPILE = 2) the channels are not connected and no channel map is required. For BWR's the next card read in is card G4b-13.

(2) Note that maximum value for both ICROSS and IDOWN is 20.

(3) This option is only possible to use when the pattern of channels is rectangular.

(4) The channel boundaries are established and numbered in the order that is described for card 20-GB of the Card Group 20 input method.

Card Type	G4b-9	IMAP = 2 Row Declarations
Required:		When IPILE = 1 and IMAP = 2
FORTRAN READ List:		ISTART, IEND
FORTRAN FORMAT:		2I4
Read from Subroutine:		CARDS4

Variable	Columns	Format	Description
ISTART	1-4	I4	First channel in each row
IEND	5-8	I4	Last channel in each row

Notes

(1) One of these cards should be given for each row.

(2) The maximum value of IEND is 20 and the maximum number of rows is also 20. If less than 20 rows are to be given, a blank card (or one with two zeros) should be given after the last row.

(3) See card 2-CNS of the Card Group 20 input method for additional details.

Card Type	G4b-10	Channel Numbers by Row (for IMAP = 3)
Required:		When IPILE = 1 and IMAP = 3
FORTRAN READ List:		MAAP(L), L = 1,20
FORTRAN FORMAT:		20I4
Read from Subroutine:		CARDS4

Variable	Columns	Format	Description
MAAP	1-80	I4	The channel numbers of the channels making up a row.

Notes

(1) One of these cards should be inputted for each row (maximum 20 rows). The value of MAAP represents the channel number with a zero indicating no channel. If less than 20 cards are to be used, the last should be all zeros (i.e., a blank card). The set of cards represents a map of the channel numbering system, which is thus under the control of the user. The boundary numbering is done by the computer.

(2) See card 3-CNS of the Card Group 20 input method for additional details.

Card Type	G4b-11	Boundary Definitions (for IMAP = 4)
Required:		When IPILE = 1 and IMAP = 4
FORTRAN READ List:		20I4
Read from Subroutine:		CARDS4

Variable	Columns	Format	Description
IK	1-4	I4	See notes below.
JK	4-8	I4	

Notes

(1) IK, JK are the channel pairs defining each boundary in turn; NK = number of boundaries specified. The set of numbers are read in, 20 to a card, continuing on as many cards as necessary. They are terminated by a zero; if the final channel number is at the end of a card, the zero must be given on the next card. (Note, the value of NK is not known at the time of reading in IK, JK; it is set to the number of pairs read in). Thus, with IMAP = 4, both channel and boundary numbering are under the control of the user. When listing the subchannel pairs, it is preferable to give the lower number first; this saves the computer reversing the order.

(2) The IMAP = 4 option can be very cumbersome and should only be used if the other IMAP options won't work.

Card Type	G4b-12	Half Boundary Identification
Required:		When IPILE = 1
FORTRAN READ List:		JB(L), L = 1
FORTRAN FORMAT		20I4
Read from Subroutine		CARDS4

Variable	Columns	Format	Description
JB	1-80	I4	List the identification number pairs for the channels making up each half-boundary, i.e. the boundaries that are split by a line of symmetry.

Notes

(1) Always terminate with a zero. If there are no half boundaries, give a single card with a zero. The parameter FACTOR(K) is set to 1.0 for full boundaries and 0.5 for "half-boundaries".

(2) The boundary number pairs should be given lowest number first.

Card Type	G4b-13	Fuel Rod Thermal Specifications
Required:		When NODESF > 0
FORTRAN READ List:		KFUEL(I), CFUEL(I), RFUEL(I), DFUEL(I), KCLAD(I), CCLAD(I), RCLAD(I), TCLAD(I), HGAP(I), I = 1, NFUELT
FORTRAN FORMAT		16E5.3
Read from Subroutine:		CARDS4

Variable	Columns	Format	Description
KFUEL	1-5	E5.3	Fuel thermal conduction (BTU/hr-ft°F)
CFUEL	6-10	E5.3	Fuel specific heat(BTU/lb°f)
RFUEL	11-15	E5.3	Fuel Density (lb/cu-ft)
DFUEL	16-20	E5.3	Pellet Diameter (in)
KCLAD	21-25	E5.3	Cladding thermal conductivity (BTU/hrft°F)
CLAD	26-30	E5.3	Cladding specific heat (BTU/lb ° F)
RCLAD	31-35	E5.3	Cladding density (lb/ft^3)
TCLAD	36-40	E5.3	Cladding thickness (in)
HGAP	41-45	E5.3	Fuel-cladding heat transfer coefficient (BTU/ft^2 hr°F)

notes

(1) The option to use the MATPRO Fuel Rod Model is only available using the Card Group 20 input method

Card Type GCC5	Subchannel Area Variation Table
Required:	When using Card Group 5
FORTRAN READ List:	NGROUP, N1, N2, N3
FORTRAN FORMAT:	4I5
Read from Subroutine:	INDAT

Variable	Columns	Format	Description
NGROUP	1-5	I5	NGROUP = 5 (to select Card Group 5)
N1 (NAFACT)	6-10	I5	No. of subchannels for which area variation data will be given. (max = 10) If N1 = 0, area variation are deleted for succeeding cases.
N2 (NAXL)	11-15	I5	No. of axial positions at which area variations will be specified. (min = 2, Max 10)
N3 (NARAMP)	16-20	I5	No. of iterations for inserting area variations. If N3 is zero or blank, N3 is set to 1.

Notes

(1) If there are no area variations, this card group may be omitted.

Card Type G5-1	Axial positions of area variations
Required:	When Card Group 5 is used
FORTRAN READ List:	AXL(I), I = 1 N2
FORTRAN FORMAT:	12F5.3
Read from Subroutine:	INDAT

Variable	Columns	Format	Description
AXL(I)	1-60	12F5.3	Relative axial locations (X/L) where area factors are given

Notes

(1) A total of n2 (card GCC5) positions must be specified

(2) Since the code finds the areas between specified axial locations by interpolation, the user should be extremely careful in choosing the locations he specifies especially for abrupt changes. If two axial locations are too close together the interpolation routine will produce a "divide by zero" type error.

Card Type	G5-2	Subchannel Number
Required:		When N1 = 0 (on GCC5)
FORTRAN READ List:		I
FORTRAN FORMAT:		I5
Read from Subroutine:		INDAT

Variable	Columns	Format	Description
I	1-5	I5	Channel number of channel for which area variation data follows (on cards of type G5-3)

Notes

(1) N1 (on GCC5) sets of area variation factors are required. Each set consists of one card G5-2 giving the channel number, and one card of type G5-3 to give N2 area variation factors.

Card Type	G5-3	Area Variation Factors
Required:		When N1 = 0 (on GCC5)
FORTRAN READ List:		AFACT(J,L), L = 1, N2)
FORTRAN FORMAT:		12F5.3
Read from Subroutine:		INDAT

Variable	Columns	Format	Description
AFACT	1-60	12F5.3	Area Variation Factors (local area/nominal area)

Notes

(1) A total of N2 area variation factors must be provided.

Card Type	GCC6	Group Control Card for Card Group 6, Gap Spacing Variation Table input,
Required:		Whenever Card Group 6 is desired
FORTRAN READ List:		NGROUP, N1, N2
FORTRAN FORMAT:		3I5
Read from Subroutine:		INDAT

Variable	Columns	Format	Description
NGROUP	1-5	I5	NGROUP =6 (to select Card Group 6)
N1 (NGAPS)	6-10	I5	No. of gaps for which spacing factors will be specified (max = 9).
N2 (NGXL)	11-15	I5	No. of axial positions at which gap spacing factors will be given. (min = 2, Max = 10)

Notes

(1) If there are no gap spacing variations, Card Group 6 may be omitted.

(2) If N1 = 0, gap variations are deleted for succeeding cases.

(3) N1 sets of Gap Spacing Data must be provided. Each set consists of one card G6-2 giving the channel numbers of the chanels forming the gap, and N2 Gap Variation Factors appearing on cards of type G6-3.

Card Type	G6-1	Axial Positions of Gap Spacing Variations
Required:		When using Card Group 6
FORTRAN READ List:		GAPXL(L), L = 1,N2
FORTRAN FORMAT:		12F5.3
Read from Subroutine:		INDAT

Variable	Columns	Format	Description
GAPXL(L)	1-60	12F5.3	Relative Axial Positions (X/L) where gap spacing factors will be given.

Notes

(1) A total of N2 relative positions must be specified, giving 12 values per card.

Card Type	G6-2	Gap Number
Required:		When N1 > 0 (on GCC6)
FORTRAN READ List:		K
FORTRAN FORMAT:		I5
Read from Subroutine:		INDAT

Variable	Columns	Format	Description
K	1-5	I5	Gap Number

notes

(1) No sequence is associated with the gap numbers since they are user supplied.

Card Type G6-3	Gap Spacing Variation Factors
Required:	When N1 = 0 (on GCC6)
FORTRAN READ List:	GFACT(L), L = 1, N2
FORTRAN FORMAT:	12F5.3
Read from Subroutine:	INDAT

Variable	Columns	Format	Description
GFACT(L)	1-60	12F5.3	Gap Spacing Variation Factors (local gap width/nominal gap width)

Notes

(1) 12 values may be given per card, and suficient cards must be used to provide all N2 values.

Card Type GCC7	Card Group 7 Group Control Card
Required:	Whenever Card Group 7 is used
FORTRAN READ List:	NGROUP, N1, N2, N3, N4, N5
FORTRAN Format	6I5
Read From Subroutine:	INDAT

Variable	Columns	Format	Description
NGROUP	1-5	I5	NGROUP = 7 (to select Card Group 7)
N1 (J6)	6-10	I5	Spacer Type Indicator N1 = 1 Wire wrapped forced diversion crossflow is included N1 = 2 Spacer pressure losses and forced diversion crossflow are included
N2 (NGRID)	11-15	I5	Total number of spacer locations (max = 10)
N3 (NGRIDT)	16-20	I5	No. of spacer types
N4 (NRAMP)	21-25	I5	No. of iterations to insert loss coefficients for wire wrap mixing.
N5 (NJUMP)	26-30	I5	Crossflow Solution Indicator N5 = 0 Solution computed for each case. N5 = 1 Use first case solution for all succeeding cases. N5 = 2 Write solution to tape and use for all succeeding cases. N5 = 3 Read solution form tape and use for succeeding cases

Notes

(1) N2 relative spacer locations (X/L) and spacer types will be read in on cards of type G7-4, if N1 = 2.

(2) N3 sets of data corresponding to each spacer type will be read in on cards of type G7-5, if N1 = 2.

(3) If N4 < 1, N4 is reset to 1.

(4) N2 and N3 are not used when N1 = 1, N4 and N5 are not used when N1 = 2.

(5) If N5 > 0; The flow condition must not change for these cases nor the basic problem setup. This option would normally be used for cases involving changes in power or mixing for nonboiling problems.

Card Type	G7-1	Wire Wrap Geometry
Required:		When N1 = 1 on GCC7
FORTRAN READ List:		PITCH, DIA and THICK
FORTRAN FORMAT:		8E10.5
Read from Subroutine:		INDAT

Variable	Columns	Format	Description
PITCH	1-10	E10.5	Wire Wrap Pitch (in)
DIA	11-20	E10.5	Pin Diameter (in)
THICK	21-20	E10.5	Wire Diameter (in)

Card Type	G7-2	Gap Specification
Required:		When N1 = 1 on GCC7
FORTRAN READ List:		K, DUM, CROSS(L), L = 1, 6
FORTRAN FORMAT:		I5, 10E5.2
Read From Subroutine:		INDAT

Variable	Columns	Format	Description
K	1-5	I5	Gap number
DUM	6-10	E5.2	Effective fraction of a pitch for forcing crossflow
CROSS(L)	11-40	E5.2	Relative pitch lengths identifying the location of wraps crossing through a gap. Up to six positions may be given.

Notes

(1) One card is required for each gap.

(2) The gap numbers are assigned in the order that subchannel pairs are identified in Card Group 4.

(3) The sign of the relative pitch length specification gives the direction in which the wrap is crossing. A positive value indicates wraps crossing from I to J where I is less than J. A negative value for wraps crosing from J to I.

Card Type	G7-3	Wire Wrap Inventory
Required:		When N1 = 1 on GCC7
FORTRAN READ List:		NWRAP
FORTRAN FORMAT:		10I5
Read from Subroutine:		INDAT

Variable	Columns	Format	Description
NWRAP	1-50	10I5	No. of wraps contained in each subchannel at the start of the bundle in ascending subchannel order.

Notes

(1) Enough cards must be used to specify the entire wire wrap Inventory giving 10 values per card.

Card Type	G7-4	Spacer Location and Type
Required:		When N1 = 2 on GCC7
FORTRAN READ List:		GRIDXL(I), IGRID(I), I = 1, N2
FORTRAN FORMAT:		6(E5.2,I5)
Read from Subroutine:		INDAT

Variable	Columns	Format	Description
GRIDXL(I)	1-5	F5.2	Relative location (X/L) where spacers are located
IGRID	6-10	I5	Spacer type at the above location.

Notes

(1) A total of N2 sets of the above data must be provided giving six sets per card.

(2) The spacer type indicates which of the user suppled spacer data sets (cards G7-5) applies to the spacer at ay location.

Card Type G7-5	Spacer Data Sets
Required:	When N1 = 2 CNGCC7
FORTRAN READ List:	J, CD, K, FXFLO
FORTRAN FORMAT:	I5, E5.0, I5, E5.0
Read from Subroutine:	INDAT

Variable	Columns	Format	Description
J	1-5	I5	Subchannel Number
CD	6-10	E5.0	Spacer Loss Coefficient
K	11-15	I5	Connection number of gap through which flow is forced.
FXFLO	16-20	E5.0	Fraction of flow diverted.

Notes

(1) If the connection number is zero and the flow fraction is zero, then there is no forced flow diverson.

(2) The forced crossflow has the same sign as the forced flow fraction.

(3) N3 sets of data must be provided, one set for each spacer type. Each set consists of a card for every subchannel, the cards appearing in sequential subchannel order.

Card Type GCC8	Group Control Card for Card Group 8
Required:	When IPILE = 0, and Card Group 8 is desired
FORTRAN READ List:	NGROUP, N1, N2, N3, N4, N5
FORTRAN FORMAT:	6I5
Read from Subroutine:	INDAT

Variable	Columns	Format	Description
NGROUP	1-5	I5	NGROUP = 8 (to select Card Group 8)
N1	6-10	I5	No. of Rod Layout Data to be read. (Card type G8-1)
N2 (NROD)	11-15	I5	Total No. of rods
N3 (NODESF)	16-20	I5	No. of radial fuel nodes including the cladding
N4 (NFUELT)	21-25	I5	Fuel types used
N5 (NCHF)	26-30	I5	CHF Correlation option indicator N5 = 0 No CHF calculation done N5 = 1 The BAW-2 correlation N5 = 2 The W-3 correlation N5 = 3 The Hench-Levy correlation N5 = 4 The CISE-4 correlation

Notes

(1) N4 = 1 implies that only cylindrical fuel is being used. If N4 = 2, then either plate fuel is being used alone or a combination of plate and cylindrical fuel is being used. If N4 = 2, data cards must appear for both fuel types; leaving the cards for cylindrical fuel blank if that fuel type is not in use.

(2) If the W-3 correlation has been chosen, N5 = 2, the user must validate that the TDC value in subroutine "CHF" is appropriate.

Card Type	G8-1	Rod Layout Data
Required:		When N1 = 0 (on GCC8)
FORTRAN READ List:		N, I, DR, RADIA, (LR(L), PHI(L), L = 1,6X)
FORTRAN FORMAT:		I1, I4, 2E5.2, 6(I5, E5.0)
Read from Suroutine:		INDAT

Variable	Columns	Format	Description
N	1	I1	Rod type; N = 1 rod fuel N = 2 plate fuel
I	2-5	I4	Rod Number
DR	6-10	E5.2	Rod diameter (in)
RADIA	11-15	E5.2	Relative rod power (Rod power/average rod power)
LR	16-20	I5	Channel number
PHI	21-25	E5.0	Fraction of rod power going to the above channel

Notes

(1) Up to 6 sets of channel number and fraction of rod power going to that channel may be specified for each rod. The sum of the fractional rod powers need not sum to 1.0 because of gamma heating.

(2) For plate fuel, the rod diameter is the plate thicknss and the fraction of power to a channel is the fraction of the circumference required to specify the plate width facing the channel.

Card Type G8-2	Fuel Thermal Properties
Required:	Always when using Card Group 8
FORTRAN READ List:	KFUEL, CFUEL, RFUEL, DFUEL, KCLAD, CCLAD, RCLAD, TCLAD, HGAP
FORTRAN FORMAT:	9E5.2
Read from Subroutine:	INDAT

Variable	Columns	Format	Description
KFUEL	1-5	E5.2	Fuel thermal coductivity (Btu/hr-ft-°F)
CFUEL	6-10	E5.2	Fuel specific heat (Btu/hr-°F)
RFUEL	11-15	E5.2	Fuel density (lbm/ft^3)
DFUEL	16-20	E5.2	Fuel pellet diameter (in.)
KCLAD	21-25	E5.2	Cladding thermal conductivity (Btu/hr-ft-°F)
CCLAD	26-30	E5.2	Cladding specific heat (Btu/hr- °F)
RCLAD	31-35	E5.2	Cladding density (lbm/ft^3)
TCLAD	36-40	E5.2	Cladding thickness (in.)
HGAP	41-45	E5.2	Gap heat transfer coefficient (Btu/hr-ft^2-°F)

Card Type GCC9	Card Group 9, Group Control Card
Required:	Always when Group 9 is desired
FORTRAN READ List:	NGROUP, N1, N2, N3
FORTRAN FORMAT:	4I5
Read from Subroutine:	INDAT

Variable	Columns	Format	Description
NGROUP	1-5	I5	NGROUP = 9 (to select Card Group 9)
N1 (NSKIPX)	6-10	I5	Axial Printing Increment N1 = 1 Every step printed N1 = 2 Every other step printed N1 = 3 Every third step printed. etc., etc., etc.
N2 (NSKIPT)	11-15	I5	Time Step Printing Inrement (functions the same as N1 above, except used to select time step printouts)
N3 (KDEBUG)	16-20	I5	Debug print option. N3 = 0, no debugging information is printed. N3 = 1, a debugging printout is provided for each step of the calculation.

Notes

(1) If N1 or N2 are given as zero or blank, the code resets them to 1.

(2) The Debug option can generate alot of paper and can use alot of time printing. The best economy is thus achieved if the Debug option is used only when necessary.

(3) See card 44-00 of the Card Group 20 input method for additional details.

Card Type G9-1	Calculation variables
Required:	Always when Card Group 9 is used
FORTRAN READ List:	KIJ, FTM, Z, THETA, , NDX, NDT, TTIME, NTRIES, FERROR, SL
FORTRAN FORMAT:	4E5.2, 2I5, E5.2, I5, 4E5.2
Read from Subroutine:	INDAT

Variable	Columns	Format	Description
KIJ	1-5	E5.2	Diversion Crossflow resistance factor
FTM	6-10	E5.2	Turbulent Momentum Factor
Z	11-15	E5.2	Bundle Length (in)
THETA	16-20	E5.2	Position from vertical (degrees)
NDX	21-25	I5	No. of axial nodes
NDT	26-30	I5	No. of time steps
TTIME	31-35	E5.2	Total Transient Time (seconds)
NTRIES	36-40	I5	Maximum number of iterations
FERROR	41-45	E5.2	Allowable fraction error in flow form convergence
SL	46-50	E5.2	Transverse momentum parameters (S/L)

Notes

(1) If the number of iterations, allowable error, or momentum factor are blank or zero, the computer will use the values 20.0, 1.E-3, and 0.5 respectively.

Card Type	GCC10	Card Group 10, Group Control Card
Required:		When Card Group 10 is used
FORTRAN READ List:		NGROUP, N1, N2, N3
FORTRAN FORMAT:		4I5
Read from Subroutine:		INDAT

Variable	Columns	Format	Description
NGROUP	1-5	I5	NGROUP = 10 (to select Card Group 10)
N1 (NSCBC)	6-10	I5	Subcooled mixing correlation indicator N1 = 0 W/GS = ABETA N1 = 1 W/GS = ABETA * RE**BBETA N1 = 2 W/GD = ABETA * RE**BBETA N1 = 3 W/GS = D/AIJ * RE**BBETA N1 = 4 Bues mixing model is used
N2 (NBBC)	11-15	I5	Two-phase mixing option N2 = 1 Two-phase mixing is the same as for subcoled conditions N2 > 1 Read in N2 pairs of data for a table of two-phase mixing data (cards G10-2)
N3 (J5)	16-20	I5	Thermal Conduction mixing option N3 = 0 No thermal conduction N3 = 1 Read in (card G10-3) the Thermal Conduction Geometry Factor

Notes

(1) Beta = W/GS where W is the turbulent crossflow. RE is the Reynolds Number. S and D are the gap size and equivalent hydraulic diameter respectively. ABETA & BBETA are read in on card G10-1.

(2) Each pair of two-phase mixing data consists of the steam quality and the corresponding value of Beta.

(3) The maximum value for N2 is 30.

Card Type	G10-1	Mixing Correlation Constants
Required:		When N1 = 0, 1, 2 or 3 (on GCC10)
FORTRAN READ List:		ABETA, BBETA
FORTRAN FORMAT:		2F5.3
Read from Subroutine:		INDAT

Variable	Columns	Format	Description
ABETA	1-5	F5.3	Subcooled mixing correlation constants (see card GCC10 for the correlations)
BBETA	6-10	F5.3	

Card Type	G10-2	Two-Phase Mixing Data
Required:		When N2 > 1 (on GCC10)
FORTRAN READ List:		XQUAL(I), BX(I), I = 1, N2
FORTRAN FORMAT:		12F5.3
Read from Subroutine:		INDAT

Variable	Columns	Format	Description
XQUAL(I)	1-5	F5.3	Steam Quality
BX(I)	6-10	F5.3	Corresponding value of Beta = W/GS

Note

(1) N2 (on GCC10) pairs of data must be provided on cards of this type giving six pairs per card.

Card Type	G10-3	Thermal Conduction Geometry Factor
Required:		When N3 = 1 on card GCC10
FORTRAN READ List:		GK
FORTRAN FORMAT		F5.3
Read from Subroutine:		INDAT

Variable	Columns	Format	Description
GK	1-5	F5.3	Thermal Conduction Geometry Factor

Card Type	GCC11	Card Group 11 Group Control Card
Required:		Whenever Card Group 11 is used
FORTRAN READ List:		NGROUP, N1, N2, N3, N4, N5, N6
FORTRAN FORMAT:		7I5
Read from Subroutine:		INDAT

Variable	Columns	Format	Description
NGROUP	1-5	I5	NGROUP = 11 (to select Card Group 11)
N1 (IN)	6-10	I5	Inlet Enthalpy Option Indicator N1 = 0 Inlet enthalpy is given N1 = 1 Inlet temperature is given N1 = 2 Read in the individual subchannel inlet enthalpies N1 = 3 Read in the individual subchannel inlet temperatures
N2 (IG)	11-15	I5	Inlet Flow Distribution Indicator N2 = 0; All subchannels given same mass velocity N2 = 1; Inlet flow divided to give equal pressure drop in all subchannels. N2 = 2; Mass velocity factors for each channel read in on cards G11-3
N3 (NP)	16-20	I5	Pressure Transient Forcing Function Indicator
N4 (NH)	21-25	I5	Inlet Enthalpy or Temperature Forcing Function. Which inlet variable is chosen is indicated by N1 above.
N5 (NG)	26-30	I5	Inlet Flow Transient Forcing Function Indicator
N6 (NQ)	31-35	I5	Heat Flux Transient Forcing Function Indicator

Notes

(1) Each of the variables N3, N4, N5 and N6 give the number of tabular data pairs to be read in for each transient forcing function. Each data pair consists of a time specifation (seconds), and the relative value (present value/initial) for the parameter in question. If any of these option numbers are zero or blank, the corresponding forcing function data is not read in and is excluded from the calculations.

Card Type G11-1	Operating Conditions
Required:	Whenever Card Group 11 is used
FORTRAN READ List:	PEXIT, HIN, GIN, AFLUX
FORTRAN FORMAT:	6F10.0
Read from Subroutine:	INDAT

Variable	Columns	Format	Description
PEXIT	1-10	F10.0	Operating Pressure (psia)
HIN	11-20	F10.0	depends on the value of N1 = 0 (on card GCC11) If N1 = 1; Inlet Enthalpy (Btu/lbm) If N1 = 2; Inlet Temperature (°F)
GIN	21-20	F10.0	Mass Velocity (Mlbm/ft^2-hr)
AFLUX	31-40	F10.0	Average Heat Flux (MBtu/ft^2-hr)

Card Type G11-2	Inlet Temperature or Enthalpy
Required:	When N1 = 2 or 3 on GCC11
FORTRAN READ List:	HINLE(I), I = 1,NCHAN
FORTRAN FORMAT:	12E5.0
Read from Subroutine:	INDAT

Variable	Columns	Format	Description
HINLE	1-60	12F5.0	If N1 = 2 Channel Inlet Enthalpies If N1 = 3 Channel Inlet Temperatures

Note

(1) These inlet variable values must be specified in the order that the channels are anumbered and sufficient cards must be used to supply all the values called for (one per channel).

Card Type G11-3	Channel Mass Velocity Factors
Required:	When N2 = 2 on GCC11
FORTRAN READ List:	FSPLI(I), I = 1,NCHAN
FORTRAN FORMAT:	12E5.0
Read from Subroutine:	INDAT

Variable	Columns	Format	Description
FSPLI	1-60	12E5.0	Channel Mass Velocity Factors (12 per card)

Notes

(1) These factors are inputted in the same order as the channels are numbered.

Card Type G11-4	Transient Forcing Function data pairs for Pressure vs. Time
Required:	When N3 > 0 on GCC11
FORTRAN READ List:	YP, FP
FORTRAN FORMAT:	12E5.0
Read from Subroutine:	INDAT

Variable	Columns	Format	Description
YP	1-5	E5.0	Time specification
FP	6-10	E5.0	Relative pressure (current/initial)

Notes

(1) A total of N3 data pairs must be provided giving 6 per card.

Card Type	G11-5	Transient Forcing Function data pairs for Inlet Enthalpy or Inlet Temperature vs. Time
Required:		When N4 = 0 on GCC11
FORTRAN READ List:		YH, FH
FORTRAN FORMAT:		12E5.0
Read from Subroutine:		INDAT

Variable	Columns	Format	Description
YH	1-5	E5.0	Time specification (seconds)
FH	6-10	E5.0	Relative Parameter Value (current/initial) If N1 = 0; Relative enthalpys given If N1 = 1; Relative temperature given

Note

(1) A total of N4 data pairs must be provided giving 6 pairs per card.

Card Type	G11-6	Transient Forcing Function data pairs for Inlet Flow vs. Time
Required:		When N5 = 0 on GCC11
FORTRAN READ List:		YG, FG
FORTRAN FORMAT:		12E5.0
Read from Subroutine:		INDAT

Variable	Columns	Format	Description
YG	1-5	E5.0	Time specification (seconds)
FG	6-10	E5.0	Relative Inlet Flow (current/initial)

Notes

(1) A total of N5 data pairs must be provided giving 6 pairs per card.

Card Type	G11-7	Transient Forcing Function data pairs Heat Flux vs. Time
Required:		When N6 > 0 on GCC11
FORTRAN READ List:		YQ, FQ
FORTRAN FORMAT:		12E5.0
Read from Subroutine:		INDAT

Variable	Columns	Format	Description
YQ	1-5	E5.0	Time specification (seconds)
FQ	6-10	E5.0	Relative Heat Flux (current/initial)

Notes

(1) A total of N6 data pairs must be provided giving 6 pairs per card.

Card Type	GCC12	Group Control Card for Card Group 12 Output Display Options
Required:		Whenever Card Group 12 is used
FORTRAN READ List:		NGROUP, N1, N2, N3, N4
FORTRAN FORMAT:		5I5
Read from Subroutine:		INDAT

Variable	Columns	Format	Description
NGROUP	1-5	I5	NGROUP = 12 (to select Card Group 12)
N1 (NOUT)	6-10	I5	Data Printout Indicator N1 = 0; Print subchanel data only N1 = 1; Print subchannel data and crossflow data table N1 = 2; Print subchannel data and fuel temperature table N1 = 3; Print subchannel data, fuel temperature table. and crossflow data table
N2 (NPCHAN)	11-15	I5	Subchannel Data Printout Indicator N2 = 0 All subchannel data printed N2 > 0 Read in N2 subchannel numbers for which results are desired. (card G12-1)
N3 (NPROD)	16-20	I5	Fuel Temperature Printout Indicator N3 = 0; Data for all rods printed if called for by N1 N3 = 0; Read in N3 rod numbers for which results are desired. (card G12-2)
N4 (NPNODE)	21-25	I5	Fuel Node Printout Indicator N4 = 0; Temperatures printed for all nodes N4 = 0; Read in N4 node numbers for which results are desired (card G12-3)

Note

(1) If CHF data has been calculated, it will be printed for each of the rods selected by N3 and card(s) G12-2 plus a summary to identify the rod and channel with the minimum CHF ratio.

Card Type G12-1	Subchannel Numbers
Required:	When N2 > 0 on GCC12
FORTRAN READ List:	PRNTC(I), I = 1,N2
FORTRAN FORMAT	36I2
Read from Subroutine:	INDAT

Variable	Columns	Format	Description
PRNTC	1-72	36I2	Channel numbers for which results are desired

Notes

(1) A total of N2 channel numbers must be specified giving 36 per card.

Card Type G12-2	Fuel Rod Numbers
Required:	When N3 > 0 on GCC12
FORTRAN READ List:	PRNTR(I), I =1,N3
FORTRAN FORMAT:	36I2
Read from Subroutine:	INDAT

Variable	Columns	Format	Description
PRNTR	1-72	36I2	Rod Numbers for which results are desired

Notes

(1) A total of N3 rod numbers must be specified giving 36 per card.

Card Type	G12-3	Node Numbers
REQuired		When N4 > 0 on GCC12
FORTRAN READ List:		PRNTN(I), I =1,N4
Read from Subroutine:		36I2

Variable	Columns	Format	Description
PRNTN	1-72	36I2	Node numbers for which results are desired.

Notes

(1) A total of N4 Node Numbers must be specified giving 36 per card.

(2) The node numbers are counted such that fuel centerline is node 1, and fuel surface is node N.

IV. SAMPLE PROBLEMS AND OUTPUT TABLES

In the following sections, sample problems demonstrating the use of the various options for IPILE and IMAP are given. The sample problems were chosen to represent the types of analyses most often performed by COBRA IIIc/MIT but do not necessarily present all the options possible. The options chosen for use in the sample problems were generally those which had the greatest effects on the order and form of the input data. The IPILE option was chosen in particular, since it determines, to a great extent, which of the other options will be available or are required. The IMAP option was chosen since it determines the manner in which the channel numbering system will be established and thus affects the shape of the entire input deck.

The option to use wire-wrap forced diversion crossflow was not used since it is not one of the more popular COBRA IIIc/MIT-2 options. For an example problem using the wire-wrap option the reader is refered to references 1 and 2. The Card Group 20 input method is used exclusively in the following sample problems due to the increased number of options available, and its popularity. Several other options have been ignored on the belief that their use was simple enough to understand from the input descriptions provided in section III.

Following the sample problems a section is provided which gives samples of the various output tables used by COBRA IIIc/MIT-2. For the sake of brevity, the entire output from the execution of the sample problems is not included, but is available on magnetic tape as explained in the preface to this manual.

IV.1 LUMPED CHANNEL ANALYSIS (IPILE = 0) SAMPLE PROBLEM

The channel map shown in Figure 27 uses both lumped channels and smeared rods. For this type of problem, both the IPILE = 0, and the IMAP = 0 options are required.

The channels in the problem can be classified into two types, the whole channels and the half channels. Note that the channels which are split vertically and those which are split diagonally are considered to be the same type since the flow areas, perimeters, and number of heated rods are the same for both. The relevant dimensions for the whole channel are summarized in the following table.

Area = 0.1705 (sq-in)
Wetted Perimeter = 1.326 (in)
Heated Perimeter = 1.326 (in)
Hydraulic Diameter = 0.514329 (in)

The dimensions for the half channels can be found by multiplying those of the whole channel by 1/2. This can either be done by

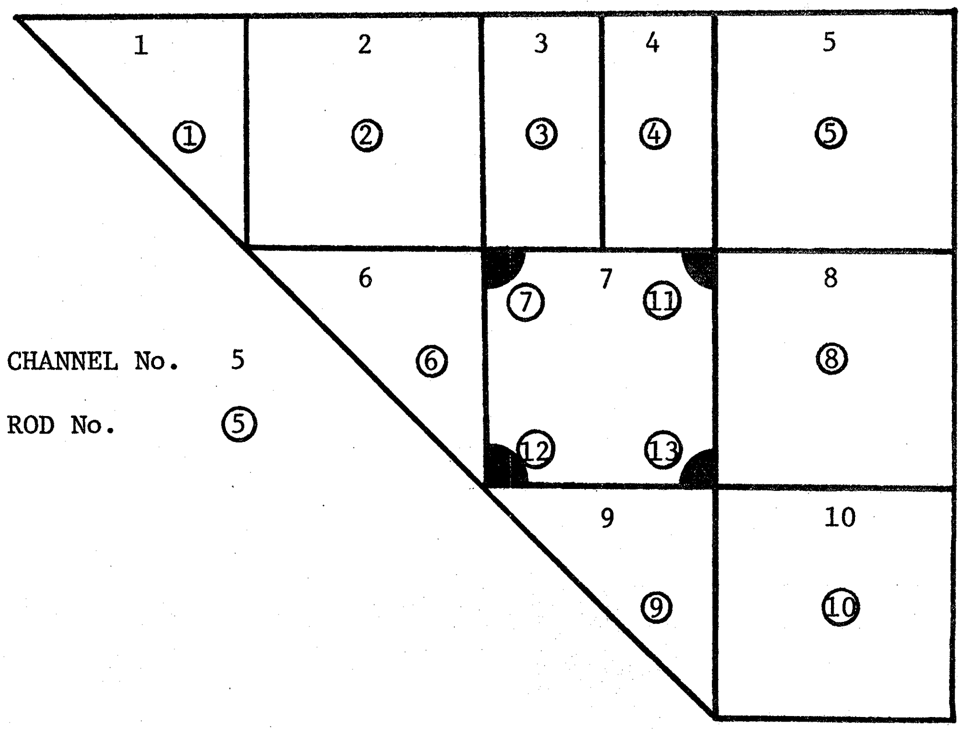


Figure 27: Channel map for the IPILE = 0 Sample problem

the user, or the value of FRAC can be set to 0.5.

The gaps in the problem can also be divided into two types. The width of a full gap is 0.2848 inches. The gaps between channels 3 and 7 and between channels 4 and 7 are only 0.1424 inches, or half the width of the full gap.

Each channel is 126.7 inches long and has the relative axial power distribution given in Table 5. The average value of the heat flux is 0.2034 Mbtu/hr-sqft. Calculating the Relative Rod Powers and the fractional powers to each channel as described in section III, gives the data in Table 6. Note that for the smeared rods (No.'s 1 through 6 and 8 through 10) the Power Fraction To Adjacent Channel is just the value of FRAC*HNR (The number of heated rods). For the half channels with smeared rods this value is 0.5, and for the whole channels the value is 1.0. Note also that the adjacent channel for the smeared rods has the same number as the rod. The Fuel thermal data needed to use the old fuel rod model is given in the Table 7.

There are three spacer types and 7 spacer locations in the problem. The spacer type and drag coefficient for each axial location are summarized in Table 8.

Table 9 gives the tabular transient forcing function values which should be input into COBRA IIIc/MIT-2 in order to perform

Table 5:
Heat Flux Distribution For
The IPILE = 0 Test Case

x/l	Relative Flux
0.000	0.041
0.050	0.302
0.100	0.554
0.150	0.792
0.200	1.011
0.250	1.202
0.300	1.360
0.350	1.484
0.400	1.568
0.450	1.612
0.465	1.616
0.475	1.618
0.500	1.613
0.550	1.571
0.600	1.489
0.650	1.452
0.700	1.209
0.750	1.020
0.800	0.804
0.850	0.566
0.900	0.313
0.950	0.053
1.000	0.000

Table 6: Rod Input Data For The IPILE = 0 Test Case

ROD NO.	DIA (IN)	RADIAL POWER FACTOR	POWER FRACTION TO ADJACENT CHANNEL	ADJACENT CHANNEL
1	0.4220	0.8000	0.50	1
2	0.4220	0.8000	1.00	2
3	0.4220	1.0000	0.50	3
4	0.4220	1.0000	0.50	4
5	0.4220	0.6000	1.00	5
6	0.4220	1.2000	0.50	6
7	0.4220	1.8000	0.25	7
8	0.4220	1.0000	1.00	8
9	0.4220	1.4000	0.50	9
10	0.4220	0.6000	1.00	10
11	0.4220	1.8000	0.25	7
12	0.4220	1.8000	0.25	7
13	0.4220	1.8000	0.25	7

Table 7: Thermal Properties For The Fuel Material in the IPILE = 0 test case

Fuel Properties				
Type no.	Cond. (b/hr-ft-f)	Sp. Heat (b/lb-f)	Density (lb/ft3)	Dia. (in.)
1	1.65	0.0789	660.1	0.3835
Clad Properties				
Cond. (b/hr-ft-f)	Sp. Heat (b/lb-f)	Density (lb/ft3)	Thick. (in.)	Gap Cond. (b/hr-ft2-f)
11.50	0.1200	494.4	0.0165	1000.00

Table 8: Spacer Data For The IPILE = 0 Test Case

Location (x/l)	0.005	0.159	0.325	0.492	0.658	0.824	0.995
Drag Coefficient	4.011	0.978	1.565	1.565	1.565	1.565	4.011
Spacer Type No.	1	2	3	3	3	3	1

Table 9: Transient Forcing Function Data Points For The IPILE = 0 Test Case

TIME (SEC)	INLET FLOW FACTOR	PRESSURE FACTOR	HEAT FLUX FACTOR	INLET ENTHALPY FACTOR
0.00	1.00	1.000	1.00	1.00
0.25	0.90		1.00	
0.50	0.81	1.005	0.95	
0.75	0.73			
1.00	0.66	1.020	0.90	
1.50	0.63			
2.00	0.62	1.030		
3.00	0.62	1.040	0.85	0.95

the desired transient analysis. Note that the transient forcing function data pairs (time vs. parameter value) need only be given for those values listed in the table. Parameter values at times intermediate to those specified in the table will be found by linear interpolation.

The remaining constants, parameters, and options desired for this test problem are specified in Table 10.

Table 11 shows the input data as it appeared when the test problem was executed for this manual. The data deck shown in Table 11 is not the only configuration of the input data which would be acceptable. Examples of the several ways in which the form of the data deck could be altered include, using the other input method, and variations of the channel data through the use of different combinations of the variable FRAC and the channel dimensions.

IV.2 PWR SAMPLE PROBLEM (IPILE = 1)

The channel map shown in Figure 28 represents the PWR geometry which will be used for the next sample problem. The PWR analysis can be performed using IPILE = 0 or 2. It is simpler however, to use the IPILE = 2 option whenever the rod and gap dimensions are uniform throughout the analysis section. The channel map for this problem could be input using either IMAP = 2 0r 3. For this problem the IMAP = 2 option has been selected.

The axial power distribution for this sample problem is given in Table 12, and the radial power factors for each of the 34 rods are given in Table 13. In PWR analysis, (IPILE = 2) each assembly is assumed to have only one rod and that rod must have the same number as the channel it is in.

The channels in the problem are of four types, as shown in Table 14. The difference between the type is in the number of unheated rods. This can be seen by noting that the only difference between any two channel types in Table 14 is the value for the heated perimeter. Since the value for the wetted perimeter is always the same, the total number of rods has not changed, only the number of rods which are heated.

As shown in Table 15, there are 9 axial positions at which spacers are located and all the spacers are the same in all channels.

The fuel thermal properties necessary for use of the fuel rod models are given in Table 16.

Table 17 summarizes the rest of the thermal-hydraulic options which are desired for this sample problem.

Using the data in Tables 12 through 17 the data file shown in Table 18 was created. This of course is not the only form for the input data that is acceptable, and a useful exercise for the reader would be to recreate this input file using other options.

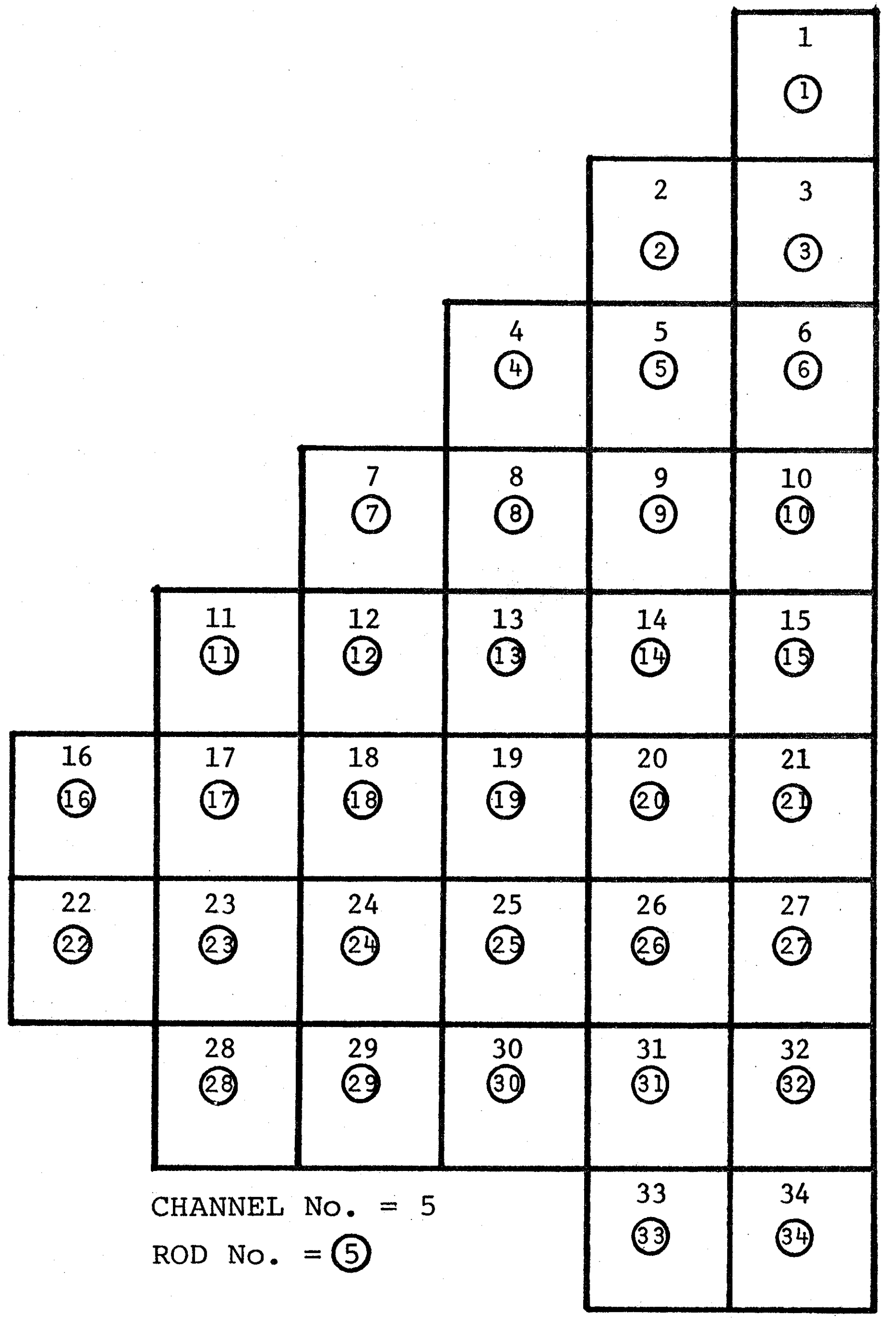


FIGURE 28: 1/8 Section of PWR Core Used for the IPILE = 1 Test Case

Table 10: Thermal - Hydraulic Model
Options For The IPILE = 0 Test Case

OPERATING CONDITIONS
SYSTEM PRESSURE = 2150.0 PSIA
INLET ENTHALPY = 548.8 BTU/LB
AVG. MASS VELOCITY = 2.217 MLB/(HR-FT^2)
AVG. HEAT FLUX = 0.203400 MBTU/(HR-FT^2)

UNIFORM INLET ENTHALPY
UNIFORM INLET MASS VELOCITY

MIXING CORRELATIONS
SUBCOOLED MIXING, BETA = 0.02
BOILING MIXING, BETA IS ASSUMED SAME AS SUBCOOLED

FRICTION FACTOR CORRELATION (FOR ALL CHANNEL TYPES):
FRICT = 0.184*RE**(-.200) + 0.0000

TWO-PHASE FLOW CORRELATIONS
LEVY SUBCOOLED VOID CORRELATION
HOMOGENEOUS BULK VOID MODEL
HOMOGENEOUS MODEL FRICTION MULTIPLIER

W-3 CRITICAL HEAT FLUX CORRELATION

NO ENTHALPY COUPLING PARAMETER IN THE MIXING TERM
NO HALF BOUNDARIES

CALCULATION PARAMETERS
CROSS-FLOW RESISTANCE (KIJ) = 0.500
MOMENTUM TURBULENT FACTOR (FTM) = 0.000
TRANSVERSE MOMENTUM FACTOR (S/L) = 0.500
CHANNEL ANGLE FROM VERTICAL = 0.000 DEGREES
CHANNEL LENGTH = 126.70 INCHES
NUMBER OF AXIAL NODES = 21
NODE LENGTH = 6.033 INCHES
NUMBER OF TIME STEPS = 3
TOTAL TRANSIENT TIME = 3.0 SECONDS
TIME STEP = 1.0 SECONDS

ITERATION CONTROL
MAX. ALLOWABLE NO. ITERATIONS = 20
FLOW CONVERGENCE FACTOR = 0.01

TABLE 11: EXAMPLE PROBLEM INPUT DATA FOR COBRA IIIc/MIT WITH IPILE = 0

```
    VARIABLES                                                      CARD IMAGES
                              0....*....1....*....2....*....3....*....4....*....5....*....6....*....7....*....8
MC  MG  MN  MR  MX          ***   10   13    5   13   22                                                       ***
MAXT                        *** 2000                                                                           ***
IPILE  KASE  J1  TEXT       ***0   1    1    IPILE = 0; EXAMPLE CASE COBRA IIIc/MIT-2                          ***
NGROUP NOPRIN               ***   20    0                                                                      ***
IMAP ND1X ND2X              ***    3    5    3                                                                 ***
ND2=  1 NTHBOX              ***    1    2    3    4    5                                                       ***
ND2=  2 NTHBOX              ***         6    7    7    8                                                       ***
ND2=  3 NTHBOX              ***              9    9   10                                                       ***
NAX AFLUX                   ***   23.2034                                                                      ***
AXIAL HEAT FLUX             ***   .0.0407  .05.3017   .1.5544  .15.7925   .21.011  .251.202   .31.360          ***
                            ***  .351.484   .41.568  .451.612 .4651.616 .4751.618   .51.613  .551.571          ***
                            ***   .61.489  .651.452   .71.209  .751.020   .8.8040  .85.5659   .9.3132          ***
                            ***  .95.0532      1..0                                                            ***
RADIAL POWERS               ***   .8   .8  1.0  1.0   .6  1.2  0.0  1.0  1.4   .6                              ***
Z NDX NDT TTIME             ***126.7   21    3   3.                                                            ***
INDICATORS                  ***    0    2    7    3    4    0                                                  ***
CHANNEL DATA, TYPE  1       ***    1    1   1.        1. .422.17051.3261.326                                   ***
GRID DATA, TYPE  1          ***4.011.97821.565                                                                 ***
CHANNEL DATA, TYPE  2       ***    1    1   1.        .5 .422.0852.6630.6630                                   ***
GRID DATA, TYPE  2          ***4.011.97821.565                                                                 ***
CHANNELS OF TYPE  2         ***    1    3    4    6    9                                                       ***
GRID POSITIONS              *** .005    1 .159    2 .325    3 .492    3 .658    3 .824    3 .995    1          ***
INDICATORS                  ***    4   13    4    1                                                            ***
ROD DATA                    ***1   7 .422  1.8  7 .25                                                          ***
ROD DATA                    ***1  11 .422  1.8  7 .25                                                          ***
ROD DATA                    ***1  12 .422  1.8  7 .25                                                          ***
ROD DATA                    ***1  13 .422  1.8  7 .25                                                          ***
FUEL THERMAL DATA           *** 1.65.0789660.1.383511.50.1200494.4.01651000.                                   ***
GAP INTERCONNECTIONS        ***.2848.2848.2848.2848.2848.1424.1424.2848.2848.2848.2848.2848.2848               ***
HYDRAULIC MODEL INDICATORS  ***    0    0    0    1    0   1    0   1    0                                     ***
VOID FRACTION (J2, J3)      ***    1    0                                                                      ***
CONSTANTS                   ***    2   .5   .0   .5   .0                                                       ***
NPROP, N, PH, P2            ***   30    1 650.2300.                                                            ***
IN H(OR T)IN GIN PEXIT      ***    0548.82.2172150.                                                            ***
TRANS INDIC FOR P H G Q     ***    5    2    8    5                                                            ***
PRESSURE TRANSIENT          ***   .0   1.   .51.005   1. 1.02   2. 1.03   3. 1.04                              ***
INLET ENTHALPY TRANSIENT    ***   .0   1.   3.  .95                                                            ***
INLET FLOW TRANSIENT        ***   .0   1.  .25   .9   .5  .81  .75  .73   1.  .66  1.5  .63   2.  .62          ***
                            ***   3.  .62                                                                      ***
INLET POWER TRANSIENT       ***   .0   1.  .25   1.   .5  .95   1.   .9   3.  .85                              ***
KDEBUG                      ***    0                                                                           ***
PRINTING                    ***    0    0    3    4    4    0                                                  ***
PRINT CHANNELS              ***    3    4    7    9                                                            ***
PRINT RODS                  ***    3    4    7    9                                                            ***
                              0....*....1....*....2....*....3....*....4....*....5....*....6....*....7....*....8
```

Table 12:
Axial Heat Flux Distribution
For The IPILE = 1 Test Case

x/l	Relative Flux
0.000	0.666
0.042	0.833
0.125	1.163
0.209	1.124
0.292	1.019
0.375	0.943
0.458	0.909
0.542	0.916
0.625	0.961
0.708	1.044
0.792	1.146
0.875	1.154
0.958	0.789
1.000	0.604

IV.3 BWR SAMPLE PROBLEM (IPILE = 2)

The channel map for the BWR sample problem is illustrated in Figure 29. In general, the channel map for any separated channel anaysis is not important except that it establishes the channel numbering system, and provides the user with a picture of the physical locations of the channels. The arrangement of the channels for this analysis is a three by three square, and thus most readily adaptable to the IMAP = 1 option.

Table 19 presents the axial power distribution which will be used in this problem. The radial power factors for each of the nine rods are given in Table 20. Again, since the IPILE = 2 method considers only smeared rods, the rod number must be the same as the channel number for the channel it is in.

The channels in this problem are all of the same type. Table 21 gives the relevant dimensions for the channels. The spacers are also the same for every channel and at every axial location. Table 22 gives the locations and drag coefficients for the spacers used in this problem.

Table 23 gives the necessary coefficients for the fuel rod model.

The remaining thermal-hydraulic options selected for this sample case are specified in Table 24.

Table 25 presents the organization of the data deck which was actually used to run this sample problem. Again, other forms of the data deck are possible and the interested user should attempt to reassemble this deck from the data specified in Tables 19 through 25 to familiarize himself with the methods available.

Table 13: The Radial Power Factors For The Rods in The IPILE = 1 Test Case

Rod No.	Power Factor	Rod No.	Power Factor	Rod No.	Power Factor
1	.978	13	1.012	25	.984
2	.981	14	1.176	26	1.169
3	1.137	15	1.008	27	1.022
4	.982	16	1.066	28	.592
5	1.141	17	1.153	29	.782
6	.988	18	1.019	30	.971
7	1.088	19	1.162	31	1.135
8	1.134	20	1.014	32	1.123
9	.994	21	1.157	33	.613
10	1.159	22	.682	34	.758
11	1.033	23	1.033		
12	1.196	24	1.098		

Table 14: Subchannel Input Data For The IPILE = 1 Test Case

Type	Area (sq-in)	Wetted Perim. (in)	Heated Perim. (in)	Hydraulic Diameter (in)	Channel Numbers
1	32.04	261.7	243.3	0.4897	1,2,4,6,8,9,11,13, 15,18,20,22,25,27, 28,29,33,34
2	32.04	261.7	221.2	0.4897	16,23
3	32.04	261.7	232.2	0.4897	30,31
4	32.04	261.7	226.7	0.4897	3,5,8,10,12,14,17, 19,21,24,26,32

Table 15: Spacer Data For
The IPILE = 1 Test Case

Spacer Location (x/l)	Spacer Type No.	Drag Coefficient
0.000	1	0.653
0.090	1	0.653
0.228	1	0.653
0.366	1	0.653
0.504	1	0.653
0.642	1	0.653
0.780	1	0.653
0.918	1	0.653
1.000	1	0.653

Table 16: Thermal Properties For The Fuel
Material In The IPILE = 1 Test Case

Fuel Properties

Type No.	Cond. (B/hr-ft-F)	Sp. Heat (B/lb-F)	Density (lb/ft3)	Dia. (in.)
1	1.40	0.0800	650.0	0.3765

Clad Properties

Cond. (B/hr-ft-F)	Sp. Heat (B/lb-F)	Density (LB/ft3)	Thick. (in.)	Gap Cond. (B/hr-ft2-F)
8.80	0.0780	410.0	0.0280	600.00

Table 17: Thermal - Hydraulic Model Options For The IPILE = 1 Test Case

```
OPERATING CONDITIONS
  SYSTEM PRESSURE     =   2100.0  PSIA
  INLET ENTHALPY      =   526.7   BTU/LB
  AVG. MASS VELOCITY  =   2.480   MLB/(HR-SQFT)
  INLET TEMPERATURE   =   532.0   DEGREES F
  AVG. HEAT FLUX      =   0.173   MBTU/(HR-SQFT)

MIXING CORRELATIONS
   SUBCOOLED MIXING,   BETA = 0.0200
   BOILING MIXING, BETA IS ASSUMED SAME AS SUBCOOLED

UNIFORM INLET TEMPERATURE
FLOWS SPLIT TO GIVE EQUAL PRESSURE GRADIENT

FRICTION FACTOR CORRELATION (FOR ALL CHANNEL TYPES)
   FRICT = 0.200*RE**(-.200) + 0.0000
   WALL VISCOCITY CORRECTION TO FRICTION FACTOR IS NOT INCLUDED

TWO-PHASE FLOW CORRELATIONS
   LEVY SUBCOOLED VOID CORRELATION
   HOMOGENEOUS BULK VOID MODEL
   HOMOGENEOUS MODEL FRICTION MULTIPLIER

W-3 CRITICAL HEAT FLUX CORRELATION

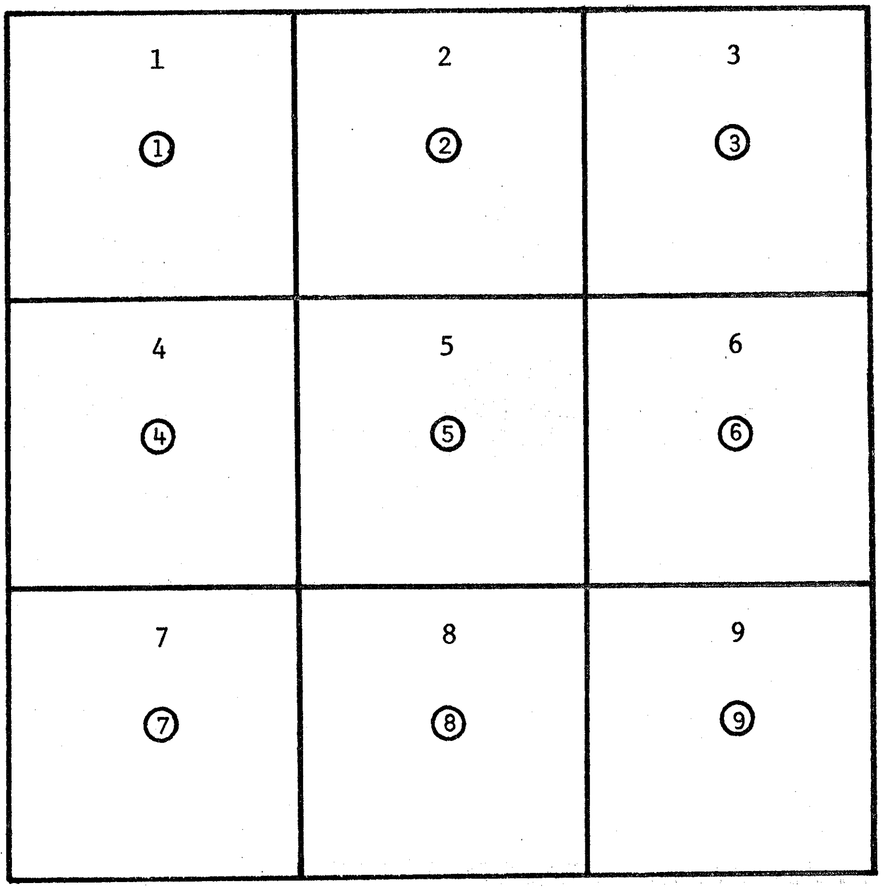
NO ENTHALPY COUPLING PARAMETER IS USED
NO HALF BOUNDARIES

CALCULATION PARAMETERS
  CROSSFLOW RESISTANCE (KIJ)            =  0.500
  MOMENTUM TURBULENT FACTOR (FTM)       =  1.000
  TRANSVERSE MOMENTUM FACTOR (S/L)      =  0.500
  CHANNEL LENGTH                        =  136.7   INCHES
  CHANNEL ORIENTATION                   =  0.0     DEGREES
  NUMBER OF AXIAL NODES                 =  12
  NODE LENGTH                           =  11.392 INCHES
  NUMBER OF TIME STEPS                  =  0

ITERATION CONTROL
  ALLOWABLE ITERATIONS                  =  20
  FLOW CONVERGENCE FACTOR               =  0.01
```

TABLE 18: EXAMPLE PROBLEM INPUT DATA FOR COBRA IIIc/MIT WITH IPILE = 1

```
    VARIABLES                                              CARD IMAGES
                              0....*....1....*....2....*....3....*....4....*....5....*....6....*....7....*....8
MC  MG  MN  MR  MX          ***   35   68    6   35   20                                                       ***
MAXT                        *** 6000                                                                           ***
IPILE  KASE J1   TEXT       ***1   1    1    PWR TEST CASE (IPILE = 1) COBRA IIIc/MIT-2                        ***
NGROUP NOPRIN               ***   20                                                                           ***
IMAP ND1X ND2X              ***    2    6    9                                                                 ***
ND2=  1 ISTART IFIN         ***    6    6                                                                      ***
ND2=  2 ISTART IFIN         ***    5    6                                                                      ***
ND2=  3 ISTART IFIN         ***    4    6                                                                      ***
ND2=  4 ISTART IFIN         ***    3    6                                                                      ***
ND2=  5 ISTART IFIN         ***    2    6                                                                      ***
ND2=  6 ISTART IFIN         ***    1    6                                                                      ***
ND2=  7 ISTART IFIN         ***    1    6                                                                      ***
ND2=  8 ISTART IFIN         ***    2    6                                                                      ***
ND2=  9 ISTART IFIN         ***    5    6                                                                      ***
NAX AFLUX                   ***   14 .173                                                                      ***
AXIAL HEAT FLUX             ***   0. .666.0417 .833 .1251.163.20881.124.29171.019 .375.9427.4583.9094          ***
                            ***.5417.9156 .625.9606.70831.044.79171.146 .8751.154.9583.7894   1..6043          ***
RADIAL POWERS               *** .978 .9811.137 .9821.141 .9881.0881.134 .9941.1591.0331.1961.0121.176          ***
                            ***1.0081.0661.1531.0191.1621.0141.157 .6821.0331.098 .9841.1691.022 .592          ***
                            *** .782 .9711.1351.123 .613 .758                                                  ***
Z NDX NDT TTIME             ***136.7   12                                                                      ***
INDICATORS                  ***    1    4    9    1    3                                                       ***
CHANNEL DATA, TYPE  1       ***    1    1   1. 1.82 176.  .4432.04261.7243.3                                   ***
GRID DATA, TYPE  1          *** .653                                                                           ***
CHANNEL DATA, TYPE  2       ***    1    1   1. 1.82 168.  .4432.04261.7232.2                                   ***
GRID DATA, TYPE  2          *** .653                                                                           ***
CHANNELS OF TYPE  2         ***   16   23                                                                      ***
CHANNEL DATA, TYPE  3       ***    1    1   1. 1.82 164.  .4432.04261.7226.7                                   ***
GRID DATA, TYPE  3          *** .653                                                                           ***
CHANNELS OF TYPE  3         ***   30   31                                                                      ***
CHANNEL DATA, TYPE  4       ***    1    1   1. 1.82 160.  .4432.04261.7221.2                                   ***
GRID DATA, TYPE  4          *** .653                                                                           ***
CHANNELS OF TYPE  4         ***    3    5    8   10   12   14   17   19   21   24   26   32                    ***
GRID POSITIONS              ***   0.     1.0901    1.2280    1.3660    1 .504    1.6419    1.7799   1          ***
GRID POSITIONS              ***.9179    1   1.    1                                                            ***
FUEL THERMAL DATA           ***  1.4  .08 650..3765  8.8 .078 410. .028 600.                                   ***
HALF-BOUNDARY CHANNEL PAIRS ***                                                                                ***
HYDRAULIC MODEL INDICATORS  ***         1         1    1    1                                                  ***
SINGLE-PHASE FRICTION       ***    0   .2  -.2                                                                 ***
VOID FRACTION (J2, J3)      ***    1    0                                                                      ***
INLET FLOW DIVISION (IG)    ***    1                                                                           ***
CONSTANTS                   ***    2   .5   1.   .5   0.                                                       ***
IN H(OR T)IN GIN PEXIT      ***    1 532. 2.482100.                                                            ***
TRANS INDIC FOR P H G Q     ***                                                                                ***
KDEBUG                      ***                                                                                ***
PRINTING                    ***              3    2    2                                                       ***
PRINT CHANNELS              ***    1    2    7   22   31                                                       ***
PRINT RODS                  ***    1    2    7   22   31                                                       ***
                              0....*....1....*....2....*....3....*....4....*....5....*....6....*....7....*....8
```



CHANNEL No. = 5 ROD No. = ⑤

Figure 29: Channel and rod arrangement used in the IPILE = 2 sample problem.

Table 19:
Axial Heat Flux Distribution
For The IPILE = 2 Test Case

x/l	Relative Flux	x/l	Relative Flux
0.000	0.430	0.521	1.390
0.021	0.470	0.563	1.360
0.063	0.550	0.604	1.300
0.104	0.640	0.646	1.230
0.146	0.740	0.688	1.150
0.188	0.850	0.729	1.080
0.229	0.970	0.771	1.010
0.271	1.100	0.813	0.930
0.313	1.210	0.854	0.840
0.354	1.290	0.896	0.740
0.396	1.340	0.938	0.600
0.438	1.380	0.979	0.430
0.479	1.400	1.000	0.350

Table 20: The Radial Power
Factors For The Rods in The
IPILE = 2 test case

Rod No.	Power Factor
1	1.290
2	1.314
3	1.269
4	1.292
5	1.326
6	1.262
7	1.308
8	1.291
9	1.269

Table 21: Subchannel Geometry Data

Area (sq-in) = 15.82
Wetted Perimiter (in) = 118.3
Heated Perimiter (in) = 94.08
Hydraulic Diameter (in) = 0.5349

Table 22: Spacer Data For The IPILE = 2 Test Case

Location (x/l)	0.083	0.208	0.333	0.458	0.583	0.708	0.833
Drag Coefficient	0.883	0.883	0.883	0.883	0.883	0.883	0.883
Spacer Type No.	1	1	1	1	1	1	1

Table 23: Thermal Properties For The Fuel Material In The IPILE = 2 Test Case

Fuel Properties

Type No.	Cond. (B/hr-ft-F)	Sp. Heat (B/lb-F)	Density (lb/ft3)	Dia. (in.)
1	2.00	0.0800	640.0	0.4100

Clad Properties

Cond. (B/hr-ft-F)	Sp. Heat (B/lb-F)	Density (lb/ft3)	Thick. (in.)	Gap Cond. (B/hr-ft2-F)
8.80	0.0760	405.0	0.0320	500.90

Table 24: Thermal - Hydraulic Model
Options For The IPILE = 2 Test case

```
OPERATING CONDITIONS
  SYSTEM PRESSURE     =    1020.0 PSIA
  INLET ENTHALPY      =     526.9 BTU/LB
  AVG. MASS VELOCITY  =     1.119 MILLION LB/(HR-SQFT)
  INLET TEMPERATURE   =       0.0 DEGREES F
  AVG. HEAT FLUX      =  0.145500 MILLION BTU/(HR-SQFT)

MIXING CORRELATIONS
   SUBCOOLED MIXING,   BETA = 0.0200
   BOILING MIXING, BETA IS ASSUMED SAME AS SUBCOOLED

   UNIFORM INLET ENTHALPY
   UNIFORM INLET MASS VELOCITY

FRICTION FACTOR CORRELATION (FOR ALL CHANNELS)
   FRICT = 0.184*RE**(-.200) + 0.0000
   WALL VISCOCITY CORRECTION TO FRICTION FACTOR IS NOT INCLUDED

TWO-PHASE FLOW CORRELATIONS
   LEVY SUBCOOLED VOID CORRELATION
   SMITH SLIP CORRELATION AND THE SLIP MODEL
   BAROCZY FRICTION MULTIPLIER

CALCULATION PARAMETERS
  CROSSFLOW RESISTANCE (KIJ)          =  0.500
  MOMENTUM TURBULENT FACTOR           =  1.0000
  TRANSVERSE MOMENTUM FACTOR (S/L)    =  0.500
  CHANNEL LENGTH                      =  150.00 INCHES
  CHANNEL ORIENTATION                 =  0.0    DEGREES
  NUMBER OF AXIAL NODES               =  24
  NODE LENGTH                         =  6.250  INCHES
  NUMBER OF TIME STEPS                =  0

ITERATION CONTROL
  ALLOWABLE ITERATIONS                =  20
  FLOW CONVERGENCE FACTOR             =  0.01
```

TABLE 25: EXAMPLE PROBLEM INPUT DATA FOR COBRA IIIc/MIT WITH IPILE = 2

```
    VARIABLES                                          CARD IMAGES
                              0....*....1....*....2....*....3....*....4....*....5....*....6....*....7....*....8
MC  MG  MN  MR  MX          ***    9   18    4    9   40                                                       ***
MAXT                        *** 2000                                                                           ***
IPILE  KASE  J1  TEXT       ***2   1    2    BWR TEST CASE (IPILE = 2) COBRA IIIc/MIT-2                        ***
NGROUP NOPRIN               ***   20                                                                           ***
IMAP ND1X ND2X              ***    1    3    3                                                                 ***
NAX AFLUX                   ***   26.1455                                                                      ***
AXIAL HEAT FLUX             ***   0. .430.0208 .470.0625 .550.1042 .640.1458 .740.1875 .850.2292 .970          ***
                            ***.2708 1.10.3125 1.21.3542 1.29.3958 1.34.4375 1.38.4792 1.40.5208 1.39          ***
                            ***.5630 1.36.6042 1.30.6458 1.23.6875 1.15.7292 1.08.7708 1.01.8125 .930          ***
                            ***.8542 .840.8958 .740.9375 .600 .979 .430 1.00 .350                              ***
RADIAL POWERS               ***1.2901.3141.2691.2921.3261.2621.3081.2911.269                                   ***
Z NDX NDT TTIME             *** 150.   24    0   0.                                                            ***
INDICATORS                  ***    2    1    7    1    3    0                                                  ***
CHANNEL DATA, TYPE  1       ***    1    1   1.       62. .48315.82118.394.08                                   ***
GRID DATA, TYPE  1          *** .883                                                                           ***
GRID POSITIONS              ***.0833    1.2083    1.3333    1.4583    1.5833    1.7083    1.8333    1          ***
FUEL THERMAL DATA           ***   2.  .08 640..4100 8.80 .076 405..0320500.9                                   ***
HYDRAULIC MODEL INDICATORS  ***              1    1    1    1                                                  ***
TWO-PHASE FRICTION (J4)     ***    2                                                                           ***
VOID FRACTION (J2, J3)      ***    1    2                                                                      ***
INLET FLOW DIVISION (IG)    ***    0                                                                           ***
CONSTANTS                   ***    2  0.5   1.  0.5                                                            ***
IN H(OR T)IN GIN PEXIT      ***    0526.91.1191020.                                                            ***
TRANS INDIC FOR P H G Q     ***                                                                                ***
KDEBUG                      ***                                                                                ***
PRINTING                    ***    2         3                                                                 ***
                              0....*....1....*....2....*....3....*....4....*....5....*....6....*....7....*....8
```

IV.4 SAMPLE COBRA IIIc/MIT-2 OUTPUT TABLES

The output from the COBRA IIIc/MIT-2 calculations is presented in tables such as those illustrated in Tables 26 through 32. Tables 26 - 32 were actually taken from the printout obtained when the sample problem for IPILE = 0 presented in the previous section was executed. The only alterations made to the tables to prepare them for inclusion in this manual were those necessary to center the tables and add table headings.

Table 26 presents the locations and lengths of the various problem specific data arrays which are contained in the consolidated data array "DATA". This table would normally appear on two pages in the form of a long column, but has been folded over to appear on a single page for this manual.

The channel exit results for all the channels as well as the mass and energy balances for the entire calculation are presented in Table 27. Table 28 presents the axial distribution of the bundle averaged results. These tables are printed only once per case, and their printing cannot be suppressed.

Following the average and summary printouts come the individual channel results. For each of the channels that have been requested in the input data, a table similar to that shown in Table 29 is printed. The form of Table 29 is identical to that of Table 28 except that the results are for an individual channel instead of the bundle average. Depending on the output options selected at execution time, the printing of the individual channels can be limited to only those desired by the user. The option, however, to entirely suppress the channel results is not available. One set of tables for the channels requested will be printed at every time step for which printing has been selected. One set is also printed for the time-zero steady state calculations.

The crossflow mixing table is printed next. This table gives the diversion crossflow mixing at each axial level for which printing has been requested and for every gap. Table 30 shows a diversion crossflow table similar to those printed by COBRA. The tables actually printed by COBRA have ten (10) channels per page, printed on a single level. The double tiered presentation shown in Table 30 has been prepared from the actual results for use in this manual. Printing of the diversion crossflow table is done once for each requested time step and once for the steady state calculations, or it can be suppressed entirely.

Table 31 gives an example of the tables used by COBRA to present the fuel rod heat flux and temperature data. One table is printed for each rod requested in the input and for each requested time step in the analysis including one set for the steady state calculations. The radial fuel nodes which are printed can be selected by the user. The option to suppress the printing of radial fuel nodes entirely is not available unless the printing of the rod temperature and heat flux tables is completely eliminated.

Tables similar to Table 32 are used to present the critical heat flux or critical power summary whenever one of these calculations has been selected. One table is printed for the steady state calculations and at each of the time steps for which printing has been selected.

IV.5 AVAILABILITY OF THE ACTUAL DATA FILES AND CALCULATION RESULTS

As mentioned in the preface to this manual, the actual data files used in the execution of the sample problems and the printed results are available on magnetic tape from the MIT computer code librarian.

TABLE 26: COBRA IIIC/MIT OUTPUT TABLE SHOWING THE LENGTHS AND LOCATIONS OF DATA ARRAYS STORED IN THE CONSOLIDATED DATA ARRAY NAMED "DATA".

```
INDEX     NAME      LENGTH    ORIGIN   TYPE                    INDEX     NAME      LENGTH    ORIGIN   TYPE
-----     ------    ------    ------   ----                    -----     ------    ------    ------   ----
    1     A             10         1      1                       50     LENGTH        13      2468      1
    2     AAA          143      7179      1                       51     LOCA         182      2481      2
    3     AC            10        12      1                       52     LR            78      2663      2
    4     ALPHA         10        22      1                       53     MCHFR         23      2741      1
    5     AN            10        32      1                       54     MCHFRC        23      2764      2
    6     ANSWER        13        42      1                       55     MCHFRR        23      2787      2
    7     B             13        55      1                       56     NTYPE         10      2810      2
    8     CCHANL       299        68      2                       57     NWRAP         10      2820      2
    9     CD            50       367      1                       58     NWRAPS        10      2830      2
   10     CHFR         299       417      1                       59     P            230      2840      1
   11     CON           10       716      1                       60     PERIM         10      3070      1
   12     COND          13       726      1                       61     PH            10      3080      1
   13     CP            10       739      1                       62     PHI           78      3090      1
   14     D             13       749      1                       63     PRINTC        10      3168      2
   15     DC            10       762      1                       64     PRINTR        13      3178      2
   16     DFDX          10       772      1                       65     PRINTN         5      3191      2
   17     DHDX          10       782      1                       66     PW            10      3196      1
   18     DHYD          10       792      1                       67     PWRF         130      3206      1
   19     DHYDN         10       802      1                       68     QC           230      3336      1
   20     DIST          40       812      1                       69     QF           230      3566      1
   21     DPDX          10       852      1    TYPES:             70     QPRIM         10      3796      1
   22     DPK           10       862      1    1=REAL             71     QUAL          10      3806      1
   23     DUR           13       872      1    2=INTEGER          72     RADIAL        13      3816      1
   24     DR            13       885      1    3=LOGICAL          73     RHO          230      3829      1
   25     F            230       898      1                       74     RHOOLD       230      4059      1
   26     FACTOR        13      1128      1                       75     SP           299      4289      1
   27     FDIV          13      1141      3                       76     T             10      4588      1
   28     FINLET        10      1154      1                       77     TDUMY          5      4598      1
   29     FLUX         299      1164      1                       78     TINLET        10      4603      1
   30     FMULT         10      1463      1                       79     TROD        1495      4613      1
   31     FOLD         230      1473      1                       80     U             10      6108      1
   32     FSP           10      1703      1                       81     UH            10      6118      1
   33     FSPLIT        10      1713      1                       82     SAVE          13      6128      1
   34     FXFLOW        65      1723      1                       83     USTAR         13      6141      1
   35     GAP           13      1788      1                       84     V             10      6154      1
   36     GAPN          13      1801      1                       85     VISC          10      6164      1
   37     GAPS          52      1814      1                       86     VISCW         10      6174      1
   38     H            230      1866      1                       87     VP            10      6184      1
   39     HFILM         10      2096      1                       88     VPA           10      6194      1
   40     HINLET        10      2106      1                       89     W            299      6204      1
   41     HOLD         230      2116      1                       90     WOLD         299      6503      1
   42     HPERIM        10      2346      1                       91     WP            13      6802      1
   43     IDAREA        10      2356      2                       92     WSAVE         13      6815      1
   44     IDFUEL        13      2366      2                       93     X             23      6828      1
   45     IDGAP         13      2379      2                       94     XCROSS        78      6851      1
   46     IK            13      2392      2                       95     A             15      6929      1
   47     JBOIL         10      2405      2                       96     B              5      6944      1
   48     JK            13      2415      2                       97     XPOLD        230      6949      1
   49     LC            40      2428      2
```

TABLE 27: COBRA IIIc/MIT OUTPUT TABLE OF CHANNEL EXIT SUMMARY RESULTS

```
MASS BALANCE - -                                       ENERGY BALANCE - -
   MASS FLOW IN      0.54677E+01 LB/SEC                   FLOW ENERGY IN       0.30007E+04 BTU/SEC
   MASS FLOW OUT     0.54677E+01 LB/SEC                   ENERGY ADDED         0.49439E+03 BTU/SEC
   MASS FLOW ERROR  -0.41723E-06 LB/SEC                   FLOW ENERGY OUT      0.55744E+04 BTU/SEC
                                                          ENERGY ERROR         0.20793E+04 BTU/SEC

          CHANNEL ENTHALPY TEMPERATURE DENSITY   EQUIL     VOID     FLOW    MASS FLUX
           (NO.)  (BTU/LB)  (DEG-F)   (LB/FT3) QUALITY FRACTION (LB/SEC) (MLB/HR-FT2)
             1    1075.87    646.17     6.55    0.893    0.981   0.3438     2.0918
             2    1058.34    646.17     6.80    0.852    0.973   0.6977     2.1213
             3    1036.25    646.17     7.15    0.801    0.962   0.3587     2.1823
             4    1018.56    646.17     7.46    0.760    0.953   0.3659     2.2261
             5    1001.56    646.17     7.78    0.721    0.942   0.7427     2.2583
             6    1040.37    646.17     7.08    0.811    0.964   0.3568     2.1709
             7    1016.67    646.17     7.50    0.756    0.951   0.7306     2.2213
             8     997.64    646.17     7.86    0.712    0.940   0.7459     2.2680
             9    1002.00    646.17     7.77    0.722    0.943   0.3732     2.2705
            10     991.23    646.17     7.99    0.697    0.936   0.7524     2.2877
```

TABLE 28:COBRA IIIc/MIT OUTPUT TABLE GIVING BUNDLE AVERAGED RESULTS

```
DISTANCE   DELTA-P    ENTHALPY   TEMPERATURE DENSITY   EQUIL    VOID      FLOW     MASS FLUX
 (IN.)      (PSI)     (BTU/LB)    (DEG-F)  (LB/CU-FT) QUALITY FRACTION  (LB/SEC) (MLB/HR-FT2)
  0.0       71.57      548.80      549.51     45.96    0.000    0.000    5.4677     2.2170
  6.0       67.26      552.47      552.36     42.36    0.000    0.000    5.4677     2.2170
 12.1       66.75      561.58      559.39     37.79    0.000    0.000    5.4677     2.2170
 18.1       66.23      575.98      570.31     33.94    0.000    0.117    5.4677     2.2170
 24.1       64.36      595.38      584.62     30.62    0.000    0.222    5.4677     2.2170
 30.2       63.76      619.08      601.41     27.61    0.000    0.317    5.4677     2.2170
 36.2       63.09      646.73      619.89     24.80    0.000    0.406    5.4677     2.2170
 42.2       59.38      677.82      639.12     22.07    0.000    0.492    5.4677     2.2170
 48.3       58.43      710.96      646.17     19.26    0.049    0.580    5.4677     2.2170
 54.3       57.22      747.12      646.17     16.37    0.132    0.671    5.4677     2.2170
 60.3       55.94      783.33      646.17     14.17    0.216    0.741    5.4677     2.2170
 66.4       49.43      819.45      646.17     12.49    0.300    0.794    5.4677     2.2170
 72.4       48.07      854.70      646.17     11.20    0.381    0.834    5.4677     2.2170
 78.4       46.69      888.21      646.17     10.20    0.459    0.866    5.4677     2.2170
 84.5       38.32      920.52      646.17      9.33    0.534    0.894    5.4677     2.2170
 90.5       37.01      948.96      646.17      8.76    0.599    0.912    5.4677     2.2170
 96.5       35.71      972.75      646.17      8.31    0.654    0.926    5.4677     2.2170
102.6       34.47      992.05      646.17      7.96    0.699    0.937    5.4677     2.2170
108.6       24.97     1006.14      646.17      7.71    0.732    0.945    5.4677     2.2170
114.6       23.88     1015.56      646.17      7.54    0.753    0.950    5.4677     2.2170
120.7       22.89     1019.14      646.17      7.46    0.762    0.952    5.4677     2.2170
126.7        0.00     1019.52      646.17      7.46    0.763    0.953    5.4677     2.2170
```

TABLE 29: COBRA IIIc/MIT OUTPUT TABLE GIVING INDIVIDUAL CHANNEL RESULTS

TIME = 0.00000 SECONDS DATA FOR CHANNEL 3

DISTANCE (IN.)	DELTA-P (PSI)	ENTHALPY (BTU/LB)	TEMPERATURE (DEG-F)	DENSITY (LB/CU-FT)	EQUIL QUALITY	VOID FRACTION	FLOW (LB/SEC)	MASS FLUX (MLB/HR-FT2)
0.0	71.56	548.80	549.51	45.96	0.000	0.000	0.3644	2.2170
6.0	67.26	554.34	553.81	40.66	0.000	0.000	0.3560	2.1663
12.1	66.75	566.71	563.32	34.25	0.000	0.107	0.3422	2.0822
18.1	66.23	585.48	577.38	29.12	0.000	0.269	0.3308	2.0129
24.1	64.36	609.93	595.02	25.02	0.000	0.399	0.3254	1.9797
30.2	63.76	638.91	614.78	21.38	0.000	0.513	0.3148	1.9151
36.2	63.09	672.38	635.88	18.05	0.000	0.619	0.3031	1.8444
42.2	59.38	709.49	646.17	15.02	0.045	0.714	0.2976	1.8106
48.3	58.43	748.81	646.17	12.73	0.136	0.786	0.2923	1.7783
54.3	57.22	787.84	646.17	11.27	0.227	0.832	0.3031	1.8442
60.3	55.94	828.90	646.17	10.10	0.322	0.869	0.3110	1.8924
66.4	49.43	865.75	646.17	9.27	0.407	0.895	0.3178	1.9335
72.4	48.07	901.45	646.17	8.65	0.489	0.915	0.3265	1.9865
78.4	46.69	933.98	646.17	8.17	0.565	0.930	0.3345	2.0352
84.5	38.32	965.49	646.17	7.67	0.638	0.946	0.3352	2.0392
90.5	37.01	991.55	646.17	7.46	0.698	0.952	0.3438	2.0921
96.5	35.71	1011.19	646.17	7.30	0.743	0.957	0.3513	2.1377
102.6	34.47	1026.18	646.17	7.18	0.778	0.961	0.3572	2.1733
108.6	24.97	1036.00	646.17	7.11	0.801	0.964	0.3552	2.1614
114.6	23.88	1041.37	646.17	7.06	0.813	0.965	0.3590	2.1841
120.7	22.89	1039.49	646.17	7.06	0.809	0.965	0.3613	2.1981
126.7	0.00	1036.25	646.17	7.15	0.801	0.962	0.3587	2.1823

TABLE 30: COBRA IIIc/MIT OUTPUT TABLE GIVING THE DIVERSION CROSSFLOWS BETWEEN ADJACENT CHANNELS, W(I,J), (LB/SEC-FT).

X	W(1, 2)	W(2, 3)	W(3, 4)	W(4, 5)	W(2, 6)	W(3, 7)	W(4, 7)
0.0	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
6.0	0.01659	0.00164	0.00666	0.01832	-0.00165	0.01159	0.00492
12.1	0.02807	0.00376	0.01174	0.03102	-0.00169	0.01971	0.00795
18.1	0.02303	0.00355	0.01002	0.02566	-0.00094	0.01660	0.00658
24.1	0.01421	0.00542	0.00694	0.01505	0.00234	0.00967	0.00275
30.2	0.02429	0.01179	0.01389	0.02745	0.00605	0.01954	0.00527
36.2	0.03101	0.01746	0.01844	0.03141	0.01083	0.02286	0.00376
42.2	0.01717	0.01247	0.01079	0.01918	0.00760	0.01322	0.00226
48.3	0.01172	0.06360	0.04017	0.05155	0.04563	0.03454	-0.00856
54.3	-0.01203	0.01013	-0.00204	-0.01666	0.01032	-0.00914	-0.00549
60.3	-0.01367	0.00350	-0.00302	-0.01991	0.00472	-0.00916	-0.00470
66.4	-0.01008	-0.00847	-0.00973	-0.01803	-0.00478	-0.01224	-0.00076
72.4	-0.01280	-0.00062	-0.00652	-0.02076	0.00199	-0.01160	-0.00384
78.4	-0.01283	-0.00307	-0.00720	-0.02059	0.00003	-0.01202	-0.00374
84.5	-0.00282	-0.00683	-0.00421	-0.00539	-0.00475	-0.00405	0.00101
90.5	-0.01486	-0.00537	-0.00900	-0.02226	-0.00105	-0.01381	-0.00399
96.5	-0.01415	-0.00718	-0.00922	-0.02155	-0.00310	-0.01308	-0.00321
102.6	-0.01213	-0.00923	-0.00947	-0.01803	-0.00537	-0.01167	-0.00165
108.6	0.00096	-0.00450	-0.00099	0.00173	-0.00352	0.00024	0.00155
114.6	-0.01101	-0.01210	-0.00931	-0.01436	-0.00758	-0.01033	-0.00068
120.7	-0.00414	-0.00921	-0.00661	-0.01134	-0.00582	-0.00736	-0.00049
126.7	-0.00120	-0.00192	0.00068	0.00687	-0.00218	0.00255	0.00208

X	W(5, 8)	W(6, 7)	W(7, 8)	W(7, 9)	W(8,10)	W(9,10)
0.0	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
6.0	0.00172	0.01494	0.01532	-0.00050	0.00050	0.01609
12.1	0.00294	0.02539	0.02668	-0.00012	0.00097	0.02699
18.1	0.00230	0.02142	0.02227	0.00035	0.00128	0.02216
24.1	0.00160	0.01311	0.01478	0.00286	0.00148	0.01235
30.2	0.00336	0.02582	0.02746	0.00571	0.00253	0.02200
36.2	0.00147	0.03032	0.03203	0.01005	0.00622	0.02480
42.2	0.00364	0.01900	0.02285	0.00913	0.00343	0.01426
48.3	0.00238	0.05444	0.07094	0.03732	0.01857	0.04171
54.3	0.00874	-0.00812	-0.00396	0.01206	0.00276	-0.01335
60.3	-0.00157	-0.00941	-0.01839	0.00329	0.00188	-0.01834
66.4	-0.00277	-0.01525	-0.02160	-0.00446	-0.00196	-0.01714
72.4	-0.00174	-0.01362	-0.01996	0.00135	0.00125	-0.01891
78.4	-0.00159	-0.01468	-0.01959	0.00035	0.00031	-0.01856
84.5	-0.00137	-0.00569	-0.00812	-0.00513	-0.00156	-0.00392
90.5	-0.00179	-0.01788	-0.02085	-0.00049	-0.00028	-0.01994
96.5	-0.00205	-0.01700	-0.02110	-0.00299	-0.00118	-0.01861
102.6	-0.00227	-0.01543	-0.01917	-0.00522	-0.00181	-0.01517
108.6	-0.00051	-0.00053	-0.00031	-0.00420	-0.00180	0.00227
114.6	-0.00215	-0.01478	-0.01600	-0.00718	-0.00281	-0.01141
120.7	-0.00194	-0.01068	-0.01289	-0.00639	-0.00262	-0.00897
126.7	0.00038	0.00296	0.00522	-0.00281	-0.00115	0.00700

TABLE 31:COBRA IIIc/MIT OUTPUT TABLE GIVING FUEL ROD THERMAL RESULTS RESULTS

```
TIME =  0.00000 SECONDS     TEMPERATURE DATA FOR ROD  3,  FUEL TYPE 1

   DISTANCE   FLUX       DNBR  CHANNEL                 TEMPERATURE(F)
    (IN.)   (MBTU/HR-FT2)                       T( 1)     T( 2)     T( 3)     T( 4)     T( 5)
      0.0   0.0000      0.000   0                 0.0       0.0       0.0       0.0       0.0
      6.0   0.0336      0.000   0               777.3     757.4     697.8     598.5     557.1
     12.1   0.0834      0.000   0              1132.5    1083.1     935.0     688.1     585.4
     18.1   0.1312      0.000   0              1443.0    1365.3    1132.2     743.8     582.2
     24.1   0.1760      7.034   3              1746.1    1641.9    1329.3     808.3     591.5
     30.2   0.2167      4.896   3              2027.4    1899.0    1514.1     872.5     605.5
     36.2   0.2521      3.421   3              2276.1    2126.8    1679.0     932.6     622.0
     42.2   0.2814      2.348   3              2486.2    2319.6    1819.8     986.7     640.0
     48.3   0.3043      1.499   3              2645.0    2464.9    1924.5    1023.7     648.9
     54.3   0.3198      0.785   3              2746.7    2557.4    1989.5    1042.8     648.9
     60.3   0.3280      0.000   0              2800.7    2606.5    2023.9    1053.0     648.9
     66.4   0.3281      0.000   0              2801.2    2606.9    2024.2    1053.0     648.9
     72.4   0.3199      0.000   0              2747.7    2558.3    1990.0    1042.9     648.8
     78.4   0.3045      0.000   0              2646.0    2465.7    1925.0    1023.8     648.7
     84.5   0.2964      0.000   0              2593.2    2417.7    1891.3    1013.9     648.7
     90.5   0.2553      0.000   0              2323.4    2172.2    1718.7     962.9     648.4
     96.5   0.2166      0.000   0              2069.3    1941.0    1556.3     915.0     648.2
    102.6   0.1761      0.000   0              1803.1    1698.9    1386.1     864.9     647.9
    108.6   0.1312      0.000   0              1508.6    1430.9    1197.8     809.3     647.6
    114.6   0.0833      0.000   0              1193.6    1144.3     996.4     749.9     647.2
    120.7   0.0335      0.000   0               866.4     846.6     787.1     688.0     646.7
    126.7   0.0052      0.000   0               680.1     677.1     667.9     652.7     646.3
```

TABLE 32 COBRA IIIc/MIT OUTPUT TABLE
SUMMARIZING THE CHF RESULTS

```
TIME =  0.00000 SECONDS

     W-3   CRITICAL HEAT  FLUX SUMMARY
DISTANCE    FLUX    MDNBR       ROD    CHANNEL
     0.0   0.000    0.000         0        0
     6.0   0.000    0.000         0        0
    12.1   0.000    0.000         0        0
    18.1   0.236    6.527        13        7
    24.1   0.317    4.425        13        7
    30.2   0.390    3.314        13        7
    36.2   0.454    2.461        13        7
    42.2   0.507    1.787        13        7
    48.3   0.548    1.235        13        7
    54.3   0.256    0.449         1        1
    60.3   0.000    0.000         0        0
    66.4   0.000    0.000         0        0
    72.4   0.000    0.000         0        0
    78.4   0.000    0.000         0        0
    84.5   0.000    0.000         0        0
    90.5   0.000    0.000         0        0
    96.5   0.000    0.000         0        0
   102.6   0.000    0.000         0        0
   108.6   0.000    0.000         0        0
   114.6   0.000    0.000         0        0
   120.7   0.000    0.000         0        0
   126.7   0.000    0.000         0        0
```

REFERENCES

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APPENDIX A
(taken from Reference 2)
DERIVATION OF EQUATIONS FOR FLUID TRANSPORT MODEL

The equations of continuity, energy and momentum for each subchannel are derived by applying the conservation equations to a control volume that consists of a segment of Subchannel (i) connected to an arbitrary Subchannel (j). The primary assumptions given in the description of the mathematical model are used together with a few additional assumptions that are required to formulate complete equations.

A.1 Continuity Equation

Apply the continuity equation for the control volume shown in Figure A-1 to Subchannel (i) which is adjacent to Subchannel (j).

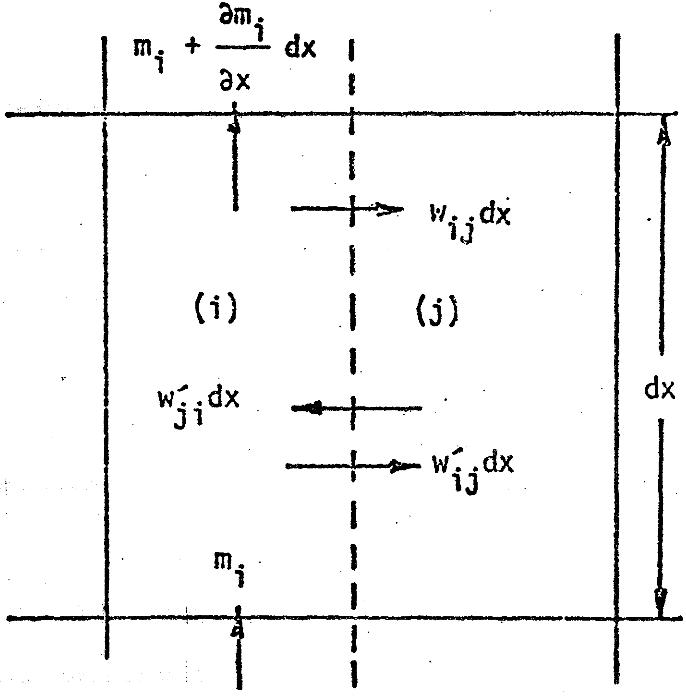


FIGURE A-1: Control Volume for the Continuity Equation

$$\frac{\partial}{\partial t} \rho_i A_i dx - m_i + m_i + \frac{\partial m_i}{\partial x} dx - w'_{ji} dx + w'_{ij} dx + w_{ij} dx = 0. \tag{A.1}$$

By assuming $w'_{ij} = w'_{ji}$ and $\partial A/\partial t = 0$

$$A_i \frac{\partial \rho_i}{\partial t} + \frac{\partial m_i}{\partial x} = -w_{ij} \tag{A.2}$$

By considering all adjacent subchannels and taking w_{ij} to be positive for flow from i to j, Equation (A.2) can be written as

$$A_i \frac{\partial \rho_i}{\partial t} + \frac{\partial m_i}{\partial x} = -\sum_{j=1}^{N} w_{ij} \; ; \; i = 1,2,3,\text{---}N. \tag{A.3}$$

A.2 Energy Equation

Apply the energy equation for the control volume shown in figure A-2 to Subchannel (i) which is adjacent to Subchannel (j).

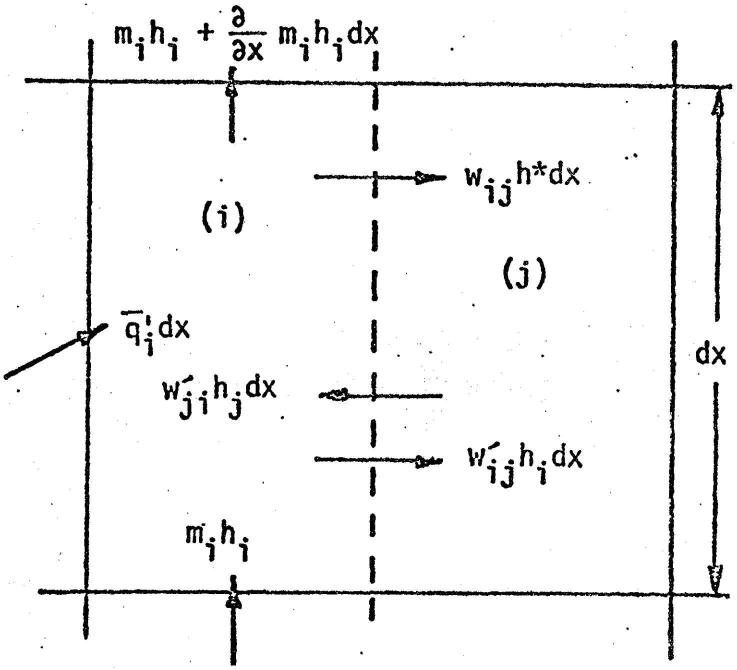


FIGURE A-2: Control Volume for the Energy Equation

$$\frac{\partial}{\partial t} \rho_i'' u_i A_i h_i dx - m_i h_i + m_i h_i + \frac{\partial}{\partial x} m_i h_i dx - \bar{q}_i' dx$$

$$- w_{ji}' h_j dx + w_{ij}' h_i dx + w_{ij} h^* dx = 0 \tag{A.4}$$

The internal energy is defined by the relationship

$$\rho_i'' u_i = \rho_i'' h_i - \rho_i \tag{A.5}$$

By assuming $\partial A/\partial t = 0$ and using Equation (A.5), this reduces to

$$A_i \frac{\partial}{\partial t} \rho_i'' h_i + \frac{\partial}{\partial x} m_i h_i = \bar{q}_i' + (h_j - h_i) w_{ij}' - w_{ij} h^* + A_i \frac{\partial p_i}{\partial t} \qquad (A.6)$$

where h* is the enthalpy carried by the diversion crossflow and ρ''_i is the effective density for heat capacity (Ref. 18). By using the function Ψ as presented by Tong, pg. 208, Equation (A.2) and neglecting $\partial p_i/\partial t$ this may be reduced to

$$A_i \left[\rho_i - h_{fg} \frac{\partial \Psi}{\partial h}\right] \frac{\partial h_i}{\partial t} + m_i \frac{\partial h_i}{\partial x} = \bar{q}_i' - (h_i - h_j)\, w_{ij} + (h_i - h^*)\, w_{ij}' \qquad (A.7)$$

By neglecting $\partial p_i/\partial t$, sonic velocity propagation is omitted from this mathematical model.

The heat transfer term $\bar{q}_i$ may be divided into two terms. The first is the heat transfer rate from the fuel surface q_i'. For steady state this term can be specified quite easily; however, for transients it depends upon the fluid temperature, fuel surface temperature and surface heat transfer coefficient. The transient heat transfer effect on the fuel is calculated using the fuel rod models presented in section II. As an alternate, the value of q_i' is specified as a function of time. The second term of q_i' is the thermal conduction between adjacent subchannels. It is assumed to be proportional to the subchannel temperature difference and constant of proportionality is assumed to depend upon the subchannel geometry and fluid thermal conductivity.

By considering the thermal conduction term and all the adjacent subchannels, the energy equation can be written as

$$\frac{1}{u_i''} \frac{\partial h_i}{\partial t} + \frac{\partial h_i}{\partial x} = \frac{q_i'}{m_i} - \sum_{j=1}^{N} (t_i - t_j) \frac{c_{ij}}{m_i} - \sum_{j=1}^{N} (h_i - h_j) \frac{w_{ij}'}{m_i} + \sum_{j=1}^{N} (h_i - h^*) \frac{w_{ij}}{m_i} \qquad (A.8)$$

where an effective enthalpy transport velocity may be defined as

$$u_i'' = \frac{m}{A(\rho - h_{fg}\frac{\partial\Psi}{\partial h})} \qquad \text{(A.9)}$$

For homogeneous two-phase flow or for single-phase flow, the quantity in brackets reduces 1 and $u_i'' = u_i$.

A.3 Axial Momentum Equation

Apply the momentum equation for the control volume shown n Figure A-3 to Subchannel (i) which is adjacent to Subchannel (j)

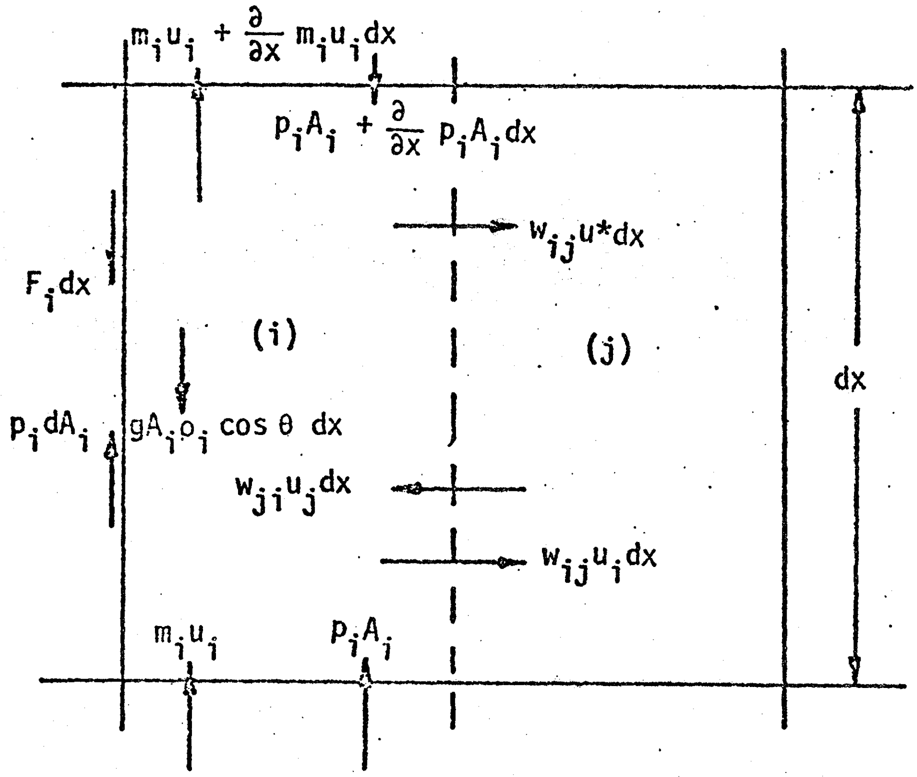


FIGURE A-3: Control Volume for the Axial Momentum Equation

$$\begin{aligned} - F_i dx + p_i dA_i - gA_i\rho_i \cos\theta\, dx + p_iA_i - p_iA_i - \frac{\partial}{\partial x} p_iA_i dx &= \\ \frac{\partial}{\partial t} m_i dx - m_iu_i + m_iu_i + \frac{\partial}{\partial x} m_iu_i dx & \\ - w'_{ji}u_j dx + w'_{ij}u_i dx + w_{ij}u^* dx \ . & \end{aligned} \qquad \text{(A.10)}$$

Since $w'_{ij} = w'_{ji}$, this reduces to

$$-F_i - gA_i\rho_i\cos\theta - A_i\frac{\partial p_i}{\partial x} = \frac{\partial m_i}{\partial t} + \frac{\partial}{\partial x} m_i u_i + (u_i-u_j)w'_{ij} + u^* w_{ij} \tag{A.11}$$

By using the equations

$$u_i = \frac{m_i v'_i}{A_i}\ ; \qquad F_i = \left[\frac{A_i v_i f_i \phi_i}{2D_i} + \frac{A_i K_i v'_i}{2\Delta x}\right]\left(\frac{m_i}{A_i}\right)^2 \tag{A.12,1}$$

and Equation (A.2); Equation (A.11) may be written as

$$\frac{\partial m_i}{\partial t} - 2u_i\frac{\partial}{\partial t}\rho_i A_i + A_i\frac{\partial p_i}{\partial x} = -A_i\left(\frac{m_i}{A_i}\right)^2\left[\frac{v_i f_i \phi_i}{2D_i} + \frac{K_i v'_i}{2\Delta x} + A_i\frac{\partial}{\partial x}\left(\frac{v'_i}{A_i}\right)\right] - gA_i\rho_i\cos\theta - (u_i-u_j)w'_{ij} + (2u_i-u^*)w_{ij} \tag{A.14}$$

By considering all adjacent subchannels and assuming $\partial A/\partial t = 0$, this can be written as

$$\frac{1}{A_i}\frac{\partial}{\partial t}m_i - 2u_i\frac{\partial \rho_i}{\partial t} + \frac{\partial p_i}{\partial x} = -\left(\frac{m_i}{A_i}\right)^2\left[\frac{v_i f_i \phi_i}{2D_i} + \frac{K_i v'_i}{2\Delta x} + A_i\frac{\partial}{\partial x}\left(\frac{v'_i}{A_i}\right)\right] - g\rho_i\cos\theta - f_T\sum_{j=1}^{N}(u_i-u_j)\frac{w'_{ij}}{A_i} + \sum_{j=1}^{N}(2u_i-u^*)\frac{w_{ij}}{A_i}\ . \tag{A.15}$$

The factor f_T is included to help account for the imperfect analogy between the eddy diffusivity of heat and momentum.

Transverse Momentum Equation

Consider a rectangular control volume placed in the gap between two subchannels as shown in figure A-4. Assume that the difference between crossflow momentum flux entering and leaving

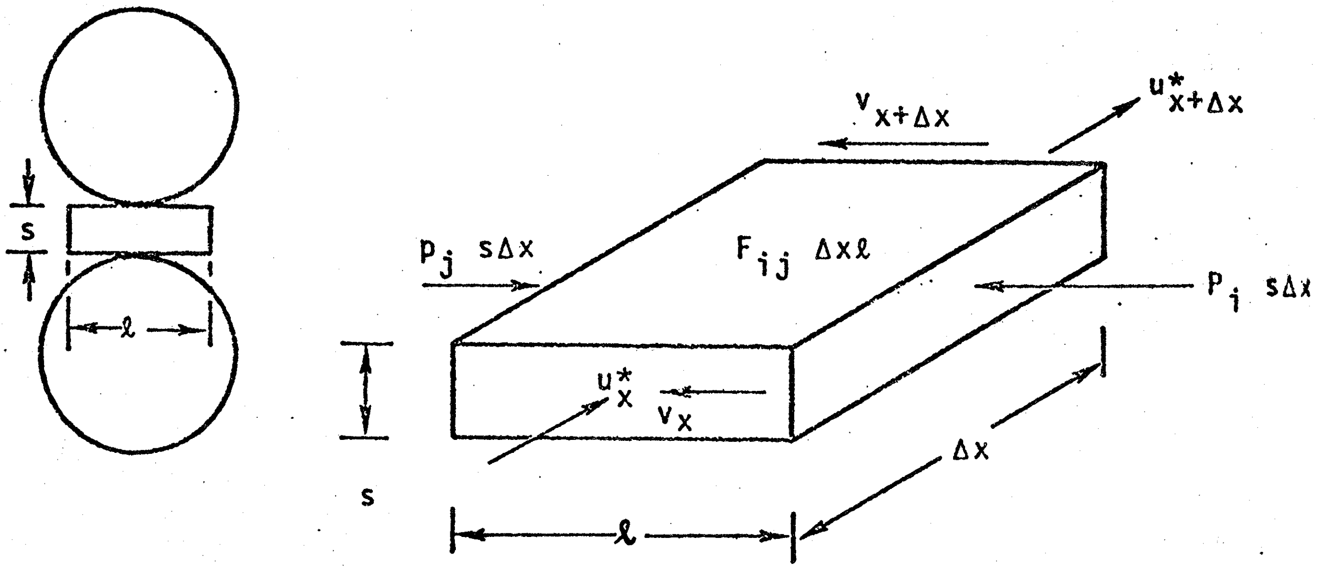


FIGURE A-4: Control Volume for the Transverse Momentum Equation

the control volume through the transverse surfaces is negligibly small. Applying the conservation of momentum equation to this control volume in the transverse direction gives

$$-F_{ij}\ \Delta x\ell\ - p_j s\Delta x + p_i s\Delta x = \frac{\partial \rho^*}{\partial t}\ s\ell\Delta x v - (\rho^* s\ell u^* v)_x + (\rho^* s\ell u^* v)_{x+\Delta x}. \tag{A.16}$$

By rearranging this equation and taking the limit at Δx → 0, the following equation is obtained

$$\frac{\partial w_{ij}}{\partial t} + \frac{\partial (u^* w_{ij})}{\partial x} = \frac{s}{\ell}(p_i - p_j) - F_{ij} \tag{A.17}$$

where $w_{ij} = \rho^* s v$. F_{ij} represents the friction and form pressure loss due to crossflow. For steady flow let

$$p_i - p_j = K\frac{\rho^* v^2}{2} \tag{A.18}$$

Therefore,

$$F = \frac{K|w|w}{2s^2\rho^*}\ \left(\frac{s}{\ell}\right) \tag{A.19}$$

To put this in the form used previously in COBRA IIIc, let

$$F = Cw\ (s/l) \tag{A.20}$$

where $C = K|w|/2s^2\rho^*$ and ρ^* is the density of the diversion crossflow. Presently ρ^* is assumed to be the density of the doner dnor subchannel defined by

$$\rho^* = \begin{Bmatrix} \rho_i & ; w_{ij} > 0 \\ \rho_j & ; w_{ij} < 0 \end{Bmatrix} \tag{A.21}$$

The loss coefficient K_{ij} consists of both the friction and the form loss components of the transverse pressure drop. The K_{ij} replaces the factor fl in the earlier versions of COBRA. The relationship between them is given by

$$K_{ij} = \frac{f\ell}{2s_{ij}} \tag{A.22}$$

In the present version of COBRA IIIc/MIT the quantity K_{ij} is input as the constant crossflow resistance factor K. Other forms of these equations can be used by changing the function subprogram CIJ.

APPENDIX B
SUMMARY OF PRE-CHF CORRELATIONS USED IN OLD AND NEW HEAT TRANSFER MODELS

The pre-CHF heat transfer correlations used in the old and new models are summarized in Tables B.1 and B.2. Table B.1 lists the correlations used. Table B.2 gives references, equations and range of data base for each correlation.

Table B.1

Pre-CHF Correlations Used in the Old and New Heat Transfer Models

Correlation Used and Selection Criterion		
Regime	New Model	Old Model
Forced Convection to single phase liquid	Sieder Tate Forced convection $x < 99\%$ $T \; < T$	Thom modified Dittus-Boelter $x < 0$ (Levy model not used) $x < x$ (Levy model used)
Natural convection to single phase liquid	McAdams Natural convection $x < 99\%$ $T \; < T$	Not considered
Local boiling or bulk boiling	Chen $x < 99\%$ $T \; < T \; < T$	Thom modified Jens-Lottes $x > 0$ (Levy model not used) $x > x$ (Levy model used)

*See list of nomenclature on page B-5.

TABLE B.2

Summary of Pre-CHF Correlations
Used in New and Old Heat Transfer Models

Correlation	Equation	Range of Data Base
Sieder Tate (Ref. 38)	$h = 0.023\frac{k}{D}Re^{0.8}Pr^{0.33}(\mu/\mu_w)^{0.14}$ Fluid properties at bulk fluid temperature, except μ_w at T_w $Re = \frac{GD}{\mu} \qquad Pr = \frac{\mu C_p}{k}$	Flow of water through tubes $10^2 < Re < 10^5$
McAdams (Ref. 39)	$h = 0.13k[Gr \cdot Pr]^{0.33}$ Fluid properties should be at fluid film temperature $G_r = \frac{\rho^2 g\beta(T_w - T)}{\mu^2}$	$10^9 < Gr \cdot Pr < 10^{12}$
Chen (Ref. 40) Note: This eqn. is in SI units. All other eqns. in Table are in English units.	$q'' = h_{FC}(T_w - T_f) + h_{NB}(T_w - T_s)$ $h_{FC} = 0.023\frac{k_f}{D}Re_f^{0.8}Pr_f^{0.4}F$ $\left\{ h_{NB} = 0.00122S \ \frac{k_f C_{p_f}}{\sigma}\ {}^{0.5} Pr_f^{-0.29} \right.$ $* \ \rho_f^{0.25}(P_w - P)^{0.75}$ $* \ \left[\frac{C_{p_f}(T_w - T_s)\rho_f}{h_{fg}\rho_g}\right]^{0.24}$	Based on upflow and downflow through heated tubes and annuli. Originally developed for bulk boiling and two phase forced convective regimes. Extension to subcooled boiling regimes has produced satisfactory results (Ref.48) P - 505 psia $V_{f,in}$ 0.2 - 14.8 ft/sec x 0 - 71% q'' .03 - 0.76 $\frac{MBTU}{hr\text{-}ft^2}$

TABLE B.2 (cont.)

Correlation	Equation	Range of Data Base
Chen (cont.)	$F = \begin{cases} 1 \text{ for } X_{tt}^{-1} \le 0.1 \\ 2.35(X_{tt}^{-1} + 0.213)^{0.736} \\ \quad \text{for } X_{tt}^{-1} > 0.1 \end{cases}$ $X_{tt}^{-1} = [x/(1 - x)]^{0.9}(\rho_f/\rho_g^{0.5}$ $\quad * (\mu_g/\mu_f)^{0.1}$ $S = \begin{cases} [1 + 0.23Re_{TP}^{1.14}]^{-1.0} \\ \quad \text{for } Re_{TP} < 32.5 \\ [1 + 0.42Re_{TP}^{0.78}]^{-1.0} \\ \text{for } 32.5 \le Re_{TP} \le 70 \\ 0.1 \text{ for } Re_{TP} > 70 \end{cases}$ $Re_{TP} = 10^{-4}F^{1.25}(1 - \alpha)(Re)_f$	
Thom modified Dittus-Boelter and Jens-Lottes (Ref. 41)	$h = 0.134\frac{k}{D}Re^{0.65}Pr^{0.4}$ for forced convection to liquid $T_w = T_{sat} + \frac{0.072(q'')^{0.5}}{e^{p/1260}}$ $h = \frac{T_w - T_b}{q''}$ for local boiling	Based on upflow through heated tubes and annuli. Developed as a forced convective and subcooled boiling correlation. $P = 750$ to 2000 psia $V_{f,in} = 5$ to 20 ft/sec

NOMENCLATURE FOR TABLES B.1 AND B.2

Symbols

C_p	heat capacity	BTU/lbm°F
D	diameter	ft
g	gravitational acceleration	ft/hr^2
G	mass flow rate	lbm/ft^2hr
Gr	Grashof number $(\frac{\rho^2 g\beta[T_w - T]}{\mu^2})$	-
h	heat transfer coefficient	$BTU/hr\ ft^2{}^\circ F$
h_{fg}	latent heat of vaporization	BTU/lbm
k	thermal conductivity	BTU/hr ft°F
P	pressure	psia
Pr	Prandtl number ($= \mu c_p/k$)	-
q"	heat flux	$BTU/hr\ ft^2$
Re	Reynolds number ($= GD_h/\mu$)	-
T	temperature	°F
V	velocity	ft/sec
x	quality	-
x_d	quality at which bubble departure starts according to Levy model	-
x_{tt}	Martinelli parameter	-
α	void fraction	-
β	thermal expansion coefficient	$^\circ F^{-1}$
μ	viscosity	lbm/ft hr
ρ	density	lbm/ft^3
σ	surface tension	lbf/ft

Subscripts

b	bulk fluid
f	liquid phase
s	saturation
g	vapor phase
w	wall
FC	forced convection
in	inlet
MSFB	minimum stable film boiling
NB	nucleate boiling
TP	two phase

APPENDIX C
SUMMARY OF CORRELATIONS PROVIDED FOR CALCULATION OF DNBR, CHFR AND CPR

The correlations now provided in COBRA IIIc/MIT-2 for calculation of DNBR, CHFR and CPR are summarized in Tables C.1 and C.2. Table C.1 lists the correlations provided. Table C.2 gives references, equations and range of data base for each correlation.

Table C.1
Correlations Provided for Calculation of DNBR, CHFR and CPR

Option Indicator (NCHF)	Correlation	Quantity Calculated		
		DNBR	CHFR	CPR
1	B&W-2	XXXX		
2	W-3	XXXX		
3	Hench-Levy		XXXX	
4	CISE-4			XXXX
5	Biasi/Void-CHF		XXXX	

Notes:

1. The new heat transfer model requires a CHF calculation in order to consider post-CHF heat transfer. Any of the correlations listed above can be used for this calculation. (Ref. discussion in Section II.B.1)

2. The W-3 correlation requires calculation of the start of local boiling. When the old heat transfer model is being used, the Thom modified Jens-Lottes correlation is used (Ref. Table B.2 of Appendix B). When the new heat transfer model is being used, the start of local boiling is determined by $T_w > T_s$.

TABLE C.2

Summary of Correlations Provided for
Calculation of DNBR, CHFR and CPR*

CORRELATION	EQUATION	RANGE OF DATA BASE
B&W-2 (Ref. 42)	$\frac{q''CHF,EU}{10^6}$ $= \{(1.155 - 0.407D_e)[0.37 * 10^8$ $*(0.591G/10^6)^{[0.83+0.6859p/10^3-2)]}$ $-0.1521GX_{CHF}H_{fg}]\}/ 12.71$ $*(3.054G/10^6)^{[0.712+0.2073(p/10^3-2)]}\}$ δ where $q''_{CHF,EU}$ is in BTU $hr^{-1} ft^{-2}$	p = 2000 to 2400 psia $G = 0.75 * 10^6$ to $4.0 *$ Mlb/hr-ft^2 D_e = 0.2 to 0.5 in. X_{exit} = -0.03 to 0.20 L = 72 in. Geometry = rod bundles 72 in. long having 15 in. grid span
(Ref. 27)	$F_c = \frac{q''_{CHF,EU}}{q''_{CHF,NU}}$ $= \frac{1.025C\int_0^{\ell} CHFq''(z)\exp[-C(\ell_{CHF} - z)]dZ}{q''_{loc} * [1 - \exp(-C(\ell_{CHF,EU})]}$ where ℓ is measured from the channel inlet $C = \frac{0.249(1 - X_{CHF})^{7.82}}{(G/10^6)^{0.457}}$	p = 2000 to 2400 psia $G = 1 * 10^6$ to $3.5 *$ Mlb/hr-ft^2 D_e = 0.2 to 0.5 in. X_{exit} = 0.02 to 0.25

*See list of nomenclature on page

TABLE C.2 (cont.)

CORRELATION	EQUATION	RANGE OF DATA BASE
W-3 (Ref. 43)	$\frac{q''_{crit,EU}}{10^6} = \{(2.02 - 0.0004302p)$ $+ (0.1722 - 0.0000984p)$ $* \exp[(18.177 - 0.004129p)X]\}$ $* [(0.1484 - 1.596X$ $+ 0.1729X\vert X\vert)(G/10^6) + 1.037$ $* (1.157 - 0.869X)[0.2664$ $+ 0.8357\exp(-3.151D_e)][0.8258$ $+ 0.000794(H_{sat} - H_{in})]$ where $q''_{CHF,EU}$ is in BTU $hr^{-1}ft^{-2}$	p = 1000 to 2300 psia G = 1.0 * 10^6 to 5.0 * Mlb/hr-ft^2 D_e = 0.2 to 0.7 X_{loc} = -0.25 to +0.15 L = 10 to 144 in. $\frac{\text{Heated Perimeter}}{\text{Wetted Perimeter}}$ = 0.88 to 1.00 Geometries = circular tube, rectangular channel, and bare rod-bundle
(Ref. 44)	Non-uniform flux shape factor: $F_c = \frac{q''_{DNB,EU}}{q''_{CHF,NU}} = \frac{C}{q''_{crit,NU}(1 - e^{-C\ell_{crit}})}$ $* \int_0^{\ell_{crit}} q''(z)e^{-C(\ell_{crit}-z)}dz$ where ℓ is measured from start of local boiling. $C = 0.15 \frac{(1 - X_{crit})^{4.31}}{(G/10^6)^{0.478}}$ in.$^{-1}$	p = 1000 to 2300 psia G = 1.0 to 10^6 to 3.0 Mlb/hr-ft^2 D_e = 0.2 to 0.7 in. $X_{exit} \leq 0.15$ L = 10 to 144 in.

TABLE C.2 (cont.)

CORRELATION	EQUATION	RANGE OF DATA BASE
W-3 (cont.) (Ref. 45)	Spacer-grid effect $F_S = \frac{q''_{crit,\ spacer}}{q''_{crit,bare\ rod\ bundle}}$ $F_S = 1.0 + 0.03(\frac{G}{10^6})(\frac{TDC}{0.019})^{0.35}$ where TDC is thermal diffusion coefficient denoting the mixing caused by the spacer. Further, TDC = $\varepsilon/(Va)$, where ε is the eddy diffusivity, V is the axial velocity, and a is the gap between two adjacent fuel rods.	rod bundles 8 to 14 ft. long
(Ref. 46)	$\frac{CHF_{cold\ wall}}{CHF_{W-3,D_h}} = 1.0 - Ru \Big[13.76$ $- 1.372e^{1.78X} - 4.732$ $* (\frac{G}{10^6})^{-0.0535} - 0.0619$ $* (\frac{P}{10^3})^{0.14} - 8.509 D_h^{0.107} \Big]$ where, $Ru = 1 - (D_e/D_h)$ and D_e and D_h are the equivalent diameters based on wetted and heated perimeters, respectively. Also if cold wall is present use D_h in place of D_e in calculation of $q''_{CHF,EU}$.	$X_{DNB} \leq 0.10$ $1.0 \leq G/Mlb/ft\text{-}hr^2 \leq 5.0$ $L \geq 10$ in. Gap ≥ 0.10 in.

TABLE C.2 (cont.)

CORRELATION	EQUATION	RANGE OF DATA BASE
Hench-Levy (Ref. 35	$(q''_c/10^6) = F_p \frac{BTU}{hr\text{-}ft^2}$ for $(\langle x_e \rangle) \leq 0.273 - 0.212TANH^2(3G/10^6)$ $(q''_c/10^6) = F_p[1.9 - 3.3 \langle x_e \rangle - 0.7\ TANH^2 *(3G/10^6)]$, BTU $hr^{-1} ft^{-2}$ for $0.273 - 0.212\ TANH^2\ (3G/10^6) \leq (\langle x_e \rangle) \leq 0.5 - 0.269\ TANH^2\ (3G/10^6) + 0.0346 * TANH^2\ (\frac{2G}{10^6})$ $(q''_c/10^6) = F_p[0.6 - 0.7 \langle x_e \rangle - 0.09 * TANH^2\ (2G/10^6)]$, BTU $hr^{-1} ft^{-2}$ for $(\langle x_e \rangle) \geq 0.5 - 0.269\ TANH^2\ (3G/10^6) + 0.0346\ TANH\ (\frac{2G}{10^6})$ where $F_p = [1.1 - 0.1(\frac{P - 600}{400})^{1.25}]$	$P = 600$ to 1450 $G = 0.2 * 10^6$ to $1.6 *$ Mlb/hr-ft^2 $D_e = 0.324$ to 0.485 rod to rod and rod to wall spacings greater than 0.060 in.
CISE-4 (Ref. 47)	$\langle x_e \rangle_c = \frac{D_h}{D_e} [a \frac{L_{B_c}}{L_{B_c} + b}]$	$P = 720$ to 1000 psia $G = 0.8$ to $3.0 \times$ Mlb/hr-ft^2 $L = 30$ to 144 in. Rod O.D. = 0.40 to 0.78 No. rods = 7 to 37

TABLE C.2 (cont.)

CORRELATION	EQUATION	RANGE OF DATA BASE
CISE-4 (cont.)	where $a = \frac{1}{1 + 0.20(1 - P/P_{CR})^{-3}a/10^6}$ for $G < G*$ and $a = \frac{1 - P/P_{CR}}{(1.35G/10^6)^{1/3}}$ for $G > G*$ where $G* = 2.5 * 10^6(1 - P/P_{CR})^3$ and $b = 168(P_{CR}/P - 1)^{0.4}G/10^6{D_e}^{1.4}$	
Biasi/Void-CHF (Ref. 48)	For $\lvert G \rvert \geq 10^6$ lb $hr^{-1}ft^{-2}$ use the highest of the values of q''_{CHF} given by the following equations: 1) $q''_{CHF} = 2.633(10^7)(30.48D)^{-n}G^{-1/6}$ $* [4.412F(p)G^{-1/6} - x]$ 2) $q''_{CHF} = 1.181(10^6)H(p)(30.48D)^{-n}$ $* G^{-0.6}(1.0 - x)$ where $F(p) = 0.7249 + 0.00683p \exp(-0.0021p)$	Eqns. 1 & 2 are based on the Biasi correlation (Ref.36). The range of data for this correlation is: $P = 39$ to 2058 psia $G/10^6 = 0.74$ to 4.4 lb $hr^{-1}ft^{-2}$ $D = 0.01$ to 0.12 ft. $L = 0.66$ to 19.7 ft. $X = (\frac{1}{1 + \rho_f/\rho_g})$ to 1.0 NOTE: Data base is for water in flow through vertical, uniformly heated tubes. The correlation is principally a dryout correlation and consequently is not

TABLE C.2 (cont.)

CORRELATION	EQUATION	RANGE OF DATA BASE
Biasi/Void-CHF (cont.)	$H(p) = -1.159 + 0.01029p \exp(-0.00131p) + 130.4p(2103 + p^2)^{-1}$ $n = \begin{cases} 0.4 \text{ for } D \geq 0.0328 \text{ ft.} \\ 0.6 \text{ for } D < 0.0328 \text{ ft.} \end{cases}$ For $10^6 > \|G\| > 2 * 10^4$ lb hr^{-1}ft^{-2} use a linear interpolation between the value obtained for q''_{CHF} at G = 10 and the value obtained by the following equation at $G = 2 * 10^4$: 3) $q''_{CHF} = (1 - \alpha)0.9\pi 24^{-1} H_{fg}\rho_g^{0.5} * [g g_c \sigma(\rho_f - \rho_g)]^{0.25}$ For $2 * 10^4 \geq \|G\| \geq 0$ use Eqn. 3 with void fraction calculated for $G = +2 * 10^4$. Exception: For $P \geq 2300$ psia and $x \geq 0.5$, use Eqns. 1 and 2 for $\|G\| \geq 2 * 10^5$ lbs hr^{-1}ft^{-2}. Use linear interpolation between Eqns. 1 and 2 at $G = 2 * 10^5$ and Eqn. 3 at $G = 2 * 10^4$.	expected to work well for low qualities and low flows. Eqn. 3 is based on the Void-CHF correlation (Ref.37). This correlation contains the physically based pool boiling CHF relationship of Zuber (Ref.49). Data base covers low flow upflow, downflow and countercurrent flow conditions in Freon. Extension to water is justified on the basis of the proven wide range of applicability of the Zuber correlation.

NOMENCLATURE FOR TABLE C.2

a	Gap between two adjacent fuel rods	ft
C	Function of G and X_{CHF} or X_{crit}	ft^{1}
CHF	Critical heat flux	BTU $hr^{-1} ft^{-2}$
D	diameter of tube	ft
D_e	Equivalent diameter based on wetted perimeter	ft
D_h	Equivalent diameter based on heated perimeter	ft
F_c	Flux shape factor	-
F_P	Function of P	-
F_S	Spacer grid factor	-
G	Mass velocity	lb $hr^{-1} ft^{-2}$
g	Acceleration of gravity	ft/sec^2
g_c	Conversion factor	$lbf\text{-}sec^2$
H	Enthalpy	BTU/lbm
hfg	Latent heat of evaporation	BTU/lbm
L	Length of heated channel	ft
L_B	Boiling length	ft
L_{BC}	Critical boiling length	ft
l_{CHF}	Distance from start of local boiling to CHF location (W-3)	ft
l_{crit}	Distance from channel inlet to critical heat flux location (B&W-2)	ft
$l_{CHF,EU}$	Distance from start of local boiling to CHF location for equivalent uniform heat flux condition (W-3)	ft

P	Pressure	psia
P_c	Critical pressure	psia
q'' q''_{crit} q''_c	Critical heat flux	BTU $hr^{-1} ft^{-2}$
$q''_{crit,EU}$ $q''_{CHF,EU}$ $q''_{DNB,EU}$	Critical heat flux for equivalent uniform heat flux	BTU $hr^{-1} ft^{-2}$
$q''_{crit,NU}$ $q''_{CHF,NU}$	Critical heat flux for non-uniform heat flux distribution	BTU $hr^{-1} ft^{-2}$
q''_{loc}	Local heat flux	BTU $hr^{-1} ft^{-2}$
v	velocity	ft/hr
$\langle x_e \rangle$	Bundle average quality	-
$\langle x_e \rangle_c$	Bundle average critical quality	-
x_{CHF} x_{DNB}	Quality at the critical heat flux location	-
x_{exit}	Quality of channel exit	-
x_{loc}	Local quality	-
Z	Axial length	ft
α	Void fraction	-
ε	Eddy diffusivity or Reynolds flux	ft^2/hr
ρ_f	Density of saturated liquid	lbm/ft^3
ρ_g	Density of saturated vapor	lbm/ft^3
σ	Surface tension	lb/ft

APPENDIX D
DERIVATION OF EQUATIONS FOR THE OLD FUEL HEAT TRANSFER MODEL

The equations of the heat transfer model were derived by using a Taylor's series approximation to the heat conduction equation at each location i designated in Figure 7.

$$\rho c \frac{\partial T}{\partial t} = k \left(\frac{\partial T}{\partial r^2} + \frac{1}{r} \frac{\partial T}{\partial r} \right) + q''' \tag{D.1}$$

For i=1:

By using L' Hospital's rule and the boundary condition $\partial T / \partial r = 0$, the differential equation at r = 0 is

$$\rho c \frac{\partial T}{\partial t} = 2k \frac{\partial^2 T}{\partial r^2} + q''' \tag{D.2}$$

From Taylor's series

$$T_2 = T_1 + \Delta r \frac{\partial T}{\partial r}^0 \Big| r = 0 + \frac{\Delta r^2}{\partial 2!} \frac{\partial T}{\partial r^2} + --- \tag{D.3}$$

and

$$T_1 = \bar{T}_1 + \Delta t \frac{\partial T}{\partial t} + --- \tag{D.4}$$

Substituting these into the differential equation gives the finite difference equation

$$\rho c \left(\frac{T_1 - \bar{T}_1}{\Delta t} \right) = 4k \left(\frac{T_2 - T_1}{\Delta r^2} \right) + q'''_1 \tag{D.5}$$

Where the overscore bar ($^-$) denotes previous time.

For 1<i<N:

By using the above procedure the finite difference equation can be written as

$$\rho c \frac{T_i - \bar{T}_i}{\Delta t} = k \left[\frac{T_{i-1} - 2T_i + 2T_{i+1}}{\Delta r^2} + \frac{T_{i+1} - T_{i-1}}{2(i-1)\,\Delta r^2} \right] + q'''_i \tag{D.6}$$

For i=N:
The fuel-clad interface condition is

$$-k\frac{\partial T}{\partial r}\Big|_{i=N} = h_{gap}\left(T_N - T_{N+1}\right) \tag{D.7}$$

By using Taylor's series

$$T_{N-1} = T_N - \Delta r\,\frac{\partial T}{\partial r}\Big|_{i=N} + \frac{\Delta r^2}{2}\,\frac{\partial^2 T}{\partial r^2}\Big|_{i=N} \tag{D.8}$$

and substituting this and Equation (D.7) into Equation (D.1) gives the finite difference equation

$$\rho c\left(\frac{T_N-\bar{T}_N}{\Delta t}\right) = 2k\left(\frac{T_{N-1}-T_N}{\Delta r^2}\right) + \left(\frac{2}{\Delta r} + \frac{1}{(N-1)\,\Delta r}\right)h_{gap}\,(T_{N+1}-T_N) + q_N''' \tag{D.9}$$

For i=N+1:
The cladding is treated as lumped parameter node. The conductance through the cladding is lumped with the gap heat transfer coefficient to give an effective coefficient.

$$\frac{1}{h_{gap}} = \frac{1}{h_{\substack{gap\\cond}}} + \frac{t_{clad}}{k_{clad}} \tag{D.10}$$

By performing a transient heat balance on the cladding the finite difference equation can be written as

$$(\rho c)_{clad}\left(\frac{T_{N+1}-\bar{T}_{N+1}}{\Delta t}\right) = \frac{h_{gap}}{t_{clad}}\,\frac{r_N}{r_{N+1}}\,(T_N-T_{N+1}) - \frac{h_{surf}}{t_{clad}}\,(T_{N+1}-T_{fluid}) + q_{N+1}''' \tag{D.11}$$

The previous set of equations are arranged into a tridiagonal system of equations and are solved by using a compact Gauss elimination routine. The same set of equations, except for the radial coordinate term $(1/r)(\partial T/\partial r)$, are used for the plate fuel model.

The fuel power density is defined in terms of the equivalent impressed flux as if there is no fuel model. The total power is

$$q = \pi D \Delta x q'' \tag{D.12}$$

and dividing by the fuel volume gives

$$q''' = q'' \frac{\pi D \Delta x}{\frac{\pi D_f^2}{4} \Delta x} = q'' \frac{4D}{D_f^2} \tag{D.13}$$

where D_f is the fuel pellet diameter.

The plate fuel is considered to be an equivalent unwrapped rod with its thickness equal to the radius of the fuel rod. The thickness in this case being the distance from the outer surface of the cladding to the adiabatic centerline of the plate as shown in Figure D-1. The power density is defined as for the rod where

$$q = q'' \pi D \Delta x \tag{D.14}$$

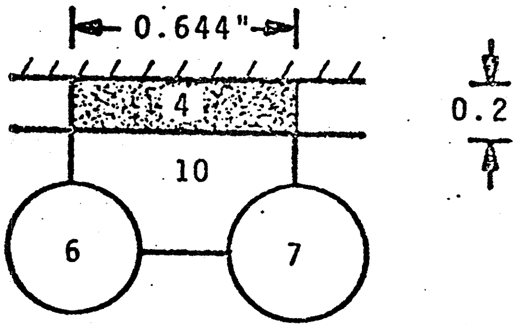
or

$$q''' = q'' \frac{\pi D \Delta x}{\pi D \frac{D_f}{2}} = q'' \frac{2}{D_f} \tag{D.15}$$

When using the equivalent rod as a flat plate the plate width is assumed to be the circumference πD. To account for the actual width facing a given subchannel, use the factor in COBRA (card group 8) for specifying the fraction of power from a rod to a subchannel. This fraction is defined as

Actual width facing Subchannel/πD

As an example, if the plate is used to model the wall shown in



the sketch The wall is modeled as rod 4 and it is designated fuel type 2 for the code input. The diameter is (2)*(0.2) = 0.4

inches. The fraction of power from Rod 4 to Channel 10 is 0.644/(π*0.4) = 0.513.

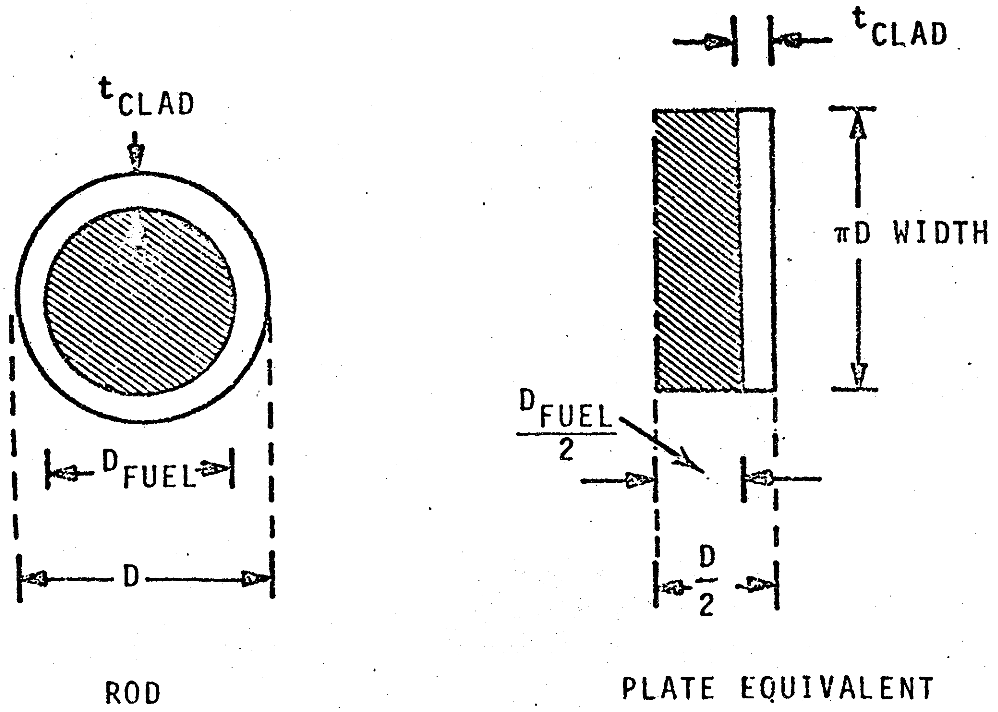


FIGURE D-1: Rod and Plate Fuel Dimension Equivalents

APPENDIX E
LISTING OF COBRA IIIc/MIT-2

The following pages contain a listing of COBRA IIIc/MIT-2. The subroutines are listed first in alphabetical order. following the subroutines are the functions. The functions are also in alphabetical order.

```
C***********************************************************************
C*************************** COBRA IIIC/MIT-2 **************************
C*************************** REVISED MAY 1981 **************************
C***********************************************************************
C
C     UNITS - ALL COMPUTATIONS ARE DONE USING FT, LB, SEC, BTU AND
C     DEG-F, EXCEPT FOR SOME ASSOCIATED WITH NEW FUEL ROD AND HEAT
C     TRANSFER MODEL. UNIT CHANGES FOR INPUT AND OUTPUT ARE DONE
C     IN THE PROGRAM.
C
C     KMAX IN SUBROUTINE CORE MUST EQUAL THE
C     LENGTH OF THE DATA ARRAY GIVEN BELOW
C-----------------------------------------------------------------------
C
      COMMON DATA(80000)
      INIT = 1
  2   CALL INDAT(INIT,NOPRIN)
      IF(NOPRIN.EQ.0)  CALL INPRIN
      CALL CALC
      INIT = 2
      GO TO 2
       END
```

```
C********************** SUBROUTINE ACOL ********************************
      SUBROUTINE ACOL(IFROM,IK,JK,KMAX,LOCA,MA,MS,NK,MG,IPILE)
C
C     SET LOCA ARRAY, WHICH DEFINES INTERACTING BOUNDARIES
C     IF CALLED FROM CARDS4, IFROM = 1
C     IF CALLED FROM        ,IFROM = 2 (OLD COBRA)
C     LOCA(K,1)=K.    LOCA(K,L),L=2,7 SPECIFIES UP TO  LOCA(K,8)
C     BOUNDARIES ADJACENT TO CHANNELS DEFINING BOUNDARY K.
C-----------------------------------------------------------------------
      DIMENSION  IK(NK),JK(NK),LOCA(MG,14)
C-----------------------------------------------------------------------
C
         DO 8 K=1,NK
         IF (IPILE.GT.0) GO TO 107
            DO 103 L=2,13
 103        LOCA(K,L)=0
         GO TO 110
 107        DO 3 L=2,7
  3         LOCA(K,L)=0
 110     N=1
         LOCA(K,1) = K
         II = IK(K)
         JJ = JK(K)
  4         DO 7 KK=1,NK
            III = IK(KK)
            IF (III.GT.II) GO TO 7
            JJJ = JK(KK)
            IF ( (II.EQ.III) .OR. (II.EQ.JJJ) ) GO TO 6
            GO TO 7
  6         IF ( (III+JJJ - II-JJ) .EQ. 0) GO TO 7
            N = N+1
            LL = III
            IF (II.EQ.III) LL=JJJ
            WV = FLOAT(II-LL)/FLOAT(II-JJ)
            LOCA(K,N) = KK
            IF (WV.LT.0.0) LOCA(K,N)=-KK
  7         CONTINUE
         IF (IPILE.GT.0) GO TO 108
         LOCA(K,14)=N
         GO TO 109
 108     LOCA(K,8)=N
 109     IF(II.GE.JJ) GO TO 8
         II = JK(K)
         JJ = IK(K)
         GO TO 4
  8      CONTINUE
C
C     FIND STRIPE WIDTH FOR AAA MATRIX IN DIVERT
      MAX = 0
         DO 10 K=1,NK
         N=LOCA(K,8)
         IF (IPILE.GT.0) GO TO 111
```

```
      N=LOCA(K,14)
111      DO 10 L=2,N
         LKL = IABS(LOCA(K,L))
         J = IABS(K-LKL)
         IF (J.LT.MAX) GO TO 10
         MAX = J
         KMAX = K
10       CONTINUE
      MS = 2*MAX + 1
      CALL CORE2(MS,NK)
      RETURN
      END
```

```
C********************** SUBROUTINE AREA *********************************
      SUBROUTINE AREA(J)
C
      IMPLICIT INTEGER (I)
      DIMENSION  AFAC(10), GFAC(10)
      INTEGER IDAT(1)
      LOGICAL  GRID,LDAT(1)
      REAL KIJ, KF, KKF, KCLAD, KFUEL
C
      COMMON  DATA(1)
      EQUIVALENCE  (DATA(1),IDAT(1),LDAT(1))
C
      COMMON /COBRA1/  ABETA ,AFLUX ,ATOTAL,BBETA ,DIA   ,DT    ,DX     ,
     1   ELEV  ,FERROR,FLO   ,FTM   ,GC    ,GK    ,GRID  ,HSURF ,HF     ,
     2   HFG   ,HG    ,I2    ,I3    ,IERROR,IQP3  ,ITERAT,J1    ,J2     ,
     3   J3    ,J4    ,J5    ,J6    ,J7    ,KDEBUG,KF    ,KIJ   ,
     4   NAFACT,NARAMP,NAX   ,NAXL  ,NBBC  ,NCHAN ,NCHF  ,NDX   ,NF     ,
     5   NGAPS ,NGRID ,NGRIDT,NGTYPE,NGXL  ,NK    ,NODES ,NODESF,NPROP  ,
     6   NRAMP ,NROD  ,NSCBC ,NV    ,NVISCW,PI    ,PITCH ,POWER ,PREF   ,
     7   QAX   ,RHOF  ,RHOG  ,SIGMA ,SL    ,TF    ,TFLUID,THETA ,THICK  ,
     8   UF    ,VF    ,VFG   ,VG    ,Z
C
      COMMON /COBRA2/  AA(4), AF(7), AFACT(10,10), AV(7), AXIAL(30),
     1   AXL(10), BB(4), BX(30), CC(4), CCLAD(2), CFUEL(2), DFUEL(2),
     2   GAPXL(10), GFACT(9,10), GRIDXL(10), HGAP(2), HHF(30), HHG(30),
     3   IGRID(10), KCLAD(2), KFUEL(2), KKF(30), NCH(10), NGAP(9),
     4   PP(30), RCLAD(2),RFUEL(2),SSIGMA(30), TCLAD(2), UUF(30),
     5   VVF(30), VVG(30), XQUAL(30), Y(30), TT(30)
C
      COMMON /COBRA3/  MA    ,MC    ,MG    ,MN    ,MR    ,MS    ,MX     ,
     1          III   ,IA    ,IAAA  ,IAC   ,IALPHA,IAN   ,IANSWE,IB     ,
     1   ICCHAN,ICD   ,ICHFR ,ICON  ,ICOND ,ICP   ,ID    ,IDC   ,IDFDX  ,
     2   IDHDX ,IDHYD ,IDHYDN,IDIST ,IDPDX ,IDPK  ,IDUR  ,IDR   ,IF     ,
     3   IFACTO,IFDIV ,IFINLE,IFLUX ,IFMULT,IFOLD ,IFSP  ,IFSPLI,IFXFLO,
     4   IGAP  ,IGAPN ,IGAPS ,IH    ,IHFILM,IHINLE,IHOLD ,IHPERI,IIDARE,
     5   IIDFUE,IIDGAP,IIK   ,IJBOIL,IJK   ,ILC   ,ILENGT,ILOCA ,ILR    ,
     6   IMCHFR,IMCFRC,IMCFRR,INTYPE,INWRAP,INWRPS,IP    ,IPERIM,IPH    ,
     7   IPHI  ,IPRNTC,IPRNTR,IPRNTN,IPW   ,IPWRF ,IQC   ,IQF   ,IQPRIM,
     8   IQUAL ,IRADIA,IRHO  ,IRHOOL,ISP   ,IT    ,ITDUMY,ITINLE,ITROD  ,
     9   IU    ,IUH   ,IUSAVE,IUSTAR,IV    ,IVISC ,IVISCW,IVP   ,IVPA   ,
     A   IW    ,IWOLD ,IWP   ,IWSAVE,IX    ,IXCROS,IIA  ,IIB  ,IXPOLD
C------------------------------------------------------------------------
C
C        CALCULATE CHANNEL AREA IF REQUIRED.
         DO 5 I=1,NCHAN
         DATA(IA    +I)=DATA(IAN   +I)
 5       DATA(IDHYD +I)=DATA(IDHYDN+I)
      IF(NK.EQ.0) GO TO 888
         DO 6 K=1,NK
 6       DATA(IGAP  +K)=DATA(IGAPN +K)
 888  CONTINUE
      IF(NAXL.EQ.0) GO TO 101
```

```
         DO 100 I=1,NCHAN
         JJ=IDAT(IIDARE+I)
         IF(JJ.LT.1) GO TO 100
            DO 10 K=1,NAXL
 10         AFAC(K) = AFACT(JJ,K)
         CALL CURVE(FF,(DATA(IX+J)/Z),AFAC,AXL,NAXL,IERROR,1)
         IF(IERROR.GT.1) GO TO 1000
         IF(DT.LT.100.) GO TO 20
         DUMY = FLOAT(ITERAT)/FLOAT(NARAMP)
         IF(DUMY.GT.1.) DUMY = 1.
         IF(FF.LE.0.) GO TO 1000
         FF = 1.-(1.-FF)*DUMY
 20      DATA(IA    +I)=DATA(IAN   +I)*FF
         DATA(IDHYD +I)=DATA(IDHYDN+I)*FF
 100     CONTINUE
 101  IF(J6.NE.1) GO TO 110
C     MODIFY AREA AND HYDRAULIC DIAMETER FOR WIRE WRAPS IN SUBCHANNELS.
         DO 102 I=1,NCHAN
         DATA(IA+I)=DATA(IA+I)-FLOAT(IDAT(INWRAP+I))*PI*THICK**2*0.25
 102     DATA(IDHYD+I)=4.*DATA(IA+I)/(DATA(IPERIM+I)+
     1   FLOAT(IDAT(INWRAP+I)) * PI*THICK)
C
C     CALCULATE GAP SPACING IF REQUIRED.
 110  IF(NGXL.EQ.0) GO TO 210
       IF(NK.EQ.0) RETURN
         DO 200 K=1,NK
         L=IDAT(IIDGAP+K)
         IF(L.LT.1) GO TO 200
            DO 120 I=1,NGXL
 120        GFAC(I) = GFACT(L,I)
         CALL CURVE(FF,(DATA(IX+J)/Z),GFAC,GAPXL,NGXL,IERROR,1)
         IF(IERROR.GT.1) GO TO 1000
         IF(FF.LE.0.) GO TO 1000
         DATA(IGAP  +K)=DATA(IGAPN +K)*FF
 200     CONTINUE
 210  RETURN
1000  IERROR = 9
      RETURN
      END
```

```
C********************** SUBROUTINE BAROC *******************************
      SUBROUTINE BAROC(IPART,P,Q,GWV,FMULT,PPI)
C
      DIMENSION A1(4),A2(4),CORAB(14,7),COEF(12,8),DAT(12,5,5),X(5)
     1,       GG(7),QQ(14),PP(8),ZNN(3,6)
C
      COMMON/COSAVE/CORAB
      DATA I3/6/
      DATA ZNN/1.2621,0.6749,0.073,1.9551,1.0043,0.1097,1.4985,0.8408,
     10.0971,0.7965,0.5531,0.0673,0.771,0.5638,0.0713,0.4838,0.4793,
     20.0657/
      DATA PP/0.0001,0.001,0.004,0.01,0.03,0.1,0.3,1.0/
      DATA GG/0.0,0.25,0.5,1.0,2.0,3.0,1000.0/
      DATA QQ/0.0,0.001,0.01,0.035,0.05,0.075,0.1,0.15,0.2,
     10.3,0.4,0.6,0.8,1.0/
      DATA COEF/2.2,9.2,26.5,47.0,99.0,163.0,376.0,630.0,1300.0,2050.0,
     1 4300.0,6600.0,
     2 2.15,8.8,22.8,34.2,48.2,70.0,108.0,148.0,240.0,330.0,538.0,760.0,
     3 2.08,7.8,16.3,22.8,29.0,36.0,49.5,63.0,86.0,110.0,155.0,203.0,
     4 1.59,4.8,9.6,12.4,16.0,20.0,27.0,33.5,43.5,53.0,69.0,85.0,
     5 1.12,1.81,3.45,4.7,6.1,7.9,11.0,13.2,17.3,21.2,26.0,30.0,
     6 1.04,1.22,1.78,2.05,2.5,2.8,3.6,4.2,5.5,6.5,8.0,9.1,
     7 1.01,1.06,1.26,1.36,1.5,1.59,1.77,1.93,2.25,2.48,2.86,3.2,12*1.0/
      DATA DAT/1.669,1.669,1.626,1.6,1.59,1.58,1.58,1.58,1.534,
     1 1.492,1.362,1.178,
     2 1.16,1.158,1.059,1.0,1.21,1.42,1.42,1.42,1.324,1.234,1.139,1.103,
     31.22,1.307,1.355,1.384,1.502,1.36,1.36,1.36,1.33,1.34,1.162,1.086,
     4 1.11,1.166,1.42,1.572,1.695,1.818,1.818,1.818,1.619,1.445,
     5 1.204,1.07,12*1.0,
     6 1.3,1.33,1.311,1.3,1.3,1.3,1.304,1.308,1.284,1.26,1.2,1.1,
     71.13,1.25,1.17,1.12,1.148,1.276,1.256,1.236,1.195,1.153,1.11,1.07,
     8 1.1,1.15,1.15,1.214,1.21,1.219,1.223,1.24,1.235,1.23,1.13,1.084,
     9 1.078,1.086,1.232,1.32,1.334,1.460,1.472,1.596,1.457,
     A 1.318,1.164,1.061,12*1.0,60*1.0,
     B0.75,0.74,0.749,0.754,0.752,0.75,0.736,0.722,0.746,0.77,0.82,0.91,
     C 0.864,0.66,0.676,0.686,0.704,0.721,0.746,0.75,0.788,0.806,0.86,
     D 0.932,0.905,0.88,0.829,0.798,0.805,0.812,0.788,0.764,0.73,
     E 0.696,0.705,0.82,
     F 0.97,0.912,0.817,0.76,0.73,0.7,0.665,0.63,0.602,0.574,0.574,0.7,
     G 12*1.0,0.63,0.61,0.625,0.634,0.634,0.634,0.606,0.598,0.624,0.65,
     H.718,.836,.78,.484,.501,.512,.551,.59,.605,.62,.667,.714,.782,.88,
     I.865,.81,.741,.7,.701,.702,.673,.643,.593,.542,.542,.69,.937,.884,
     J .769,.7,.671,.642,.587,.540,.493,.454,.454,.58,12*1.0/
      DATA A2/0.220112,-0.299745,0.440706,-0.325823/
      DATA A1/2.46896E-04,1.95508E-01,-3.14163E-02,2.64363E-01/
      DATA X/-8.25483,-5.572754,-2.8647,-1.619488,0.0/
C-----------------------------------------------------------------------
C     ZLINE IS VALUE OF YB AT XB, INTERPOLATED LINEARLY BETWEEN (XA,YA)
C     AND (XC,YC)
C     ZRECT IS VALUE OF Z AT (XX,YY), LINEARLY INTERPOLATED BETWEEN Z11
C     AT (X1,Y1), Z12 AT (X1,Y2), Z21 AT (X2,Y1) AND Z22 AT (X2,Y2)
C
```

```
      ZLINE(XA,YA,XC,YC,XB)=((YA-YC)*XB+(YC*XA-YA*XC))/(XA-XC)
      ZRECT(X1,X2,Y1,Y2,Z11,Z12,Z21,Z22,XX,YY) =
     1 ( (Y2-YY)*(Z11*(X2-XX) + Z21*(XX-X1))
     2 - (Y1-YY)*(Z12*(X2-XX) + Z22*(XX-X1)) )
     3 /((Y1-Y2)*(X1-X2))
C-----------------------------------------------------------------------
C     IPART = 1,  ENTER WITH PRESSURE AND SET ARRAY CORAB
C     IPART = 2,  ENTER WITH MASS VELOCITY AND QUALITY, INTERPOLATE
C     IN CORAB TO OBTAIN MULTIPLIER.
C-----------------------------------------------------------------------
C
      IF (IPART.EQ.2) GO TO 41
C     SET PHYSICAL PROPERTY INDEX FROM PRESSURE.
      IF((P.LT.11.429).OR.(P.GT.3204.0)) WRITE(I3,1001) P
      IF(P.GT.1429.5) GO TO 8
      YY=A1(4)
         DO 2 I=1,3
         L=4-I
  2      YY=YY*P/3204+A1(L)
      PX = YY
      GO TO 12
  8   CONTINUE
      YY=A2(4)
         DO 10 I=1,3
         L=4-I
 10      YY=YY*P/3204+A2(L)
      PX = YY*P/(3204-P+YY*P)
 12   PPI = ALOG(PX)
 13   CONTINUE
      IMAX=14
      IF(PX.LT.PP(1)) PX = PP(1)
      J=1
 14   IF(PX.LE.PP(J)) GO TO 16
      J=J+1
      GO TO 14
C
C     SET MULTIPLIER AT G = 1.0
 16      DO 22 I=1,IMAX
         IF(I.EQ.1) CORAB(1,4)=1.0
         IF(I.EQ.IMAX) CORAB(IMAX,4)=1.0/PX
         IF((I.EQ.1).OR.(I.EQ.IMAX)) GO TO 22
         M=I-1
         IF(J.GT.2) GO TO 15
         WV=ZLINE(ALOG(PP(1)),ALOG(COEF(M,1)),ALOG(PP(2)),
     1   ALOG(COEF(M,2)),PPI)
         CORAB(I,4)=EXP(WV)
         GO TO 22
 15      IF(I.GE.8) GO TO 17
         IF((J.LT.4).OR.(J.GT.5)) GO TO 17
         ZN=EXP(ZNN(1,M)+ZNN(2,M)*PPI+ZNN(3,M)*PPI*PPI)
         GO TO 19
 17      IF (J.LE.7) GO TO 18
```

```
         WV = ZLINE(ALOG(PP(7)),ALOG(COEF(M,7)), 0.0,0.0,PPI)
         CORAB(I,4)=EXP(WV)
         GO TO 22
 18      IF(J.EQ.1) J=2
         ZN1 = ALOG((COEF(M,J-1) - 1.0 + QQ(I))*PP(J-1))/ALOG(QQ(I))
         ZN2 = ALOG((COEF(M,J  ) - 1.0 + QQ(I))*PP(J  ))/ALOG(QQ(I))
         ZN = ZLINE(ALOG(PP(J-1)),ALOG(ZN1),ALOG(PP(J)),ALOG(ZN2),PPI)
         ZN = EXP(ZN)
 19      CORAB(I,4) = 1.0 - QQ(I) + (QQ(I)**ZN)/PX
 22      CONTINUE
C
C     SET CORAB MATRIX USING MASS VELOCITY CORRECTION FACTOR.
      IND1=1.0
      BIT=0.15
 30   IF(PPI.LT.X(IND1+1)) GO TO 32
      IND1=IND1+1
      GO TO 30
 32   IND2=0.0
         DO 34 K=2,4
 34      IF((PPI.GT.(X(K)-BIT)).AND.(PPI.LT.(X(K)+BIT))) IND2=K
         DO 38 I=1,IMAX
         N=I-1
            DO 38 J=1,7
            IF((I.EQ.1).AND.(J.LT.7)) GO TO 35
            IF((I.EQ.IMAX).AND.(J.LT.7)) GO TO 35
            M=J-1
            IF(J.EQ.1) M=J
            IF(J.EQ.7) GO TO 37
            YY=ZLINE(X(IND1),DAT(N,IND1,M),X(IND1+1),DAT(N,IND1+1,M)
     1      ,PPI)
            IF(IND2.EQ.0.0) GO TO 36
            X1=X(IND2)-BIT
            X2=X(IND2)+BIT
            Y1=ZLINE(X(IND2-1),DAT(N,IND2-1,M),X(IND2),DAT(N,IND2,M),X1)
            Y2=ZLINE(X(IND2),DAT(N,IND2,M),X(IND2+1),DAT(N,IND2+1,M),X2)
            YY=0.5*(ZLINE(X1,Y1,X2,Y2,PPI)+YY)
            GO TO 36
 35         YY=1.0
 36         CORAB(I,J)=YY*CORAB(I,4)
            GO TO 38
 37         CORAB(I,J)=1.0
 38         CONTINUE
      RETURN
C
C     INTERPOLATE IN CORAB ARRAY TO FIND MULTIPLIER.
 41   G=GWV*1.0E-06
      IF(G.GE.1000.0)G = 1000.0
      IND1=1
 42   IF(Q.LE.QQ(IND1)) GO TO 44
      IND1=IND1+1
      GO TO 42
 44   CONTINUE
```

```
      IND2=1
 46   IF(G.LT.GG(IND2)) GO TO 48
      IND2=IND2+1
      GO TO 46
 48   G2=GG(IND2)
      G1=GG(IND2-1)
      G3=G
      IF(G.LE.1.0) GO TO 50
      G1=1.0/G1
      G2=1.0/G2
      G3=1.0/G3
 50   CONTINUE
C
      Z11 = CORAB(IND1-1,IND2-1)
      Z12 = CORAB(IND1-1,IND2  )
      Z21 = CORAB(IND1  ,IND2-1)
      Z22 = CORAB(IND1  ,IND2  )
      X1 = QQ(IND1-1)
      X2 = QQ(IND1  )
      XX = Q
      FMULT = ZRECT(X1,X2,G1,G2,Z11,Z12,Z21,Z22,XX,G3)
      PPI=ALOG10(EXP(PPI))
      RETURN
C
C-----------------------------------------------------------------------
 1001 FORMAT('  PRESSURE = ', 1PE15.4, ' OUTSIDE VALID RANGE OF 11.43 TO
     1 3204 PSIA')
C-----------------------------------------------------------------------
      END
```

```
C*********************** SUBROUTINE CALC **********************************
      SUBROUTINE CALC
C
      IMPLICIT INTEGER (I)
      INTEGER IDAT(1),SIGNAL(18)
      LOGICAL LDAT(1),GRID
      REAL KIJ, KF, KKF, KCLAD, KFUEL
C
      COMMON  DATA(1)
      EQUIVALENCE  (DATA(1),IDAT(1),LDAT(1))
C
      COMMON /COBRA1/  ABETA ,AFLUX ,ATOTAL,BBETA ,DIA   ,DT    ,DX    ,
     1   ELEV  ,FERROR,FLO   ,FTM   ,GC    ,GK    ,GRID  ,HSURF ,HF    ,
     2   HFG   ,HG    ,I2    ,I3    ,IERROR,IQP3  ,ITERAT,J1    ,J2    ,
     3   J3    ,J4    ,J5    ,J6    ,J7    ,KDEBUG,KF    ,KIJ   ,
     4   NAFACT,NARAMP,NAX   ,NAXL  ,NBBC  ,NCHAN ,NCHF  ,NDX   ,NF    ,
     5   NGAPS ,NGRID ,NGRIDT,NGTYPE,NGXL  ,NK    ,NODES ,NODESF,NPROP ,
     6   NRAMP ,NROD  ,NSCBC ,NV    ,NVISCW,PI    ,PITCH ,POWER ,PREF  ,
     7   QAX   ,RHOF  ,RHOG  ,SIGMA ,SL    ,TF    ,TFLUID,THETA ,THICK ,
     8   UF    ,VF    ,VFG   ,VG    ,Z
C
      COMMON /COBRA2/  AA(4), AF(7), AFACT(10,10), AV(7), AXIAL(30),
     1   AXL(10), BB(4), BX(30), CC(4), CCLAD(2), CFUEL(2), DFUEL(2),
     2   GAPXL(10), GFACT(9,10), GRIDXL(10), HGAP(2), HHF(30), HHG(30),
     3   IGRID(10), KCLAD(2), KFUEL(2), KKF(30), NCH(10), NGAP(9),
     4   PP(30), RCLAD(2),RFUEL(2),SSIGMA(30), TCLAD(2), UUF(30),
     5   VVF(30), VVG(30), XQUAL(30), Y(30), TT(30)
C
      COMMON /COBRA3/  MA    ,MC    ,MG    ,MN    ,MR    ,MS    ,MX    ,
     1          III   ,IA    ,IAAA  ,IAC   ,IALPHA,IAN   ,IANSWE,IB    ,
     1   ICCHAN,ICD   ,ICHFR ,ICON  ,ICOND ,ICP   ,ID    ,IDC   ,IDFDX ,
     2   IDHDX ,IDHYD ,IDHYDN,IDIST ,IDPDX ,IDPK  ,IDUR  ,IDR   ,IF    ,
     3   IFACTO,IFDIV ,IFINLE,IFLUX ,IFMULT,IFOLD ,IFSP  ,IFSPLI,IFXFLO,
     4   IGAP  ,IGAPN ,IGAPS ,IH    ,IHFILM,IHINLE,IHOLD ,IHPERI,IIDARE,
     5   IIDFUE,IIDGAP,IIK   ,IJBOIL,IJK   ,ILC   ,ILENGT,ILOCA ,ILR   ,
     6   IMCHFR,IMCFRC,IMCFRR,INTYPE,INWRAP,INWRPS,IP    ,IPERIM,IPH   ,
     7   IPHI  ,IPRNTC,IPRNTR,IPRNTN,IPW   ,IPWRF ,IQC   ,IQF   ,IQPRIM,
     8   IQUAL ,IRADIA,IRHO  ,IRHOOL,ISP   ,IT    ,ITDUMY,ITINLE,ITROD ,
     9   IU    ,IUH   ,IUSAVE,IUSTAR,IV    ,IVISC ,IVISCW,IVP   ,IVPA  ,
     A   IW    ,IWOLD ,IWP   ,IWSAVE,IX    ,IXCROS,IIA  ,IIB  ,IXPOLD
C
      COMMON/LINK2/CROSS(6),FG(30),FH(30),FP(30),FQ(30),IM(9),JM(9),
     1OUTPUT(10),PRINT(12),TEXT(17),YG(30),YH(30),YP(30),YQ(30)
      COMMON/LINK3/DXX,ETIME,GIN,HIN,I8,IG,IN,ISAVE,JUMP,KASE,KT,MAXT,
     1 NDT,NDXP1,NFUELT,NG,NH,NJUMP,NOUT,NP,NPCHAN,NPNODE,NPROD,NQ,NR,
     2 NSKIPT,NSKIPX,NTRIES,PEXIT,PHTOT,SAVEDT,TIN,TTIME,ZZ
      COMMON /LINK4/IFRM,IHTM,IPROP,NCC,NCF,NDM1,NDS,NGP
C
      COMMON /TIMEST/ NT
      COMMON /REFP/ PO
      COMMON /PPSV/ PPI
      COMMON /TSAVER/TSTART
```

```
C
      DATA SIGNAL /4HMAIN,4HDIFF,4HDVRT,4HMIX ,
     14HSCHM,4HFORC,4HVOID,4HSPLT,4HAREA,4HCURV,4HPROP,
     24HDCOM,4HSOLV,4HHEAT,4HTEMP,4HHCOL,4HGAUS,4HCIJ /
C-----------------------------------------------------------------------
C
C     HYDRAULIC CONTROL
C     START SUBCHANNEL FLOW AND ENTHALPY CALCULATIONS.
 400  KT = NSKIPT
      IPILE = J7
      DT = SAVEDT
         DO 401 J=1,NDXP1
 401     DATA(IX+J)=DX*FLOAT(J-1)
      NDTP1 = NDT+1
C
C     TIMING IS EXPEECTED TO RETURN CPU TIME (IN HUNDREDTHS OF A SECOND)
C     AS AN INTEGER. TSTART IS THE VALUE OF 'ICPU' AT THE START OF
C     EXECUTION. THE DIFFERENCE BETWEEN TSTART AND THE VALUE OF 'ICPU'
C     AT LATER TIMES IS COMPARED WITH THE MAXIMUM VALUE GIVEN IN THE
C     INPUT DATA AS PROTECTION AGAINST EXCESSIVE RUN TIME.
C
      CALL TIMING(ICPU)
      TSTART=FLOAT(ICPU)/100.
C
C     INITIALIZE FUEL ROD VARIABLES IF NEW FUEL ROD MODEL USED
C
      IF (IFRM.EQ.0) GO TO 409
      CALL INITRC
C
C        START TRANSIENT DO LOOP
 409     DO 500 NT=1,NDTP1
         IERROR = 0
         IF (IQP3.GT.1) GO TO 710
         CALL QPR3(TEXT)
 710     CONTINUE
         DT = SAVEDT
         IF(NT.EQ.1) DT = 1.E+10
         ETIME = DT*FLOAT(NT-1)
C        ESTABLISH CHANNEL BOUNDARY CONDITIONS AND FORCING FUNCTION VALU
C
C        SET TRANSIENT PRESSURE
         DUMY = 1.
         IF(NP.GT.1)
     1   CALL CURVE (DUMY,ETIME,FP,YP,NP,IERROR,1)
         IF(IERROR.GT.1) GO TO 505
         PREF = DUMY*PEXIT
         CALL PROP(1,1)
         IF(IERROR.GT.1) GO TO 505
C
C        SET TRANSIENT INLET ENTHALPY
         DUMY = 1.
         IF(NH.GT.1)
```

```
     1    CALL CURVE (DUMY,ETIME,FH,YH,NH,IERROR,1)
          IF(IERROR.GT.1) GO TO 505
             DO 402 I=1,NCHAN
             DATA(IHOLD+I)=DATA(IH    +I)
             DATA(IH    +I)=DATA(IHINLE+I)*DUMY
             IF(IN.EQ.1 .OR. IN.EQ.3) CALL CURVE(DATA(IH+I)
     1       ,DATA(ITINLE+I)*DUMY,HHF,TT,NPROP,IERROR,1)
 402         CONTINUE
C
C         SET TRANSIENT INLET FLOW
          DUMY = 1.
          IF(NG.GT.1)
     1    CALL CURVE(DUMY,ETIME,FG,YG,NG,IERROR,1)
          IF(IERROR.GT.1) GO TO 505
          IF ( (IPILE.EQ.2) .AND. (NT.GT.1) ) GO TO 404
C         STEADY STATE AND PWR.
             DO 403 I=1,NCHAN
             DATA(IFOLD+I)=DATA(IF+I)
 403         DATA(IF    +I)=DATA(IFINLE+I)*DUMY
          GO TO 407
C         BWR.  UPDATE INLET FLOW FOR DUMY AND LAST TRANSIENT.
 404      SUMSS = 0.0
          SUMTR = 0.0
             DO 405 I=1,NCHAN
             SUMSS = SUMSS + DATA(IFINLE+I)
 405         SUMTR = SUMTR + DATA(IF+I)
          WV = DUMY*SUMSS/SUMTR
             DO 406 I=1,NCHAN
             DATA(IFOLD+I)=DATA(IF+I)
 406         DATA(IF+I) = WV*DATA(IF+I)
 407      CONTINUE
C
C         SET TRANSIENT POWER
          DUMY = 1.
          IF(NQ.GT.1)
     1    CALL CURVE (DUMY,ETIME,FQ,YQ,NQ,IERROR,1)
          IF(IERROR.GT.1) GO TO 505
          POWER = DUMY
C
C         SET BAROCZY PRESSURE DROP ARRAY
          IF (J4.EQ.2) CALL BAROC(1,PREF,0.0,0.0,RUB,PPI)
C
C            BEGIN ITERATION TO OBTAIN SOLUTION.
             DO 430 NN=1,NTRIES
                DO 410 I=1,NCHAN
 410            IDAT(INWRAP+I)=IDAT(INWRPS+I)
             ITERAT = NN
             CALL SCHEME(JUMP,DATA(IAAA+1))
             IF(IERROR.GT.1) GO TO 440
             CALL TIMING(ICPU)
             MTIME=IFIX(FLOAT(ICPU)/100.-TSTART)
             IF(MTIME.LT.MAXT) GO TO 429
```

```
            WRITE(I3,102)
            GO TO 440
 429        IF(JUMP.LT.1 .OR. JUMP.GT.3) GO TO 505
            GO TO (430,440,440),JUMP
 430        CONTINUE
         WRITE(I3,22) NTRIES
         IERROR = 1
C
C        SET CONDITIONS FOR NEXT TIME STEP
 440     IF(JUMP.EQ.3) GO TO 441
         IF(NJUMP.GT.0) JUMP = 3
         IF(NJUMP.NE.2) GO TO 441
         REWIND I8
         WRITE(I8) ((DATA(IW+I+MG*(J-1)),I=1,MG),J=1,MX),
     1            ((DATA(IP+I+MC*(J-1)),I=1,MC),J=1,MX),
     2           ((DATA(IRHO+I+MC*(J-1)),I=1,MC),J=1,MX),
     3           ((DATA(IF  +I+MC*(J-1)),I=1,MC),J=1,MX)
         END FILE I8
         REWIND I8
 441        DO 445 J=1,NDXP1
      IF(NK.EQ.0) GO TO 888
               DO 443 K=1,NK
               DATA(IWOLD+K+MG*(J-1))=
     1         DATA(IW   +K+MG*(J-1))
 443           CONTINUE
888        CONTINUE
               DO 444 I=1,NCHAN
               DATA(IFOLD +I+MC*(J-1))=DATA(IF    +I+MC*(J-1))
               DATA(IHOLD +I+MC*(J-1))=DATA(IH    +I+MC*(J-1))
               DATA(IRHOOL+I+MC*(J-1))=DATA(IRHO  +I+MC*(J-1))
 444           CONTINUE
 445        CONTINUE
         CALL EXPRIN
         IF(KT.GE.NSKIPT) KT=0
         IF(ISAVE.GT.0) GO TO 505
         IF(IERROR.GT.0) GO TO 505
 500     CONTINUE
C
C     END OF PROBLEM,  LOOK FOR NEW CASE
      GO TO 990
 505  WRITE(I3,55) SIGNAL(IERROR)
      WRITE(I3,55) SIGNAL(ISAVE)
 990  RETURN
C
C-----------------------------------------------------------------------
  22  FORMAT (23HOFAILURE INTEGRATION IN,I4,17H ITERATIONS AT X=
     1,F8.4,2I10)
  55  FORMAT(10H ERROR IN ,A6,'  **  CALCULATION FOR THIS CASE STOPPED')
 102  FORMAT(///' * * * ABNORMAL EXIT THROUGH MAXIMUM TIME * * *'//)
C-----------------------------------------------------------------------
      END
```

```
C********************** SUBROUTINE CARDS1 *******************************
      SUBROUTINE CARDS1(PP,TT,VVF,VVG,HHF,HHG,UUF,KKF,SSIGMA,N1,I2)
C
      DIMENSION  PP(N1),TT(N1),VVF(N1),VVG(N1),HHF(N1),HHG(N1),UUF(N1),
     *KKF(N1),SSIGMA(N1)
      REAL KKF
C-----------------------------------------------------------------------
      I2=5
C
C     PHYSICAL PROPERTIES FROM CARDS OR POLYNOMIALS
      IF (N1.LE.0) GO TO 6
      READ(I2,4) (PP(I),TT(I),VVF(I),VVG(I),HHF(I),HHG(I),UUF(I),
     1 KKF(I),SSIGMA(I),I=1,N1)
      RETURN
C
C     P2 TO BE HIGHER THAN OPERATING PRESSURE
C     N=1,PH TO BE LOWER THAN P FOR H-IN
C     N=2,PH TO BE LOWER THAN H-IN.
C     N1=NUMBER OF PRESSURE INTERPOLATION STEPS
  6   READ(I2,8) N,PH,P2,N1
      P1=PH
      IF(N.EQ.1) GO TO 10
      P1=10.0
      IF(PH.LT.161.3) GO TO 10
      H=0.01*PH
      P1=6.0*H*H*H*(H-1.35)/(H-0.35)
 10   IF(N1.LT.3) N1=3
      A=(P2-P1)/(N1-1)
         DO 12 I=1,N1
         P=P1+(I-1.0)*A
         PP(I)=P
         TT(I)=SATTEM(P)
         RL=ROLIQ(P)
         VVF(I)=1.0/RL
         RG=ROVAP(P)
         VVG(I)=1.0/RG
         H=HLIQ(P)
         HHF(I)=H
         HHG(I)=HVAP(P)
         CALL HAPROP(P,H,CP,UUF(I),KKF(I))
         CALL SURTEN(P,RL,RG,SSIGMA(I))
 12      CONTINUE
      RETURN
C-----------------------------------------------------------------------
  4   FORMAT(E5.2,F5.1,7F10.0)
  8   FORMAT(I5,2F10.3,I5)
C-----------------------------------------------------------------------
      END
```

```
C********************** SUBROUTINE CARDS4 ******************************
      SUBROUTINE CARDS4(AC,DC,DIST,DR,GAPS,LC,MA,MG,N1,N2,NCHF,NFUELT,
     *PH,PHTOT,PRINT,PW,MC)
C
C     ENTERED FOR PWR AND BWR SIMPLIFIED INPUT DATA. COMBINES CARD
C     GROUPS 4, 7,AND 8 IE. CHANNEL GEOMETRY, SPACERS AND RODS. READ
C     (A) INDICATORS, (B) CHANNEL GEOMETRY AND SPACERS FOR EACH GROUP,
C     (C) ROD POWERS, (D) SPACER X/L, (E) CHANNELS IN GROUPS 2,3 ETC,
C     (F) GAP CONNECTIONS, (G) FUEL DATA
C
C=====NOTE THAT THESE COMMON AREAS ARE NOT IDENTICAL WITH THOSE
C     IN OTHER ROUTINES
C-----------------------------------------------------------------------
      IMPLICIT INTEGER (I)
      DIMENSION AC(MC),DC(MC),DR(MC),PH(MC),PRINT(12),PW(MC),DIST(MC,4),
     1    GAPS(MG,4),LC(MC,4),FXF(5),IGROUP(15),JB(20),IFRIC(15),
     2    TEXT(20),MAAP(2,20)
      INTEGER IDAT(1)
      LOGICAL LDAT(1),GRID,PRINT
      REAL KIJ, KF, KKF, KCLAD, KFUEL
C
      COMMON  DATA(1)
      EQUIVALENCE  (DATA(1),IDAT(1),LDAT(1))
C
      COMMON /COBRA1/  ABETA ,AFLUX ,ATOTAL,BBETA ,DIA   ,DT    ,DX    ,
     1   ELEV  ,FERROR,FLO   ,FTM   ,GC    ,GK    ,GRID  ,HSURF ,HF    ,
     2   HFG   ,HG    ,I2    ,I3    ,IERROR,IQP3  ,ITERAT,J1    ,J2    ,
     3   J3    ,J4    ,J5    ,J6    ,J7    ,KDEBUG,KF    ,KIJ   ,
     4   NAFACT,NARAMP,NAX   ,NAXL  ,NBBC  ,NCHAN ,DUM1  ,NDX   ,NF    ,
     5   NGAPS ,NGRID ,NGRIDT,NGTYPE,NGXL  ,NK    ,NODES ,NODESF,NPROP ,
     6   NRAMP ,NROD  ,NSCBC ,NV    ,NVISCW,PI    ,PITCH ,POWER ,PREF  ,
     7   QAX   ,RHOF  ,RHOG  ,SIGMA ,SL    ,TF    ,TFLUID,THETA ,THICK ,
     8   UF    ,VF    ,VFG   ,VG    ,Z
C
      COMMON /COBRA2/  AA(4), AF(7), AFACT(10,10), AV(7), AXIAL(30),
     1   AXL(10), BB(4), BX(30), CC(4), CCLAD(2), CFUEL(2), DFUEL(2),
     2   GAPXL(10), GFACT(9,10), GRIDXL(10), HGAP(2), HHF(30), HHG(30),
     3   IGRID(10), KCLAD(2), KFUEL(2), KKF(30), NCH(10), NGAP(9),
     4   PP(30), RCLAD(2),RFUEL(2),SSIGMA(30), TCLAD(2), UUF(30),
     5   VVF(30), VVG(30), XQUAL(30), Y(30), TT(30)
C
      COMMON /COBRA3/  DUM2  ,DUMC  ,DUM3  ,MN    ,MR    ,MS    ,MX    ,
     1          III   ,IA    ,IAAA  ,IAC   ,IALPHA,IAN   ,IANSWE,IB    ,
     1   ICCHAN,ICD   ,ICHFR ,ICON  ,ICOND ,ICP   ,ID    ,IDC   ,IDFDX ,
     2   IDHDX ,IDHYD ,IDHYDN,IDIST ,IDPDX ,IDPK  ,IDUR  ,IDR   ,IF    ,
     3   IFACTO,IFDIV ,IFINLE,IFLUX ,IFMULT,IFOLD ,IFSP  ,IFSPLI,IFXFLO,
     4   IGAP  ,IGAPN ,IGAPS ,IH    ,IHFILM,IHINLE,IHOLD ,IHPERI,IIDARE,
     5   IIDFUE,IIDGAP,IIK   ,IJBOIL,IJK   ,ILC   ,ILENGT,ILOCA ,ILR   ,
     6   IMCHFR,IMCFRC,IMCFRR,INTYPE,INWRAP,INWRPS,IP    ,IPERIM,IPH   ,
     7   IPHI  ,IPRNTC,IPRNTR,IPRNTN,IPW   ,IPWRF ,IQC   ,IQF   ,IQPRIM,
     8   IQUAL ,IRADIA,IRHO  ,IRHOOL,ISP   ,IT    ,ITDUMY,ITINLE,ITROD ,
     9   IU    ,IUH   ,IUSAVE,IUSTAR,IV    ,IVISC ,IVISCW,IVP   ,IVPA  ,
```

```
     A   IW     ,IWOLD ,IWP    ,IWSAVE,IX     ,IXCROS,IIA   ,IIB   ,IXPOLD
C-----------------------------------------------------------------------
C
C     READ INDICATORS.     INITIALISE
      READ (I2,1001) N1,N2,NGRID,NGRIDT,NODESF,NFUELT,NCHF, IMAP, ITEXT
      IF (N1.LE.15) GO TO 1
      WRITE (I3,2001)
      IERROR = 1
      RETURN
    1 IF (ITEXT.LE.0) GO TO 3
         DO 2 I=1,ITEXT
         READ (I2,1005) TEXT
    2    WRITE(I3,1005) TEXT
    3 NCHAN = N2
      NROD = N2
      J6 = 2
      NRAMP = 1
      GRID = .FALSE.
      NGRT = MAX0(NGRIDT,1)
      IPILE = J7
         DO 4 I=1,NCHAN
            DO 4 L=1,6
            IDAT(ILR+I+MR*(L-1))=0
            DATA(IPHI+I+MR*(L-1))=0.
            IF (L.GT.4) GO TO 4
            LC(I,L) = 0
            GAPS(I,L) = 0.0
            DIST(I,L) = 0.0
    4       CONTINUE
C
C        READ GEOM AND SPACER DATA FOR EACH CHANNEL GROUP. SET GROUP 1
         DO 10 J=1,N1
         READ (I2,1002) N,I,FRAC,AC(I),PW(I),PH(I),GAPS(I,1),DIST(I,1),
     *   DR(I),DATA(IPHI+I),M
         DATA(ICD+I)=0.
         FXF(1) = 0.0
         IF (FRAC.LE.0.0) FRAC = 1.0
         AC(I) = FRAC*AC(I)
         PW(I) = FRAC*PW(I)
         PH(I) = FRAC*PH(I)
         DATA(IPHI+I)=FRAC*DATA(IPHI+I)
         IF (NGRID.EQ.0) GO TO 6
         READ(I2,1003) (DATA(ICD+I+MC*(L-1)),L=1,NGRIDT),(FXF(L),
     *   L=1,NGRIDT)
    6    IDAT(INTYPE+I)=J
         IFRIC(J) = MAX0(N,1)
         IDAT(IIDFUE+I)=MAX0(M,1)
         IGROUP(J) = I
         IF (J.GT.1) GO TO 10
C        SET ALL CHANNELS TEMPORARILY TO GROUP 1 VALUES.
            DO 8 K=1,NCHAN
            AC(K) = AC(I)
```

```
            PW(K) = PW(I)
            PH(K) = PH(I)
            GAPS(K,1) = GAPS(I,1)
            DIST(K,1) = DIST(I,1)
            DR(K) = DR(I)
            DATA(IPHI  +K)=DATA(IPHI  +I)
            IDAT(INTYPE+K)=1
            IDAT(IIDFUE+K)=IDAT(IIDFUE+I)
               DO 8 L=1,NGRT
               DATA(ICD+K+MC*(L-1))=DATA(ICD+I+MC*(L-1))
    8          CONTINUE
   10    CONTINUE
         DO 12 K=1,MG
            DO 12 L=1,NGRT
   12       DATA(IFXFLO+K+MG*(L-1))=FXF(L)
C
C     READ ROD POWER FACTORS AND SPACER LOCATIONS.
      II = MINO(NROD,16)
      READ(I2,1003) (DATA(IRADIA+I),I=1,II)
      IF(DATA(IRADIA+1).GE.0.0)  GO TO 16
         DO 14 I=1,NROD
   14    DATA(IRADIA+I)=1.0
      GO TO 18
   16 IF(NROD.GT.16) READ(I2,1003) (DATA(IRADIA+I),I=17,NROD)
   18 IF (NGRID.GT.0) READ (I2,1004) (GRIDXL(I),IGRID(I),I=1,NGRID)
C
C     READ CHANNEL NUMBERS NOT IN GROUP 1, SET DATA
      JCHECK = 1
      IF (N1.EQ.1) GO TO 28
         DO 26 J=2,N1
         ICHECK = 0
   20    READ(I2,1001) (JB(I),I=1,20)
            DO 22 JJ=1,20
            K = JB(JJ)
            IF (K.LE.0) GO TO 24
            I = IGROUP(J)
            AC(K) = AC(I)
            PW(K) = PW(I)
            PH(K) = PH(I)
            GAPS(K,1) = GAPS(I,1)
            DIST(K,1) = DIST(I,1)
            DR(K) = DR(I)
            DATA(IPHI+K)=DATA(IPHI+I)
            IDAT(INTYPE+K)=J
            IDAT(IIDFUE+K)=IDAT(IIDFUE+I)
            IF (K.EQ.I) ICHECK=1
            IF (K.EQ.IGROUP(1) ) JCHECK=0
               DO 22 L=1,NGRT
               DATA(ICD+K+MC*(L-1))=DATA(ICD+I+MC*(L-1))
   22          CONTINUE
         GO TO 20
   24    IF (ICHECK.EQ.1) GO TO 26
```

```
         WRITE(I3,2002) J, IGROUP(J)
         IERROR = 1
         RETURN
  26     CONTINUE
      IF (JCHECK.EQ.1) GO TO 28
      J = 1
      WRITE(I3,2002) J, IGROUP(J)
      IERROR = 1
      RETURN
C
C     SET ROD POWER FRACTIONS AND CHANNEL PARAMETERS
 28   PHTOT = 0.0
      ATOTAL = 0.0
         DO 32 I = 1,NCHAN
            DO 30 J=1,NROD
 30         DATA(IPWRF+I+MC*(J-1))=0
         DATA(IPWRF+I+MC*(I-1))=DATA(IPHI +I)
         IDAT(ILR+I)=I
         DATA(ID+I)=DR(I)/12.0
         DATA(IPERIM+I)=PW(I)/12.0
         DATA(IHPERI+I)=PH(I)/12.0
         DATA(IAN   +I)=AC(I)/144.0
         DATA(IA    +I)=DATA(IAN+I)
         DC(I) = 4.*AC(I)/PW(I)
         DATA(IDHYD +I)=DC(I)/12.0
         DATA(IDHYDN+I)=DATA(IDHYD+I)
         PHTOT=PHTOT+   DATA(IHPERI+I)
 32      ATOTAL=ATOTAL+ DATA(IAN+I)
C
      IF (IPILE.EQ.1) GO TO 34
C     BWR.     NO CHANNEL INTERACTION
      NSCBC = 0
      NBBC = 1
      J5 = 0
      ABETA = 0.0
      BBETA = 0.0
      GK = 0.0
      NK=0
      GO TO 120
C
C     PWR.    READ AND SET GAP CONNECTIONS (IE BOUNDARIES)
C     IMAP=1 FOR RECTANGULAR MAP. SAY HOW MANY CHAN ACROSS AND DOWN.
C     IMAP=2 FOR PWR MAP. GIVE START AND END OF EACH ROW. LAST ROW ALL 0
C     IMAP=3 FOR CHANNEL-NUMBERED MAP. LAST ROW ALL 0.
C     IMAP=4 FOR SPECIFYING CHANNEL BOUNDARY NUMBERS
 34   NK = 0
      IRAD = 0
      ISIZE = 20
      NEXT = 1
      WRITE (I3,3001) IMAP
      IF (IMAP.EQ.4) GO TO 70
      IF (IMAP-2) 40,42,48
```

```
 40   READ (I2,1001) ICROSS, IDOWN
      ISTART = 1
      IEND = ICROSS
      GO TO 44
 42   READ(I2,1001) ISTART, IEND
 44   JS = 0
         DO 46 J=1,ISIZE
         MAAP(2,J) = 0
         IF ( (J.LT.ISTART) .OR. (J.GT.IEND) ) GO TO 46
         JS = JS+1
         MAAP(2,J) = JS
 46      CONTINUE
      GO TO 49
 48   READ (I2,1001) (MAAP(2,J),J=1,ISIZE)
C
C     SET BOUNDARIES FOR IMAP = 1,2,3
 49   JSMAX = 0
      WRITE (I3,3008)
         DO 66 I=1,ISIZE
C
C           SET BOUNDARIES ACROSS
            DO 50 J=1,ISIZE
            MAAP(1,J) = MAAP(2,J)
            JSMAX = MAX0(JSMAX,MAAP(2,J))
            IF (MAAP(2,J).NE.0) JMAX=J
            IF (J.EQ.ISIZE) GO TO 50
            IF ( (MAAP(2,J).EQ.0) .OR. (MAAP(2,J+1).EQ.0) ) GO TO 50
            NK = NK+1
            IDAT(IIK+NK) = MAAP(2,J)
            IDAT(IJK+NK) = MAAP(2,J+1)
 50         CONTINUE
         IF (I.GT.1) GO TO 51
         WRITE (I3,3002) (MAAP(1,J),J=1,JMAX)
         JUMP = 1
         GO TO 64
 51      IF (I.EQ.ISIZE) GO TO 66
         IF (IMAP-2) 52,54,60
 52      IF (I.GE.IDOWN) ISTART = ISIZE+1
         GO TO 56
 54      READ(I2,1001) ISTART, IEND
 56         DO 58 J=1,ISIZE
            MAAP(2,J) = 0
            IF ( (J.LT.ISTART) .OR. (J.GT.IEND) ) GO TO 58
            JS = JS+1
            MAAP(2,J) = JS
 58         CONTINUE
         GO TO 62
 60      READ(I2,1001) (MAAP(2,J),J=1,ISIZE)
 62      IC = NK
C
C           SET BOUNDARIES DOWN
            DO 63 J=1,ISIZE
```

```
               IF (MAAP(2,J).NE.0) JMAX=J
               IF ( (MAAP(1,J).EQ.0) .OR. (MAAP(2,J).EQ.0) ) GO TO 63
               NK = NK+1
               IDAT(IIK+NK) = MAAP(1,J)
               IDAT(IJK+NK) = MAAP(2,J)
 63            CONTINUE
            IF (IC.EQ.NK) GO TO 68
            WRITE (I3,3002) (MAAP(2,J),J=1,JMAX)
C           SET WOLD TO PRINT MAP OF RADIAL POWERS
            JUMP = 2
 64         IRAD = IRAD+1
            JB(IRAD) = JMAX
               DO 65 J=1,JMAX
               L = MAAP(JUMP,J)
               DATA(IWOLD+IRAD+MG*(J-1))=-100.
               IF (L.LE.0) GO TO 65
               DATA(IWOLD+IRAD+MG*(J-1))=DATA(IRADIA+L)
 65            CONTINUE
            IF (JUMP.EQ.1) GO TO 51
 66         CONTINUE
 68      CONTINUE
C
C        PRINT RADIAL POWER MAP
         WRITE (I3,3010)
            DO 69 I=1,IRAD
            JMAX = JB(I)
 69         WRITE(I3,3011)  (DATA(IWOLD+I+MG*(J-1)),J=1,JMAX)
         IF (JSMAX.EQ.NCHAN) GO TO 76
         WRITE (I3,2006) JSMAX,NCHAN
         IERROR = 1
         RETURN
C
C        SET BOUNDARIES FOR IMAP = 4
  70     READ (I2,1001) (JB(J),J=1,20)
            DO 74 I=1,20
            IF (JB(I).EQ.0) GO TO 76
            IF (NEXT.EQ.0) GO TO 72
            NK = NK+1
            IDAT(IIK+NK) = JB(I)
            NEXT = 0
            GO TO 74
 72         IDAT(IJK+NK) = JB(I)
            NEXT = 1
 74         CONTINUE
         GO TO 70
 76         DO 90 K=1,NK
 78         I=IDAT(IIK+K)
            IF(IABS(I)-IABS(IDAT(IJK+K)))  84,80,82
 80         WRITE(I3,2003)  K,I,IDAT(IJK+K)
            IERROR = 1
            RETURN
 82         IDAT(IIK+K) = IDAT(IJK+K)
```

```
      IDAT(IJK+K) = I
      GO TO 78
 84   M = IDAT(IJK+K)
         DO 86 L=1,4
         IF (LC(I,L).EQ.0) GO TO 88
 86     CONTINUE
      WRITE (I3,2004) K,M,I
      IERROR = 1
      RETURN
 88   LC(I,L) = M
      NG = IDAT(INTYPE+I)
      N = IGROUP(NG)
      GAPS(I,L)=AMAX1(GAPS(M,1),GAPS(N,1))
      DIST(I,L)=DIST(N,1)
      DATA(IGAPN+K)=GAPS(I,L)/12.0
      DATA(IGAP +K)=DATA(IGAPN+K)
      DATA(ILENGT+K)=DIST(I,L)/12.0
      DATA(IFACTO+K)=1.0
 90   CONTINUE
C
C     READ HALF-BOUNDARIES AND SET FACTOR(K) = 0.5
 92   READ (I2,1001) (JB(L),L=1,20)
      IF (JB(1).EQ.0) GO TO 110
      IEND = 100
      MARK = 1
         DO 98 M=1,10
         L = 2*M - 1
         JBL = JB(L)
         IF (JBL-JB(L+1)) 98,94,96
 94      IEND = M
         IF (JBL.EQ.0) GO TO 100
         WRITE (I3,2005) JBL,JB(L+1)
         IERROR = 1
         RETURN
 96      JB(L) = JB(L+1)
         JB(L+1) = JBL
 98      CONTINUE
 100  IC = MARK
         DO 102 K=1,NK
         IF((IDAT(IIK+K).NE.JB(MARK)).OR.
     1   (IDAT(IJK+K).NE.JB(MARK +1)))  GO TO 102
         DATA(IFACTO+K)=0.5
         MARK = MARK+2
         IF (MARK.EQ.IEND) GO TO 110
         IF (MARK.GE.20) GO TO 92
 102     CONTINUE
      IF (IC.LT.MARK) GO TO 100
      WRITE (I3,2005) JB(MARK), JB(MARK+1)
      IERROR = 1
      RETURN
C
 110  CALL ACOL(1,IDAT(IIK+1),IDAT(IJK+1),KMAX,IDAT(ILOCA+1),MA,MS,NK,
```

```
     *MG,IPILE)
 112  WRITE (I3,3003) NK
      M = 1
 114  MM = MIN0( (M+7),NK)
      WRITE(I3,3004)  M,(IDAT(IIK+K),IDAT(IJK+K),K=M,MM)
      M = MM+1
      IF (M.LE.NK) GO TO 114
      WRITE (I3,3005) NK
      M = 1
 116  MM = MIN0( (M+24),NK)
         DO 118 L=1,8
 118     WRITE(I3,3006)  L,(IDAT(ILOCA+K+MG*(L-1)) ,K=M,MM)
      M = MM+1
      WRITE (I3,3007)
      IF (M.LE.NK) GO TO 116
      L = MS*NK
      WRITE (I3,3009) MS,KMAX,L,MA
C
C     SET NTYPE BACK TO INDICATE FRICTION TYPE
 120     DO 122 I=1,NCHAN
         NG=IDAT(INTYPE+I)
         IDAT(INTYPE+I)=IFRIC(NG)
         IF (LC(I,1).GT.0) GO TO 122
         GAPS(I,1) = 0.0
         DIST(I,1) = 0.0
 122     CONTINUE
C
C     READ FUEL DATA
      IF(NODESF.EQ.0) GO TO 126
      READ(I2,1003) (KFUEL(I),CFUEL(I),RFUEL(I),DFUEL(I),
     1 KCLAD(I), CCLAD(I), RCLAD(I), TCLAD(I), HGAP(I),I=1,NFUELT)
         DO 124 I=1,NFUELT
         KFUEL(I) = KFUEL(I)/3600.
         KCLAD(I) = KCLAD(I)/3600.
         DFUEL(I) = DFUEL(I)/12.
         TCLAD(I) = TCLAD(I)/12.
 124     HGAP(I) = HGAP(I)/3600.
C
C     SET PRINT REQUIREMENTS
 126  IF (J1.GT.1) RETURN
      PRINT(4) = .TRUE.
      PRINT(7) = .TRUE.
      PRINT(8) = .TRUE.
      RETURN
C
C-----------------------------------------------------------------------
1001  FORMAT(20I4)
1002  FORMAT(I1,I4,8E9.3,I2)
1003  FORMAT(16E5.3)
1004  FORMAT(8(E5.3,I5))
1005  FORMAT(20A4)
2001  FORMAT(' CARDS4  N1.GT.15')
```

```
2002  FORMAT(' CARDS4  CHANNEL GROUP',I3,' CHANNEL',I4,' INCORRECT')
2003  FORMAT(' CARDS4  GAP CONNECTION ', I3, 'I AND J SAME IE ', 2I3)
2004  FORMAT(' CARDS4  GAP CONNECTION ', I3, '  CHANNEL ', I3,
     1 ' IS 5TH ADJACENT TO ', I3)
2005  FORMAT(' CARDS4  HALF-BOUNDARY ', I4, ' - ', I4, 'NOT IN BOUNDARY
     1SET')
2006  FORMAT(' CARDS4  HIGHEST NUMBER CHANNEL FOUND TO BE ', I3,
     1 ' AND THIS NOT EQUAL TO NUMBER SPECIFIED, IE ', I3)
3001  FORMAT(1H1, '  CHANNEL DATA SET IN SUBROUTINE CARDS4 ( IMAP =',
     1 I2, ' )', //)
3002  FORMAT( /,20I6)
3003  FORMAT(1H1, I5, ' BOUNDARIES AS BELOW (IK(K) - JK(K))', /)
3004  FORMAT(' (', I3, ') ', 8(6X, I3, ' - ', I3) )
3005  FORMAT(///, '  LOCA(K,8) ARRAY SET IN ACOL', 5X,'K = 1 TO ',I3,//)
3006  FORMAT(' (', I1, ') ', 25I5)
3007  FORMAT(/)
3008  FORMAT('  CHANNEL NUMBERING MAP', //)
3009  FORMAT(///, '  MAXIMUM OVERALL STRIPE WIDTH FOR ARRAY AAA IN DIVER
     1T = ', I3, ' FOR BOUNDARY NO. ', I3, //, '  REQUIRE ', I6,' STORES
     2 FOR AAA SIZE AND THIS OK SINCE LESS THAN ', I6, ' PROVIDED', //)
3010  FORMAT(1H1, '  RADIAL POWER MAP    (-100 OR *** INDICATES NO CHANN
     1EL)', /)
3011  FORMAT(/, 20F6.3)
C-----------------------------------------------------------------------
      END
```

```
C********************** SUBROUTINE CARD20 ******************************
      SUBROUTINE CARD20(NOPRIN)
C
      IMPLICIT INTEGER (I)
      DIMENSION NTHBOX(25,25),CARD(20)
      LOGICAL LDAT(1),GRID
      INTEGER IDAT(1)
      REAL KIJ, KF, KKF, KCLAD, KFUEL
C
      COMMON  DATA(1)
      EQUIVALENCE  (DATA(1),IDAT(1),LDAT(1))
C
      COMMON /COBRA1/  ABETA ,AFLUX ,ATOTAL,BBETA ,DIA   ,DT    ,DX    ,
     1   ELEV  ,FERROR,FLO   ,FTM   ,GC    ,GK    ,GRID  ,HSURF ,HF    ,
     2   HFG   ,HG    ,I2    ,I3    ,IERROR,IQP3  ,ITERAT,J1    ,J2    ,
     3   J3    ,J4    ,J5    ,J6    ,J7    ,KDEBUG,KF    ,KIJ   ,
     4   NAFACT,NARAMP,NAX   ,NAXL  ,NBBC  ,NCHAN ,NCHF  ,NDX   ,NF    ,
     5   NGAPS ,NGRID ,NGRIDT,NGTYPE,NGXL  ,NK    ,NODES ,NODESF,NPROP ,
     6   NRAMP ,NROD  ,NSCBC ,NV    ,NVISCW,PI    ,PITCH ,POWER ,PREF  ,
     7   QAX   ,RHOF  ,RHOG  ,SIGMA ,SL    ,TF    ,TFLUID,THETA ,THICK ,
     8   UF    ,VF    ,VFG   ,VG    ,Z
C
      COMMON /COBRA2/  AA(4), AF(7), AFACT(10,10), AV(7), AXIAL(30),
     1   AXL(10), BB(4), BX(30), CC(4), CCLAD(2), CFUEL(2), DFUEL(2),
     2   GAPXL(10), GFACT(9,10), GRIDXL(10), HGAP(2), HHF(30), HHG(30),
     3   IGRID(10), KCLAD(2), KFUEL(2), KKF(30), NCH(10), NGAP(9),
     4   PP(30), RCLAD(2),RFUEL(2),SSIGMA(30), TCLAD(2), UUF(30),
     5   VVF(30), VVG(30), XQUAL(30), Y(30), TT(30)
C
      COMMON /COBRA3/  MA    ,MC    ,MG    ,MN    ,MR    ,MS    ,MX    ,
     1          III   ,IA    ,IAAA  ,IAC   ,IALPHA,IAN   ,IANSWE,IB    ,
     1   ICCHAN,ICD   ,ICHFR ,ICON  ,ICOND ,ICP   ,ID    ,IDC   ,IDFDX ,
     2   IDHDX ,IDHYD ,IDHYDN,IDIST ,IDPDX ,IDPK  ,IDUR  ,IDR   ,IF    ,
     3   IFACTO,IFDIV ,IFINLE,IFLUX ,IFMULT,IFOLD ,IFSP  ,IFSPLI,IFXFLO,
     4   IGAP  ,IGAPN ,IGAPS ,IH    ,IHFILM,IHINLE,IHOLD ,IHPERI,IIDARE,
     5   IIDFUE,IIDGAP,IIK   ,IJBOIL,IJK   ,ILC   ,ILENGT,ILOCA ,ILR   ,
     6   IMCHFR,IMCFRC,IMCFRR,INTYPE,INWRAP,INWRPS,IP    ,IPERIM,IPH   ,
     7   IPHI  ,IPRNTC,IPRNTR,IPRNTN,IPW   ,IPWRF ,IQC   ,IQF   ,IQPRIM,
     8   IQUAL ,IRADIA,IRHO  ,IRHOOL,ISP   ,IT    ,ITDUMY,ITINLE,ITROD ,
     9   IU    ,IUH   ,IUSAVE,IUSTAR,IV    ,IVISC ,IVISCW,IVP   ,IVPA  ,
     A   IW    ,IWOLD ,IWP   ,IWSAVE,IX    ,IXCROS,IIA  ,IIB  ,IXPOLD
C
      COMMON/LINK3/DXX,ETIME,GIN,HIN,I8,IG,IN,ISAVE,JUMP,KASE,KT,MAXT,
     1 NDT,NDXP1,NFUELT,NG,NH,NJUMP,NOUT,NP,NPCHAN,NPNODE,NPROD,NQ,NR,
     2 NSKIPT,NSKIPX,NTRIES,PEXIT,PHTOT,SAVEDT,TIN,TTIME,ZZ
C-----------------------------------------------------------------------
C
      WRITE (I3,1010)
         DO 2 ND1 = 1,20
            DO 2 ND2 = 1,20
  2         NTHBOX(ND1,ND2) = 0
      NTHBXX = 0
```

```
      READ (I2,1001) CARD, IMAP, ND1X, ND2X
      WRITE (I3,1011) CARD
      IF ( (ND1X.LE.25) .AND. ( ND2X.LE.25) ) GO TO 4
      WRITE (I3,1012) ND1X,ND2X
      STOP
    4 IF (IMAP-2) 6,10,14
C
C     IMAP = 1.   RECTANGULAR MATRIX
    6    DO 8 ND2 = 1,ND2X
            DO 8 ND1 = 1,ND1X
            NTHBXX = NTHBXX+1
    8       NTHBOX(ND1,ND2) = NTHBXX
      GO TO 18
C
C     IMAP = 2.   GIVE START AND END OF EACH ROW.
   10    DO 12 ND2=1,ND2X
         READ (I2,1001) CARD, ISTART, IFIN
         WRITE (I3,1013) ND2, CARD
            DO 12 ND1=1,ND1X
            IF ( (ND1.LT.ISTART) .OR. (ND1.GT.IFIN) ) GO TO 12
            NTHBXX = NTHBXX+1
            NTHBOX(ND1,ND2) = NTHBXX
   12       CONTINUE
      GO TO 18
C
C     IMAP = 3.   READ NTHBOX
   14 MAXRD = 14
      MP1 = MAXRD+1
      MORE = ND1X - MAXRD
         DO 16 ND2 = 1,ND2X
         READ (I2,1001) CARD, (NTHBOX(ND1,ND2),ND1=1,MAXRD)
         WRITE (I3,1014) ND2, CARD
         IF (MORE.LE.0) GO TO 15
         READ (I2,1001) CARD, (NTHBOX(ND1,ND2),ND1=MP1,ND1X)
         WRITE (I3,1014) ND2, CARD
   15       DO 16 ND1=1,ND1X
            IF (NTHBOX(ND1,ND2).GT.NTHBXX) NTHBXX=NTHBOX(ND1,ND2)
   16       CONTINUE
C
C     READ HEAT FLUX PARAMETERS.
   18 READ (I2,1003) CARD, N1, AFLUX
      WRITE (I3,1015) CARD
      IF (N1.GT.1) GO TO 22
      IQP3 = N1
         DO 20 I=1,NTHBXX
   20    DATA(IRADIA+I) = 1.0
      GO TO 24
   22 NAX = N1
      CALL READIN(8,NAX,Y,AXIAL,CARD,2)
      CALL READIN(9,NTHBXX,DATA(IRADIA+1),CARD,CARD,1)
   24 READ (I2,1004) CARD,Z, NDX, NDT, TTIME
      WRITE (I3,1016) CARD
```

```
      CALL ITHO(NTHBOX,NTHBXX,ND1X,ND2X)
      IF (NOPRIN.EQ.0) CALL TIDY
      CALL PRECAL
      RETURN
C
C-----------------------------------------------------------------------
1001  FORMAT(20A4, T1, 14I5)
1003  FORMAT(20A4, T1, I5, 13E5.0)
1004  FORMAT(20A4, T1, E5.0, 2I5, 10E5.0)
1010  FORMAT(1H1, 42X, 'COBRA INPUT DATA', /, 43X,
     1 '----------------', //, '  NB. DATA READ FROM CARD20 WOULD BE REA
     2D OR SET WITH THE NEUTRONICS DATA IN MEKIN', ///, '  CARD IMAGES',
     3 /, 2X, '---- ------', /, 32X, '0....*....1....*....2....*....3...
     4.*....4....*....5....*....6....*....7....*....8')
1011  FORMAT('  IMAP ND1X ND2X', 14X, '***', 20A4, '*** CARD20')
1012  FORMAT('  INPUT DATA ERROR IN CARD20. ND1X, ND2X = ', 2I5,
     1 ' IE GREATER THAN 25 FOR EACH ALLOWED')
1013  FORMAT('  ND2=',I3, ' ISTART IFIN', 9X, '***', 20A4, '*** CARD20')
1014  FORMAT('  ND2=', I3, ' NTHBOX', 14X, '***', 20A4, '*** CARD20')
1015  FORMAT('  NAX AFLUX', 19X, '***', 20A4, '*** CARD20')
1016  FORMAT('  Z NDX NDT TTIME', 13X, '***', 20A4, '*** CARD20')
C-----------------------------------------------------------------------
      END
```

```
C*********************** SUBROUTINE CHAN *********************************
      SUBROUTINE CHAN(IPART,NTHBOX,NTHBXX,ND1X,ND2X)
C
      IMPLICIT INTEGER (I)
      DIMENSION CARD(20),CDG(5),GP(250),JBSTOR(150),JB(20),
     1 NTHBOX(25,25),GAPREC(400)
      INTEGER IDAT(1)
      LOGICAL LDAT(1),GRID,PRINT
      REAL KIJ, KF, KKF, KCLAD, KFUEL
C
      COMMON  DATA(1)
      EQUIVALENCE  (DATA(1),IDAT(1),LDAT(1))
C
      COMMON /COBRA1/  ABETA ,AFLUX ,ATOTAL,BBETA ,DIA   ,DT    ,DX    ,
     1   ELEV  ,FERROR,FLO   ,FTM   ,GC    ,GK    ,GRID  ,HSURF ,HF    ,
     2   HFG   ,HG    ,I2    ,I3    ,IERROR,IQP3  ,ITERAT,J1    ,J2    ,
     3   J3    ,J4    ,J5    ,J6    ,J7    ,KDEBUG,KF    ,KIJ   ,
     4   NAFACT,NARAMP,NAX   ,NAXL  ,NBBC  ,NCHAN ,NCHF  ,NDX   ,NF    ,
     5   NGAPS ,NGRID ,NGRIDT,NGTYPE,NGXL  ,NK    ,NODES ,NODESF,NPROP ,
     6   NRAMP ,NROD  ,NSCBC ,NV    ,NVISCW,PI    ,PITCH ,POWER ,PREF  ,
     7   QAX   ,RHOF  ,RHOG  ,SIGMA ,SL    ,TF    ,TFLUID,THETA ,THICK ,
     8   UF    ,VF    ,VFG   ,VG    ,Z
C
      COMMON /COBRA2/  AA(4), AF(7), AFACT(10,10), AV(7), AXIAL(30),
     1   AXL(10), BB(4), BX(30), CC(4), CCLAD(2), CFUEL(2), DFUEL(2),
     2   GAPXL(10), GFACT(9,10), GRIDXL(10), HGAP(2), HHF(30), HHG(30),
     3   IGRID(10), KCLAD(2), KFUEL(2), KKF(30), NCH(10), NGAP(9),
     4   PP(30), RCLAD(2),RFUEL(2),SSIGMA(30), TCLAD(2), UUF(30),
     5   VVF(30), VVG(30), XQUAL(30), Y(30), TT(30)
C
      COMMON /COBRA3/  MA    ,MC    ,MG    ,MN    ,MR    ,MS    ,MX    ,
     1          III   ,IA    ,IAAA  ,IAC   ,IALPHA,IAN   ,IANSWE,IB    ,
     1   ICCHAN,ICD   ,ICHFR ,ICON  ,ICOND ,ICP   ,ID    ,IDC   ,IDFDX ,
     2   IDHDX ,IDHYD ,IDHYDN,IDIST ,IDPDX ,IDPK  ,IDUR  ,IDR   ,IF    ,
     3   IFACTO,IFDIV ,IFINLE,IFLUX ,IFMULT,IFOLD ,IFSP  ,IFSPLI,IFXFLO,
     4   IGAP  ,IGAPN ,IGAPS ,IH    ,IHFILM,IHINLE,IHOLD ,IHPERI,IIDARE,
     5   IIDFUE,IIDGAP,IIK   ,IJBOIL,IJK   ,ILC   ,ILENGT,ILOCA ,ILR   ,
     6   IMCHFR,IMCFRC,IMCFRR,INTYPE,INWRAP,INWRPS,IP    ,IPERIM,IPH   ,
     7   IPHI  ,IPRNTC,IPRNTR,IPRNTN,IPW   ,IPWRF ,IQC   ,IQF   ,IQPRIM,
     8   IQUAL ,IRADIA,IRHO  ,IRHOOL,ISP   ,IT    ,ITDUMY,ITINLE,ITROD ,
     9   IU    ,IUH   ,IUSAVE,IUSTAR,IV    ,IVISC ,IVISCW,IVP   ,IVPA  ,
     A   IW    ,IWOLD ,IWP   ,IWSAVE,IX    ,IXCROS,IIA   ,IIB   ,IXPOLD
C
      COMMON/LINK2/CROSS(6),FG(30),FH(30),FP(30),FQ(30),IM(9),JM(9),
     1OUTPUT(10),PRINT(12),TEXT(17),YG(30),YH(30),YP(30),YQ(30)
      COMMON/LINK3/DXX,ETIME,GIN,HIN,I8,IG,IN,ISAVE,JUMP,KASE,KT,MAXT,
     1 NDT,NDXP1,NFUELT,NG,NH,NJUMP,NOUT,NP,NPCHAN,NPNODE,NPROD,NQ,NR,
     2 NSKIPT,NSKIPX,NTRIES,PEXIT,PHTOT,SAVEDT,TIN,TTIME,ZZ
      COMMON/LINK4/IFRM,IHTM,IPROP,NCC,NCF,NDM1,NDS,NGP
C
      COMMON/FRDATA/BURN,CPR,EFFB,EPSF,EXPR,FPRESS,FPU02,FRAC,FTD,
     1  GMIX(4),GRGH,PGAS,RADR,RDELT,THC,THG
```

```
      COMMON/ITPSV/ITMP
      COMMON /GAPFAC/ FACSL(100), FACSLK(100)
C-----------------------------------------------------------------------
C
C     IPART = 1   READ CHANNEL INPUT DATA
C     IPART = 2   PRINT CHANNEL INPUT DATA
C     OWN-ARRAY MAX SIZES. CARD(20), CDG(NGRIDT), GP(NCHAN ), JB(MAXRD),
C       JBSTOR(NCTYP+3+NUMBER OF CHANNELS NOT OF TYPE 1)
C     DEFINE JBSTOR(L),L=1,NCTYP+1 = ARRAY POSITIONS STARTING EACH TYPE,
C     JBSTOR(NCTYP+2) = A CHANNEL NUMBER OF TYPE 1,
C     CHN OF TYPE N IN JBSTOR(L),L=J,K WHERE J=JBSTOR(N),K=JBSTOR(N+1)-1
C-----------------------------------------------------------------------
C
      IF (IPART.EQ.2) GO TO 102
      JBSTOR(3)=0
      JBSTOR(4)=0
      MAXRD = 14
      NFUELT = 1
      NCHAN  = NTHBXX
      ITMP=0
      READ (I2,1001) CARD,IPILE,NCTYP,NGRID,NGRIDT,NODESF,NFXF,IFRM,
     1  IHTM,IPROP
      WRITE (I3,1002) CARD
      IF(NODESF.EQ.0) GO TO 2
      IF (IFRM.EQ.0.AND.IHTM.EQ.0) GO TO 2
      READ(I2,2016) CARD,EPSF
      WRITE(I3,2009) CARD
C     IF EPSF=0. THEN SET TO DEFAULT VALUE
      IF (EPSF.EQ.0.) EPSF=0.01
  2   NROD = NCHAN
      J6 = 2
      NRAMP = 1
      GRID = .FALSE.
      NGRT = MAX0(NGRIDT,1)
      J7 = IPILE
         DO 1109 I=1,MC
            DO 1109 J=1,MR
1109        DATA(IPWRF+I+MC*(J-1))=0.0
         DO 4  I=1,MR
            DO 4  L=1,6
            IDAT(ILR+I+MR*(L-1))=0
            DATA(IPHI+I+MR*(L-1)) =0.0
  4        CONTINUE
C
C     READ AND SET CHANNEL DATA. (A) CHANNEL PARAMETERS, (B) GRID DATA,
C     (C) CHANNELS MAKING EACH TYPE (EXCEPT TYPE 1)
      JBIC = NCTYP+2
      JBSTOR(1) = JBIC
      JBSTOR(2) = JBIC+1
         DO 20 I=1,NCTYP
         READ(I2,1003)CARD,N,J,FRAC,GAPWV,HRNUM,HRDI,CRNUM,CRDI,SIDE,
     *   CORN
```

```
      WRITE(I3,1004) I,CARD
      IF(FRAC.LE.0.0) FRAC=1.0
      IF(J.EQ.2) GO TO 6
      CHAR=CRNUM
      CHPW=CRDI
      CHPH=SIDE
      GO TO 8
 6    CHAR = SIDE*SIDE - 4.0*CORN*CORN - PI*(0.25*HRNUM*HRDI*HRDI
     1 + 0.25*CRNUM*CRDI*CRDI - CORN*CORN)
      CHPH=HRNUM*PI*HRDI
      CHPW=CHPH+4.0*(SIDE-2.0*CORN)+2.0*PI*CORN+CRNUM*PI*CRDI
 8    CHDI = 4.0*CHAR/CHPW
      CDG(1)=0.0
      IF(NGRID.LE.0) GO TO 9
      READ(I2,1005) CARD,(CDG(L),L=1,NGRIDT)
      WRITE(I3,1006) I,CARD
 9    M=1
      IF(I.EQ.1) GO TO 12
      IFIRST=1
10    READ(I2,1001) CARD,(JB(L),L=1,MAXRD)
      IF(IFIRST.EQ.0) WRITE(I3,1008) CARD
      IF (IFIRST.EQ.0) GO TO 12
      WRITE(I3,1007) I,CARD
      IFIRST=0
      M=JB(1)
      IF((M.GT.0).AND.(M.LE.NCHAN )) GO TO 12
      IERROR=1
      WRITE(I3,2001) I,M
      RETURN
12    DATA(IA+M) = CHAR*FRAC/144.0
      DATA(IPERIM+M) = CHPW*FRAC/12.0
      DATA(IHPERI+M) = CHPH*FRAC/12.0
      DATA(IPHI+M) = HRNUM*FRAC
      DATA(IDHYD+M) = CHDI/12.0
      DATA(ID+M) = HRDI/12.0
      IDAT(INTYPE+M) = MAX0(N,1)
      GP(M)=GAPWV
         DO 18 L=1,NCHAN
         J=L
         IF(I.EQ.1) GO TO 14
         IF(L.GT.MAXRD) GO TO 10
         J=JB(L)
         IF(J.LE.0) GO TO 20
         JBIC=JBIC+1
         JBSTOR(JBIC)=J
         JBSTOR(I+1) = JBIC+1
14       DATA(IA+J) = DATA(IA+M)
         DATA(IAN+J) = DATA(IA+M)
         DATA(IPERIM+J) = DATA(IPERIM+M)
         DATA(IHPERI+J) = DATA(IHPERI+M)
         DATA(IDHYD+J) = DATA(IDHYD+M)
         DATA(IDHYDN+J) = DATA(IDHYD+M)
```

```
            DATA(IDR+J) = DATA(ID+M)*12.
            DATA(ID +J) = DATA(ID+M)
            GP(J) = GP(M)
            IDAT(INTYPE+J) = IDAT(INTYPE+M)
            IDAT(IIDFUE+J) = 1
            IF(DATA(IRADIA+J).EQ.0.0) GO TO 17
            DATA(IPHI+J) = DATA(IPHI+M)
            DATA(IPHI+J+MR*(1-1))=DATA(IPHI+M)
            DATA(IPWRF+J+MC*(J-1)) = DATA(IPHI+M)
            IDAT(ILR+J) = J
            IDAT(ILR+J+MR*(1-1)) =J
 17         CONTINUE
               DO 16 K=1,NGRT
 16            DATA(ICD+J+MC*(K-1)) = CDG(K)
 18         CONTINUE
 20      CONTINUE
C
C     SET CHANNEL OF TYPE 1 INTO JBSTOR
      L = JBSTOR(2)
      M = JBSTOR(NCTYP+1) - 1
         DO 26 I=1,NCHAN
            DO 24 J=L,M
            IF (JBSTOR(J).EQ.I) GO TO 26
 24         CONTINUE
         JBSTOR(NCTYP+2) = I
         GO TO 28
 26      CONTINUE
C
 28   IF (NGRID.EQ.0) GO TO 30
C     READ GRID POSITIONS
      READ (I2,1009) CARD,(GRIDXL(I),IGRID(I),I=1,7)
      WRITE (I3,1010) CARD
      IF (NGRID.LE.10) GO TO 29
      WRITE (I3,2007) NGRID
      STOP
 29   IF (NGRID.LE.7) GO TO 30
      READ (I2,1009) CARD,(GRIDXL(I),IGRID(I),I=8,NGRID)
      WRITE (I3,1010) CARD
C     READ ROD LAYOUT
 30   IF(IPILE) 2031,2031,2032
2031  READ(I2,2033) CARD,NN11,NN22,NN33,NN44,ITMP
      WRITE(I3,2034) CARD
      IF (IFRM.EQ.1.AND.NN44.NE.1) GO TO 146
      NROD=NN22
      IF (NN11.EQ.0) GO TO 2182
         DO 2181 J=1,NN11
         READ (I2,2035) CARD,N,I,DATA(IDR+I),DATA(IRADIA+I),
     1   (IDAT(ILR+I+MR*(L-1)),DATA(IPHI+I+MR*(L-1)),L=1,6)
         WRITE (I3,2047) CARD
         IDAT(IIDFUE+I)=N
         IF(N.LT.1) IDAT(IIDFUE+I)=1
2181     CONTINUE
```

```
2182     DO 2185 I=1,NROD
            DO 2184 L=1,6
            IF(IDAT(ILR+I+MR*(L-1))) 2184,2184,2183
2183        K=IDAT(ILR+I+MR*(L-1))
            DATA (IPWRF+K+MC*(I-1))=DATA(IPHI+I+MR*(L-1))
2184        CONTINUE
2185     DATA(ID+I)=DATA(IDR+I)/12.
      IF(J1.LE.1) PRINT(8)=.TRUE.
      NODESF=NN33
      NFUELT=NN44
2032  IF(NODESF.EQ.0) GO TO 34
C
C     READ FUEL THERMAL DATA
      READ(I2,1005) CARD, (KFUEL(I),CFUEL(I),RFUEL(I),DFUEL(I),
     1 KCLAD(I), CCLAD(I), RCLAD(I), TCLAD(I), HGAP(I),I=1,NFUELT)
      WRITE (I3,1011) CARD
      IF(IFRM.EQ.0) GO TO 31
      READ(I2,1003)CARD,NCF,NCC,THG
      WRITE(I3,2010)CARD
      THG=THG/12.
      IF ((NCF+NCC+1).NE.NODESF) GO TO 146
      IF(NODESF.GT.21) GO TO 146
      IF (IPROP.EQ.0) GO TO 31
      READ(I2,1005)CARD,FTD,FPUO2
      WRITE(I3,2012)CARD
      IF(IPROP.LE.1) GO TO 31
      READ(I2,1005)CARD,BURN,CPR,EXPR,FPRESS,GRGH,GMIX,PGAS
      WRITE(I3,2014)CARD
      IF((GMIX(1)+GMIX(2)+GMIX(3)+GMIX(4)).GT.1.01) GO TO 146
      GRGH=GRGH/12.
 31      DO 32 I=1,NFUELT
         KFUEL(I) = KFUEL(I)/3600.
         KCLAD(I) = KCLAD(I)/3600.
         DFUEL(I) = DFUEL(I)/12.
         TCLAD(I) = TCLAD(I)/12.
 32      HGAP(I) = HGAP(I)/3600.
C
C     SET WHOLE-CHANNEL AREA AND PH
 34   ATOTAL = 0.0
      PHTOT = 0.0
         DO 36 I=1,NCHAN
         ATOTAL = ATOTAL + DATA(IA+I)
 36      PHTOT = PHTOT + DATA(IHPERI+I)
      NK = 0
      IF (IPILE.EQ.2) GO TO 999
C
C     SET GAP BOUNDARY NUMBERING SYSTEM (PWR ONLY)
      IF(IPILE.GT.0) GO TO 3010
         DO 242 ND2=1,ND2X
            DO 238 ND1=2,ND1X
            I=NTHBOX(ND1-1,ND2)
            J=NTHBOX(ND1,ND2)
```

```
              IF((I.LE.0).OR.(J.LE.0)) GO TO  238
              IF((I-J).EQ.0) GO TO  238
              NKK=NK
              IF(NKK.LE.0) NKK=1
                 DO 5216 K=1,NKK
                 IF((I.EQ.IDAT(IIK+K)).OR.(I.EQ.IDAT(IJK+K))) GO TO 5215
                 GO TO 5216
 5215            IF((J.EQ.IDAT(IJK+K)).OR.(J.EQ.IDAT(IIK+K))) GO TO 238
 5216            CONTINUE
              NK=NK+1
              IDAT(IIK+NK) = I
              IDAT(IJK+NK) = J
  238         CONTINUE
           IF(ND2.EQ.ND2X) GO TO  242
              DO 240 ND1=1,ND1X
              J=NTHBOX(ND1,ND2)
              I=NTHBOX(ND1,ND2+1)
              IF((I.LE.0).OR.(J.LE.0)) GO TO  240
              IF((I-J).EQ.0) GO TO  240
               NKK=NK
               IF(NKK.LE.0) NKK=1
                 DO 6216 K=1,NKK
                 IF((I.EQ.IDAT(IIK+K)).OR.(I.EQ.IDAT(IJK+K))) GO TO 6215
                 GO TO 6216
 6215            IF((J.EQ.IDAT(IJK+K)).OR.(J.EQ.IDAT(IIK+K))) GO TO 240
 6216            CONTINUE
              NK=NK+1
              IDAT(IIK+NK) = I
              IDAT(IJK+NK) = J
  240         CONTINUE
  242      CONTINUE
        GO TO 3020
 3010      DO 42 ND2=1,ND2X
              DO 38 ND1=2,ND1X
              I=NTHBOX(ND1-1,ND2)
              J=NTHBOX(ND1,ND2)
              IF((I.LE.0).OR.(J.LE.0)) GO TO 38
              NK=NK+1
              IDAT(IIK+NK) = I
              IDAT(IJK+NK) = J
  38          CONTINUE
           IF(ND2.EQ.ND2X) GO TO 42
              DO 40 ND1=1,ND1X
              J=NTHBOX(ND1,ND2)
              I=NTHBOX(ND1,ND2+1)
              IF((I.LE.0).OR.(J.LE.0)) GO TO 40
              NK=NK+1
              IDAT(IIK+NK) = I
              IDAT(IJK+NK) = J
  40          CONTINUE
  42       CONTINUE
C
```

```
C     SET GAP BOUNDARY PARAMETERS
3020  IF(IPILE.GT.0) GO TO 9006
      M=1
9014  MM=MIN0((M+13),NK)
      READ (I2,9007) CARD,(GAPREC(I),I=M,MM)
      WRITE(I3,9107) CARD
      M=MM+1
      IF(M.LE.NK) GO TO 9014
      IF (ITMP.EQ.0) GO TO 9076
      IF (NK.LE.100) GO TO 9012
      WRITE(I3,9010)
      GO TO 146
C
C     READ TRANSVERSE MOMENTUM COUPLING PARAMTERS
9012  M=1
9020  MM=MIN0((M+6),NK)
      READ(I2,9007) CARD,(FACSL(I),FACSLK(I),I=M,MM)
      WRITE(I3,9025) CARD
      M=MM+1
      IF(M.LE.NK) GO TO 9020
9076     DO 9008 K=1,NK
9078     I=IDAT(IIK+K)
         IF (I-IDAT(IJK+K)) 9084,9080,9082
9080     WRITE(I3,2003) K,I,IDAT(IJK+K)
         IERROR=1
         RETURN
9082     IDAT(IIK+K)=IDAT(IJK+K)
         IDAT(IJK+K)=I
         GO TO 9078
9084     M=IDAT(IJK+K)
         DATA(IGAPN+K)=GAPREC(K)/12.
         DATA(IGAP+K)=DATA(IGAPN+K)
         DATA(ILENGT+K)=0.0
         DATA(IFACTO+K)=1.0
9008     CONTINUE
      GO TO 9009
9006     DO 90 K=1,NK
 78      I =  IDAT(IIK+K)
         IF (I-IDAT(IJK+K)) 84,80,82
 80      WRITE (I3,2003) K,I,IDAT(IJK+K)
         IERROR = 1
         RETURN
 82      IDAT(IIK+K) = IDAT(IJK+K)
         IDAT(IJK+K) = I
         GO TO 78
 84      M = IDAT(IJK+K)
         DATA(IGAPN+K) = 0.5*(GP(I)+GP(M))/12.0
         DATA(IGAP+K) = DATA(IGAPN+K)
         DATA(ILENGT+K) = 0.0
         DATA(IFACTO+K) = 1.0
 90      CONTINUE
9009  CONTINUE
```

```
C
C     SET LOCA ARRAY
C     DYNAMIC STORAGE CALL TO CORE2 FROM ACOL TO SET MA, MS IF GAPS.
      CALL ACOL(1,IDAT(IIK+1),IDAT(IJK+1),KMAX,IDAT(ILOCA+1),MA,MS,NK,
     *MG,IPILE)
C
      IF (IPILE.EQ.0) GO TO 99
C
C     READ HALF-BOUNDARIES AND SET FACTOR(K)=0.5
      MMAX=MAXRD/2
 92   READ(I2,1001) CARD, (JB(L),L=1,MAXRD)
      WRITE(I3,1012) CARD
      MM = 0
         DO 98 M=1,MMAX
         MM = MM+1
         L=2*M-1
         IF(JB(L).LE.0) GO TO 99
         I=MIN0(JB(L),JB(L+1))
         J=MAX0(JB(L),JB(L+1))
            DO 94 K=1,NK
            IF ( (I.EQ.IDAT(IIK+K)) .AND. (J.EQ.IDAT(IJK+K)) ) GO TO 96
 94         CONTINUE
         IERROR=1
         WRITE(I3,2005) MM,I,J
         RETURN
 96      DATA(IFACTO+K) = 0.5
 98      CONTINUE
      GO TO 92
C
C     READ FORCED FLOW BOUNDARIES HERE IF PROGRAMMED LATER
 99      DO 100 K=1,NK
            DO 100 L=1,5
 100        DATA(IFXFLO+K+MG*(L-1)) = 0.0
 999  IF (NFXF.EQ.0) GO TO 101
      WRITE (I3,1013)
      IERROR = 1
 101  CONTINUE
      RETURN
C
C     IPART = 2.   PRINT CHANNEL DATA
 102  IPILE=J7
      WRITE(I3,1040) IPILE,NCHAN ,NCTYP,NGRID,NGRIDT,NODESF,NFXF
      IF(NODESF.GT.0) WRITE(I3,1045) IFRM,IHTM,IPROP
      WRITE(I3,1050)
C
C     DRAW MAP OF CHANNELS AND CHECK TOTAL
      NUMCH=0
         DO 106 ND2=1,ND2X
         IMAX=0
            DO 104 ND1=1,ND1X
            NUMCH=MAX0(NUMCH,NTHBOX(ND1,ND2))
            IF(NTHBOX(ND1,ND2).GT.0) IMAX=ND1
```

```
 104        CONTINUE
         IF(IMAX.EQ.0) GO TO 108
         WRITE(I3,1052) (NTHBOX(I,ND2),I=1,IMAX)
 106     CONTINUE
 108  IF(NUMCH.EQ.NCHAN ) GO TO 110
      IERROR=1
      WRITE(I3,2006) NUMCH,NCHAN
      RETURN
C
C     PRINT CHANNEL NUMBER IN EACH TYPE
 110  IF (NCTYP.EQ.1) GO TO 115
      WRITE (I3,1053)
         DO 114 I=2,NCTYP
         L=JBSTOR(I)
         M=JBSTOR(I+1) - 1
         WRITE(I3,1054) I,(JBSTOR(K),K=L,M)
 114     CONTINUE
C
C     PRINT CHANNEL DATA FOR EACH TYPE
 115  WRITE(I3,1055)
         DO 116 I=1,NCTYP
         L=JBSTOR(I)
         J=JBSTOR(L)
         DROD = DATA(ID+J)*12.0
 116     WRITE(I3,1056) I,IDAT(INTYPE+J),DATA(IA+J),DATA(IPERIM+J),
     1   DATA(IHPERI+J), DATA(IPHI+J), DROD, GP(J)
C
C     PRINT GRID DATA
      IF(NGRID.GT.0) GO TO 118
      WRITE(I3,1057)
      GO TO 124
 118  WRITE(I3,1058) NGRID,NGRIDT,(IGRID(I),GRIDXL(I),I=1,NGRID)
      WRITE(I3,1059) NGRIDT
      ITMAX = 1
      IF (NFXF.GT.0) ITMAX = 2
         DO 122 ITTR=1,ITMAX
            DO 120 I=1,NCTYP
            L=JBSTOR(I)
            J=JBSTOR(L)
            IF(ITTR.EQ.1) WRITE(I3,1060) I,(DATA(ICD+J+MC*(K-1)),
     *      K=1,NGRIDT)
            IF(ITTR.EQ.2) WRITE(I3,1060) I,(DATA(IFXFLO+J+MG*(K-1))
     *      ,K=1,NGRIDT)
 120        CONTINUE
         IF(ITTR.LT.ITMAX) WRITE(I3,1061) NGRIDT
 122     CONTINUE
C
 124  IF(IPILE.GT.0) GO TO 125
      WRITE(I3,2008) (I,IDAT(IIDFUE+I),DATA(IDR+I),DATA(IRADIA+I),
     1(DATA(IPHI+I+MR*(L-1)),IDAT(ILR+I+MR*(L-1)),L=1,6),I=1,NROD)
C
C     PRINT FUEL THERMAL DATA
```

```
 125  IF(NODESF.EQ.0) GO TO 130
      WRITE (I3,1062) NODESF
         DO 126 J=1,NFUELT
         WV1 = KFUEL(J)*3600.0
         WV2 = DFUEL(J)*12.0
         WV3 = KCLAD(J)*3600.0
         WV4 = TCLAD(J)*12.0
         WV5 = HGAP(J)*3600.0
 126     WRITE(I3,1063) J,WV1,CFUEL(J),RFUEL(J),WV2,WV3,CCLAD(J),
     *   RCLAD(J),WV4,WV5
      IF(IFRM.EQ.1) WV6=THG*12.
      IF(IFRM.EQ.1) WRITE(I3,1080) NCF,NCC,WV6
      IF(IPROP.GE.1) WRITE(I3,1082) FTD,FPUO2
      IF(IPROP.EQ.2) WRITE(I3,1084) BURN,CPR,EXPR,FPRESS,GRGH,GMIX,PGAS
      IF(IHTM.EQ.1) WRITE(I3,1090)
      IF(IHTM.EQ.2) WRITE(I3,1092)
C
 130  IF (IPILE.EQ.2) GO TO 144
      IF(IPILE.EQ.0) GO TO 132
         DO 131 K=1,NK
 131     GAPREC(K)=DATA(IGAPN+K)*12.0
C
C     PRINT ARRAYS IK, JK AND LOCA
 132  WRITE (I3,1064)
      WRITE (I3,1065) NK
      M = 1
 134  MM=MINO((M+5),NK)
      WRITE (I3,1066) M,(IDAT(IIK+K),IDAT(IJK+K),GAPREC(K),K=M,MM)
      M = MM+1
      IF (M.LE.NK) GO TO 134
      WRITE (I3,1067) NK

      M = 1
 136  MM = MINO( (M+24),NK)
      IF (IPILE.GT.0) GO TO 4207
         DO 8138 L=1,14
8138     WRITE(I3,1068) L,(IDAT(ILOCA+K+MG*(L-1)),K=M,MM)
      GO TO 4208
4207     DO 138 L=1,8
 138     WRITE (I3,1068) L, (IDAT(ILOCA+K+MG*(L-1)),K=M,MM)
4208  M=MM+1
      WRITE (I3,1069)
      IF (M.LE.NK) GO TO 136
      L = MS*NK
      WRITE (I3,1070) MS,KMAX,L,MA
      IF (ITMP.EQ.0) GO TO 139
C
C     PRINT TRANSVERSE MOMENTUM COUPLING PARAMTERS
      WRITE(I3,1076)
      WRITE(I3,1078) (K,FACSL(K),FACSLK(K),K=1,NK)
C
C     PRINT HALF-BOUNDARIES
```

```
  139 IC = 0
        DO 140 K=1,NK
        IF (DATA(IFACTO+K).EQ.1.0) GO TO 140
        IC = IC+1
        JBSTOR(IC) = K
  140   CONTINUE
      IF (IC.GT.1) GO TO 142
      WRITE (I3,1072)
      GO TO 144
  142 WRITE (I3,1073) (JBSTOR(K),K=1,IC)
  144 CONTINUE
      WRITE (I3,1074)
      RETURN
C
  146 WRITE(I3,1000)
      IERROR=1
      RETURN
C
C-----------------------------------------------------------------------
 1000 FORMAT(1H ,' INPUT ERROR DETECTED BY CHAN.')
 1001 FORMAT(20A4, T1, 14I5)
 1002 FORMAT('  INDICATORS', 18X, '***', 20A4, '*** CHAN')
 1003 FORMAT(20A4, T1, 2I5, 8E5.0)
 1004 FORMAT('  CHANNEL DATA, TYPE', I3, 7X, '***', 20A4, '*** CHAN')
 1005 FORMAT(20A4, T1, 14E5.0)
 1006 FORMAT('  GRID DATA, TYPE', I3, 10X, '***' ,20A4, '*** CHAN')
 1007 FORMAT('  CHANNELS OF TYPE', I3, 9X, '***', 20A4, '*** CHAN')
 1008 FORMAT(30X, '***', 20A4, '*** CHAN')
 1009 FORMAT(20A4, T1, 7(E5.0,I5))
 1010 FORMAT('  GRID POSITIONS', 14X, '***', 20A4, '*** CHAN')
 1011 FORMAT('  FUEL THERMAL DATA', 11X, '***', 20A4, '*** CHAN')
 1012 FORMAT('  HALF-BOUNDARY CHANNEL PAIRS',1X, '***',20A4, '*** CHAN')
 1013 FORMAT('  FORCED FLOW NOT PROGRAMMED. STOP CALCULATION IN CHAN')
 1040 FORMAT(///, 43X, 'CHANNEL, ROD AND GRID DATA', /, 43X,
     1 '-------  --- --- ---- ----', //, '  REACTOR TYPE', 8X,
     2 '=', I3, 5X, '(1=PWR,  2=BWR)', /, ' *NO. FUEL ASSEMBLIES =', I3,
     3 /, '  NO. ASSEMBLY TYPES  =', I3, /, '  NO. GRIDS', 11X, '=',
     4 I3, /, '  NO. GRID TYPES', 6X, '=', I3,/, '  NO. FUEL NODES', 6X,
     5 '=', I3, /, '  NO. FCD FLOW TYPES', 2X, '=', I3, /)
 1045 FORMAT(1H ,' FUEL ROD MODEL IND. =',I3,/,
     1  '  HEAT TRANSFER MODEL IND.=',I3,/,
     2  '  FUEL ROD PROP. IND. =',I3,//)
 1050 FORMAT(///,'  CHANNEL DATA', /, ' ------- ----',15X,
     1  '*CHANNEL NUMBERING MAP', /)
 1052 FORMAT(/, 25I5)
 1053 FORMAT(//, '  TYPE', 15X, 'CHANNEL NUMBERS')
 1054 FORMAT(I5, 3X, 30I4)
 1055 FORMAT(//, '  TYPE', 6X, 'FRIC', 9X, 'AREA', 10X, 'WT PER', 9X,
     1 'HT PER', 8X, 'NO. RODS', 7X, 'ROD DIA', 10X, 'GAP', /, 24X,
     2 'SQ FT', 12X, 'FT', 13X, 'FT', 28X, 'IN', 13X, 'IN')
 1056 FORMAT(I5, 5X, I5, F15.5, 2F15.3, F15.0, 2F15.4)
 1057 FORMAT(/, '  NO GRIDS', /)
```

```
1058  FORMAT(////, '  GRID DATA', /, '  ---- ----',
     1                              //, '  NO. GRIDS', 9X, '=', I3, /,
     2 '  NO. GRID TYPES', 4X, '=', I3, /, '  TYPE AT X/L', 7X, '=',
     3 8(I5,F8.4))
1059  FORMAT(//,'  ASSY. TYPE',10X, 'GRID COEFF FOR GRID TYPES 1 -', I3)
1060  FORMAT(I8, 7X, 11F10.4)
1061  FORMAT(//,'  ASSY. TYPE',10X, 'FORCED FLOW DIVERSION FACTORS FOR T
     1YPES 1 -', I3)
1062  FORMAT(////, 39H THERMAL PROPERTIES FOR FUEL MATERIAL
     1 I8,18H RADIAL FUEL NODES  /
     2 ' ------- ---------- --- ---- --------- ',//,
     3 37H                           FUEL PROPERTIES 25X,'CLAD PROPERTIES', /
     4 50H     TYPE     COND.     SP. HEAT    DENSITY    DIA.
     5            50H  COND.     SP. HEAT    DENSITY   THICK.    GAP COND. /
     6 49H      NO. (B/HR-FT-F) (B/LB-F)    (LB/FT3)  (IN.)
     7            52H(B/HR-FT-F) (B/LB-F)    (LB/FT3)  (IN.)  (B/HR-FT2-F))
1063  FORMAT(I7,2X,F7.2,F11.4,F11.1,F9.4,2X,F7.2,F11.4,F11.1,F9.4,2X,
     1 F9.2)
1064  FORMAT(////, '  GAP BOUNDARY DATA', /, '  --- -------- ----', //)
1065  FORMAT (I5,' BOUNDARIES AS BELOW (IK(K)-JK(K))',' - (EFFECTIVE ROD
     1 GAP)',/)
1066  FORMAT(' (',I3, ') ',6(2X,I3,'-',I3,'  (',F7.4,')'))
1067  FORMAT(///, '  LOCA(K,8) ARRAY SET IN ACOL', 5X,'K = 1 TO ',I3,//)
1068  FORMAT(' (',I2, ')',25I5)
1069  FORMAT(/)
1070  FORMAT(///, '  MAXIMUM OVERALL STRIPE WIDTH FOR ARRAY AAA IN DIVER
     1T = ', I3, ' FOR BOUNDARY NO. ', I3, //, '  REQUIRE ', I6,' STORES
     2 FOR AAA SIZE AND THIS OK SINCE .LE.',I6, ' PROVIDED', //)
1072  FORMAT(/, '  NO HALF BOUNDARIES')
1073  FORMAT(/, '  GAP BOUNDARIES CROSSED BY LINE OF SYMMETRY, IE FACTOR
     1(K) = 0.5', /, 25I5)
1074  FORMAT(1H1)
1076  FORMAT(/,'  TRANSVERSE MOMENTUM COUPLING PARAMETERS',
     1        '  ---------- -------- -------- ----------',
     2        '  GAP NO.    FACSL        FACSLK')
1078  FORMAT(1H ,I6,5X,E9.2,3X,E9.2)
1080  FORMAT(// ,' NEW FUEL ROD MODEL',/,
     1  ' --- ---- --- -----',/,
     2  '  NUMBER OF FUEL PELLET NODES =',I5,/,
     3  '  NUMBER OF CLAD NODES        =',I5,/,
     4  '  GAP THICKNESS(IN)',11X,'= ',E12.5,/)
1082  FORMAT(// ,' FUEL AND CLAD PROPERTIES WILL BE CALCULATED USING ',
     1  ' FUEL ROD TEMPERATURES.',/,
     2  '  FRACTION THEORETICAL DEN(FUEL)=',E12.5,/,
     3  '  FRACTION PUO2 =',E12.5,/)
1084  FORMAT(//,' GAP HEAT TRANSFER COEFFICIENTS WILL BE ',
     1  'CALCULATED USING FUEL ROD TEMPERATURES.',/,
     2  '  BURNUP(MWD/MTU) =',E12.5,/,
     3  '  COEFF. OF FUEL PRESSURE =',E12.5,/,
     4  '  EXPONENT OF FUEL PRESSURE =',E12.5,/,
     5  '  FUEL PRESSURE =',E12.5,/,
     6  '  GAP ROUGHNESS, RMS(FT) =',E12.5,/,
```

```
     7 '  HELIUM FRACTION =',E12.5,/,
     8 '  ARGON FRACTION =',E12.5,/,
     9 '  KRYPTON FRACTION =',E12.5,/,
     1 '  XENON FRACTION =',E12.5,/,
     2 '  GAP GAS PRESSURE(PSIA) =',E12.5)
1090  FORMAT(// ,' ROD-TO-COOLANT HEAT TRANSFER USING NEW MODEL FOR ',
     1 'PRE-CHF CONDITIONS')
1092  FORMAT(// ,' ROD-TO-COOLANT HEAT TRANSFER USING NEW MODEL FOR ',
     1 'PRE- AND POST-CHF CONDITIONS')
2001  FORMAT('  INPUT DATA ERROR IN ITHO. FIRST CHANNEL OF TYPE', I3,
     1 ' IS', I3)
2003  FORMAT(' ITHO  GAP CONNECTION ', I3, '  I AND J SAME IE ', 2I3)
2005  FORMAT(I5, ' TH HALF-BOUNDARY ', I4, ' - ', I4,' NOT IN BOUNDARY S
     1ET')
2006  FORMAT(' ITHO  HIGHEST NUMBER CHANNEL FOUND TO BE ', I3,
     1 ' AND THIS NOT EQUAL TO NUMBER SPECIFIED, IE ', I3)
2007  FORMAT('  NGRID GIVEN AS ', I3, '.  THIS TOO LARGE AS MAX ALLOWED
     1 IS 10.  CALCULATION STOPPED IN CHAN.')
2008  FORMAT(////, '  ROD INPUT DATA',/,'  --- ----- ----',  /,
     1 ' ROD  TYPE  DIA  RADIAL POWER    FRACTION OF POWER TO ADJA',
     2 'CENT CHANNELS (ADJ. CHANNEL NO.)',/,'   NO.  NO.   (IN)   ',
     3 'FACTOR',/(2I5,F8.4,F9.4,F11.4,1H(I2,1H)F9.4,1H(I2,1H)F9.4,
     4  1H(I2,1H)F9.4,1H(I2,1H)F9.4,1H(I2,1H)F9.4,1H(I2,1H)))
2009  FORMAT(1H ,1X,'EPSF',24X,'***',20A4,'*** CHAN')
2010  FORMAT(1H ,1X,'NCF, NCC, THG',15X,'***',20A4,'*** CHAN')
2012  FORMAT(1H ,1X,'FTD, FPUO2',18X,'***',20A4,'*** CHAN')
2014  FORMAT(1H ,1X,'GAP DATA',20X,'***',20A4,'*** CHAN')
2016  FORMAT(20A4, T1, E8.0)
2033  FORMAT(20A4,T1,5I5)
2034  FORMAT('  INDICATORS    ',14X,'***',20A4,'*** CHAN')
2035  FORMAT(20A4,T1,I1,I4,2E5.0,6(I3,E7.0))
2047  FORMAT('  ROD DATA',20X,'***',20A4,'*** CHAN')
9007  FORMAT(20A4,T1,14E5.0)
9107  FORMAT('  GAP INTERCONNECTIONS',8X,'***',20A4,'*** CHAN')
9010  FORMAT(1H ,' ERROR DETECTED IN CHAN - TRANSVERSE ',
     1 'COUPLING PARAMETER ARRAYS NOT LARGE ENOUGH FOR GREATER THAN',
     2 /,' 70 GAP INTERCONNECTIONS.')
9025  FORMAT('  GAP FACTOR PAIRS',12X,'***',20A4,'*** CHAN')
C-----------------------------------------------------------------------
      END
```

```
C*********************** SUBROUTINE CHF *********************************
      SUBROUTINE CHF(JSTART,JEND)
C
C     CHF SEARCHES COBRA-IIIC OUTPUT AT THE END OF EACH TIME STEP FOR
C     THE OCCURANCE OF CRITICAL HEAT FLUX.  THE SEARCH IS MADE ON EACH
C     ROD AT A SPECIFIED AXIAL LOCATION RANGE BY CONSIDERING EACH ROD
C     AND THE ADJACENT CHANNELS.
C     ALTHOUGH THE BAW-2 AND W-3 CORRELATIONS ARE INCLUDED, USERS SHOULD
C     PROGRAM OTHER CORRELATIONS OF THEIR CHOICE AS OPTIONS.
C-----------------------------------------------------------------------
      IMPLICIT INTEGER (I)
      INTEGER IDAT(1)
      LOGICAL LDAT(1),GRID
      REAL KIJ, KF, KKF, KCLAD, KFUEL
C
      COMMON  DATA(1)
      EQUIVALENCE  (DATA(1),IDAT(1),LDAT(1))
C
      COMMON /COBRA1/  ABETA ,AFLUX ,ATOTAL,BBETA ,DIA   ,DT    ,DX    ,
     1   ELEV  ,FERROR,FLO   ,FTM   ,GC    ,GK    ,GRID  ,HSURF ,HF    ,
     2   HFG   ,HG    ,I2    ,I3    ,IERROR,IQP3  ,ITERAT,J1    ,J2    ,
     3   J3    ,J4    ,J5    ,J6    ,J7    ,KDEBUG,KF    ,KIJ   ,
     4   NAFACT,NARAMP,NAX   ,NAXL  ,NBBC  ,NCHAN ,NCHF  ,NDX   ,NF    ,
     5   NGAPS ,NGRID ,NGRIDT,NGTYPE,NGXL  ,NK    ,NODES ,NODESF,NPROP ,
     6   NRAMP ,NROD  ,NSCBC ,NV    ,NVISCW,PI    ,PITCH ,POWER ,PREF  ,
     7   QAX   ,RHOF  ,RHOG  ,SIGMA ,SL    ,TF    ,TFLUID,THETA ,THICK ,
     8   UF    ,VF    ,VFG   ,VG    ,Z
C
      COMMON /COBRA2/  AA(4), AF(7), AFACT(10,10), AV(7), AXIAL(30),
     1   AXL(10), BB(4), BX(30), CC(4), CCLAD(2), CFUEL(2), DFUEL(2),
     2   GAPXL(10), GFACT(9,10), GRIDXL(10), HGAP(2), HHF(30), HHG(30),
     3   IGRID(10), KCLAD(2), KFUEL(2), KKF(30), NCH(10), NGAP(9),
     4   PP(30), RCLAD(2),RFUEL(2),SSIGMA(30), TCLAD(2), UUF(30),
     5   VVF(30), VVG(30), XQUAL(30), Y(30), TT(30)
C
      COMMON /COBRA3/  MA    ,MC    ,MG    ,MN    ,MR    ,MS    ,MX    ,
     1           III   ,IA    ,IAAA  ,IAC   ,IALPHA,IAN   ,IANSWE,IB    ,
     1   ICCHAN,ICD   ,ICHFR ,ICON  ,ICOND ,ICP   ,ID    ,IDC   ,IDFDX ,
     2   IDHDX ,IDHYD ,IDHYDN,IDIST ,IDPDX ,IDPK  ,IDUR  ,IDR   ,IF    ,
     3   IFACTO,IFDIV ,IFINLE,IFLUX ,IFMULT,IFOLD ,IFSP  ,IFSPLI,IFXFLO,
     4   IGAP  ,IGAPN ,IGAPS ,IH    ,IHFILM,IHINLE,IHOLD ,IHPERI,IIDARE,
     5   IIDFUE,IIDGAP,IIK   ,IJBOIL,IJK   ,ILC   ,ILENGT,ILOCA ,ILR   ,
     6   IMCHFR,IMCFRC,IMCFRR,INTYPE,INWRAP,INWRPS,IP    ,IPERIM,IPH   ,
     7   IPHI  ,IPRNTC,IPRNTR,IPRNTN,IPW   ,IPWRF ,IQC   ,IQF   ,IQPRIM,
     8   IQUAL ,IRADIA,IRHO  ,IRHOOL,ISP   ,IT    ,ITDUMY,ITINLE,ITROD ,
     9   IU    ,IUH   ,IUSAVE,IUSTAR,IV    ,IVISC ,IVISCW,IVP   ,IVPA  ,
     A   IW    ,IWOLD ,IWP   ,IWSAVE,IX    ,IXCROS,IIA   ,IIB   ,IXPOLD
C
      COMMON/CHFSV/CHSAVE(20,20,31)
      COMMON/LINK4/IFRM,IHTM,IPROP,NCC,NCF,NDM1,NDS,NGP
C-----------------------------------------------------------------------
C
```

```
      NDXP1 = NDX + 1
         DO 100 J=1,NDXP1
         DATA(IMCHFR+J)=10.0
         IDAT(IMCFRC+J)=0
         IDAT(IMCFRR+J)=0
            DO 100 N=1,NROD
            DATA(ICHFR +N+MR*(J-1))=10.
            IDAT(ICCHAN+N+MR*(J-1))=0
 100        CONTINUE
      IF (NCHF.EQ.5.AND.IHTM.NE.2) WRITE(6,2000)
         DO 500 J=JSTART,JEND
         CHFROD = 0
            DO 300 N=1,NROD
            XMCHFR = 10.
            IF(DATA(IFLUX+N+MR*(J-1)).LE.0.0)  GO TO 300
               DO 290 L=1,6
               IF(IDAT(ILR  +N+MR*(L-1)))  200,290,200
C              CALCULATE CHF RATIO FOR ROD N FACING CHANNEL I.
 200           I= IDAT(ILR  +N+MR*(L-1))
               XCHFR = 0.
               IF(NCHF.EQ.1) XCHFR = CHF1(N,I,J)/DATA(IFLUX+N+MR*(J-1))
               IF(NCHF.EQ.2) XCHFR = CHF2(N,I,J)/DATA(IFLUX+N+MR*(J-1))
               IF(NCHF.EQ.3) XCHFR = CHF3(N,I,J)/DATA(IFLUX+N+MR*(J-1))
               IF(NCHF.EQ.4) XCHFR = CHF4(N,I,J)
C
C              OPTION NCHF=5 OPERATIONAL ONLY IF IHTM=2
C              BECAUSE CHSAVE CALCULATED IN HTCOR AND SAVED
               IF (NCHF.EQ.5.AND.IHTM.EQ.2)
     1         XCHFR = CHSAVE(N,I,J)/DATA(IFLUX+N+MR*(J-1))
               IF(XCHFR.LE.0.) GO TO 1000
C
C              CALCULATE MINIMUM CHF RATIO FOR ROD N FACING CHANNEL I.
               IF(XCHFR.GT.DATA(ICHFR+N+MR*(J-1)))  GO TO 290
               DATA(ICHFR+N+MR*(J-1))=XCHFR
               IDAT(ICCHAN+N+MR*(J-1))=I
               CHFROD = N
 290           CONTINUE
C           DETERMINE MINIMUM CHF RATIO AT AXIAL LOCATION J.
            XMCHFR      =DATA(ICHFR+N+MR*(J-1))
            IF(XMCHFR.GT.DATA(IMCHFR+J        ) )  GO TO 300
            DATA(IMCHFR+J)=XMCHFR
            IDAT(IMCFRR+J)=CHFROD
            IDAT(IMCFRC+J)=IDAT(ICCHAN+N+MR*(J-1))
 300        CONTINUE
 500     CONTINUE
      RETURN
1000  PRINT 1
      RETURN
C-----------------------------------------------------------------------
2000  FORMAT(1H ,'  ERROR DETECTED IN CHF - ',
     1  ' NCHF=5 AND IHTM DOES NOT = 2.')
   1  FORMAT (' ERROR IN CHF ROUTINE')
```

```
C-----------------------------------------------------------------------
      END
```

```
C*********************** SUBROUTINE CHF5 **********************************
      SUBROUTINE CHF5(QCHF,ALP,ROV,ROL,G,P,X,HD,HFG,SIG)
C
      DATA GCON/9.8066/
      DATA EE /2.7182818E+0/
C--------------------------------------------------------------------------
C
      PBAR=1.0E-5*P
      GHI=1350.0
      GLO=27.0
      IF(PBAR.GE.83.0.AND.X.GE.0.5)GHI=270.0
      IF(G.LT.GLO)GO TO 20
C
C     BIASI CORRELATION FOR HIGH FLOW
C
      EN=-0.4
      IF(HD.LT.0.01)EN=-0.6
      GT=AMAX1(G,GHI)
      Q10=0.0
      IF(GT.LT.300.0)GO TO 10
      F=.7249 + .099*PBAR* EE**(-(.032)*PBAR)
      G6=GT**(-.166667)
      Q10=2.764E7* (100.E0*HD)**EN *G6*(1.468*F*G6-X)
 10   CONTINUE
      H=-1.159 + .149*PBAR* EE**(-.019E0*PBAR) + 8.99*PBAR/
     & (10.+PBAR*PBAR)
      Q11=15.048E7*H* (100.E0*HD)**EN * GT**(-.6) *(1.0-X)
      QB=AMAX1(Q10,Q11)
      QCHF=QB
C
      IF(G.GE.GHI)GO TO 100
 20   CONTINUE
C
C     CHF-VOID CORRELATION FOR LOW FLOW
      T1=SIG*GCON*GCON*(ROL-ROV)*ROV*ROV
      QVC=.1178*(1.-ALP)*HFG* T1**0.25
      QCHF=QVC
      IF(G.LE.GLO)GO TO 100
C
C     LINEAR INTERPOLATION BETWEEN BIASI AND CHF-VOID
      WT=(G-GLO)/(GHI-GLO)
      QCHF=WT*QB+(1.-WT)*QVC
C
 100  CONTINUE
      RETURN
      END
```

```
C*********************** SUBROUTINE CORE ***********************************
      SUBROUTINE CORE
C
      IMPLICIT INTEGER (I)
      DIMENSION  ITYPE(97)
      DOUBLE PRECISION  INAMES(97)
      INTEGER  ILX(97)
C
      COMMON DATA(1)
      COMMON /COBRA3/  MA,MC,MG,MN,MR,MS,MX,III,IORG(97)
      COMMON /COBRA5/  INAMES,ILX,ITYPE
C---------------------------------------------------------------------------
C
      MA = 1
      MS = 1
      IF (MG.LE.0) MG=1
      IF (MN.LE.0) MN=1
C     ******
      III=97
         DO 100  I=1,III
 100     ILX(I)=MC
      ILX( 2)=1
      ILX( 6)=MG
      ILX( 7)=MG
      ILX( 8)=MR*MX
      ILX( 9)=MC*5
      ILX(10)=MR*MX
      ILX(12)=MG
      ILX(14)=MR
      ILX(20)=MC*4
      ILX(23)=MG
      ILX(24)=MR
      ILX(25)=MC*MX
      ILX(26)=MG
      ILX(27)=MG
      ILX(29)=MR*MX
      ILX(31)=MC*MX
      ILX(34)=MG*5
      ILX(35)=MG
      ILX(36)=MG
      ILX(37)=MG*4
      ILX(38)=MC*MX
      ILX(41)=MC*MX
      ILX(44)=MR
      ILX(45)=MG
      ILX(46)=MG
      ILX(48)=MG
      ILX(49)=MC*4
      ILX(50)=MG
      ILX(51)=MG*14
      ILX(52)=MR*6
      ILX(53)=MX
```

```
      ILX(54)=MX
      ILX(55)=MX
      ILX(59)=MC*MX
      ILX(62)=MR*6
      ILX(64)=MR
      ILX(65)=MN
      ILX(67)=MC*MR
      ILX(68)=MC*MX
      ILX(69)=MC*MX
      ILX(72)=MR
      ILX(73)=MC*MX
      ILX(74)=MC*MX
      ILX(75)=MG*MX
C     PROVIDE SPACE FOR SP IN BWR ITERATION.
      IF (ILX(75) .LT.3*MC) ILX(75) = 3*MC
      ILX(77)=MN
      ILX(79)=MN*MR*MX
      ILX(82)=MG
      ILX(83)=MG
      ILX(89)=MG*MX
      ILX(90)=MG*MX
      ILX(91)=MG
      ILX(92)=MG
      ILX(93)=MX
      ILX(94)=MG*6
      ILX(95)=3*MN
      ILX(96)=MN
C   *******
      ILX(97)=MC*MX
      IORG(1)=1
      ILXX=0
         DO 110  I=1,III
         ILXX=ILXX+ILX(I)
         IF(I.GT.1)  IORG(I)=IORG(I-1)+ILX(I-1)
 110     CONTINUE
      KS=1
C
C     KMAX IN SUBROUTINE CORE EQUALS
C     LENGTH OF DATA ARRAY GIVEN BELOW
C
      KMAX=80000
      KFREE=KS
      KTOP = KS + KMAX - 1
      KS=KS+MOD(KS+1,2)
      IF(KMAX.LT.ILXX) GO TO 902
         DO 300 K=KS,KTOP
 300     DATA(K) = 0.0
         DO 400  N=1,III
 400     IORG(N)=IORG(N)+KS-1
      RETURN
C-----------------------------------------------------------------------
C
```

```
      ENTRY CORE2(MSP,NKP)
      NK=NKP
      MS=MSP
      MA=NK*MS
      ILX(2)=MA
C   *******
      IORG(2)=IORG(97)+ILX(97)
      ILXX=ILXX+ILX(2)
      IF(KMAX.LT.ILXX)  GO TO 902
      RETURN
 901  WRITE(6,3001)
      STOP 1
 902  WRITE(6,3002)  KMAX,ILXX
      STOP 1
C-----------------------------------------------------------------------
C
      ENTRY CORE3
C     FROM ITHO FOR PRINTING
      WRITE (6,1000) MA, MC, MG, MN, MR, MS, MX
      WRITE(6,4500)
      WRITE(6,5000)
      WRITE(6,4000) (N,INAMES(N),ILX(N),IORG(N),ITYPE(N),N=1,III)
      WRITE(6,3000)  KMAX
      LOWER = 4.0*FLOAT(KMAX-ILXX)/1024.0
      WRITE (6,1004) ILXX, LOWER
      RETURN
C
C-----------------------------------------------------------------------
1000  FORMAT(///, '  DYNAMIC ARRAY SIZES', /, '  MA = ', I5, /,
     1 '  MC = ', I5, /, '  MG = ', I5, /, '  MN = ', I5, /,
     2 '  MR = ', I5, /, '  MS = ', I5, /, '  MX = ', I5)
1004  FORMAT(/, ' DYNAMIC STORAGE REQUIRED = ', I14, ' WORDS', //,
     1 ' REGION SIZE ON JCL CARD COULD HAVE BEEN REDUCED BY ', I4, ' K')
3000  FORMAT('0DYNAMIC ALLOCATION OF CORE GOT ',I10,' WORDS'/)
3001  FORMAT('0DYNAMIC ALLOCATION OF CORE FAILED'///)
3002  FORMAT('0DYNAMIC ALLOCATION OF CORE GOT ONLY ',I10,' WORDS'/
     1  ' NUMBER OF WORDS REQUIRED FOR THIS PROBLEM IS ',I10///)
4000  FORMAT('0',T35,40X,'1=REAL'/T35,40X,'2=INTEGER'/T35,40X,'3=LOGICAL
     1'//
     2    T35,'INDEX     NAME      LENGTH    ORIGIN    TYPE'/
     3    T35,'-----     ------    ------    ------    ----'/
     4    (T35,I5,5X,A6,I10,I10,I8))
4500  FORMAT(1H ,' THIS VERSION OF COBRA-IIIC/MIT DOES NOT ALLOW',
     1  ' DYNAMIC STORAGE.')
5000  FORMAT(//,'  MAXIMUM PROBLEM SIZE LIMITED TO',/,
     1  '   80000 WORDS BY DIMENSION OF DATA ARRAY IN',/,
     2  '   MAIN PROGRAM AND VALUE OF KMAX SET IN',/,
     3  '   CORE SUBROUTINE.')
C-----------------------------------------------------------------------
      END
C********************** BLOCK DATA SEGMENT ******************************
       BLOCK DATA
```

```
       IMPLICIT INTEGER*4 (I)
       DOUBLE PRECISION INAMES,INAME1,INAME2
       DIMENSION ILX(97),INAME1(46),INAME2(51),INAMES(97)
      COMMON /COBRA5/  INAMES,ILX,ITYPE
      EQUIVALENCE  (INAMES(1),INAME1(1)),(INAMES(47),INAME2(1))
      DATA INAME1 /         8HA       ,8HAAA     ,8HAC      ,8HALPHA   ,
     18HAN      ,8HANSWER  ,8HB       ,8HCCHANL  ,8HCD      ,8HCHFR    ,
     28HCON     ,8HCOND    ,8HCP      ,8HD       ,8HDC      ,8HDFDX    ,
     38HDHDX    ,8HDHYD    ,8HDHYDN   ,8HDIST    ,8HDPDX    ,8HDPK     ,
     48HDUR     ,8HDR      ,8HF       ,8HFACTOR  ,8HFDIV    ,8HFINLET  ,
     58HFLUX    ,8HFMULT   ,8HFOLD    ,8HFSP     ,8HFSPLIT  ,8HFXFLOW  ,
     68HGAP     ,8HGAPN    ,8HGAPS    ,8HH       ,8HHFILM   ,8HHINLET  ,
     78HHOLD    ,8HHPERIM  ,8HIDAREA  ,8HIDFUEL  ,8HIDGAP   ,8HIK      /
      DATA INAME2/
     88HJBOIL   ,8HJK      ,8HLC      ,8HLENGTH  ,8HLOCA    ,8HLR      ,
     98HMCHFR   ,8HMCHFRC  ,8HMCHFRR  ,8HNTYPE   ,8HNWRAP   ,8HNWRAPS  ,
     A8HP       ,8HPERIM   ,8HPH      ,8HPHI     ,8HPRINTC  ,8HPRINTR  ,
     B8HPRINTN  ,8HPW      ,8HPWRF    ,8HQC      ,8HQF      ,8HQPRIM   ,
     C8HQUAL    ,8HRADIAL  ,8HRHO     ,8HRHOOLD  ,8HSP      ,8HT       ,
     D8HTDUMY   ,8HTINLET  ,8HTROD    ,8HU       ,8HUH      ,8HSAVE    ,
     G8HUSTAR   ,8HV       ,8HVISC    ,8HVISCW   ,8HVP      ,8HVPA     ,
     F8HW       ,8HWOLD    ,8HWP      ,8HWSAVE   ,8HX       ,8HXCROSS  ,
     G8HA       ,8HB       ,8HXPOLD   /
      INTEGER ITYPE(97)/7*1,2,18*1,3,15*1,7*2,1,2*2,1,5*2,4*1,3*2,32*1/
      END
```

```
C*********************** SUBROUTINE CURVE ********************************
      SUBROUTINE CURVE (FX,X,F,Y,N,J,ISAVE)
C
C     FX - QUANTITY TO BE FOUND
C      X - INDEPENDENT VARIABLE
C      F - INPUT ARRAY FOR THE ORDINATE(MONOTONIC WITH Y)
C      Y - INPUT ARRAY FOR THE ABCISSA (MONOTONIC INCREASE)
C      N - NUMBER OF F(I) OR Y(I) VALUES
C      J - ERROR SIGNAL, J=10
C
C     THE INDEX I IS SAVED IN COMMON INDSAV
C-------------------------------------------------------------------------
      DIMENSION F(30), Y(30)
      COMMON/INDSAV/I
      DATA I3/6/
C-------------------------------------------------------------------------
C
      IF(ISAVE.LT.1 .OR. ISAVE.GT.2) GO TO 70
      GO TO (10,50),ISAVE
 10      DO 20 I=1,N
         IF(X-Y(I)) 30,15,20
 15      IF(I.EQ.N) GO TO 40
 20      CONTINUE
      GO TO 60
 30   IF(I.EQ.1) GO TO 60
 40   B = (X-Y(I-1))/(Y(I)-Y(I-1))
 50   FX = F(I-1) + B*(F(I)-F(I-1))
      RETURN
 60   WRITE(I3,1) FX,X,(F(I),Y(I),I=1,N)
 70   J = 10
      RETURN
C-------------------------------------------------------------------------
  1   FORMAT(49H TABULAR LOOKUP FAILED IN SUBROUTINE CURVE, FX = E12.6,
     * 6H   X = E12.6 / (10E12.4))
C-------------------------------------------------------------------------
      END
```

```
C*********************** SUBROUTINE DECOMP ******************************
      SUBROUTINE DECOMP (NN,IERROR,LMAX,MID,UL,X,B,NK)
C
C     SIMPLIFIED VERSION OF DECOMP WITH NO PIVOTING
C     STORE DIAGONAL BAND OF AAA MATRIX.   POSITION (K,L) IN SQUARE
C     ARRAY BECOMES (K,(MID-K+L) ) IN NEW ARRAY.
C-----------------------------------------------------------------------
      DIMENSION UL(NK,LMAX),X(1),B(1)
C-----------------------------------------------------------------------
C
      IF(NN.EQ.1) RETURN
C
      DATA I3/6/
      NM1 = NN-1
         DO 17  K = 1,NM1
         PIVOT = UL(K ,MID)
         KP1 = K+1
         LIMIT = MIN0(NN,(K+MID-1) )
            DO 16 I = KP1,LIMIT
            KK = MID+K-I
            EM = -UL(I,KK)/PIVOT
            UL(I,KK) = -EM
            IF (EM) 20,16,20
 20            DO 21 J=KP1,LIMIT
               JI = MID-I+J
               JK = MID-K+J
 21            UL(I,JI) = UL(I,JI) + EM*UL(K,JK)
 16         CONTINUE
 17      CONTINUE
C
      IF (UL(NN,MID)) 19,18,19
 18   WRITE(I3,112)
 100  WRITE(I3,113) ((UL(K,L),L=1,NN),K=1,NN)
      IERROR = 12
 19   RETURN
C-----------------------------------------------------------------------
 113  FORMAT(7E14.8)
 112  FORMAT(54HOSINGULAR MATRIX IN DECOMPOSE.  ZERO DIVIDE IN SOLVE.  )
C-----------------------------------------------------------------------
      END
```

```
C********************** SUBROUTINE DIFFER *******************************
      SUBROUTINE DIFFER(IPART,J)
C
      IMPLICIT INTEGER (I)
      LOGICAL LDAT(1), GRID
      INTEGER IDAT(1)
C
      COMMON  DATA(1)
      EQUIVALENCE  (DATA(1),IDAT(1),LDAT(1))
C
      COMMON /COBRA1/  ABETA ,AFLUX ,ATOTAL,BBETA ,DIA   ,DT    ,DX    ,
     1   ELEV  ,FERROR,FLO   ,FTM   ,GC    ,GK    ,GRID  ,HSURF ,HF    ,
     2   HFG   ,HG    ,I2    ,I3    ,IERROR,IQP3  ,ITERAT,J1    ,J2    ,
     3   J3    ,J4    ,J5    ,J6    ,J7    ,KDEBUG,KF    ,KIJ   ,
     4   NAFACT,NARAMP,NAX   ,NAXL  ,NBBC  ,NCHAN ,NCHF  ,NDX   ,NF    ,
     5   NGAPS ,NGRID ,NGRIDT,NGTYPE,NGXL  ,NK    ,NODES ,NODESF,NPROP ,
     6   NRAMP ,NROD  ,NSCBC ,NV    ,NVISCW,PI    ,PITCH ,POWER ,PREF  ,
     7   QAX   ,RHOF  ,RHOG  ,SIGMA ,SL    ,TF    ,TFLUID,THETA ,THICK ,
     8   UF    ,VF    ,VFG   ,VG    ,Z
C
      COMMON /COBRA2/  AA(4), AF(7), AFACT(10,10), AV(7), AXIAL(30),
     1   AXL(10), BB(4), BX(30), CC(4), CCLAD(2), CFUEL(2), DFUEL(2),
     2   GAPXL(10), GFACT(9,10), GRIDXL(10), HGAP(2), HHF(30), HHG(30),
     3   IGRID(10), KCLAD(2), KFUEL(2), KKF(30), NCH(10), NGAP(9),
     4   PP(30), RCLAD(2),RFUEL(2),SSIGMA(30), TCLAD(2), UUF(30),
     5   VVF(30), VVG(30), XQUAL(30), Y(30), TT(30)
C
      COMMON /COBRA3/  MA    ,MC    ,MG    ,MN    ,MR    ,MS    ,MX    ,
     1          III   ,IA    ,IAAA  ,IAC   ,IALPHA,IAN   ,IANSWE,IB    ,
     1   ICCHAN,ICD   ,ICHFR ,ICON  ,ICOND ,ICP   ,ID    ,IDC   ,IDFDX ,
     2   IDHDX ,IDHYD ,IDHYDN,IDIST ,IDPDX ,IDPK  ,IDUR  ,IDR   ,IF    ,
     3   IFACTO,IFDIV ,IFINLE,IFLUX ,IFMULT,IFOLD ,IFSP  ,IFSPLI,IFXFLO,
     4   IGAP  ,IGAPN ,IGAPS ,IH    ,IHFILM,IHINLE,IHOLD ,IHPERI,IIDARE,
     5   IIDFUE,IIDGAP,IIK   ,IJBOIL,IJK   ,ILC   ,ILENGT,ILOCA ,ILR   ,
     6   IMCHFR,IMCFRC,IMCFRR,INTYPE,INWRAP,INWRPS,IP    ,IPERIM,IPH   ,
     7   IPHI  ,IPRNTC,IPRNTR,IPRNTN,IPW   ,IPWRF ,IQC   ,IQF   ,IQPRIM,
     8   IQUAL ,IRADIA,IRHO  ,IRHOOL,ISP   ,IT    ,ITDUMY,ITINLE,ITROD ,
     9   IU    ,IUH   ,IUSAVE,IUSTAR,IV    ,IVISC ,IVISCW,IVP   ,IVPA  ,
     A   IW    ,IWOLD ,IWP   ,IWSAVE,IX    ,IXCROS,IIA  ,IIB  ,IXPOLD
C
      COMMON/LINK9/ENEH(400)
C-----------------------------------------------------------------------
C
      IPILE = J7
      JM1 = J-1
      IF(IPART.LT.1 .OR. IPART.GT.4) GO TO 1000
      GO TO (100,200,300,400),IPART
C
C     PART 1, CALCULATE DH/DX FOR STEADY STATE AT X AND T.
 100     DO 120 I=1,NCHAN
 120     DATA(IDHDX+I)=0.
      IF (IPILE.EQ.2) GO TO 185
```

```
         DO 180 K=1,NK
         I=IDAT(IIK+K)
         L=IDAT(IJK+K)
         WV=(DATA(IH+I+MC*(J-1))-DATA(IH+L+MC*(J-1)))
         IF(DATA(IW+K+MG*(J-1)).LT.0.)  GO TO 140
         HWI = 0.0
         HWL=  DATA(IW+K+MG*(J-1)) * WV
         GO TO 160
 140     HWI=  DATA(IW+K+MG*(J-1)) * WV
         HWL = 0.0
 160     CONTINUE
         DATA(IDHDX+I)=DATA(IDHDX+I)+HWI-WV*DATA(IWP+K)/ENEH(K)
     1   -(DATA(IT+I) -DATA(IT+L))*DATA(ICOND+K)
         DATA(IDHDX+L)=DATA(IDHDX+L)+HWL+WV*DATA(IWP+K)/ENEH(K)
     1   +(DATA(IT+I)-DATA(IT+L))*DATA(ICOND+K)
 180     CONTINUE
 185     DO 190 I=1,NCHAN
 190     DATA(IDHDX+I)=(DATA(IDHDX+I)+DATA(IQPRIM+I)+
     1   DATA(IQC+I+MC*J)/DX) /DATA(IF+I+MC*(J-1))
      GO TO 500
C'
C     PART 2, CALCULATE DF/DX FOR STEADY STATE AT X AND T
 200     DO 220 I=1,NCHAN
 220     DATA(IDFDX+I)=0.
      IF (IPILE.EQ.2) GO TO 500
         DO 240 K=1,NK
         I =IDAT(IIK+K)
         L =IDAT(IJK+K)
         DATA(IDFDX+I)=DATA(IDFDX+I)-DATA(IW+K+MG*(J-1))
 240     DATA(IDFDX+L)=DATA(IDFDX+L)+DATA(IW+K+MG*(J-1))
      GO TO 500
C
C     PART 3, CALCULATE DP/DX WITHOUT W
 300     DO 302 I=1,NCHAN
 302     DATA(IDPDX+I)=0.
      IF (FTM.LE.0.0) GO TO 306
      IF (IPILE.EQ.2) GO TO 306
         DO 304 K=1,NK
         I=IDAT(IIK+K)
         L=IDAT(IJK+K)
         WV=(DATA(IU+I)-DATA(IU+L))*DATA(IWP+K)
         DATA(IDPDX+I)=DATA(IDPDX+I)+WV
         DATA(IDPDX+L)=DATA(IDPDX+L)-WV
 304     CONTINUE
 306     DO 390 I=1,NCHAN
         SAVE=0.5*DATA(IFSP+I)*DATA(IFMULT+I)*DATA(IV+I)/DATA(IDHYD+I)
     1   +(DATA(IVP+I)/DATA(IA+I)-DATA(IVPA+I))*DATA(IA+I)/DX
         IF(.NOT.GRID) GO TO 310
         IF(NRAMP.LE.0) GO TO 1000
         DUMY = FLOAT(ITERAT)/FLOAT(NRAMP)
         IF(DUMY.GT.1.) DUMY = 1.
         SAVE=SAVE+.5*DUMY*DATA(ICD+I+MC*(NGTYPE-1))*DATA(IVP+I)/DX
```

```
 310     DATA(IDPK+I)=SAVE/(DATA(IA+I)*DATA(IA+I))
         JJ = JM1
         IF (J.GT.1) GO TO 382
         JJ = 1
 382     FLOWSQ=ABS(DATA(IF+I+MC*(JJ-1)))*DATA(IF+I+MC*(JJ-1))
         IF(IPILE.EQ.2)  FLOWSQ= DATA(IF+I+MC*(J-1))**2
         DATA(IDPDX+I)=-DATA(IDPK+I)*FLOWSQ/GC-DATA(IRHO+I+MC*(J-1))*
     1   ELEV-DATA(IDPDX+I)*FTM/(DATA(IA+I)*GC)
         IF(DT.GT.100.) GO TO 390
         RHODIF=DATA(IRHO+I+MC*(J-1))-DATA(IRHOOL+I+MC*(J-1))
         RHODOT=RHODIF/DT
         IF(IPILE.NE.2)  GO TO 385
         DATA(IDPDX+I)=DATA(IDPDX+I)+RHODOT/GC*2.*DATA(IU+I)
     1   +(DATA(IFOLD+I+MC*(J-1))-DATA(IF+I+MC*(J-1)))/DATA(IA+I)/DT/GC
         GO TO 390
 385     DATA(IDPDX+I)=DATA(IDPDX+I)+RHODOT/GC*(2.*DATA(IU+I)+DX/DT
     1   +DATA(IDPK+I)*ABS(DATA(IF+I+MC*(JM1-1))+DATA(IF+I+MC*(J-1)))*
     2   DATA(IA+I)*DX)+      (DATA(IFOLD+I+MC*(J-1))-DATA(IF+I+MC*(JM1
     3   -1)))/DATA(IA+I)/DT/GC
  390    CONTINUE
      GO TO 500
C
C     PART 4, CALCULATE DP/DX WITH W
 400  IF (J.EQ.1) GO TO 500
         DO 410 I=1,NCHAN
 410     DATA(IDHDX+I)=0.
      IF (IPILE.EQ.2) GO TO 425
         DO 420 K=1,NK
         I=IDAT(IIK+K)
         L=IDAT(IJK+K)
         DATA(IDHDX+I)=DATA(IDHDX+I)+((2.*DATA(IU+I)-
     1   DATA(IUSTAR+K)+DX/DT)/DATA(IA+I)+DATA(IDPK+I)
     2   *ABS(DATA(IF+I+MC*(JM1-1))+DATA(IF+I+MC*(J-1)))*DX)
     3   *DATA(IW+K+MG*(J-1))
         DATA(IDHDX+L)=DATA(IDHDX+L)-((2.*DATA(IU+L)-DATA(IUSTAR+K)
     1   +DX/DT)/DATA(IA+L)+DATA(IDPK+L)*ABS(DATA(IF+L+MC*(JM1-1))+
     2   DATA(IF+L+MC*(J-1)))*DX)*DATA(IW+K+MG*(J-1))
 420     CONTINUE
 425     DO 430 I=1,NCHAN
 430     DATA(IDPDX+I)=DATA(IDPDX+I)+DATA(IDHDX+I)/GC
C
 500  CONTINUE
      RETURN
1000  IERROR = 2
      RETURN
      END
```

```
C*********************** SUBROUTINE DIVERT ********************************
      SUBROUTINE DIVERT(J)
C
      IMPLICIT INTEGER (I)
      INTEGER IDAT(1)
      LOGICAL LDAT(1),GRID
      REAL KIJ, KF, KKF, KCLAD, KFUEL
C
      COMMON  DATA(1)
      EQUIVALENCE  (DATA(1),IDAT(1),LDAT(1))
C
      COMMON /COBRA1/  ABETA ,AFLUX ,ATOTAL,BBETA ,DIA   ,DT    ,DX    ,
     1   ELEV  ,FERROR,FLO   ,FTM   ,GC    ,GK    ,GRID  ,HSURF ,HF    ,
     2   HFG   ,HG    ,I2    ,I3    ,IERROR,IQP3  ,ITERAT,J1    ,J2    ,
     3   J3    ,J4    ,J5    ,J6    ,J7    ,KDEBUG,KF    ,KIJ   ,
     4   NAFACT,NARAMP,NAX   ,NAXL  ,NBBC  ,NCHAN ,NCHF  ,NDX   ,NF    ,
     5   NGAPS ,NGRID ,NGRIDT,NGTYPE,NGXL  ,NK    ,NODES ,NODESF,NPROP ,
     6   NRAMP ,NROD  ,NSCBC ,NV    ,NVISCW,PI    ,PITCH ,POWER ,PREF  ,
     7   QAX   ,RHOF  ,RHOG  ,SIGMA ,SL    ,TF    ,TFLUID,THETA ,THICK ,
     8   UF    ,VF    ,VFG   ,VG    ,Z
C
      COMMON /COBRA2/  AA(4), AF(7), AFACT(10,10), AV(7), AXIAL(30),
     1   AXL(10), BB(4), BX(30), CC(4), CCLAD(2), CFUEL(2), DFUEL(2),
     2   GAPXL(10), GFACT(9,10), GRIDXL(10), HGAP(2), HHF(30), HHG(30),
     3   IGRID(10), KCLAD(2), KFUEL(2), KKF(30), NCH(10), NGAP(9),
     4   PP(30), RCLAD(2),RFUEL(2),SSIGMA(30), TCLAD(2), UUF(30),
     5   VVF(30), VVG(30), XQUAL(30), Y(30), TT(30)
C
      COMMON /COBRA3/  MA    ,MC    ,MG    ,MN    ,MR    ,MS    ,MX    ,
     1          III   ,IA    ,IAAA  ,IAC   ,IALPHA,IAN   ,IANSWE,IB    ,
     1   ICCHAN,ICD   ,ICHFR ,ICON  ,ICOND ,ICP   ,ID    ,IDC   ,IDFDX ,
     2   IDHDX ,IDHYD ,IDHYDN,IDIST ,IDPDX ,IDPK  ,IDUR  ,IDR   ,IF    ,
     3   IFACTO,IFDIV ,IFINLE,IFLUX ,IFMULT,IFOLD ,IFSP  ,IFSPLI,IFXFLO,
     4   IGAP  ,IGAPN ,IGAPS ,IH    ,IHFILM,IHINLE,IHOLD ,IHPERI,IIDARE,
     5   IIDFUE,IIDGAP,IIK   ,IJBOIL,IJK   ,ILC   ,ILENGT,ILOCA ,ILR   ,
     6   IMCHFR,IMCFRC,IMCFRR,INTYPE,INWRAP,INWRPS,IP    ,IPERIM,IPH   ,
     7   IPHI  ,IPRNTC,IPRNTR,IPRNTN,IPW   ,IPWRF ,IQC   ,IQF   ,IQPRIM,
     8   IQUAL ,IRADIA,IRHO  ,IRHOOL,ISP   ,IT    ,ITDUMY,ITINLE,ITROD ,
     9   IU    ,IUH   ,IUSAVE,IUSTAR,IV    ,IVISC ,IVISCW,IVP   ,IVPA  ,
     A   IW    ,IWOLD ,IWP   ,IWSAVE,IX    ,IXCROS,IIA   ,IIB   ,IXPOLD
C
      COMMON /GAPFAC/ FACSL(100), FACSLK(100)
C-------------------------------------------------------------------------
C
      ABIT(IZ,Z1,Z2,Z3,Z4,Z5,Z6) = IZ*((2.0*Z1 - Z2 + DX/DT)/Z3 +
     1 Z4*ABS(Z5+Z6)*DX)
C-------------------------------------------------------------------------
C
      IPILE =J7
      JM1 = J-1
      SLDX = SL*DX
      DTGC = DT*GC
```

```
      DXGC = DX*GC
C     CALCULATE USTAR
         DO 5 K=1,NK
         II=IDAT(IIK+K)
         JJ=IDAT(IJK+K)
         DATA(IUSAVE+K)=DATA(IUSTAR+K)
         DATA(IUSTAR+K)=0.5*(DATA(IU+II)+DATA(IU+JJ))
    5    CONTINUE
C
C     SET AAA ARRAY USING LOCA (SET IN ACOL BASED ON INPUT DATA)
      LMAX = MS
      MID = (MS+1)/2
         DO 310 K=1,NK
            DO 290 L=1,LMAX
  290       DATA(IAAA+K+NK*(L-1))=0.
         II=IDAT(IIK+K)
         JJ=IDAT(IJK+K)
C        TRANSVERSE MOMENTUM PARAMETER IN NEXT EQUATION
         DATA(IB+K)=(DATA(ISP+K+MG*(J-1))-(DATA(IDPDX+II)
     1   -DATA(IDPDX+JJ))*DX)*SL*FACSL(K)*DATA(IFACTO+K)
     2   +DATA(IUSAVE+K)*DATA(IW+K+MG*(JM1-1))/DXGC+
     3   DATA(IWOLD+K+MG*(J-1))/DTGC
         SAVE=ABIT(1,DATA(IU+II),DATA(IUSTAR+K),DATA(IA+II),
     1   DATA(IDPK+II),DATA(IF+II+MC*(JM1-1)),DATA(IF+II+MC*(J-1)))
     2   +ABIT(1,DATA(IU+JJ),DATA(IUSTAR+K),DATA(IA+JJ),DATA(IDPK+JJ),
     3   DATA(IF+JJ+MC*(JM1-1)),DATA(IF+JJ+MC*(J-1)))
         IF (IPILE.GT.0) GO TO 7213
         NBOUND=IDAT(ILOCA+K+MG*13)
         GO TO 7214
7213     NBOUND=IDAT(ILOCA+K+MG*7)
7214     DO 300 LL=1,NBOUND
            L = IDAT(ILOCA+K+MG* (LL-1))
            IF(LL.EQ.1) GO TO 295
            IZ = 1
            IF (L.LT.0) IZ=-1
            L = IABS(L)
            IJ = JJ
            IF( (II.EQ.IDAT(IIK+L)).OR.
     1      (II.EQ.IDAT(IJK+L)))  IJ=II
            SAVE = ABIT(IZ,DATA(IU+IJ),DATA(IUSTAR+L),DATA(IA+IJ),
     1      DATA(IDPK+IJ),DATA(IF+IJ+MC*(JM1-1)),DATA(IF+IJ+MC*(J-1)))
  295       L = MID - K + L
C           TRANSVERSE MOMENTUM PARAMETER IN NEXT EQUATION
  300       DATA(IAAA+K+NK*(L-1))=SAVE*SLDX*FACSL(K)/GC*DATA(IFACTO+K)
C         TRANSVERSE MOMENTUM PARAMETER IN NEXT EQUATION
          DATA(IAAA+K+NK*(MID-1))=DATA(IAAA+K+NK*(MID-1))+SL*FACSLK(K)
     1    *CIJ(K,J)*DATA(IFACTO+K)+DATA(IUSTAR+K)/DXGC+1./DTGC
  310     CONTINUE
       IF(J6.LT.1) GO TO 105
C
C      MODIFY SIMULTANEOUS EQUATIONS TO ACCOUNT FOR SPECIFIED VALUES OF
C      CROSSFLOW GIVEN IN SUBROUTINE FORCE
```

```
         DO 90 K=1,NK
         IF(LDAT(IFDIV+K))  GO TO 90
            DO 85 L=1,NK
            LL=MID-K+L
            IF(LL.EQ.MID) GO TO 85
            IF(LL.GT.LMAX.OR.LL.LT.1) GO TO 85
            IF(LDAT(IFDIV+L)) DATA(IB+K)=DATA(IB+K)
     1      -DATA(IAAA+K+NK*(LL-1))* DATA(IW+L+MG*(J-1))
 85         CONTINUE
 90      CONTINUE
         DO 100 K=1,NK
         IF(.NOT.LDAT(IFDIV+K))  GO TO 100
            DO 95 L=1,LMAX
            DATA(IAAA+K+NK*(L-1)) = 0.0
            LL = MAX0(1,(L+K-MID))
            LL=MIN0(LL,NK)
            MPICU=MID+K-LL
 95         DATA(IAAA+LL+NK*(MPICU-1))=0.0
         DATA(IAAA+K +NK*(MID-1)) = 1.0
         DATA(IB+K)=DATA(IW+K+MG*(J-1))
 100     CONTINUE
 105  IF(KDEBUG.LT.1) GO TO 110
      WRITE(I3,2) ((DATA(IAAA+K+NK*(L-1)),L=1,LMAX),DATA(IB+K),K=1,NK)
 110  CALL DECOMP(NK,IERROR,LMAX,MID,DATA(IAAA+1),DATA(IANSWE+1),
     1DATA(IB+1),NK)
      IF(IERROR.GT.1) GO TO 1000
      CALL SOLVE(NK,LMAX,MID,DATA(IAAA+1),DATA(IANSWE+1),DATA(IB+1),NK)
         DO 150 K=1,NK
 150     DATA(IW+K+MG*(J-1))=DATA(IANSWE+K)
      RETURN
1000  WRITE(I3,1)
      IERROR = 3
      RETURN
C-----------------------------------------------------------------------
  1   FORMAT(24H ERROR IN DECOMP, DIVERT  )
  2   FORMAT(1H0, 1P7E15.4)
C-----------------------------------------------------------------------
      END
```

```
C********************** SUBROUTINE EXPRIN ******************************
      SUBROUTINE EXPRIN
C
      IMPLICIT INTEGER (I)
      DIMENSION CHFCOR(5),CHFLBL(5)
      DATA CHFCOR /4HBAW2,4HW-3 ,4HH-L ,4HC-4 ,4HB-VC/
      DATA CHFLBL /4HDNBR,4HDNBR,4HCHFR,4HCPR ,4HCHFR/
      DATA H1,H2,H3,H4,H5 / 1H(, 1H,, 1H), 4H  W(, 4H)WP( /
      DATA H6, H7, H8 /1HW, 1HX, 2HT( /
C
      INTEGER IDAT(1)
      LOGICAL LDAT(1), GRID
      REAL KIJ, KF, KKF, KCLAD, KFUEL
C
      COMMON  DATA(1)
      EQUIVALENCE  (DATA(1),IDAT(1),LDAT(1))
C
      COMMON /COBRA1/  ABETA ,AFLUX ,ATOTAL,BBETA ,DIA   ,DT    ,DX    ,
     1   ELEV  ,FERROR,FLO   ,FTM   ,GC    ,GK    ,GRID  ,HSURF ,HF    ,
     2   HFG   ,HG    ,I2    ,I3    ,IERROR,IQP3  ,ITERAT,J1    ,J2    ,
     3   J3    ,J4    ,J5    ,J6    ,J7    ,KDEBUG,KF    ,KIJ   ,
     4   NAFACT,NARAMP,NAX   ,NAXL  ,NBBC  ,NCHAN ,NCHF  ,NDX   ,NF    ,
     5   NGAPS ,NGRID ,NGRIDT,NGTYPE,NGXL  ,NK    ,NODES ,NODESF,NPROP ,
     6   NRAMP ,NROD  ,NSCBC ,NV    ,NVISCW,PI    ,PITCH ,POWER ,PREF  ,
     7   QAX   ,RHOF  ,RHOG  ,SIGMA ,SL    ,TF    ,TFLUID,THETA ,THICK ,
     8   UF    ,VF    ,VFG   ,VG    ,Z
C
      COMMON /COBRA2/  AA(4), AF(7), AFACT(10,10), AV(7), AXIAL(30),
     1   AXL(10), BB(4), BX(30), CC(4), CCLAD(2), CFUEL(2), DFUEL(2),
     2   GAPXL(10), GFACT(9,10), GRIDXL(10), HGAP(2), HHF(30), HHG(30),
     3   IGRID(10), KCLAD(2), KFUEL(2), KKF(30), NCH(10), NGAP(9),
     4   PP(30), RCLAD(2),RFUEL(2),SSIGMA(30), TCLAD(2), UUF(30),
     5   VVF(30), VVG(30), XQUAL(30), Y(30), TT(30)
C
      COMMON /COBRA3/  MA    ,MC    ,MG    ,MN    ,MR    ,MS    ,MX    ,
     1          III   ,IA    ,IAAA  ,IAC   ,IALPHA,IAN   ,IANSWE,IB    ,
     1   ICCHAN,ICD   ,ICHFR ,ICON  ,ICOND ,ICP   ,ID    ,IDC   ,IDFDX ,
     2   IDHDX ,IDHYD ,IDHYDN,IDIST ,IDPDX ,IDPK  ,IDUR  ,IDR   ,IF    ,
     3   IFACTO,IFDIV ,IFINLE,IFLUX ,IFMULT,IFOLD ,IFSP  ,IFSPLI,IFXFLO,
     4   IGAP  ,IGAPN ,IGAPS ,IH    ,IHFILM,IHINLE,IHOLD ,IHPERI,IIDARE,
     5   IIDFUE,IIDGAP,IIK   ,IJBOIL,IJK   ,ILC   ,ILENGT,ILOCA ,ILR   ,
     6   IMCHFR,IMCFRC,IMCFRR,INTYPE,INWRAP,INWRPS,IP    ,IPERIM,IPH   ,
     7   IPHI  ,IPRNTC,IPRNTR,IPRNTN,IPW   ,IPWRF ,IQC   ,IQF   ,IQPRIM,
     8   IQUAL ,IRADIA,IRHO  ,IRHOOL,ISP   ,IT    ,ITDUMY,ITINLE,ITROD ,
     9   IU    ,IUH   ,IUSAVE,IUSTAR,IV    ,IVISC ,IVISCW,IVP   ,IVPA  ,
     A   IW    ,IWOLD ,IWP   ,IWSAVE,IX    ,IXCROS,IIA  ,IIB  ,IXPOLD
C
      COMMON/LINK2/CROSS(6),FG(30),FH(30),FP(30),FQ(30),IM(9),JM(9),
     1OUTPUT(10),PRINT(12),TEXT(17),YG(30),YH(30),YP(30),YQ(30)
      COMMON/LINK3/DXX,ETIME,GIN,HIN,I8,IG,IN,ISAVE,JUMP,KASE,KT,MAXT,
     1 NDT,NDXP1,NFUELT,NG,NH,NJUMP,NOUT,NP,NPCHAN,NPNODE,NPROD,NQ,NR,
     2 NSKIPT,NSKIPX,NTRIES,PEXIT,PHTOT,SAVEDT,TIN,TTIME,ZZ
```

```
C-----------------------------------------------------------------------
C
C     PRINT OUTPUT
      ISAVE = IERROR
      IERROR = 0
      IF(NCHF.GT.0 .AND. ISAVE.EQ.0) CALL CHF(3,NDXP1)
      KT = KT+1
      IF(KT.LT.NSKIPT) GO TO 500
C
C     PRINT RESULTS
      IF(ETIME.GT.0.) GO TO 457
C     COMPUTE MASS AND ENERGY BALANCE
      FLOIN = 0.
      FLOOUT = 0.
      ENGIN = 0.
      ENGOUT = 0.
      NDXP1 = NDX+1
         DO 448 I=1,NCHAN
         FLOIN =FLOIN +DATA(IF+I)
         FLOOUT=FLOOUT+DATA(IF+I+MC*(NDXP1-1))
         ENGIN =ENGIN +DATA(IF+I)*DATA(IH+I)
 448     ENGOUT=ENGOUT+DATA(IF+I+MC*(NDXP1-1))*DATA(IH+I+MC*(NDXP1-1))
      FLOERR = FLOOUT - FLOIN
      ENGADD = AFLUX*Z*PHTOT/.0036
      ENGERR =  ENGOUT - ENGIN - ENGADD
      WRITE(I3,99) KASE,TEXT,FLOIN,ENGIN,FLOOUT,ENGADD,FLOERR,
     1ENGOUT,ENGERR
C     PREPARE CHANNEL EXIT SUMMARY
      J = NDXP1
         DO 450 I=1,NCHAN
         OUTPUT(1) = TF
         IF(DATA(IH+I+MC*(J-1)).LT.HF)  CALL CURVE(OUTPUT(1),
     1   DATA(IH+I+MC*(J-1)),TT,HHF,NPROP,IERROR,1)
         OUTPUT(2)=(DATA(IH+I+MC*(J-1))-HF)/HFG
         IF(OUTPUT(2).LT.0.) OUTPUT(2) = 0.
         OUTPUT(3)=(RHOF-DATA(IRHO+I+MC*(J-1)))/(RHOF-RHOG)
         IF(OUTPUT(3).LT.0.) OUTPUT(3) = 0.
         OUTPUT(4)=DATA(IF+I+MC*(J-1))/DATA(IAN+I)*.0036
         WRITE(I3,100) I,DATA(IH+I+MC*(J-1)),OUTPUT(1),DATA(IRHO+I+
     1   MC*(J-1)),OUTPUT(2),OUTPUT(3),DATA(IF  +I+MC*(J-1)),OUTPUT(4)
 450     CONTINUE
      IF(IERROR.GT.1) GO TO 505
C     COMPUTE BUNDLE AVERAGED RESULTS
 452  WRITE(I3,25) KASE,TEXT
      WRITE(I3,101)
      WRITE(I3,82)
         DO 456 J=1,NDXP1,NSKIPX
         SAVE1 = 0.
         SAVE2 = 0.
         SAVE3 = 0.
         SAVE4 = 0.
            DO 454 I=1,NCHAN
```

```
              SAVE1=SAVE1+DATA(IP+I+MC*(J-1))*DATA(IAN+I)
              SAVE2=SAVE2+DATA(IH+I+MC*(J-1))*DATA(IF+I+MC*(J-1))
              SAVE3=SAVE3+DATA(IF+I+MC*(J-1))
 454          SAVE4=SAVE4+DATA(IRHO+I+MC*(J-1))*DATA(IAN+I)
           OUTPUT(1)=DATA(IX+J)*12.
           OUTPUT(2) = SAVE1/ATOTAL/144.
           OUTPUT(3) = SAVE2/SAVE3
           OUTPUT(4) = TF
           IF(OUTPUT(3).LT.HF)CALL CURVE(OUTPUT(4),OUTPUT(3),TT,HHF,NPROP,
     1     IERROR,1)
           IF(IERROR.GT.1) GO TO 505
           OUTPUT(5) = SAVE4/ATOTAL
           OUTPUT(6) = 0.
           IF(OUTPUT(3).GT.HF) OUTPUT(6) = (OUTPUT(3)-HF)/HFG
           OUTPUT(7) = 0.
           IF(OUTPUT(5).LT.RHOF) OUTPUT(7) = (RHOF-OUTPUT(5))/(RHOF-RHOG)
           OUTPUT(8) = SAVE3
           OUTPUT(9) = SAVE3/ATOTAL*.0036
           WRITE(I3,81) (OUTPUT(II),II=1,9)
 456       CONTINUE
        IF(IERROR.GT.1) GO TO 505
C       PRINT CHANNEL AND ROD RESULTS AS DEFINED BY OUTPUT OPTIONS
 457       DO 460 JJ=1,NPCHAN
           I=IDAT(IPRNTC+JJ)
           WRITE(I3,25) KASE, TEXT
           WRITE(I3,80) ETIME,I
           WRITE(I3,82)
              DO 458 J=1,NDXP1,NSKIPX
              OUTPUT(1)=DATA(IX+J)*12.
              OUTPUT(3)=DATA(IH+I+MC*(J-1))
              OUTPUT(2)=DATA(IP+I+MC*(J-1))/144.
              OUTPUT(4) = TF
              IF(DATA(IH+I+MC*(J-1)).LT.HF)CALL CURVE(OUTPUT(4),
     1        DATA(IH+I+MC*(J-1)),TT,HHF,NPROP,IERROR,1)
              IF(IERROR.GT.1) GO TO 505
              OUTPUT(5)=DATA(IRHO+I+MC*(J-1))
              OUTPUT(6) = 0.
              IF(DATA(IH+I+MC*(J-1)).GT.HF)  OUTPUT(6)=(
     1        DATA(IH+I+MC*(J-1))-HF)/HFG
              OUTPUT(7) = 0.
              IF(DATA(IRHO+I+MC*(J-1)).LT.RHOF)  OUTPUT(7)=(RHOF-
     1        DATA(IRHO+I+MC*(J-1)))/(RHOF-RHOG)
              OUTPUT(8)=DATA(IF+I+MC*(J-1))
              OUTPUT(9)=DATA(IF+I+MC*(J-1))/DATA(IAN+I)*.0036
              WRITE(I3,81) (OUTPUT(II),II=1,9)
 458          CONTINUE
 460       CONTINUE
        IF(NOUT.LT.1) GO TO 499
        IF(NOUT.EQ.2) GO TO 470
        IF(NK.EQ.0) GO TO 888
           DO 465 M=1,NK,10
           MM = M+9
```

```
      IF(NK.LE.MM) MM=NK
      WRITE(I3,31)KASE,TEXT,H7,(H6,H1,IDAT(IIK+K),H2,
     1 IDAT(IJK+K),H3,K=M,MM)
         DO 465 J=1,NDXP1,NSKIPX
         XDUMY=DATA(IX+J)*12.
         WRITE(I3,30) XDUMY,(DATA(IW+K+MG*(J-1)),K=M,MM)
 465     CONTINUE
 888  CONTINUE
      IF(NOUT.EQ.1) GO TO 499
 470  IF(NPROD.LT.1) GO TO 4990
      DO 485 NN=1,NPROD
      N=IDAT(IPRNTR+NN)
      NDUMY=IDAT(IIDFUE+N)
      II=1
      IF(NCHF.GT.0) II=NCHF
      WRITE(I3,94) KASE, TEXT, ETIME, N, NDUMY,
     1 CHFLBL(II), (H8,IDAT(IPRNTN+I),H3,I=1,NPNODE)
         DO 483 J=1,NDXP1,NSKIPX
         XDUMY=DATA(IX+J)*12.
            DO 480 II=1,NPNODE
            I=IDAT(IPRNTN+II)
 480        DATA(ITDUMY+II)= DATA(ITROD+I+MN*(N-1+MR*(J-1)))
         DFLUX=DATA(IFLUX+N+MR*(J-1))*.0036
         IF(IDAT(ICCHAN+N+MR*(J-1)).EQ.0)DATA(ICHFR+N+MR*(J-1))=0.
         IF(NODESF.GT.1) WRITE(I3,95) XDUMY,DFLUX,
     1   DATA(ICHFR+N+MR*(J-1)),IDAT(ICCHAN+N+MR*(J-1)),
     2   (DATA(ITDUMY+I),I=1,NPNODE)
         IF(NODESF.LT.1) WRITE(I3,95) XDUMY,DFLUX,
     1   DATA(ICHFR+N+MR*(J-1)),IDAT(ICCHAN+N+MR*(J-1))
 483     CONTINUE
 485  CONTINUE
4990  IF(NCHF.LT.1) GO TO 499
      WRITE(I3,96)  KASE,TEXT,ETIME,CHFCOR(NCHF),CHFLBL(NCHF)
      DO 4995 J=1,NDXP1,NSKIPX
      XDUMY=DATA(IX+J)*12.
      N=    IDAT(IMCFRR+J)
      DFLUX = 0.
      IF(N.NE.0)  DFLUX=DATA(IFLUX+N+MR*(J-1))*.0036
      IF(N.EQ.0)  DATA(IMCHFR+J)=0.
      WRITE(I3,97) XDUMY,DFLUX,DATA(IMCHFR+J),IDAT(IMCFRR+J),
     1                                   IDAT(IMCFRC+J)
4995  CONTINUE
 499  WRITE(I3,75) ITERAT
 500  CONTINUE
 505  CONTINUE
      RETURN
C
C-----------------------------------------------------------------------
 25   FORMAT(17H1CHANNEL RESULTS   /5H CASEI5,5X17A4/)
 30   FORMAT(F7.1,10F10.5)
 31   FORMAT (68H1DIVERSION CROSSFLOW BETWEEN ADJACENT CHANNELS, W(I,J),
     1 (LB/SEC-FT). // 5H CASEI5 , 5X, 17A4/// 5X,A1,2X,
```

```
     2 10(2X,A1,A1,I2,A1,I2,A1))
  75  FORMAT (// 14H ITERATIONS =   I4)
  80  FORMAT(8H TIME =  F8.5,  29H SECONDS     DATA FOR CHANNEL   I3/)
  81  FORMAT(F6.1,F12.2,2F12.2,F10.2,2F9.3,F11.4,F12.4)
  82  FORMAT (' DISTANCE   DELTA-P    ENTHALPY   TEMPERATURE DENSITY
     1EQUIL    VOID        FLOW      MASS FLUX'/ '  (IN.)      (PSI)      (
     1BTU/LB)     (DEG-F)    (LB/CU-FT) QUALITY FRACTION    (LB/SEC) (MLB/H
     1R-FT2)')
  94  FORMAT(5H1CASEI5,5X17A4//8H TIME =  F8.5,9H SECONDS
     2 28H    TEMPERATURE DATA FOR ROD  I3,12H,  FUEL TYPE  I2//
     4 ' DISTANCE  FLUX       ',A4,'  CHANNEL                TEMP',
     5  'ERATURE(F)'/,22H  (IN.)  (MBTU/HR-FT2)   13X,10(4X,A2,I2,A1))
  95  FORMAT(F8.1,F9.4,F9.3,I4,5X,10(F9.1))
  96  FORMAT(5H1CASEI5,5X17A4//
     1 8H TIME =  F8.5,9H SECONDS  //A7,' CRITICAL HEAT FLUX SUMMARY'/
     2 ' DISTANCE    FLUX   M',A4,'      ROD     CHANNEL')
  97  FORMAT(F8.1,2F8.3,2I8)
  99  FORMAT('1CHANNEL EXIT SUMMARY RESULTS'/
     1  5H CASEI5,5X17A4//' MASS BALANCE - -      ',17X,
     410X,'ENERGY BALANCE - -       ',/
     3,'     MASS FLOW IN      ',E12.5,' LB/SEC',
     410X,'   FLOW ENERGY IN        ',E12.5,' BTU/SEC',/
     3'     MASS FLOW OUT    ',E12.5,' LB/SEC',
     410X,'   ENERGY ADDED          ',E12.5,' BTU/SEC',/
     3'     MASS FLOW ERROR  ',E12.5,' LB/SEC',
     410X,'   FLOW ENERGY OUT       ',E12.5,' BTU/SEC',/
     449X,'   ENERGY ERROR          ',E12.5,' BTU/SEC',//
     7' CHANNEL ENTHALPY TEMPERATURE DENSITY   EQUIL      VOID     FLOW
     8 MASS FLUX'/
     9'  (NO.) (BTU/LB)  (DEG-F)    (LB/FT3) QUALITY  FRACTION  (LB/SEC)
     1 (MLB/HR-FT2)')
 100  FORMAT(I6,2F10.2,F10.2,2F9.3,F10.4,F12.4)
 101  FORMAT(' BUNDLE AVERAGED RESULTS'/)
C-----------------------------------------------------------------------
      END
```

```
C*********************** SUBROUTINE FILM **********************************
      SUBROUTINE FILM(H,ALP,ROV,ROL,VVA,VLA,HD,RHD,TL,TV,TW,TSAT,HFG,
     *  CPV,CPL,P,VISV,VISL,BETAV,SIG,IHTR,X)
C
C     NOTE: IN BROMLEY'S AND MCADAMS' CORRELATIONS VAPOR PROPERTIES ARE
C        EVALUATED AT BULK VAPOR TEMPERATURE AND NOT AT VAPOR FILM
C        TEMPERATURE. IN GROENEVELD'S CORRELATION THE VAPOR PRANDTL
C        NUMBER IS EVALUATED AT BULK VAPOR TEMPERATURE AND NOT AT WALL
C        TEMPERATURE.
C
C     HIGH FLOW FILM BOILING
C     GROENEVELD 5.7 OR MODIFIED DITTUS-BOELTER (FOR LOW PRESSURE)
C-------------------------------------------------------------------------
      DATA GCON,PI2/9.8066,6.2831853E+0/
C-------------------------------------------------------------------------
C
C     THERMAL CONDUCTIVITY OF DRY STEAM (W/M DEG K)
C     AS A FUNCTION OF PRESSURE (PASCAL), AND TEMPERATURE (DEG K)
C
C     ERROR OF APPROXIMATION < 10 PERCENT FOR
C     373 < TV < 623 AND P IN SUPERHEATED REGION
C     FOR LOW P, CONDTIVITY DEPENDS MORE ON TV,
C     FOR P > 50 BAR CONDTIVITY DEPENDS MORE ON P.
C     VALUE AT SATURATION FOR 70 BAR = .061
C
      CNDV = -.0123 + P*(7.8E-9 + P*2.44E-16) + 1.25E-11*TV*(80.E5 - P)
C     -------------------------------------------------------------------
C
      REV = HD*ROV*(VLA+ALP*(VVA-VLA))/VISV
      PRV = VISV*CPV/CNDV
      IF(P.LT.1.33E6) GO TO 10
      Y = 1.-.1 * ((1.-X)*((ROL/ROV)-1.))**0.4
      HGDB=.052*CNDV*RHD * REV**.688 * PRV**1.26 * Y**(-1.06)
      IHTR = 6
      GO TO 20
   10 HGDB = .023*CNDV*RHD * REV**.8 * PRV**0.4
      IHTR = 7
   20 CONTINUE
      H = HGDB
C
C     TEST FOR LOW OR HIGH FLOW
      AJG =     ALP *ROV*VVA/SQRT(GCON*HD*ROV*(ROL-ROV))
      AJF = (1.-ALP)*ROL*VLA/SQRT(GCON*HD*ROL*(ROL-ROV))
      AJ = SQRT(AJG)+SQRT(AJF)
      IF(AJ.GE.2.0) RETURN
C
C     LOW FLOW FILM BOILING
C     BROMLEY PLUS MAX OF MCADAMS AND FORCED CONVECTION(AS FOR HIGH FLOW
      CLAM = PI2*SQRT(SIG/(ROL-ROV))
      HFGP = HFG+0.5*CPV*(TW-TSAT)
      T1 = GCON*(ROL-ROV)*ROV*(CNDV**3)*HFGP/(CLAM*VISV*(TW-TSAT))
      HMB = .62* T1**.25
```

```
      T1 = ROV*ROV*GCON*BETAV*CPV*ABS(TW-TV)/(VISV*CNDV)
      HMA = .13*CNDV* T1**0.333333
      H = (1.-ALP)*HMB + ALP*AMAX1(HGDB,HMA)
      IHTR = 8
C
      RETURN
      END
```

```
C*********************** SUBROUTINE FIZPRP ********************************
      SUBROUTINE FIZPRP(IPART,NPROP)
C
      REAL KKF
C
      COMMON /COBRA2/  AA(4), AF(7), AFACT(10,10), AV(7), AXIAL(30),
     1   AXL(10), BB(4), BX(30), CC(4), CCLAD(2), CFUEL(2), DFUEL(2),
     2   GAPXL(10), GFACT(9,10), GRIDXL(10), HGAP(2), HHF(30), HHG(30),
     3   IGRID(10), KCLAD(2), KFUEL(2), KKF(30), NCH(10), NGAP(9),
     4   PP(30), RCLAD(2),RFUEL(2),SSIGMA(30), TCLAD(2), UUF(30),
     5   VVF(30), VVG(30), XQUAL(30), Y(30), TT(30)
C-------------------------------------------------------------------------
C
C     IPART = 1, SET PHYSICAL PROPERTIES
C     IPART = 2, PRINT PHYSICAL PROPERTIES
C     ENTER WITH NPROP, PMAX (=PP(1)) AND PMIN (=PP(2))
C     SET IN OPERA OR MODEL
C-------------------------------------------------------------------------
C
      IF (IPART.EQ.2) GO TO 10
      P1 = PP(1)
      P2 = PP(2)
  6   A = (P2-P1)/FLOAT(NPROP-1)
         DO 8 I=1,NPROP
         P=P1+(I-1.0)*A
         PP(I)=P
         TT(I)=SATTEM(P)
         RL=ROLIQ(P)
         VVF(I)=1.0/RL
         RG=ROVAP(P)
         VVG(I)=1.0/RG
         H=HLIQ(P)
         HHF(I)=H
         HHG(I)=HVAP(P)
         CALL HAPROP(P,H,CP,UUF(I),KKF(I))
         CALL SURTEN(P,RL,RG,SSIGMA(I))
  8      CONTINUE
      RETURN
C
 10   WRITE (6,1003)
      WRITE (6,1004) (PP(I),TT(I),VVF(I),VVG(I),HHF(I),HHG(I),UUF(I),
     1 KKF(I),SSIGMA(I),I=1,NPROP)
      RETURN
C
C-------------------------------------------------------------------------
1003  FORMAT(////, '  PHYSICAL PROPERTIES', /, 2X,'-------- ----------',
     1 //, 4X, 'P', 9X, 'T', 8X, 'VF', 8X, 'VG', 8X, 'HF', 8X, 'HG',
     2 7X, 'VISC', 8X, 'KF', 6X, 'SIGMA', /)
1004  FORMAT(F8.1, F10.2, F8.5, F12.5, 2F10.2, 3F10.5)
C-------------------------------------------------------------------------
      END
```

```
C********************** SUBROUTINE FORCE ********************************
      SUBROUTINE FORCE(J)
C
      IMPLICIT INTEGER (I)
      INTEGER IDAT(1)
      LOGICAL LDAT(1), GRID
      REAL KIJ, KF, KKF, KCLAD, KFUEL
C
      COMMON  DATA(1)
      EQUIVALENCE  (DATA(1),IDAT(1),LDAT(1))
C
      COMMON /COBRA1/  ABETA ,AFLUX ,ATOTAL,BBETA ,DIA   ,DT    ,DX    ,
     1   ELEV  ,FERROR,FLO   ,FTM   ,GC    ,GK    ,GRID  ,HSURF ,HF    ,
     2   HFG   ,HG    ,I2    ,I3    ,IERROR,IQP3  ,ITERAT,J1    ,J2    ,
     3   J3    ,J4    ,J5    ,J6    ,J7    ,KDEBUG,KF    ,KIJ   ,
     4   NAFACT,NARAMP,NAX   ,NAXL  ,NBBC  ,NCHAN ,NCHF  ,NDX   ,NF    ,
     5   NGAPS ,NGRID ,NGRIDT,NGTYPE,NGXL  ,NK    ,NODES ,NODESF,NPROP ,
     6   NRAMP ,NROD  ,NSCBC ,NV    ,NVISCW,PI    ,PITCH ,POWER ,PREF  ,
     7   QAX   ,RHOF  ,RHOG  ,SIGMA ,SL    ,TF    ,TFLUID,THETA ,THICK ,
     8   UF    ,VF    ,VFG   ,VG    ,Z
C
      COMMON /COBRA2/  AA(4), AF(7), AFACT(10,10), AV(7), AXIAL(30),
     1   AXL(10), BB(4), BX(30), CC(4), CCLAD(2), CFUEL(2), DFUEL(2),
     2   GAPXL(10), GFACT(9,10), GRIDXL(10), HGAP(2), HHF(30), HHG(30),
     3   IGRID(10), KCLAD(2), KFUEL(2), KKF(30), NCH(10), NGAP(9),
     4   PP(30), RCLAD(2),RFUEL(2),SSIGMA(30), TCLAD(2), UUF(30),
     5   VVF(30), VVG(30), XQUAL(30), Y(30), TT(30)
C
      COMMON /COBRA3/  MA    ,MC    ,MG    ,MN    ,MR    ,MS    ,MX    ,
     1          III   ,IA    ,IAAA  ,IAC   ,IALPHA,IAN   ,IANSWE,IB    ,
     1   ICCHAN,ICD   ,ICHFR ,ICON  ,ICOND ,ICP   ,ID    ,IDC   ,IDFDX ,
     2   IDHDX ,IDHYD ,IDHYDN,IDIST ,IDPDX ,IDPK  ,IDUR  ,IDR   ,IF    ,
     3   IFACTO,IFDIV ,IFINLE,IFLUX ,IFMULT,IFOLD ,IFSP  ,IFSPLI,IFXFLO,
     4   IGAP  ,IGAPN ,IGAPS ,IH    ,IHFILM,IHINLE,IHOLD ,IHPERI,IIDARE,
     5   IIDFUE,IIDGAP,IIK   ,IJBOIL,IJK   ,ILC   ,ILENGT,ILOCA ,ILR   ,
     6   IMCHFR,IMCFRC,IMCFRR,INTYPE,INWRAP,INWRPS,IP    ,IPERIM,IPH   ,
     7   IPHI  ,IPRNTC,IPRNTR,IPRNTN,IPW   ,IPWRF ,IQC   ,IQF   ,IQPRIM,
     8   IQUAL ,IRADIA,IRHO  ,IRHOOL,ISP   ,IT    ,ITDUMY,ITINLE,ITROD ,
     9   IU    ,IUH   ,IUSAVE,IUSTAR,IV    ,IVISC ,IVISCW,IVP   ,IVPA  ,
     A   IW    ,IWOLD ,IWP   ,IWSAVE,IX    ,IXCROS,IIA  ,IIB  ,IXPOLD
C-----------------------------------------------------------------------
C
      IF(NK.EQ.0) RETURN
         DO 10 K=1,NK
         LDAT(IFDIV+K)= .FALSE.
 10      CONTINUE
      IF(J6.EQ.0) RETURN
      JM1 = J-1
      GO TO (100,200),J6
C  FORCED DIVERSION CROSSFLOW FROM WIRE WRAPS
 100  IF(PITCH.LE.0.) GO TO 1000
      NN = Z/PITCH
```

```
      NN = NN+1
         DO 115 K=1,NN
         IF(DATA(IX+J).LE.PITCH*FLOAT(K))  GO TO 118
 115     CONTINUE
 118  PL = K-1
C     PL IS THE PITCH LENGTH CONTAINING X(J).
C     FIND THE WRAP CROSSINGS IN DX.
         DO 130 K=1,NK
         II=IDAT(IIK+K)
         JJ=IDAT(IJK+K)
            DO 130 L=1,6
            IF(DATA(IXCROS+K+MG*(L-1)))  119,130,119
 119        XC = (ABS(DATA(IXCROS+K+MG*(L-1)))+PL)*PITCH
            IF(XC.GT.DATA(IX+J).OR.
     1      XC.LE.DATA(IX+JM1))  GO TO 130
            LDAT(IFDIV+K) = .TRUE.
C           ADD AND SUBSTRACT WIRE WRAPS FROM SUBCHANNEL AT EACH
C           WRAP CROSSING.
            IF(DATA(IXCROS+K+MG*(L-1)))  120,130,121
 120        IDAT(INWRAP+II)=IDAT(INWRAP+II)+1
            IDAT(INWRAP+JJ)=IDAT(INWRAP+JJ)-1
            GO TO 123
 121        IDAT(INWRAP+II)=IDAT(INWRAP+II)-1
            IDAT(INWRAP+JJ)=IDAT(INWRAP+JJ)+1
 123        IF(NRAMP.LE.0) GO TO 1000
            DUMY = FLOAT(ITERAT)/FLOAT(NRAMP)
            IF(DUMY.GT.1.) DUMY = 1.
            DATA(IW+K+MG*(J-1))=DATA(IGAP+K)*PI*(DIA+THICK)*
     1      DATA(IDUR+K)/DX*DUMY
            IF(DATA(IXCROS+K+MG*(L-1)))  124,130,125
 124        DATA(IW+K+MG*(J-1))=-DATA(IW+K+MG*(J-1))*
     1      DATA(IF+JJ+MC*(J-1))/DATA(IA+JJ)
            DATA(IW+K+MG*(J-1))=DATA(IW+K+MG*(J-1))*DATA(IFACTO+K)
            GO TO 130
 125        DATA(IW+K+MG*(J-1))=DATA(IW+K+MG*(J-1))*DATA(IF+II+MC*(J-1))
     1      /DATA(IA+II)
            DATA(IW+K+MG*(J-1))=DATA(IW+K+MG*(J-1))*DATA(IFACTO+K)
 130        CONTINUE
      RETURN
 200  IF(.NOT.GRID) RETURN
         DO 230 K=1,NK
         IF(ABS(DATA(IFXFLO+K+MG*(NGTYPE-1))).LT.1.0E-10)  GO TO 230
C        ZERO FORCED FLOW FRACTION DOES NOT BLOCK THE NATURAL DIVERSION
C        CROSSFLOW
         II=IDAT(IIK+K)
         JJ=IDAT(IJK+K)
         LDAT(IFDIV+K)=.TRUE.
         IF(NRAMP.LE.0) GO TO 1000
         DUMY = FLOAT(ITERAT)/FLOAT(NRAMP)
         IF(DUMY.GT.1.) DUMY = 1.
         DUMY=DUMY*DATA(IFXFLO+K+MG*(NGTYPE-1))/DX
         IF(DUMY.GT.0.)  DATA(IW+K+MG*(J-1))=DUMY*DATA(IF+II+MC*(J-1))
```

```
        IF(DUMY.LT.0.)  DATA(IW+K+MG*(J-1))=DUMY*DATA(IF+JJ+MC*(J-1))
        DATA(IW+K+MG*(J-1))=DATA(IW+K+MG*(J-1))*DATA(IFACTO+K)
 230    CONTINUE
      RETURN
1000  IERROR = 6
      RETURN
      END
```

```
C*********************** SUBROUTINE HAPROP ********************************
      SUBROUTINE HAPROP(P,H,CP,XMU,XK)
C
      X=0.001*H
      X3=X*X*X
      CP=0.864+1.66*X-7.0*X*X+10.6*X3-7.0*X*X3
      CP=1.0/CP
      XMU=0.008+118.0/H
      IF(H-90.0)1,2,2
  1   XMU=0.008+118.0/(H+0.25*(90.0-H))
  2   X=X-0.25
      XK=0.47-0.45*X-0.072/EXP(6.25*X)
      RETURN
      END
```

```
C***********************************************************************
      SUBROUTINE HEAT(J)
C
C     CALCULATE THE HEAT INPUT TO EACH SUBCHANNEL AT POSITION J.
C     IF NODES GREATER THAN ZERO, CALCULATE HEAT INPUT USING THERMAL
C     CONDUCTION. OTHERWISE HEAT INPUT IS DEFINED BY HEAT GENERATION.
C     POWER = AVERAGE INTERNAL HEAT GENERATION.
C-----------------------------------------------------------------------
C
      IMPLICIT INTEGER (I)
      INTEGER  IDAT(1)
      LOGICAL  LDAT(1)
C
      COMMON DATA(1)
      EQUIVALENCE  (DATA(1),IDAT(1),LDAT(1))
C
      COMMON /COBRA1/  ABETA ,AFLUX ,ATOTAL,BBETA ,DIA   ,DT    ,DX    ,
     1   ELEV  ,FERROR,FLO   ,FTM   ,GC    ,GK    ,GRID  ,HSURF ,HF    ,
     2   HFG   ,HG    ,I2    ,I3    ,IERROR,IQP3  ,ITERAT,J1    ,J2    ,
     3   J3    ,J4    ,J5    ,J6    ,J7    ,KDEBUG,KF    ,KIJ   ,
     4   NAFACT,NARAMP,NAX   ,NAXL  ,NBBC  ,NCHAN ,NCHF  ,NDX   ,NF    ,
     5   NGAPS ,NGRID ,NGRIDT,NGTYPE,NGXL  ,NK    ,NODES ,NODESF,NPROP ,
     6   NRAMP ,NROD  ,NSCBC ,NV    ,NVISCW,PI    ,PITCH ,POWER ,PREF  ,
     7   QAX   ,RHOF  ,RHOG  ,SIGMA ,SL    ,TF    ,TFLUID,THETA ,THICK ,
     8   UF    ,VF    ,VFG   ,VG    ,Z
C
      COMMON /COBRA2/  AA(4), AF(7), AFACT(10,10), AV(7), AXIAL(30),
     1   AXL(10), BB(4), BX(30), CC(4), CCLAD(2), CFUEL(2), DFUEL(2),
     2   GAPXL(10), GFACT(9,10), GRIDXL(10), HGAP(2), HHF(30), HHG(30),
     3   IGRID(10), KCLAD(2), KFUEL(2), KKF(30), NCH(10), NGAP(9),
     4   PP(30), RCLAD(2),RFUEL(2),SSIGMA(30), TCLAD(2), UUF(30),
     5   VVF(30), VVG(30), XQUAL(30), Y(30), TT(30)
C
      COMMON /COBRA3/  MA    ,MC    ,MG    ,MN    ,MR    ,MS    ,MX    ,
     1         III   ,IA    ,IAAA  ,IAC   ,IALPHA,IAN   ,IANSWE,IB    ,
     1   ICCHAN,ICD   ,ICHFR ,ICON  ,ICOND ,ICP   ,ID    ,IDC   ,IDFDX ,
     2   IDHDX ,IDHYD ,IDHYDN,IDIST ,IDPDX ,IDPK  ,IDUR  ,IDR   ,IF    ,
     3   IFACTO,IFDIV ,IFINLE,IFLUX ,IFMULT,IFOLD ,IFSP  ,IFSPLI,IFXFLO,
     4   IGAP  ,IGAPN ,IGAPS ,IH    ,IHFILM,IHINLE,IHOLD ,IHPERI,IIDARE,
     5   IIDFUE,IIDGAP,IIK   ,IJBOIL,IJK   ,ILC   ,ILENGT,ILOCA ,ILR   ,
     6   IMCHFR,IMCFRC,IMCFRR,INTYPE,INWRAP,INWRPS,IP    ,IPERIM,IPH   ,
     7   IPHI  ,IPRNTC,IPRNTR,IPRNTN,IPW   ,IPWRF ,IQC   ,IQF   ,IQPRIM,
     8   IQUAL ,IRADIA,IRHO  ,IRHOOL,ISP   ,IT    ,ITDUMY,ITINLE,ITROD ,
     9   IU    ,IUH   ,IUSAVE,IUSTAR,IV    ,IVISC ,IVISCW,IVP   ,IVPA  ,
     A   IW    ,IWOLD ,IWP   ,IWSAVE,IX    ,IXCROS,IIA   ,IIB  ,IXPOLD
C
      COMMON/LINK3/DXX,ETIME,GIN,HIN,I8,IG,IN,ISAVE,JUMP,KASE,KT,MAXT,
     1 NDT,NDXP1,NFUELT,NG,NH,NJUMP,NOUT,NP,NPCHAN,NPNODE,NPROD,NQ,NR,
     2 NSKIPT,NSKIPX,NTRIES,PEXIT,PHTOT,SAVEDT,TIN,TTIME,ZZ
      COMMON/LINK4/IFRM,IHTM,IPROP,NCC,NCF,NDM1,NDS,NGP
C
      COMMON/FRDATA/BURN,CPR,EFFB,EPSF,EXPR,FPRESS,FPUO2,FRAC,FTD,
```

```
     1  GMIX(4),GRGH,PGAS,RADR,RDELT,THC,THG
      COMMON /TIMEST/ NT
C-----------------------------------------------------------------------
C
      IPILE = J7
      NP1 = NODESF+1
C
C     BYPASS THE HEAT FLUX CALCULATION IF BEYOND THE FIRST ITERATION
C     AND IF FUEL TEMPERATURES ARE NOT TO BE CALCULATED.
      IF(ITERAT.GT.1 .AND. NODESF.LT.1) GO TO 60
C
C     BYPASS THE HEAT FLUX CALCULATION USING THE FUEL TEMPERATURE MODEL
C     IF BEYOND THE FIRST ITERATION, AND IF FUEL TEMPERATURES HAVE BEEN
C     CALCULATED AND IF A TRANSIENT CALCULATION IS BEING PERFORMED.
      IF(ITERAT.GT.1 .AND. NODESF.GT.0 .AND. DT.LT.100.) GO TO 60
      IF(IQP3.LE.1) GO TO 170
      CALL CURVE(QAX,(DATA(IX+J)-DX*0.5)/Z,AXIAL,Y,NAX,IERROR,1)
C
C     DETERMINE THE HEAT FLUX FROM EACH ROD.
 170  XAT = (DATA(IX+J)-DX*0.5)/Z
         DO 50 N=1,NROD
         IF(IQP3.LE.1) GO TO 160
C
C        CALCULATE THE FORCED HEAT FLUX FROM EACH ROD
 165     DATA(IFLUX+N+MR*(J-1))=AFLUX*DATA(IRADIA+N)*QAX*POWER/.0036
         GO TO 150
 160     K=IDAT(IIDFUE+N)
         IF(K.EQ.1)  DATA(IFLUX+N+MR*(J-1))=DATA(IQF+N+MC*(J-1))
     1   /(DATA(IHPERI+N)*DX)
         IF(K.EQ.2) DATA(IFLUX+N+MR*(J-1))=DATA(IQF+N+MC*(J-1))
     1   /(DATA(IHPERI+N)*DX)
 150     CONTINUE
         IF(NODESF.LT.1) GO TO 50
C
C        CORRECT HEAT FLUX FOR THERMAL CAPACITY USING TRANSIENT FUEL .
C        MODEL CALCULATE AVERAGE FLUID TEMPERATURE, HEAT TRANSFER .
C        COEFFICIENT START OF LOOP FOR OBTAINING STEADY STATE FUEL ROD
C        TEMPERATURES.
            DO 40 INN=1,50
            SAVE = 0.
            TFLUID = 0.
            HSURF = 0.
            IF (IPILE.EQ.0) GO TO 6
            TFLUID=DATA(IT+N)
            CALL HTRAN(N,N,J-1,HSURF,TFLUID,IHTM,NT)
            IF (IERROR.GT.1) RETURN
            GO TO 7
  6            DO 9 L=1,6
               IF(IDAT(ILR+N+MR*(L-1))) 9,9,10
 10            I=IDAT(ILR+N+MR*(L-1))
               DUMY=DATA(IPHI+N+MR*(L-1))
               SAVE = SAVE + DUMY
```

```
               TFLUID=TFLUID+DATA(IT+I)*DUMY
               CALL HTRAN(N,I,J-1,HTC,DATA(IT+I),IHTM,NT)
               HSURF = HSURF + DUMY*HTC
               IF(IERROR.GT.1) RETURN
  9            CONTINUE
            IF(SAVE.LE.0.) GO TO 1000
            TFLUID = TFLUID/SAVE
            HSURF = HSURF/SAVE
C
C           CALCULATE FUEL TEMPERATURE
  7            DO 8 I=1,NP1
  8            DATA(ITDUMY+I)=DATA(ITROD+I+MN*(N-1+MR*(J-1)))
            IF(IFRM.EQ.0) GO TO 20
            QP=DATA(IFLUX+N+MR*(J-1))*4.*DATA(ID+N)/(DFUEL(1)**2)
            CALL TEMFR(DATA(ITDUMY+1),DT,N,TFLUID,HGAP(1),HSURF,QP,INN,
     1      NT,MN)
            GO TO 22
 20         CALL TEMP(DATA(ITDUMY+1),DT,N,J,DATA(IIA+1),DATA(IIB+1))
            IF(IERROR.GT.1) RETURN
 22            DO 24 I=1,NP1
 24            DATA(ITROD+I+MN*(N-1+MR*(J-1)))=DATA(ITDUMY+I)
            IF (IHTM.EQ.0.AND.IPROP.EQ.0) GO TO 45
            IF (NT.GT.1) GO TO 45
            IF(INN.LT.2) GO TO 40
            IF (ABS(DATA(ITDUMY+1)-FTOLD).GT.EPSF) GO TO 40
            GO TO 45
 40      FTOLD=DATA(ITDUMY+1)
         WRITE(I3,55) N,J
         GO TO 1000
 45      DATA(IFLUX+N+MR*(J-1))=HSURF*(DATA(ITROD+NP1+MN*(N-1+MR*(J-1)))
     1   -TFLUID)
 50      CONTINUE
 60   IF (IPILE.EQ.0) GO TO 70
      IF (NODESF.LT.1) GO TO 66
         DO 65 I=1,NCHAN
         CALL HTRAN(I,I,J-1,HSURF,DATA(IT+I),IHTM,NT)
 65      DATA(IQPRIM+I)= DATA(IPWRF+I+MC*(I-1))* PI * DATA(ID+I)
     1   *HSURF *(DATA(ITROD+NP1+MN*(I-1+MR*(J-1)))- DATA(IT+I))
      RETURN
 66      DO 68 I=1,NCHAN
 68      DATA(IQPRIM+I)=DATA(IPWRF+I+MC*(I-1))*PI*DATA(ID+I)*
     1   DATA(IFLUX+I+MR*(J-1))
      RETURN
C
C     CALCULATE HEAT INPUT TO EACH CHANNEL.
 70      DO 100 I=1,NCHAN
         SAVE = 0.
            DO 90 N=1,NROD
            IF(DUMY.GT.0.)  SAVE=SAVE+DUMY*DATA(IFLUX+N+MR*(J-1))*PI*
     1      DATA(ID+N)
 90         CONTINUE
100      DATA(IQPRIM+I)=SAVE
```

```
      RETURN
1000  IERROR = 14
      RETURN
C
C-----------------------------------------------------------------------
 55      FORMAT(1H1,' FUEL TEMPERATURES FAILED TO CONVERGE IN FUEL ROD'
     1   ,I3,' AT AXIAL LEVEL',I3,'.  MAXIMUM ITERATIONS = 50.')
C-----------------------------------------------------------------------
      END
```

```
C********************** SUBROUTINE HTCOR ********************************
      SUBROUTINE HTCOR(IHTR,QV,QL,HVFC,HLNB,HLFC,TW,TL,TV,P,ALP,X,
     1ROV,ROL,VV,VL,HD,IHTM,CHFR,TSAT,FLUX,NCHF,NN,II,JJ,I3)
C
C     THIS ROUTINE COMPUTES HEAT TRANSFER COEFFICIENTS AND/OR HEAT
C     FLUXES. THE TOTAL HEAT FLUX IS ASSUMED TO BE OF THE FORM:
C     Q=QV+QL+HVFC(TW-TV)+HLNB(TW-TSAT)+HLFC(TW-TL)
C     NORMALLY QV AND QL WILL BE ZERO AND ONE OR MORE OF THE HEAT
C     TRANSFER COEFFICIENTS HVFC, HLNB, AND HLFC WILL BE NON-ZERO.
C     IN TRANSITION BOILING, HOWEVER, THE HEAT TRANSFER COEFFICIENTS ARE
C     ZERO AND Q=QV+QL.
C
C     NOMENCLATURE:
C     QV      HEAT FLUX TO VAPOR (W/M**2)
C     QL      HEAT FLUX TO LIQUID (W/M**2)
C     HVFC    CONVECTION HEAT TRANSFER COEFFICIENT TO VAPOR (W/M**2 K)
C     HLNB    NUCLEATE BOILING HEAT TRANSFER COEFFICIENT (W/M**2 K)
C     HLFC    CONVECTION HEAT TRANSFER COEFFICIENT TO LIQUID (W/M**2 K)
C     TW      WALL TEMPERATURE (K)
C     TL      LIQUID TEMPERATURE (K)
C     TV      VAPOR TEMPERATURE (K)
C     P       PRESSURE (P)
C     ALP     VAPOR VOLUME FRACTION
C     ROV     VAPOR DENSITY (KG/M**3)
C     ROL     LIQUID DENSITY (KG/M**3)
C     VV      VAPOR VELOCITY (M/S)
C     VL      LIQUID VELOCITY (M/S)
C     HD      HYDRAULIC DIAMETER (M)
C     TSAT    SATURATION TEMPERATURE (K)
C
C
C     NOTE: THE FOLLOWING QUANTITIES ARE AVAILABLE AND,
C     IF DESIRED, COULD BE ADDED TO THE ARGUMENT LIST OF
C     HTCOR AND THE CORRESPONDING CALL STATEMENT:
C
C     TCHF    TEMPERATURE AT CRITICAL HEAT FLUX
C     TMSFB   MINIMUM STABLE FILM BOILING TEMPERATURE
C     QCHF    CRITICAL HEAT FLUX
C     QMSFB   HEAT FLUX AT TMSFB
C-----------------------------------------------------------------------
      DATA GCON/9.8066/
      COMMON/HTSAVE/BETAV,BETAL,CPV,CPL,HFG,SPVV,SPVL,
     1ROVS,ROLS,EV,EL,DTSDP,DELDP,DEVDP,DELDT,DEVDT,
     2DRLDP,DRVDP,DRLDT,DRVDT
      COMMON/CHFSV/CHSAVE(20,20,31)
C-----------------------------------------------------------------------
C
      HVFC=0.0
      HLFC=0.0
      HLNB=0.0
      CHFR=1.0
      QV=0.0
```

```
      QL=0.0
      IHTR=0
      VVA=ABS(VV)
      VLA=ABS(VL)
      RHD=1./HD
C     PROPERTIES CALCULATED ONCE EACH TIME STEP AND SAVED
      IF(JJ.GT.1.OR.II.GT.1) GO TO 4
C
C     OBTAIN FLUID PROPERTIES
C     (RUNNING TIME COULD BE SHORTENED BY REPLACING THE
C     FOLLOWING CALL TO STATE AND THE SUBSEQUENT COMPUTATION OF
C     HFG, BETAV, BETAL, CPV, AND CPL BY APPROPRIATE FITS TO
C     THESE QUANTITIES)
C
C     PROPERITES OBTAINED FROM STATE AT SATURATION TEMP. CORRESPONDING
C     TO PRESSURE P.
C
      TSAT1 = 9.0395* P**0.223 + 255.2
      CALL STATE(P,TSAT1,TSAT1,ROVS,ROLS,EV,EL,TSAT,DTSDP,DELDP,
     1DEVDP,DELDT,DEVDT,DRLDP,DRVDP,DRLDT,DRVDT,2,IERR)
      SPVV = 1./ROVS
      SPVL = 1./ROLS
      HFG = EV+P*SPVV -EL-P*SPVL
      BETAV = -DRVDT*SPVV
      BETAL = -DRLDT*SPVL
      CPV = DEVDT -P*DRVDT*SPVV*SPVV
      CPL = DELDT -P*DRLDT*SPVL*SPVL
    4 CONTINUE
C     ----------------------------------------------------------------
C     VISCOSITY OF SATURATED LIQUID WATER (KG/M SEC)
C     AS A FUNCTION OF TEMPERATURE (DEG K)
C
C     ERROR OF APPROXIMATION = 6 PERCENT FOR  273 < TL < 623 DEG K
C     MAY ALSO BE USED FOR NON-SATURATED CONDITIONS AT SAME TL
C     THIS FIT HAS A SINGULARITY AT TL = 251 DEG K
C     VALUE AT 250 DEG C = .107E-3
C
      VISV = 25.3 / (-8.58E4 + TV*(91.+ TV))
      VISL = 25.3 / (-8.58E4 + TL*(91.+ TL))
C     -----------------------------------------------------------------
C     THERMAL CONDUCTIVITY OF DRY STEAM (W/M DEG K)
C     AS A FUNCTION OF PRESSURE (PASCAL), AND TEMPERATURE (DEG K)
C
C     ERROR OF APPROXIMATION < 10 PERCENT FOR
C     373 < TV < 623 AND P IN SUPERHEATED REGION
C     FOR LOW P, CONDTIVITY DEPENDS MORE ON TV,
C     FOR P > 50 BAR CONDTIVITY DEPENDS MORE ON P.
C     VALUE AT SATURATION FOR 70 BAR = .061
C
      CNDV = -.0123 + P*(7.8E-9 + P*2.44E-16) + 1.25E-11*TV*(80.E5 - P)
C     -----------------------------------------------------------------
C     THERMAL CONDUCTIVITY OF LIQUID WATER
```

```
C     W/M DEG K    FUNCTION OF    PASCAL,  DEG K
C
C     ERROR OF APPROXIMATION < 5 PERCENT FOR  273 < TL < 573 DEG K
C     VALUE AT 150 BAR, 300 DEG C = .55
      TS = TL - 415.
      CNDL = .686 - 5.87E-6*TS*TS + 7.3E-10*P
C     ------------------------------------------------------------------
C     SURFACE TENSION OF LIQUID WATER (KG(F)/M)
C     AS A FUNCTION OF TEMPERATURE (DEG K)
C     ( 1 KG(F)= 9.80665 KG M/SEC**2 )
C     EQUAL TO SURFACE TENSION / GRAVITATIONAL ACCELERATION CONSTANT
C     IN UNITS OF KG/M
C
C     ERROR OF APPROXIMATION = 2 PERCENT FOR 373 < TL < 623 DEG K
C     VALUE AT 250 DEG C = .0026
C
      SIG = (80.72 - TL*.126) / (5140.+ TL)
      IF(SIG.LT.0.0) SIG = 0.0
C     ------------------------------------------------------------------
C
      GV = ALP*ROV*VVA
      GL = (1.-ALP)*ROL*VLA
      G = GV + GL
 10   CONTINUE
C
C     ...... DETERMINE HEAT TRANSFER REGIME .......
C
C     TEST QUALITY
      IF(X.GE.0.99)GO TO 300
C
C     TEST FOR COLD WALL
      IF(TW.LE.TSAT)GO TO 200
      IF(IHTM.LT.2)GO TO 30
C
C     COMPUTE MINIMUM STABLE FILM BOILING TEMPERATURE
      IF (P.GT.68.96E5) GO TO 20
      THN = 581.5 + .01876*SQRT( AMAX1(P-1.0345E5,(0.)) )
      GO TO 25
 20   THN = 630.37 + .00432*SQRT(P-68.96E5)
 25   CONTINUE
      PSI=0.0
      IF (P.LT.4.827E5) PSI = 127.3 - 26.37E-5*P
C     CALL MPC(TW,RCP,COND)
C     RRKCPW = 1./(RCP*COND)
C     INVERSE OF ROCP OF ZIRCALOY TIMES CONDUCTIVITY OF OXIDE
      RRKCPW = 3.1E-7 - 1.3E-10*TW
      RKCPL=ROL*CNDL*CPL
      TMSFB = THN + (THN-TL)* (RKCPL*RRKCPW)**0.5 - PSI
C
C     TEST WHETHER TWALL EXCEEDS TMSFB
      IF(TW.LT.TMSFB)GO TO 30
C
```

```
C     COMPUTE FILM BOILING HEAT TRANSFER COEFFICIENT
      CALL FILM(HVFC,ALP,ROV,ROL,VVA,VLA,HD,RHD,TL,TV,TW,TSAT,HFG,
     1CPV,CPL,P,VISV,VISL,BETAV,SIG,IHTR,X)
      GO TO 1000
 30   CONTINUE
C
C     DETERMINE HEAT TRANSFER COEFFICIENTS USING CHEN CORRELATION
      RVISL = 1./VISL
      XTTI= (X/(1.-X))**0.9 *SQRT(ROL/ROV) * (VISV*RVISL)**0.1
      F=1.0
      GX = G
      IF(TL.LT.TSAT) GO TO 32
      IF(XTTI.GT.0.1)F=2.35* (XTTI+.213)**0.736
      GX = GL
 32   PRL = VISL*CPL/CNDL
      REL = GX*HD*RVISL
      HLF = .023*F*CNDL*RHD* REL**0.8 * PRL**0.4
      RETP = REL * F**1.25 * 1.E-4
      S=.1
      IF(RETP.LT.70.0.AND.RETP.GE.32.5) S=1./(1.+.42* RETP**0.78)
      IF(RETP.LT.32.5) S=1./(1.+.12* RETP**1.14)
      HS = .00122*S*SQRT(CNDL*CPL/(SIG*GCON) ) * PRL**(-.29) *
     * ROL**0.25 * (CPL*ROL/(HFG*ROV))**0.24
      PWALL = (.11062558*(TW-255.2))**4.4843049
      HLN = HS* (TW-TSAT)**0.24 * (PWALL-P)**0.75
C
C     COMPUTE HEAT FLUX AS PREDICTED BY CHEN'S CORRELATION AND
C     COMPARE AGAINST THE CRITICAL HEAT FLUX
      QCHEN = HLF*(TW-TL) + HLN*(TW-TSAT)
      IF(IHTM.LT.2) GO TO 400
C
C     CALCULATE CRITICAL HEAT FLUX
C     BTU/S-FT**2 = 11400. W/M**2
      CVTHF=11400.
      IF (NCHF.EQ.5.AND.(NN.GT.20.OR.II.GT.20.OR.JJ.GT.30)) GOTO 2000
      IF(NCHF.EQ.1) QCHF=CVTHF*CHF1(NN,II,JJ+1)
      IF (NCHF.EQ.2) QCHF=CVTHF*CHF2(NN,II,JJ+1)
      IF (NCHF.EQ.3) QCHF=CVTHF*CHF3(NN,II,JJ+1)
      IF (NCHF.EQ.4) QCHF=CVTHF*CHF4(NN,II,JJ+1)*FLUX
      IF(NCHF.EQ.5) CALL CHF5(QCHF,ALP,ROV,ROL,G,P,X,HD,HFG,SIG)
      CHSAVE(NN,II,JJ)=QCHF/CVTHF
      IF(QCHEN.LE.QCHF) GO TO 400
C
C     SOLVE THE EQUATION
C     HLFC*(TCHF-TL) +HLNB*(TCHF-TSAT)**1.24*(PWALL-P)**.75  = QCHF
C     FOR TCHF USING NEWTON'S ITERATION
      TCHF=AMAX1(TL,TSAT+.1)
         DO 35 K=1,10
         TCS=AMAX1(TCHF-TSAT,(0.))
         PWALL=(.11062558*(TCHF-255.2))**4.4843049
         DQ = QCHF-HLF*(TCHF-TL)-HS* TCS**1.24 * (PWALL-P)**0.75
         DQDT = HLF + HS* TCS**0.24 * (PWALL-P)**0.75 *
```

```
     *   (1.24 + 3.3632287*TCS*PWALL/((TCHF-255.2)*(PWALL-P)) )
         DTCHF = DQ/DQDT
         TCHF = TCHF + DTCHF
         IF(ABS(DTCHF).LE.0.1)GO TO 40
 35      CONTINUE
 40   CONTINUE
      GO TO 500
C
C          ... INDIVIDUAL CORRELATIONS FOLLOW ...
C
C     CONVECTION TO SINGLE PHASE LIQUID
C     MAX OF SIEDER-TATE AND MCADAMS CORRELATIONS
C
C     NOTE: MCADAMS SHOULD EVALUATE PROPERTIES AT A LIQUID FILM TEMP
C
 200  CONTINUE
      T1=ROL*ROL*GCON*BETAL*CPL*ABS(TW-TL)/(VISL*CNDL)
      HMA=.13*CNDL* T1**0.333333
      REL=ROL*VLA*HD/VISL
      PRL=VISL*CPL/CNDL
C
C     VISCOSITY CALACULATED USING THE CORRELATION FOR SATURATED
C     LIQUID WATER DESCRIBED ABOVE
      VISW = 25.3 / (-8.58E4 + TW*(91.+ TW))
      HST=.023*CNDL*RHD* REL**0.8 * PRL**0.33 * (VISL/VISW)**0.14
      HLFC=AMAX1(HMA,HST)
      CHFR=100.0
      IHTR=1
      IF(HMA.GT.HST) IHTR=2
      GO TO 1000
C
C     CONVECTION TO SINGLE PHASE VAPOR
C     MAX OF SIEDER-TATE AND MCADAMS CORRELATIONS
C
C     NOTE:  MCADAMS SHOULD EVALUATE PROPERTIES AT A VAPOR FILM TEMP
 300  CONTINUE
      T1=ROV*ROV*GCON*BETAV*CPV*ABS(TW-TV)/(VISV*CNDV)
      HMA=.13*CNDV* T1**0.333333
      REV=ROV*VVA*HD/VISV
      PRV=VISV*CPV/CNDV
C     -----------------------------------------------------------------
C     VISCOSITY OF SATURATED STEAM (KG/M SEC)
C     AS A FUNCTION OF TEMPERATURE (DEG K)
C
C     ERROR OF APPROXIMATION = 3 PERCENT FOR  373 < TV < 623 DE K
C     MAY ALSO BE USED FOR NON-SATURATED CONDITIONS AT SAME TV
C     THIS FIT HAS A SINGULARITY AT TW = 822 DEG K
C     VALUE AT 250 DEG C = .174E-4
C
      VISW = 11.4 / (1.37E6 - TW*(844.+ TW))
      IF(TW.GT.623.) VISW= 4.07E-8*TW-3.7E-7
C     -----------------------------------------------------------------
```

```
      HST=.023*CNDV*RHD* REV**0.8 * PRV**0.33 * (VISV/VISW)**0.14
      HVFC=AMAX1(HMA,HST)
      IHTR=9
      IF(HMA.GT.HST) IHTR=10
      GO TO 1000
C
C     SUBCOOLED OR SATURATED NUCLEATE BOILING
C     CHEN CORRELATION
 400  CONTINUE
      HLFC = HLF
      HLNB = HLN
      IHTR=4
      IF(TL.LT.TSAT) IHTR=3
      GO TO 1000
C
C     TRANSITION BOILING
 500  CONTINUE
      CALL FILM(HVTB,ALP,ROV,ROL,VVA,VLA,HD,RHD,TL,TV,TMSFB,TSAT,HFG,
     1 CPV,CPL,P,VISV,VISL,BETAV,SIG,IHTR,X)
      RDTMC = 1./(TMSFB-TCHF)
      EPS = (TMSFB-TW)*RDTMC
      EPS2 = EPS*EPS
      QMSFB=HVTB*(TMSFB-TV)
      QV=(1.-EPS2)*QMSFB
      QL=EPS2*QCHF
      DQLDTW = -2.*EPS*QCHF*RDTMC
      DQVDTW = 2.*EPS*QMSFB*RDTMC
      HLFC = DQLDTW
      QL = QL + DQLDTW*(TL-TW)
      HVFC = DQVDTW
      QV = QV + DQVDTW*(TV-TW)
      IHTR=5
C
1000  CONTINUE
      RETURN
2000  WRITE(I3,2020)
      CALL EXIT
C
C------------------------------------------------------------------------
2020  FORMAT(1H ,' ERROR DETECTED IN SUBROUTINE HTCOR.  ATTEMPT TO USE',
     1' NCHF=5 OPTION FOR TOO LARGE A PROBLEM.')
C------------------------------------------------------------------------
      END
```

```
C*********************** SUBROUTINE HTRAN ********************************
      SUBROUTINE HTRAN(N,I,JJ,HTC,TLIQ,IHTM,NT)
C
C     CALCULATES ROD-TO-COOLANT HEAT TRANSFER COEFFICIENT, HTC
C-----------------------------------------------------------------------
C
      COMMON DATA(1)
C
      COMMON/PSAVE/P,ROV,ROL,TSAT
      COMMON /COBRA1/  ABETA ,AFLUX ,ATOTAL,BBETA ,DIA   ,DT    ,DX    ,
     1   ELEV  ,FERROR,FLO   ,FTM   ,GC    ,GK    ,GRID  ,HSURF ,HF    ,
     2   HFG   ,HG    ,I2    ,I3    ,IERROR,IQP3  ,ITERAT,J1    ,J2    ,
     3   J3    ,J4    ,J5    ,J6    ,J7    ,KDEBUG,KF    ,KIJ   ,
     4   NAFACT,NARAMP,NAX   ,NAXL  ,NBBC  ,NCHAN ,NCHF  ,NDX   ,NF    ,
     5   NGAPS ,NGRID ,NGRIDT,NGTYPE,NGXL  ,NK    ,NODES ,NODESF,NPROP ,
     6   NRAMP ,NROD  ,NSCBC ,NV    ,NVISCW,PI    ,PITCH ,POWER ,PREF  ,
     7   QAX   ,RHOF  ,RHOG  ,SIGMA ,SL    ,TF    ,TFLUID,THETA ,THICK ,
     8   UF    ,VF    ,VFG   ,VG    ,Z
C
      COMMON /COBRA3/  MA    ,MC    ,MG    ,MN    ,MR    ,MS    ,MX    ,
     1          III   ,IA    ,IAAA  ,IAC   ,IALPHA,IAN   ,IANSWE,IB    ,
     1   ICCHAN,ICD   ,ICHFR ,ICON  ,ICOND ,ICP   ,ID    ,IDC   ,IDFDX ,
     2   IDHDX ,IDHYD ,IDHYDN,IDIST ,IDPDX ,IDPK  ,IDUR  ,IDR   ,IF    ,
     3   IFACTO,IFDIV ,IFINLE,IFLUX ,IFMULT,IFOLD ,IFSP  ,IFSPLI,IFXFLO,
     4   IGAP  ,IGAPN ,IGAPS ,IH    ,IHFILM,IHINLE,IHOLD ,IHPERI,IIDARE,
     5   IIDFUE,IIDGAP,IIK   ,IJBOIL,IJK   ,ILC   ,ILENGT,ILOCA ,ILR   ,
     6   IMCHFR,IMCFRC,IMCFRR,INTYPE,INWRAP,INWRPS,IP    ,IPERIM,IPH   ,
     7   IPHI  ,IPRNTC,IPRNTR,IPRNTN,IPW   ,IPWRF ,IQC   ,IQF   ,IQPRIM,
     8   IQUAL ,IRADIA,IRHO  ,IRHOOL,ISP   ,IT    ,ITDUMY,ITINLE,ITROD ,
     9   IU    ,IUH   ,IUSAVE,IUSTAR,IV    ,IVISC ,IVISCW,IVP   ,IVPA  ,
     A   IW    ,IWOLD ,IWP   ,IWSAVE,IX    ,IXCROS,IIA  ,IIB  ,IXPOLD
C-----------------------------------------------------------------------
C
C     CHOICE BETWEEN OLD AND NEW HEAT TRANSFER MODELS MADE HERE
      IF (IHTM.EQ.0) GO TO 300
      NP1=NODESF+1
C
C     VALUES CONVERTED  FROM DEG. F  TO DEG. K FOR USE BY HTCOR
      T = DATA(ITROD+NP1+MN*(N-1+MR*(JJ)))
      TW = 5./9. * (T-32.) + 273.15
C
C     LOW WALL TEMP. INDICATES THAT ROD TEMP. NOT YET
C     CALCULATED - SO OLD HEAT TRTANSFER MODEL USED.
      IF (TW.LT.280.) GO TO 300
      TL= 5./9. * (TLIQ-32.) + 273.15
      TV=TL
      XX=DATA(IQUAL+I)
      ALP=DATA(IALPHA+I)
      IF (XX.LE.0.) VL=.3048*DATA(IF+I+MC*(JJ-1))/
     1  (DATA(IRHO+I+MC*(JJ-1))*(1.-ALP)*DATA(IA+I))
      IF (XX.GT.0.) VL=.3048*((DATA(IF+I+MC*(JJ-1))*
     1  (1.-XX))/(RHOF*(1.-ALP)*DATA(IA+I)))
```

```
      VV=VL
      IF (XX.GT.0.) VV=.3048*DATA(IF+I+MC*(JJ-1))*XX/
     1  (RHOG*ALP*DATA(IA+I))
      HD=.3048*DATA(IDHYD+I)
C
C     CONVERTS DENSITY FROM LB/FT**3 TO KG/M**3
      ROV = RHOG * 16.0185
      ROL = RHOF * 16.0185
C
C     CONVERT PRESSURE FROM PSI TO N/M**2
      P=6.893E3*(PREF)
C
C     NO CHF CHECK IN HTCOR IF NT AND ITERAT BOTH EQUAL ONE
C     BECAUSE START OF BOILING INDICATORS WILL NOT
C     BE SET YET IN THIS CASE
      NHTM=IHTM
      IF (NT.EQ.1.AND.ITERAT.EQ.1) NHTM=1
      CALL HTCOR(IDUM1,QV,QL,HVFC,HLNB,HLFC,TW,TL,TV,P,ALP,XX,
     1  ROV,ROL,VV,VL,HD,NHTM,CHFR,TSAT,DATA(IFLUX+N+MR*(JJ)),
     2  NCHF,N,I,JJ,I3)
      HTC=4.896E-5*(HVFC+HLFC)
C
C     ONLY CONSIDER FORCED CONVECTION WHEN TW VERY CLOSE TO TL
      IF (ABS(TW-TL).LT..0001) RETURN
      HTC=HTC+4.896E-5*(QV+QL+HLNB*(TW-TSAT))/(TW-TL)
      IF (NT.GT.1) RETURN
C
C     LARGE CHANGES IN PREDICTED HEAT TRANSFER COEFF. ARE DAMPED FOR
C     STEADY STATE CALCULATIONS
      HTCOLD=DATA(IFLUX+N+MR*(JJ))/(DATA(ITROD+NP1+MN*(N-1
     1 +MR*(JJ)))-TLIQ)
      IF ((ABS(HTC-HTCOLD)/HTCOLD).LT..001) RETURN
      HTC=0.8*HTC+0.2*HTCOLD
      RETURN
C
  300 HTC=HCOOL(N,I,JJ)
      RETURN
      END
```

```
C********************** SUBROUTINE INDAT *******************************
      SUBROUTINE INDAT(INIT,NOPRIN)
C
      IMPLICIT INTEGER (I)
      INTEGER IDAT(1)
      LOGICAL LDAT(1), GRID, PRINT
      REAL KIJ, KF, KKF, KCLAD, KFUEL
C
      COMMON  DATA(1)
      EQUIVALENCE  (DATA(1),IDAT(1),LDAT(1))
C
      COMMON /COBRA1/  ABETA ,AFLUX ,ATOTAL,BBETA ,DIA   ,DT    ,DX    ,
     1   ELEV  ,FERROR,FLO   ,FTM   ,GC    ,GK    ,GRID  ,HSURF ,HF    ,
     2   HFG   ,HG    ,I2    ,I3    ,IERROR,IQP3  ,ITERAT,J1    ,J2    ,
     3   J3    ,J4    ,J5    ,J6    ,J7    ,KDEBUG,KF    ,KIJ   ,
     4   NAFACT,NARAMP,NAX   ,NAXL  ,NBBC  ,NCHAN ,NCHF  ,NDX   ,NF    ,
     5   NGAPS ,NGRID ,NGRIDT,NGTYPE,NGXL  ,NK    ,NODES ,NODESF,NPROP ,
     6   NRAMP ,NROD  ,NSCBC ,NV    ,NVISCW,PI    ,PITCH ,POWER ,PREF  ,
     7   QAX   ,RHOF  ,RHOG  ,SIGMA ,SL    ,TF    ,TFLUID,THETA ,THICK ,
     8   UF    ,VF    ,VFG   ,VG    ,Z
C
      COMMON /COBRA2/  AA(4), AF(7), AFACT(10,10), AV(7), AXIAL(30),
     1   AXL(10), BB(4), BX(30), CC(4), CCLAD(2), CFUEL(2), DFUEL(2),
     2   GAPXL(10), GFACT(9,10), GRIDXL(10), HGAP(2), HHF(30), HHG(30),
     3   IGRID(10), KCLAD(2), KFUEL(2), KKF(30), NCH(10), NGAP(9),
     4   PP(30), RCLAD(2),RFUEL(2),SSIGMA(30), TCLAD(2), UUF(30),
     5   VVF(30), VVG(30), XQUAL(30), Y(30), TT(30)
C
      COMMON /COBRA3/  MA    ,MC    ,MG    ,MN    ,MR    ,MS    ,MX    ,
     1          III   ,IA    ,IAAA  ,IAC   ,IALPHA,IAN   ,IANSWE,IB    ,
     1   ICCHAN,ICD   ,ICHFR ,ICON  ,ICOND ,ICP   ,ID    ,IDC   ,IDFDX ,
     2   IDHDX ,IDHYD ,IDHYDN,IDIST ,IDPDX ,IDPK  ,IDUR  ,IDR   ,IF    ,
     3   IFACTO,IFDIV ,IFINLE,IFLUX ,IFMULT,IFOLD ,IFSP  ,IFSPLI,IFXFLO,
     4   IGAP  ,IGAPN ,IGAPS ,IH    ,IHFILM,IHINLE,IHOLD ,IHPERI,IIDARE,
     5   IIDFUE,IIDGAP,IIK   ,IJBOIL,IJK   ,ILC   ,ILENGT,ILOCA ,ILR   ,
     6   IMCHFR,IMCFRC,IMCFRR,INTYPE,INWRAP,INWRPS,IP    ,IPERIM,IPH   ,
     7   IPHI  ,IPRNTC,IPRNTR,IPRNTN,IPW   ,IPWRF ,IQC   ,IQF   ,IQPRIM,
     8   IQUAL ,IRADIA,IRHO  ,IRHOOL,ISP   ,IT    ,ITDUMY,ITINLE,ITROD ,
     9   IU    ,IUH   ,IUSAVE,IUSTAR,IV    ,IVISC ,IVISCW,IVP   ,IVPA  ,
     A   IW    ,IWOLD ,IWP   ,IWSAVE,IX    ,IXCROS,IIA   ,IIB   ,IXPOLD
C
      COMMON/LINK2/CROSS(6),FG(30),FH(30),FP(30),FQ(30),IM(9),JM(9),
     1OUTPUT(10),PRINT(12),TEXT(17),YG(30),YH(30),YP(30),YQ(30)
      COMMON/LINK3/DXX,ETIME,GIN,HIN,I8,IG,IN,ISAVE,JUMP,KASE,KT,MAXT,
     1 NDT,NDXP1,NFUELT,NG,NH,NJUMP,NOUT,NP,NPCHAN,NPNODE,NPROD,NQ,NR,
     2 NSKIPT,NSKIPX,NTRIES,PEXIT,PHTOT,SAVEDT,TIN,TTIME,ZZ
      COMMON/LINK4/IFRM,IHTM,IPROP,NCC,NCF,NDM1,NDS,NGP
      COMMON/LINK9/ENEH(400)
      COMMON /GAPFAC/ FACSL(100), FACSLK(100)
C-----------------------------------------------------------------------
C
      IF (INIT.EQ.2) GO TO 990
```

```
C
C     THE UNIVAC 1108 SETS THE CORE TO ZERO AT THE START OF EACH JOB
C     THE INITIALIZATION BELOW IS TO INITIALIZE FOR OTHER MACHINES
C     UNITS I2,I3, AND I8 ARE THE INPUT, OUTPUT, AND SAVE TAPE UNITS.
C
C     BEGINNING OF VARIABLE BLOCK
      I2=5
      I3=6
      READ(I2,68)  MC,MG,MN,MR,MX
      WRITE(I3,3000)  MC,MG,MN,MR,MX
      MX=MX+1
      CALL CORE
C     ALL VALUES INITIALISED TO ZERO BETWEEN HERE AND 930 COULD PROBABLY
C     BE LEFT OUT SINCE NOW INITIALISED IN CORE.  HOWEVER LEFT IN FOR
C     TIME BEING FOR SAFETY AS NO TIME TO CHECK.
      IQP3 = 2
      PI = 355./113.
      I8=8
      GC = 32.2
      NAXL = 0
      NGXL = 0
      NGRID = 0
      NAX = 0
      IERROR = 0
      NGAPS = 0
      NAFACT = 0
      NSCBC = 0
      NBBC = 0
      J5 = 0
      J6 = 0
      NOPRIN=0
      J7=0
      NGRIDT = 0
      JUMP = 0
      NJUMP = 0
      NROD = 0
      NRAMP = 1
      NODESF = 0
      NFUELT = 0
      NOUT = 0
      NPCHAN = 0
      NPNODE = 0
      NARAMP = 1
      IG = 0
      ISAVE = 0
      IN = 0
C     FUEL ROD AND HEAT TRANSFER MODEL INDICATORS INITIALIZED AS ZERO
      IFRM=0
      IHTM=0
      IPROP=0
      GRID = .FALSE.
         DO 900 I=1,MC
```

```
          DATA(IHINLE+I)=0.
          DATA(IFINLE+I)=0.
  900     DATA(IQPRIM+I)=0.
          DO 905 K=1,MG
          FACSL(K)=1.
          FACSLK(K)=1.
          DATA(IWP   +K)=0.
  905     LDAT(IFDIV +K)=.FALSE.
          DO 930 J=1,MX
             DO 910 I=1,MC
             DATA(IP    +I+MC*(J-1))=0.
             DATA(IH    +I+MC*(J-1))=0.
             DATA(IF+I+MC*(J-1))=0.
             DATA(IRHO  +I+MC*(J-1))=0.
             DATA(IHOLD +I+MC*(J-1))=0.
             DATA(IFOLD +I+MC*(J-1))=0.
  910        DATA(IRHOOL+I+MC*(J-1))=0.
             DO 920 N=1,MR
             DATA(IFLUX +N+MR*(J-1))=0.
             IDAT(ICCHAN+N+MR*(J-1))=0
                DO 918 L=1,MN
  918           DATA(ITROD+L+MN*(N-1+MR*(J-1)))=0.
  920        CONTINUE
  930     CONTINUE
       READ (I2,52) MAXT
       IF(MAXT.LT.1) MAXT = 1000
C
C      READ CASE CONTROL CARD
  990  READ(I2,2) IPILE,KASE,J1,TEXT
       J7 = IPILE
       IERROR = 0
       ISAVE = 0
          DO 991 I = 1,11
          PRINT(I) = .FALSE.
          IF(J1.EQ.1) PRINT(I) = .TRUE.
  991  CONTINUE
C      CHECK FOR CONTINUATION OF CALCULATIONS
       IF(KASE.LT.1) STOP
          DO 915 J=1,MX
             DO 914 K=1,MG
             DATA(ICOND+K) = 0.0
             DATA(IW    +K+MG*(J-1))=0.
             DATA(ISP   +K+MG*(J-1))=0.
  914        DATA(IWOLD+K+MG*(J-1))=0.
             DO 915 K=1,MC
             DATA(IQC   +K+MC*(J-1))=0.
             DATA(IQF   +K+MC*(J-1))=0.
  915        CONTINUE
       IDAT(IIK+1) = 1
       IDAT(IJK+1) = 1
       WRITE(I3, 3) KASE,TEXT
       IF(IPILE.EQ.0) WRITE(I3,1000)
```

```
      IF(IPILE.EQ.1) WRITE(I3,1001)
      IF(IPILE.EQ.2) WRITE(I3,1002)
C
C     READ GROUP CONTROL CARD
 995  READ(I2,1) NGROUP,N1,N2,N3,N4,N5,N6
      IF(NGROUP.EQ.20)  GO TO 230
      IF(NGROUP.LT.1) GO TO 250
      IF(NGROUP.GT.12) GO TO 240
      IF(NGROUP.LT. 0) GO TO 240
      GO TO (110,120,130,140,150,160,170,180,190,200,210,220),NGROUP
C
C     INPUT FOR CARD GROUP 1, PROPERTY TABLE
 110  CALL CARDS1(PP,TT,VVF,VVG,HHF,HHG,UUF,KKF,SSIGMA,N1,I2)
      NPROP = N1
      IF(J1.LE.1) PRINT(1)=.TRUE.
      GO TO 995
C
C     INPUT FOR CARD GROUP 2, FRICTION FACTOR AND TWO-PHASE FLOW CORRELA
 120  READ (I2,5) (AA(I),BB(I),CC(I),I=1,4)
      J2 = N1
      J3 = N2
      J4 = N3
      NVISCW = N4
      IF(J3.GT.4) READ(I2,41) NV,AV
      IF(J4.GT.4) READ(I2,41) NF,AF
      IF(J1.LE.1) PRINT(2) = .TRUE.
      GO TO 995
C
C     INPUT FOR CARD GROUP 3, AXIAL HEAT FLUX TABLE
 130  IF (N1.GT.1) GO TO 135
      IQP3 = N1
      GO TO 995
 135  READ(I2,5) (Y(I),AXIAL(I),I=1,N1)
      NAX = N1
      IF(J1.LE.1) PRINT(3) = .TRUE.
      GO TO 995
C
C     INPUT FOR CARD GROUP 4, CHANNEL LAYOUT AND DIMENSIONS
 140  IF(IPILE.EQ.0) GO TO 1405
C     COMBINE CARD GROUPS 4, 7, 9 FOR PWR AND BWR.
      CALL CARDS4(DATA(IAC+1),DATA(IDC+1),DATA(IDIST+1),
     1  DATA(IDR+1),DATA(IGAPS+1),
     1    IDAT(ILC+1),MA,MG,N1,N2,NCHF,NFUELT, DATA(IPH+1),
     2    PHTOT,PRINT,DATA(IPW+1),MC)
      IF (IERROR.GE.1) GO TO 240
      CALL CORE3
      GO TO 995
1405     DO 141 J=1,N1
         READ(I2,7)  N,I,DATA(IAC+I),DATA(IPW+I),DATA(IPH+I),
     1   (IDAT(ILC+I+MC*(L-1)),DATA(IGAPS+I+MG*(L-1)),
     2   DATA(IDIST+I+MC*(L-1)),L=1,4)
         IDAT(INTYPE+I)=N
```

```
         IF(N.LE.1)
     1   IDAT(INTYPE+I)=1
 141     CONTINUE
 142  PHTOT = 0.
      ATOTAL = 0.
      K=0
      NCHAN = N2
         DO 147 I=1,NCHAN
            DO 146 L=1,4
            IF(IDAT(ILC+I+MC*(L-1))) 144,146,143
 143        J= IDAT(ILC+I+MC*(L-1))
            IF(J.LE.I) GO TO 146
            K=K+1
            DATA(IFACTO+K)=1.
            GO TO 145
 144        J=-IDAT(ILC+I+MC*(L-1))
            IF(J.LE.I) GO TO 146
            K=K+1
            DATA(IFACTO+K)=0.5
 145        IDAT(IJK+K)=J
            IDAT(IIK+K)=I
            DATA(IGAPN +K)=DATA(IGAPS +I+MG*(L-1))/12.
            DATA(IGAP  +K)=DATA(IGAPN +K)
            DATA(ILENGT+K)=DATA(IDIST +I+MC*(L-1))/12.
 146        CONTINUE
         DATA(IPERIM+I)=DATA(IPW+I)/12.
         DATA(IHPERI+I)=DATA(IPH+I)/12.
         DATA(IAN   +I)=DATA(IAC+I)/144.
         DATA(IA    +I)=DATA(IAN+I)
         DATA(IDC   +I)=DATA(IAC+I)*4./DATA(IPW+I)
         DATA(IDHYD +I)=DATA(IDC   +I)/12.
         DATA(IDHYDN+I)=DATA(IDHYD +I)
         PHTOT=PHTOT+DATA(IHPERI +I)
 147     ATOTAL=ATOTAL+DATA(IAN+I)
      NK=K
      CALL ACOL(2,IDAT(IIK+1),IDAT(IJK+1),KMAX,IDAT(ILOCA+1),MA,MS,NK,
     1MG,IPILE)
      IF(J1.LE.1) PRINT(4) = .TRUE.
      CALL CORE3
      GO TO 995
C
C     INPUT FOR CARD GROUP 5, CHANNEL AREA VARIATION TABLE
 150     DO 151 I=1,NCHAN
 151     IDAT(IIDARE+I)=0
      NAXL = N2
      NARAMP = N3
      IF(NARAMP.LE.0) NARAMP = 1
      IF(N2.LT.1) GO TO 995
      READ(I2,5) (AXL(I),I=1,N2)
      NAFACT=N1
         DO 152 J=1,N1
         READ(I2,8)  I,(AFACT(J,L),L=1,N2)
```

```
         IDAT(IIDARE+I)=J
 152     NCH(J)= I
      IF(J1.LE.1) PRINT(5) = .TRUE.
      GO TO 995
C
C     INPUT FOR CARD GROUP 6, GAP SIZE VARIATIONS TABLE
 160     DO 161 K=1,NK
 161     IDAT(IIDGAP+K)=0
      NGXL = N2
      IF(N2.LT.1) GO TO 995
      READ(I2,5) (GAPXL(L),L=1,NGXL)
      NGAPS = N1
         DO 162 LL=1,NGAPS
         READ(I2,1) K
         IDAT(IIDGAP+K)=LL
         NGAP(LL) = K
         READ (I2, 5) (GFACT(LL,L),L=1,NGXL)
 162     CONTINUE
      IF(J1.LE.1) PRINT(6) = .TRUE.
      GO TO 995
C
C     INPUT FOR CARD GROUP 7, SPACER DESIGN INFORMATION
 170  IF(IPILE.EQ.0) GO TO 1705
      WRITE(I3,1704) IPILE,NGROUP
      IERROR = 1
      GO TO 240
1705  J6 = N1
      NRAMP = N4
      IF(NRAMP.LT.1) NRAMP = 1
      GRID = .FALSE.
      NGRID = 0
      IF(J6.EQ.0) GO TO 995
      IF(J6.EQ.1) GO TO 171
      IF(J6.EQ.2) GO TO 176
      GO TO 995
 171  READ(I2,42) PITCH,DIA,THICK
      PITCH = PITCH/12.
      DIA = DIA/12.
      THICK = THICK/12.
      NJUMP = N5
         DO 172 M=1,NK
         READ(I2,64) K,DUM,CROSS
         DATA(IDUR+K)=DUM
            DO 172 L=1,6
 172        DATA(IXCROS+K+MG*(L-1))=CROSS(L)
      READ(I2,68)  (IDAT(INWRAP+I),I=1,NCHAN )
         DO 173 I=1,NCHAN
 173     IDAT(INWRPS+I)=IDAT(INWRAP+I)
      IF(J1.LE.1) PRINT(7) = .TRUE.
      IF(NJUMP.EQ.3) JUMP = 3
      IF(NJUMP.NE.3) GO TO 995
      REWIND I8
```

```
      READ(I8) ((DATA(IW+I+MG*(J-1)),I=1,MG),J=1,MX),
     1         ((DATA(IP+I+MC*(J-1)),I=1,MC),J=1,MX),
     2       ((DATA(IRHO+I+MC*(J-1)),I=1,MC),J=1,MX),
     3       ((DATA(IF  +I+MC*(J-1)),I=1,MC),J=1,MX)
      REWIND I8
      GO TO 995
  176 NGRID = N2
      NGRIDT = N3
      READ(I2,66) (GRIDXL(I),IGRID(I),I=1,NGRID)
         DO 178 I=1,NGRIDT
            DO 177 K=1,NK
  177       DATA(IFXFLO+K+MG*(I-1))=0.
            DO 178 II=1,NCHAN
  178       READ(I2,67)J,DATA(ICD+J+MC*(I-1)),K,DATA(IFXFLO+K+MG*(I-1))
      IF(J1.LE.1) PRINT(7) = .TRUE.
      GO TO 995
C
C     INPUT FOR CARD GROUP 8, ROD LAYOUT, DIMENSIONS, AND POWER FACTORS
  180 IF(IPILE.EQ.0) GO TO 1805
      WRITE(I3,1704) IPILE,NGROUP
      IERROR = 1
      GO TO 240
 1805 NROD = N2
         DO 181 J=1,N1
         READ (I2,11) N,I,DATA(IDR+I),DATA(IRADIA+I),
     1   (IDAT(ILR+I+MR*(L-1)),DATA(IPHI+I+MR*(L-1)),L=1,6)
         IDAT(IIDFUE+I)=N
         IF(N.LT.1)  IDAT(IIDFUE+I)=1
  181    CONTINUE
         DO 182 I=1,MC
            DO 182 J=1,MR
  182       DATA(IPWRF+I+MC*(J-1))=0.
         DO 185 I=1,NROD
            DO 184 L=1,6
            IF(IDAT(ILR+I+MR*(L-1)))  184,184,183
  183       K =IDAT(ILR+I+MR*(L-1))
            DATA(IPWRF+K+MC*(I-1))=DATA(IPHI+I+MR*(L-1))
  184       CONTINUE
  185    DATA(ID+I)=DATA(IDR+I)/12.
      IF(J1.LE.1) PRINT(8) = .TRUE.
      NODESF = N3
      NFUELT = N4
      NCHF = N5
      IF(NODESF.EQ.0) GO TO 995
      READ (I2,79) (KFUEL(I), CFUEL(I), RFUEL(I), DFUEL(I),
     1 KCLAD(I), CCLAD(I), RCLAD(I), TCLAD(I), HGAP(I),I=1,NFUELT)
         DO 187 I = 1,NFUELT
         KFUEL(I) = KFUEL(I)/3600.
         KCLAD(I) = KCLAD(I)/3600.
         DFUEL(I) = DFUEL(I)/12.
         TCLAD(I) = TCLAD(I)/12.
         HGAP(I) = HGAP(I)/3600.
```

```
 187     CONTINUE
      GO TO 995
C
C     INPUT FOR CARD GROUP  9, CALCULATION VARIABLES
 190  READ(I2,14) KIJ,FTM,Z,THETA,NDX,NDT,TTIME,NTRIES,FERROR,SL
      IF(SL.LT.1.E-5) SL = .5
      ELEV = COS(THETA*PI/180.)
      IF(NTRIES.LT.1) NTRIES=20
      IF(FERROR.LE.0) FERROR = 1.E-2
      NDXP1 = NDX + 1
      NSKIPX = N1
      NSKIPT = N2
      KDEBUG = N3
      IF(NSKIPT.LT.1) NSKIPT = 1
      IF(NSKIPX.LT.1) NSKIPX = 1
      ZZ = Z
      Z = Z/12.
      IF(Z.LE.0.) GO TO 240
      IF(NDX.LT.1) GO TO 240
      DX = Z/FLOAT(NDX)
      DT = 0.
      IF(NDT.GT.0 .AND. TTIME.LE.0.) NDT = 0
      IF(NDT.GT.0) DT = TTIME/FLOAT(NDT)
      SAVEDT = DT
      DXX = DX*12.
      IF(J1.LE.1) PRINT(9) = .TRUE.
      GO TO 995
C
C     INPUT FOR CARD GROUP 10, MIXING PARAMETERS
 200  IF(IPILE.LT.2) GO TO 205
      WRITE(I3,1704) IPILE, NGROUP
      GO TO 995
 205  NSCBC = N1
      IF (NSCBC.NE.4) READ(I2,5) ABETA,BBETA
         DO 206 I=1,MG
 206     ENEH(I)=1.0
      NBBC =N2
      J5 = N3
      IF(N2.GE.2) READ(I2,5) (XQUAL(I),BX(I),I=1,N2)
      IF(J5.EQ.0) GK = 0.
      IF(J5.EQ.1) READ(I2,5) GK
      IF(J1.LE.1) PRINT(10) = .TRUE.
      GO TO 995
C
C     INPUT FOR CARD GROUP 11, OPERATING CONDITIONS AND TRANSIENT FORCIN
 210  READ(I2,9) PEXIT,HIN,GIN,AFLUX
      PREF = PEXIT
      CALL PROP(1,1)
      IF(IERROR.GT.1) GO TO 240
      IN = N1
C     FOR N1=0, HIN IS THE INLET H.  FOR N1=1, HIN IS THE INLET T.
C     FOR N1=2, READ IN CHANNEL H.   FOR N1=3, READ IN CHANNEL T.
```

```
      IF(N1.GE.2) GO TO 214
      IF(N1.EQ.1) GO TO 211
      TIN = TF
      IF(HIN.LT.HF) CALL CURVE(TIN,HIN,TT,HHF,NPROP,IERROR,1)
      IF(IERROR.GT.1) GO TO 240
      GO TO 212
 211  TIN = HIN
      CALL CURVE(HIN,TIN,HHF,TT,NPROP,IERROR,1)
      IF(IERROR.GT.1) GO TO 240
 212     DO 213 I=1,NCHAN
 213     DATA(IHINLE+I)=HIN
      GO TO 216
 214  READ(I2,10) (DATA(IHINLE+I),I=1,NCHAN )
      IF(N1.LE.2) GO TO 216
         DO 215 I=1,NCHAN
         CALL CURVE(DATA(IHINLE+I),DATA(IHINLE+I),HHF,TT,NPROP,IERROR,1)
         IF(IERROR.GT.1) GO TO 240
 215     CONTINUE
 216     DO 2160 I=1,NCHAN
         DATA(ITINLE+I)=TF
         IF(DATA(IHINLE+I).LT.HF)CALL CURVE(DATA(ITINLE+I),
     1   DATA(IHINLE+I),TT,HHF,NPROP,IERROR,1)
         IF(IERROR.GT.1) GO TO 240
 2160    CONTINUE
C
C     FOR N2=0, GIN IS THE INLET G FOR EACH CHANNEL.  FOR N2=1, GIN IS
C     THE AVERAGE G BUT THE CHANNEL FLOWS ARE SPLIT TO GIVE EQUAL DP/DX.
C     FOR N INDIVIDUAL CHANNEL TOTAL FLOW FRACTION IS READ AS INPUT
      IG = N2
      FLO = GIN/.0036*ATOTAL
         DO 217 I=1,NCHAN
 217     DATA(IFINLE+I)=GIN*DATA(IAN+I)/.0036
      IF(N2.EQ.1) CALL SPLIT
      IF(IERROR.GT.1) GO TO 240
      IF(N2.LT.2) GO TO 219
      READ(I2,10)  (DATA(IFSPLI+I),I=1,NCHAN )
         DO 218 I=1,NCHAN
 218     DATA(IFINLE+I)=GIN*DATA(IAN+I)*DATA(IFSPLI+I)/.0036
 219  NP = N3
      IF(NP.GT.1) READ(I2,10) (YP(I),FP(I),I=1,NP)
      NH = N4
      IF(NH.GT.1) READ(I2,10) (YH(I),FH(I),I=1,NH)
      NG = N5
      IF(NG.GT.1) READ(I2,10) (YG(I),FG(I),I=1,NG)
      NQ = N6
      IF(NQ.GT.1) READ(I2,10) (YQ(I),FQ(I),I=1,NQ)
      IF(J1.LE.2) PRINT(11) = .TRUE.
      GO TO 995
C
C     INPUT FOR CARD GROUP 12, OUTPUT OPTIONS FOR CALCULATIONS
 220  NOUT = N1
      NPCHAN = N2
```

```
      IF(N2.LT.1) GO TO 221
      READ(I2,17)  (IDAT(IPRNTC+I),I=1,N2)
  221 NPROD = N3
      NPNODE = N4
      IF(N3.LT.1) GO TO 222
      READ 17,     (IDAT(IPRNTR+I),I=1,N3)
  222 IF(N4.LT.1) GO TO 225
      READ 17,     (IDAT(IPRNTN+I),I=1,N4)
  225 GO TO 995
C     CARD GROUP 20  .  READ DATA VIA ITHO
  230 NOPRIN=N1
      CALL CARD20(NOPRIN)
      IF(IERROR.GT.0)  GO TO 240
      GO TO 995
C
C     INPUT DATA ERROR MESSAGE
  240 WRITE(I3,54)
      STOP
  250 RETURN
C
C     END OF INPUT
C-----------------------------------------------------------------------
    1 FORMAT(7I5)
    2 FORMAT(I1, I4, I5, 17A4)
    3 FORMAT(15H1INPUT FOR CASE           I6,5X,16A4,A2,A1)
    5 FORMAT (12F5.3)
    7 FORMAT(I1,I4,3E5.2,4(I5,2E5.2))
    8 FORMAT ( I5/(12F5.3))
    9 FORMAT (6F10.0)
   10 FORMAT(12E5.0)
   11 FORMAT(I1,I4,2E5.2,6(I5,E5.2))
   14 FORMAT(4E5.2,2I5,E5.2,I5,4E5.2)
   17 FORMAT (36I2)
   41 FORMAT (I5,7E10.5)
   42 FORMAT(8E10.5)
   52 FORMAT (I5,6E12.6)
   54 FORMAT(//' INPUT DATA ERROR, THIS RUN STOPPED, CHECK INPUT')
   64 FORMAT(I5,10E5.2)
   66 FORMAT (6( E5.2,I5))
   67 FORMAT (I5,E5.2,I5,E5.2)
   68 FORMAT(10I5)
   79 FORMAT ( 9E5.2)
 1000 FORMAT(/,'  NORMAL COBRA INPUT DATA PRESENTATION'/)
 1001 FORMAT(/,'  SIMILAR CHANNELS ALL CONNECTED EG.PWR'/)
 1002 FORMAT(/,'  SIMILAR CHANNELS ALL SEPARATED EG.BWR'/)
 1704 FORMAT(' IPILE=',I2,' CARD GROUP',I2,
     1 ' INCORRECTLY ENTERED .CHECK DATA')
 3000 FORMAT('1',T50,'PROBLEM SIZE'/T50,'MC=',I5/
     1    T50,'MG=',I5/T50,'MN=',I5/,T50,'MR=',I5/T50,'MX=',I5//)
C-----------------------------------------------------------------------
      END
```

```
C********************** SUBROUTINE INITRC ******************************
      SUBROUTINE INITRC
C
C     INITIALIZE ROD CONDUCTION ARRAYS FOR NEW FUEL ROD MODEL
C     AND MAKE INITIALIZING CALL TO GAP CONDUCTANCE SUBROUTINE
C-----------------------------------------------------------------------
      REAL KCLAD,KFUEL
      COMMON DATA(1)
C
      COMMON /COBRA1/  ABETA ,AFLUX ,ATOTAL,BBETA ,DIA   ,DT    ,DX    ,
     1   ELEV  ,FERROR,FLO   ,FTM   ,GC    ,GK    ,GRID  ,HSURF ,HF    ,
     2   HFG   ,HG    ,I2    ,I3    ,IERROR,IQP3  ,ITERAT,J1    ,J2    ,
     3   J3    ,J4    ,J5    ,J6    ,J7    ,KDEBUG,KF    ,KIJ   ,
     4   NAFACT,NARAMP,NAX   ,NAXL  ,NBBC  ,NCHAN ,NCHF  ,NDX   ,NF    ,
     5   NGAPS ,NGRID ,NGRIDT,NGTYPE,NGXL  ,NK    ,NODES ,NODESF,NPROP ,
     6   NRAMP ,NROD  ,NSCBC ,NV    ,NVISCW,PI    ,PITCH ,POWER ,PREF  ,
     7   QAX   ,RHOF  ,RHOG  ,SIGMA ,SL    ,TF    ,TFLUID,THETA ,THICK ,
     8   UF    ,VF    ,VFG   ,VG    ,Z
C
      COMMON /COBRA2/  AA(4), AF(7), AFACT(10,10), AV(7), AXIAL(30),
     1   AXL(10), BB(4), BX(30), CC(4), CCLAD(2), CFUEL(2), DFUEL(2),
     2   GAPXL(10), GFACT(9,10), GRIDXL(10), HGAP(2), HHF(30), HHG(30),
     3   IGRID(10), KCLAD(2), KFUEL(2), KKF(30), NCH(10), NGAP(9),
     4   PP(30), RCLAD(2),RFUEL(2),SSIGMA(30), TCLAD(2), UUF(30),
     5   VVF(30), VVG(30), XQUAL(30), Y(30), TT(30)
C
      COMMON /COBRA3/  MA    ,MC    ,MG    ,MN    ,MR    ,MS    ,MX    ,
     1          III   ,IA    ,IAAA  ,IAC   ,IALPHA,IAN   ,IANSWE,IB    ,
     1   ICCHAN,ICD   ,ICHFR ,ICON  ,ICOND ,ICP   ,ID    ,IDC   ,IDFDX ,
     2   IDHDX ,IDHYD ,IDHYDN,IDIST ,IDPDX ,IDPK  ,IDUR  ,IDR   ,IF    ,
     3   IFACTO,IFDIV ,IFINLE,IFLUX ,IFMULT,IFOLD ,IFSP  ,IFSPLI,IFXFLO,
     4   IGAP  ,IGAPN ,IGAPS ,IH    ,IHFILM,IHINLE,IHOLD ,IHPERI,IIDARE,
     5   IIDFUE,IIDGAP,IIK   ,IJBOIL,IJK   ,ILC   ,ILENGT,ILOCA ,ILR   ,
     6   IMCHFR,IMCFRC,IMCFRR,INTYPE,INWRAP,INWRPS,IP    ,IPERIM,IPH   ,
     7   IPHI  ,IPRNTC,IPRNTR,IPRNTN,IPW   ,IPWRF ,IQC   ,IQF   ,IQPRIM,
     8   IQUAL ,IRADIA,IRHO  ,IRHOOL,ISP   ,IT    ,ITDUMY,ITINLE,ITROD ,
     9   IU    ,IUH   ,IUSAVE,IUSTAR,IV    ,IVISC ,IVISCW,IVP   ,IVPA  ,
     A   IW    ,IWOLD ,IWP   ,IWSAVE,IX    ,IXCROS,IIA  ,IIB  ,IXPOLD
C
      COMMON /MCOND/ CND(22),RCP(22),RAD(22),RRDR(22),
     1  VM(22),VP(22),QPPP(22)
      COMMON/FRDATA/BURN,CPR,EFFB,EPSF,EXPR,FPRESS,FPUO2,FRAC,FTD,
     1  GMIX(4),GRGH,PGAS,RADR,RDELT,THC,THG
      COMMON/LINK4/IFRM,IHTM,IPROP,NCC,NCF,NDM1,NDS,NGP
C-----------------------------------------------------------------------
C
C     GEOMETRY ARRAYS
      RADR=DATA(ID+1)/2.
      THC=TCLAD(1)
      NDM1=NODESF
      NDS=NODESF+1
      NGP=NCF+1
```

```
      DRF=0.5*DFUEL(1)/NCF
      DRC=THC/NCC
      RAD(1)=0.0
         DO 10 K=1,NCF
 10      RAD(K+1)=K*DRF
      RAD(NGP+1)=RAD(NCF+1)+THG
         DO 20 K=1,NCC
 20      RAD(NGP+1+K)=RAD(NGP+1)+K*DRC
         DO 30 K=1,NDM1
         IF(K.EQ.NGP)RRDR(K)=.5*(RAD(K+1)+RAD(K))
         IF(K.NE.NGP)RRDR(K)=.5*(RAD(K+1)+RAD(K))/(RAD(K+1)-RAD(K))
 30      CONTINUE
      VM(1)=0.0
      VP(1)=DRF*DRF/8.0
         DO 40 K=2,NDM1
         RP=0.5*(RAD(K+1)+RAD(K))
         RM=0.5*(RAD(K)+RAD(K-1))
         VP(K)=0.5*(RP*RP-RAD(K)*RAD(K))
 40      VM(K)=0.5*(RAD(K)*RAD(K)-RM*RM)
      RM=0.5*(RADR+RAD(NDM1))
      VM(NDS)=0.5*(RADR*RADR-RM*RM)
      VP(NDS)=0.0
C     ASSUME NO HEAT GENERATED IN GAP OR CLADDING
         DO 105 K=NGP,NDM1
 105     QPPP(K)=0.
C
C        MATERIAL PROPERTY ARRAYS
         DO 110 K=1,NCF
         CND(K)=KFUEL(1)
 110     RCP(K)=CFUEL(1)*RFUEL(1)
      CND(NGP)=HGAP(1)
      RCP(NGP)=0.0
         DO 120 K=1,NCC
         CND(NGP+K)=KCLAD(1)
 120     RCP(NGP+K)=CCLAD(1)*RCLAD(1)
C
C     INITIALIZE GAP CONDUCTANCE DATA
      IF(IPROP.LT.2)GO TO 205
      CALL MPG(.TRUE.,BURN,EFFB,FRAC,D3,D4,D5,GRGH,THG,RAD(NGP),
     1 D6,D7,D8,D9,D10,D11)
 205  CONTINUE
      RETURN
      END
```

```
C********************** SUBROUTINE INPRIN ******************************
      SUBROUTINE INPRIN
C
      IMPLICIT INTEGER (I)
      DATA H1,H2,H3,H4,H5 / 1H(, 1H,, 1H), 4H  W(, 4H)WP( /
      DATA H6, H7, H8 /1HW, 1HX, 2HT( /
      INTEGER IDAT(1)
      LOGICAL LDAT(1), GRID, PRINT
      REAL KIJ, KF, KKF, KCLAD, KFUEL
C
      COMMON  DATA(1)
      EQUIVALENCE  (DATA(1),IDAT(1),LDAT(1))
C
      COMMON /COBRA1/  ABETA ,AFLUX ,ATOTAL,BBETA ,DIA   ,DT    ,DX    ,
     1   ELEV  ,FERROR,FLO   ,FTM   ,GC    ,GK    ,GRID  ,HSURF ,HF    ,
     2   HFG   ,HG    ,I2    ,I3    ,IERROR,IQP3  ,ITERAT,J1    ,J2    ,
     3   J3    ,J4    ,J5    ,J6    ,J7    ,KDEBUG,KF    ,KIJ   ,
     4   NAFACT,NARAMP,NAX   ,NAXL  ,NBBC  ,NCHAN ,NCHF  ,NDX   ,NF    ,
     5   NGAPS ,NGRID ,NGRIDT,NGTYPE,NGXL  ,NK    ,NODES ,NODESF,NPROP ,
     6   NRAMP ,NROD  ,NSCBC ,NV    ,NVISCW,PI    ,PITCH ,POWER ,PREF  ,
     7   QAX   ,RHOF  ,RHOG  ,SIGMA ,SL    ,TF    ,TFLUID,THETA ,THICK ,
     8   UF    ,VF    ,VFG   ,VG    ,Z
C
      COMMON /COBRA2/  AA(4), AF(7), AFACT(10,10), AV(7), AXIAL(30),
     1   AXL(10), BB(4), BX(30), CC(4), CCLAD(2), CFUEL(2), DFUEL(2),
     2   GAPXL(10), GFACT(9,10), GRIDXL(10), HGAP(2), HHF(30), HHG(30),
     3   IGRID(10), KCLAD(2), KFUEL(2), KKF(30), NCH(10), NGAP(9),
     4   PP(30), RCLAD(2),RFUEL(2),SSIGMA(30), TCLAD(2), UUF(30),
     5   VVF(30), VVG(30), XQUAL(30), Y(30), TT(30)
C
      COMMON /COBRA3/  MA    ,MC    ,MG    ,MN    ,MR    ,MS    ,MX    ,
     1          III   ,IA    ,IAAA  ,IAC   ,IALPHA,IAN   ,IANSWE,IB    ,
     1   ICCHAN,ICD   ,ICHFR ,ICON  ,ICOND ,ICP   ,ID    ,IDC   ,IDFDX ,
     2   IDHDX ,IDHYD ,IDHYDN,IDIST ,IDPDX ,IDPK  ,IDUR  ,IDR   ,IF    ,
     3   IFACTO,IFDIV ,IFINLE,IFLUX ,IFMULT,IFOLD ,IFSP  ,IFSPLI,IFXFLO,
     4   IGAP  ,IGAPN ,IGAPS ,IH    ,IHFILM,IHINLE,IHOLD ,IHPERI,IIDARE,
     5   IIDFUE,IIDGAP,IIK   ,IJBOIL,IJK   ,ILC   ,ILENGT,ILOCA ,ILR   ,
     6   IMCHFR,IMCFRC,IMCFRR,INTYPE,INWRAP,INWRPS,IP    ,IPERIM,IPH   ,
     7   IPHI  ,IPRNTC,IPRNTR,IPRNTN,IPW   ,IPWRF ,IQC   ,IQF   ,IQPRIM,
     8   IQUAL ,IRADIA,IRHO  ,IRHOOL,ISP   ,IT    ,ITDUMY,ITINLE,ITROD ,
     9   IU    ,IUH   ,IUSAVE,IUSTAR,IV    ,IVISC ,IVISCW,IVP   ,IVPA  ,
     A   IW    ,IWOLD ,IWP   ,IWSAVE,IX    ,IXCROS,IIA  ,IIB  ,IXPOLD
C
      COMMON/LINK2/CROSS(6),FG(30),FH(30),FP(30),FQ(30),IM(9),JM(9),
     1OUTPUT(10),PRINT(12),TEXT(17),YG(30),YH(30),YP(30),YQ(30)
      COMMON/LINK3/DXX,ETIME,GIN,HIN,I8,IG,IN,ISAVE,JUMP,KASE,KT,MAXT,
     1 NDT,NDXP1,NFUELT,NG,NH,NJUMP,NOUT,NP,NPCHAN,NPNODE,NPROD,NQ,NR,
     2 NSKIPT,NSKIPX,NTRIES,PEXIT,PHTOT,SAVEDT,TIN,TTIME,ZZ
      COMMON/LINK4/IFRM,IHTM,IPROP,NCC,NCF,NDM1,NDS,NGP
      COMMON/FRDATA/BURN,CPR,EFFB,EPSF,EXPR,FPRESS,FPUO2,FRAC,FTD,
     1  GMIX(4),GRGH,PGAS,RADR,RDELT,THC,THG
C-----------------------------------------------------------------------
```

```
C
C     SET UP VARIABLES FOR OUTPUT PRINTOUT
 250     DO 251 I=1,NCHAN
         DATA(IA    +I)=DATA(IAN   +I)
 251     DATA(IDHYD +I)=DATA(IDHYDN+I)
         IF(NK.EQ.0) GO TO 999
         DO 252 K=1,NK
 252     DATA(IGAP  +K)=DATA(IGAPN +K)
 999     CONTINUE
      IF(NPCHAN.GT.0) GO TO 257
      NPCHAN = NCHAN
         DO 256 I=1,NCHAN
 256     IDAT(IPRNTC+I)=I
 257  IF(NPROD.GT.0) GO TO 259
      NPROD = NROD
         DO 258 N=1,NROD
 258     IDAT(IPRNTR+N)=N
 259  IF(NPNODE.GT.0) GO TO 261
      NN = NODESF+1
      NPNODE = NN
         DO 260 I=1,NN
 260     IDAT(IPRNTN+I)=I
C
C     OUTPUT OF INPUT DATA
 261  IF(.NOT.PRINT(1)) GO TO 265
      WRITE(I3,13)  (PP(I),TT(I),VVF(I),VVG(I),HHF(I),HHG(I),UUF(I),
     1KKF(I),SSIGMA(I),I=1,NPROP)
 265  IF(.NOT.PRINT(2)) GO TO 270
      WRITE(I3,28)
         DO 266 J=1,4
         IF(AA(J).GT.0. .OR. CC(J).GT.0.)WRITE(I3,29)J,AA(J),BB(J),CC(J)
 266     CONTINUE
      IF(NVISCW.EQ.0) WRITE(I3,61)
      IF(NVISCW.EQ.1) WRITE(I3,62)
      WRITE (I3,44)
      IF(J2.EQ.0) WRITE(I3,45)
      IF(J2.EQ.1) WRITE(I3,46)
      IF(J3.EQ.0) WRITE(I3,47)
      IF(J3.EQ.1) WRITE(I3,48)
      IF(J3.EQ.5) WRITE(I3,49) AV(1)
      IF(J3.EQ.6) WRITE(I3,57) NV,(AV(I),I=1,NV)
      IF(J4.EQ.0) WRITE(I3,58)
      IF(J4.EQ.1) WRITE(I3,59)
      IF(J4.EQ.5) WRITE(I3,60) NF,(AF(I),I=1,NF)
 270  IF(.NOT.PRINT(3)) GO TO 275
      WRITE(I3,6) (Y(I),AXIAL(I),I=1,NAX)
 275  IF(.NOT.PRINT(4)) GO TO 280
      WRITE(I3,12)
         DO 277 I=1,NCHAN
         IF((DATA(IAC+I).LT.9.99).AND.(DATA(IPW+I).LT.9.99))GO TO 276
         WRITE(I3,1003)  I,IDAT(INTYPE+I),DATA(IAC+I),DATA(IPW+I),
     1   DATA(IPH+I),DATA(IDC+I),(IDAT(ILC+I+MC*(L-1)),
```

```
     2   DATA(IGAPS+I+MG*(L-1)),DATA(IDIST+I+MC*(L-1)),L=1,4)
         GO TO 277
 276     WRITE(I3,1004)  I,IDAT(INTYPE+I),DATA(IAC+I),DATA(IPW+I),
     1   DATA(IPH+I),DATA(IDC+I),(IDAT(ILC+I+MC*(L-1)),
     2   DATA(IGAPS+I+MG*(L-1)),DATA(IDIST+I+MC*(L-1)),L=1,4)
 277     CONTINUE
 280  IF(NAXL  .LT.1) GO TO 285
      IF(.NOT.PRINT(5)) GO TO 285
      N=1
      NN=10
         DO 284 LL=1,4
         IF(NN.GT.NAFACT) NN = NAFACT
         WRITE (I3,19) (H1,NCH(J),H3,J=N,NN)
            DO 283 I=1,NAXL
 283        WRITE(I3,38) AXL(I), (AFACT(J,I),J=N,NN)
         N=N+10
         NN=NN+10
         IF(N.GE.NAFACT) GO TO 285
 284     CONTINUE
 285  IF(NGXL .LT.1) GO TO 290
      IF(.NOT.PRINT(6)) GO TO 290
      N = 1
      NN= 10
         DO 289 LL = 1,6
         IF(NN.GT.NGAPS) NN=NGAPS
            DO 286 M=N,NN
            K = NGAP(M)
            IM(M)=IDAT(IIK+K)
 286        JM(M)=IDAT(IJK+K)
         WRITE (I3,20) (H1,IM(M),H2,JM(M),H3,M=N,NN)
            DO 287 L=1,NGXL
 287        WRITE (I3,38)  GAPXL(L),(GFACT(M,L),M=N,NN)
         N=N+10
         NN=NN+10
         IF(N.GE.NGAPS) GO TO 290
 289     CONTINUE
 290  IF(.NOT.PRINT(7)) GO TO 300
      IF(J6.EQ.0) GO TO 300
      IF(J6.GT.1) GO TO 296
      PITCH = PITCH*12.
      DIA = DIA*12.
      THICK = THICK*12.
      WRITE(I3,69) PITCH, THICK,DIA
      PITCH = PITCH/12.
      DIA = DIA/12.
      THICK = THICK/12.
      IF(NK.EQ.0) GO TO 300
      WRITE(I3,70)(K,H1,IDAT(IIK+K),H2,IDAT(IJK+K),H3,DATA(IDUR+K),
     1(DATA(IXCROS+K+MG*(L-1)),L=1,6),K=1,NK)
      WRITE(I3,74)(IDAT(INWRAP+I),I=1,NCHAN )
      GO TO 300
 296  WRITE(I3,71) (IGRID(I),I=1,NGRID)
```

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      WRITE(I3,72) (GRIDXL(I),I=1,NGRID)
         DO 297 L=1,NGRIDT
 297     WRITE(I3,73)  L,(I,DATA(ICD+I+MC*(L-1)),I=1,NCHAN )
      IF(NK.EQ.0) GO TO 300
         DO 299 I=1,NGRIDT
         II = 0
            DO 298 K=1,NK
            IF(ABS(DATA(IFXFLO+K+MG*(I-1))).GT.0)  II=1
 298        CONTINUE
         IF(II.EQ.0) GO TO 299
         WRITE(I3,76) I,(KK,H1,IDAT(IIK+KK),H2,IDAT(IJK+KK),H3,
     1   DATA(IFXFLO+KK+MG*(I-1)),KK=1,NK)
 299     CONTINUE
 300  IF(.NOT.PRINT(8)) GO TO 305
      WRITE(I3,15)(I,IDAT(IIDFUE+I),DATA(IDR+I),DATA(IRADIA+I),
     1(DATA(IPHI+I+MR*(L-1)),IDAT(ILR+I+MR*(L-1)),L=1,6),I=1,NROD)
      IF(NODESF.LT.1) GO TO 305
         DO 301 I = 1,NFUELT
         KFUEL(I) = KFUEL(I)*3600.
         KCLAD(I) = KCLAD(I)*3600.
         DFUEL(I) = DFUEL(I)*12.
         TCLAD(I) = TCLAD(I)*12.
         HGAP(I) = HGAP(I)*3600.
 301     CONTINUE
      WRITE(I3,77) NODESF
      WRITE(I3,78) (J,KFUEL(J),CFUEL(J),RFUEL(J),DFUEL(J),KCLAD(J),
     1 CCLAD(J),RCLAD(J),TCLAD(J),HGAP(J),J=1,NFUELT)
         DO 302 I = 1,NFUELT
         KFUEL(I) = KFUEL(I)/3600.
         KCLAD(I) = KCLAD(I)/3600.
         DFUEL(I) = DFUEL(I)/12.
         TCLAD(I) = TCLAD(I)/12.
         HGAP(I) = HGAP(I)/3600.
 302     CONTINUE
 305  IF(.NOT.PRINT(9)) GO TO 310
      WRITE(I3,18)KIJ,FTM,SL,ZZ,THETA,NDX,DXX,NDT,TTIME,DT,NTRIES,FERROR
 310  IF(IFRM.EQ.0.AND.IHTM.EQ.0) GO TO 307
      WRITE(I3,17) EPSF
 307  IF(.NOT.PRINT(10))GO TO 315
      WRITE(I3,35)
      IF(NSCBC.LT.1) WRITE(I3, 32) ABETA
      IF(NSCBC.EQ.1) WRITE(I3, 33) ABETA, BBETA
      IF(NSCBC.EQ.2) WRITE(I3, 34) ABETA, BBETA
      IF(NSCBC.EQ.3) WRITE(I3,39) ABETA, BBETA
      IF (NSCBC.EQ.4) WRITE(I3,41)
      IF(NBBC-1) 311,311,312
 311  IF (NSCBC.NE.4) WRITE(I3,36)
      GO TO 314
 312  WRITE (I3,37) (XQUAL(I),BX(I),I=1,NBBC)
 314  IF(J5.EQ.1) WRITE(I3,65) GK
 315  IF(.NOT.PRINT(11)) GO TO 318
      WRITE(I3,21) PEXIT,HIN,GIN,TIN,AFLUX
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      IF(IN.EQ.0) WRITE(I3,87)
      IF(IN.EQ.1) WRITE(I3,88)
      IF(IN.EQ.2) WRITE(I3,89)
      IF(IN.EQ.3) WRITE(I3,90)
      IF(IG.EQ.0) WRITE(I3,91)
      IF(IG.EQ.1) WRITE(I3,92)
      IF(IG.EQ.2) WRITE(I3,93)
      IF(NP.GT.1) WRITE(I3,83) (YP(I),FP(I),I=1,NP)
      IF(NH.GT.1) WRITE(I3,84) (YH(I),FH(I),I=1,NH)
      IF(NG.GT.1) WRITE(I3,85) (YG(I),FG(I),I=1,NG)
      IF(NQ.GT.1) WRITE(I3,86) (YQ(I),FQ(I),I=1,NQ)
  318 IF(KDEBUG) 400,400,319
  319 WRITE(I3,50) ((IDAT(ILC+I+MC*(L-1)),I=1,NCHAN ),L=1,4)
      IF(NK.EQ.0) GO TO 888
      WRITE(I3,50) (IDAT(IIK+K),IDAT(IJK+K),K=1,NK)
      WRITE(I3,51) (DATA(IFACTO+K),K=1,NK)
  888    CONTINUE
      WRITE(I3,50) ((IDAT(ILR+NR+MR*(L-1)),NR=1,NROD),L=1,6)
      WRITE(I3,51) ((DATA(IPWRF+I+MC*(NR-1)),NR=1,NROD),I=1,NCHAN )
      WRITE(I3,51) (DATA(ID+NR),NR=1,NROD),(DATA(IRADIA+NR),NR=1,NROD)
  400 CONTINUE
      RETURN
C
C-----------------------------------------------------------------------
    6 FORMAT (23H0HEAT FLUX DISTRIBUTION  /' X/L',5X,' RELATIVE FLUX'/
      1(F7.3,F12.3))
   12 FORMAT(22H0SUBCHANNEL INPUT DATA  /
     1109H CHANNEL    TYPE    AREA    WETTED     HEATED     HYDRAULIC     (ADJ
     2ACENT CHANNEL NO., SPACING, CENTROID DISTANCE)          /
     3 55H    NO.            (SQ-IN) PERIM.     PERIM.     DIAMETER         /
     4 25X,                        30H (IN)       (IN)        (IN)          /)
   13 FORMAT(22H0FLUID PROPERTY TABLE ,/,
     1 60H     P          T          VF         VG         HF         HG
     1 30H  VISC.         KF         SIGMA     ,/,
     1 (F8.1,F10.2,F8.5,F12.5,2F10.2,3F10.5))
   15 FORMAT(15H0ROD INPUT DATA  /   96H    ROD  TYPE  DIA   RADIAL POWER
     1    FRACTION OF POWER TO ADJACENT CHANNELS (ADJ. CHANNEL NO.)    /
     2 30H    NO.  NO.    (IN)    FACTOR   /(2I5,F8.4,F9.4,F11.4,1H(I2,
     11H)F9.4,1H(I2,1H)F9.4,1H(I2,1H)F9.4,1H(I2,1H)F9.4,1H(I2,1H)F9.4,
     11H(I2,1H)))
   17 FORMAT(/,28H   FUEL ROD CONV. FACTOR     ,E10.5//)
   18 FORMAT (23H0CALCULATION PARAMETERS /
     2 28H    CROSSFLOW RESISTANCE,KIJ F8.3/
     4 28H    MOMENTUM TURBULENT FACTORF8.4  /
     3 28H    PARAMETER, (S/L)         F8.3/
     4 28H    CHANNEL LENGTH           F8.2,8H INCHES /
     4 28H    CHANNEL ORIENTATION      F8.1,8H DEGREES/
     5 28H    NUMBER OF AXIAL NODES    I8/
     6 28H    NODE LENGTH              F8.3,7H INCHES /
     7 28H    NUMBER OF TIME STEPS     I8/
     8 28H    TOTAL TRANSIENT TIME     F8.3,8H SECONDS/
     X 28H    TIME STEP                F8.4,8H SECONDS/
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     1 28H    ALLOWABLE ITERATIONS     I8/
     2 28H    FLOW CONVERGENCE FACTOR   E12.5/)
 19   FORMAT (50H0 X/L    AREA VARIATION FACTORS FOR SUBCHANNEL (I) /
     1  7X,10(3X,A1,I2,A1,1X))
 20   FORMAT (69H0 X/L    GAP SPACING VARIATION FACTORS FOR ADJACENT SUB
     1CHANNELS (I,J) / 7X,10(1X,A1,I2,A1,I2,A1))
 21   FORMAT (22H0OPERATING CONDITIONS  /
     1 25H    SYSTEM PRESSURE    =  ,F8.1,5H PSIA /
     2 25H    INLET ENTHALPY     =  ,F8.1,7H BTU/LB /
     3 25H    AVG. MASS VELOCITY =  ,F8.3,21H MILLION LB/(HR-SQFT) /
     2 25H    INLET TEMPERATURE  =       ,F8.1,10H DEGREES F /
     4 25H    AVG. HEAT FLUX     =  ,F8.6,22H MILLION BTU/(HR-SQFT)  )
 28   FORMAT (/29H FRICTION FACTOR CORRELATION     )
 29   FORMAT ( 16H     CHANNEL TYPE I3,11H   FRICT = F5.3,6H*RE**(F6.3,
     14H) +  F6.4  )
 32   FORMAT(31H     SUBCOOLED MIXING,    BETA = F6.4)
 33   FORMAT(31H     SUBCOOLED MIXING,    BETA = F6.4,6H*RE**(F6.4,1H))
 34   FORMAT(31H     SUBCOOLED MIXING,    BETA = F6.4,12H*(D/S)*RE**(F6.4,
     1 1H))
 35   FORMAT(20H0MIXING CORRELATIONS )
 36   FORMAT(54H     BOILING MIXING, BETA IS ASSUMMED SAME AS SUBCOOLED)
 37   FORMAT(55H     BOILING MIXING, BETA IS A FUNCTION OF STEAM QUALITY/
     1          25H         X         BETA(X)  / (F12.3,F13.6))
 38   FORMAT  (F6.3,10F8.3)
 39   FORMAT(31H     SUBCOOLED MIXING,    BETA = F6.4,12H*(D/L)*RE**(F6.4,
     1 1H))
 41   FORMAT(1H ,' NEW(BEUS) MIXING MODEL USED')
 44   FORMAT( /  28H TWO-PHASE FLOW CORRELATIONS  )
 45   FORMAT(     33H    NO SUBCOOLED VOID CORRELATION  )
 46   FORMAT(     35H    LEVY SUBCOOLED VOID CORRELATION)
 47   FORMAT(     31H    HOMOGENEOUS BULK VOID MODEL)
 48   FORMAT(     41H    MODIFIED ARMAND BULK VOID CORRELATION )
 49   FORMAT(     50H    HOMOGENEOUS BULK VOID MODEL WITH SLIP RATIO OF,
     1 F6.2 )
 50   FORMAT(20I5)
 51   FORMAT (8E12.3)
 57   FORMAT(     33H    BULK VOID FRACTION GIVEN AS A I2,56H TERM POLYNO
     1MIAL FUNCTION OF QUALITY WITH COFFICIENTS OF/ 10X,7E10.4)
 58   FORMAT(     41H    HOMOGENEOUS MODEL FRICTION MULTIPLIER )
 59   FORMAT(     30H    ARMAND FRICTION MULTIPLIER)
 60   FORMAT(     34H    FRICTION MULTIPLIER GIVEN AS A I2,57H TERM POLYN
     1OMIAL FUNCTION OF QUALITY WITH COEFFICIENTS OF/ 10X,7E10.4)
 61   FORMAT(65H     WALL VISCOCITY CORRECTION TO FRICTION FACTOR IS NOT
     1INCLUDED      )
 62   FORMAT(65H     WALL VISCOSITY CORRECTION TO FRICTION FACTOR IS INCL
     1UDED           )
 65   FORMAT(42H     CONDUCTION MIXING,  GEOMETRY FACTOR = F6.4)
 69   FORMAT ( /62H WIRE WRAP SPACER DATA FOR FORCED DIVERSION CROSSFLOW
     1 MIXING     //20H    WRAP PITCH      = F6.1,7H INCHES /
     2              20H    WRAP THICKNESS = F6.4,7H INCHES /
     3              20H    PIN DIAMETER    = F6.4,7H INCHES //)
 70   FORMAT (23H    WRAP CROSSING DATA /
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     1   60H       GAP   SUBCHANNEL   MIXING          RELATIVE LOCATION
     2 / 60H       NO.   PAIR NO.   PARAMETER         OF WRAP CROSSINGS
     3 /(I10,4X,A1,I2,A1,I2,A1,F11.4,6F10.4))
 71    FORMAT( /12H SPACER DATA / 20H    SPACER TYPE NO.  ,10I6 )
 72    FORMAT(  21H    LOCATION (X/L)      ,10F6.3)
 73    FORMAT (15H0   SPACER TYPE I2 /
     1 62H     CHANNEL DRAG   CHANNEL DRAG   CHANNEL DRAG   CHANNEL DRAG
     2/64H       NO.   COEFF.   NO.   COEFF.   NO.   COEFF.   NO.   COEF
     3F.   /(3X,4(I6,F9.3)))
 74    FORMAT (46H   INITIAL WRAP INVENTORY FOR EACH SUBCHANNEL /(10I5))
 76    FORMAT (43H0   FLOW DIVERSION FACTORS FOR SPACER TYPE  ,I2,/,
     1    5X,46HGAP  CHANNEL FRACTION    GAP  CHANNEL FRACTION  ,/,
     2    5X,46HNO.   PAIR    DIVERTED    NO.    PAIR    DIVERTED  ,/,
     3   (2(5X,I3,1X,A1,I2,A1,I2,A1,F9.4)))
 77    FORMAT(39H THERMAL PROPERTIES FOR FUEL MATERIAL
     1 I8,18H RADIAL FUEL NODES  /
     1 37H                       FUEL PROPERTIES ,25X,15HCLAD PROPERTIES,
     2 /,50H    TYPE    COND.    SP. HEAT   DENSITY    DIA.
     3           50H  COND.    SP. HEAT   DENSITY  THICK.   GAP COND. /
     4 49H      NO. (B/HR-FT-F) (B/LB-F)    (LB/FT3)  (IN.)
     5           52H(B/HR-FT-F) (B/LB-F)    (LB/FT3)  (IN.)  (B/HR-FT2-F))
 78    FORMAT(I7,2X,F7.2,F11.4,F11.1,F9.4,2X,F7.2,F11.4,F11.1,F9.4,2X,
     1 F9.2)
 83    FORMAT (33H    FORCING FUNCTION FOR PRESSURE /
     1         23H      TIME      PRESSURE /
     2         23H     (SEC)      FACTOR   /  (F10.4,F13.4))
 84    FORMAT (38H    FORCING FUNCTION FOR INLET ENTHALPY/
     1         28H      TIME   INLET ENTHALPY          /
     2         23H     (SEC)      FACTOR   /  (F10.4,F13.4))
 85    FORMAT (38H    FORCING FUNCTION FOR INLET FLOW    /
     1         28H      TIME   INLET FLOW              /
     2         23H     (SEC)      FACTOR   /  (F10.4,F13.4))
 86    FORMAT (38H    FORCING FUNCTION FOR HEAT FLUX     /
     1         38H      TIME    HEAT FLUX              /
     2         23H     (SEC)      FACTOR   /  (F10.4,F13.4))
 87    FORMAT(30H    UNIFORM INLET ENTHALPY       )
 88    FORMAT(35H    UNIFORM INLET TEMPERATURE        )
 89    FORMAT(45H    INDIVIDUAL SUBCHANNEL ENTHALPY SPECIFIED    )
 90    FORMAT(50H    INDIVIDUAL SUBCHANNEL TEMPERATURE SPECIFIED        )
 91    FORMAT(35H    UNIFORM INLET MASS VELOCITY          )
 92    FORMAT(50H    FLOWS SPLIT TO GIVE EQUAL PRESSURE GRADIENT        )
 93    FORMAT(45H    INDIVIDUAL SUBCHANNEL FLOWS SPECIFIED          )
1003   FORMAT(I5,I7,4F10.4,4X,4(1H(I3,1H,F5.3,1H,F5.3,1H)))
1004   FORMAT(I5,I7,4F10.6,4X,4(1H(I3,1H,F5.3,1H,F5.3,1H)))
C-----------------------------------------------------------------------
       END
```

```
C*********************** SUBROUTINE ITHO ******************************
      SUBROUTINE ITHO(NTHBOX,NTHBXX,ND1X,ND2X)
C
      IMPLICIT INTEGER (I)
      DIMENSION NTHBOX(25,25), CARD(20)
      LOGICAL  GRID
      REAL KIJ, KF, KKF, KCLAD, KFUEL
C
      COMMON /COBRA1/  ABETA ,AFLUX ,ATOTAL,BBETA ,DIA   ,DT    ,DX    ,
     1   ELEV  ,FERROR,FLO   ,FTM   ,GC    ,GK    ,GRID  ,HSURF ,HF    ,
     2   HFG   ,HG    ,I2    ,I3    ,IERROR,IQP3  ,ITERAT,J1    ,J2    ,
     3   J3    ,J4    ,J5    ,J6    ,J7    ,KDEBUG,KF    ,KIJ   ,
     4   NAFACT,NARAMP,NAX   ,NAXL  ,NBBC  ,NCHAN ,NCHF  ,NDX   ,NF    ,
     5   NGAPS ,NGRID ,NGRIDT,NGTYPE,NGXL  ,NK    ,NODES ,NODESF,NPROP ,
     6   NRAMP ,NROD  ,NSCBC ,NV    ,NVISCW,PI    ,PITCH ,POWER ,PREF  ,
     7   QAX   ,RHOF  ,RHOG  ,SIGMA ,SL    ,TF    ,TFLUID,THETA ,THICK ,
     8   UF    ,VF    ,VFG   ,VG    ,Z
C-----------------------------------------------------------------------
C
C     CONTROL FOR THERMAL-HYDRAULIC INPUT DATA
C     WRITE (I3,1001)
      IPILE=J7
      CALL CHAN(1,NTHBOX,NTHBXX,ND1X,ND2X)
      CALL MODEL(1,CARD,IPILE)
      CALL OPERA(1,CARD)
      CALL FIZPRP(1,NPROP)
      CALL TABLES(CARD)
      WRITE(I3,1002)
      CALL CORE3
      IF (IERROR.EQ.0) GO TO 2
      WRITE (I3,1004)
      RETURN
    2 CONTINUE
      WRITE (I3,1003)
      CALL OPERA(2,CARD)
      CALL CHAN(2,NTHBOX,NTHBXX,ND1X,ND2X)
      CALL MODEL(2,CARD,IPILE)
      CALL FIZPRP(2,NPROP)
      RETURN
C
C-----------------------------------------------------------------------
1001  FORMAT(1H1, 42X, 'THERMAL - HYDRAULIC INPUT DATA', /, 43X,
     1 '------------------------------', ////, '  CARD IMAGES', /, 2X,
     2 '---- ------')
1002  FORMAT(32X, '0....*....1....*....2....*....3....*....4....*....5..
     1..*....6....*....7....*....8')
1003  FORMAT(1H1, 42X, 'PROCESSED INPUT DATA', /, 43X,
     1 '--------------------', /, '  * = SET IN NEUTRONICS (CARD20)',
     2 ///)
1004  FORMAT('  ERROR SIGNAL IN ITHO')
C-----------------------------------------------------------------------
      END
```

```
C********************** SUBROUTINE MIX ******************************
      SUBROUTINE MIX(J)
C
      IMPLICIT INTEGER (I)
      INTEGER IDAT(1)
      LOGICAL LDAT(1), GRID
      REAL KIJ, KF, KKF, KCLAD, KFUEL
C
      COMMON  DATA(1)
      EQUIVALENCE  (DATA(1),IDAT(1),LDAT(1))
C
      COMMON /COBRA1/  ABETA ,AFLUX ,ATOTAL,BBETA ,DIA   ,DT    ,DX    ,
     1   ELEV  ,FERROR,FLO   ,FTM   ,GC    ,GK    ,GRID  ,HSURF ,HF    ,
     2   HFG   ,HG    ,I2    ,I3    ,IERROR,IQP3  ,ITERAT,J1    ,J2    ,
     3   J3    ,J4    ,J5    ,J6    ,J7    ,KDEBUG,KF    ,KIJ   ,
     4   NAFACT,NARAMP,NAX   ,NAXL  ,NBBC  ,NCHAN ,NCHF  ,NDX   ,NF    ,
     5   NGAPS ,NGRID ,NGRIDT,NGTYPE,NGXL  ,NK    ,NODES ,NODESF,NPROP ,
     6   NRAMP ,NROD  ,NSCBC ,NV    ,NVISCW,PI    ,PITCH ,POWER ,PREF  ,
     7   QAX   ,RHOF  ,RHOG  ,SIGMA ,SL    ,TF    ,TFLUID,THETA ,THICK ,
     8   UF    ,VF    ,VFG   ,VG    ,Z
C
      COMMON /COBRA2/  AA(4), AF(7), AFACT(10,10), AV(7), AXIAL(30),
     1   AXL(10), BB(4), BX(30), CC(4), CCLAD(2), CFUEL(2), DFUEL(2),
     2   GAPXL(10), GFACT(9,10), GRIDXL(10), HGAP(2), HHF(30), HHG(30),
     3   IGRID(10), KCLAD(2), KFUEL(2), KKF(30), NCH(10), NGAP(9),
     4   PP(30), RCLAD(2),RFUEL(2),SSIGMA(30), TCLAD(2), UUF(30),
     5   VVF(30), VVG(30), XQUAL(30), Y(30), TT(30)
C
      COMMON /COBRA3/  MA    ,MC    ,MG    ,MN    ,MR    ,MS    ,MX    ,
     1          III   ,IA    ,IAAA  ,IAC   ,IALPHA,IAN   ,IANSWE,IB    ,
     1   ICCHAN,ICD   ,ICHFR ,ICON  ,ICOND ,ICP   ,ID    ,IDC   ,IDFDX ,
     2   IDHDX ,IDHYD ,IDHYDN,IDIST ,IDPDX ,IDPK  ,IDUR  ,IDR   ,IF    ,
     3   IFACTO,IFDIV ,IFINLE,IFLUX ,IFMULT,IFOLD ,IFSP  ,IFSPLI,IFXFLO,
     4   IGAP  ,IGAPN ,IGAPS ,IH    ,IHFILM,IHINLE,IHOLD ,IHPERI,IIDARE,
     5   IIDFUE,IIDGAP,IIK   ,IJBOIL,IJK   ,ILC   ,ILENGT,ILOCA ,ILR   ,
     6   IMCHFR,IMCFRC,IMCFRR,INTYPE,INWRAP,INWRPS,IP    ,IPERIM,IPH   ,
     7   IPHI  ,IPRNTC,IPRNTR,IPRNTN,IPW   ,IPWRF ,IQC   ,IQF   ,IQPRIM,
     8   IQUAL ,IRADIA,IRHO  ,IRHOOL,ISP   ,IT    ,ITDUMY,ITINLE,ITROD ,
     9   IU    ,IUH   ,IUSAVE,IUSTAR,IV    ,IVISC ,IVISCW,IVP   ,IVPA  ,
     A   IW    ,IWOLD ,IWP   ,IWSAVE,IX    ,IXCROS,IIA   ,IIB   ,IXPOLD
C-----------------------------------------------------------------------
C
        DO 240 K=1,NK
        DATA(ICOND+K)=0.
        II=IDAT(IIK+K)
        JJ=IDAT(IJK+K)
        ABAR=DATA(IA+II)+DATA(IA+JJ)
        FBAR=DATA(IF+II+MC*(J-1))+DATA(IF+JJ+MC*(J-1))
        PBAR=DATA(IPERIM+II)+DATA(IPERIM+JJ)
        QBAR=DATA(IQUAL +II)+DATA(IQUAL +JJ)
        VBAR=DATA(IVISC +II)+DATA(IVISC +JJ)
        DAVG=4.*ABAR/PBAR
```

```
      GAVG=FBAR/ABAR
      XAVG = 0.
      IF(AMAX1(DATA(IQUAL+II),DATA(IQUAL+JJ)).GT.0.) XAVG=0.5*QBAR
      IF(XAVG.GT.0..AND.NBBC.GE.2) GO TO 80
      UAVG=0.5*VBAR
      IF(NSCBC.GE.1) RE =  GAVG*DAVG/UAVG
      IF(NSCBC.EQ.0) DATA(IWP+K)=DATA(IGAP+K)*GAVG*ABETA
      IF(NSCBC.EQ.1) DATA(IWP+K)=DATA(IGAP+K)*GAVG*ABETA*RE**BBETA
      IF(NSCBC.EQ.2) DATA(IWP+K)=DAVG         *GAVG*ABETA*RE**BBETA
      IF(NSCBC.EQ.3.AND.DATA(ILENGT+K).LE.0.)  GO TO 1000
      IF(NSCBC.EQ.3) DATA(IWP+K)=DATA(IGAP+K)/DATA(ILENGT+K)*DAVG
     1*GAVG*ABETA*RE**BBETA
      IF(NSCBC.EQ.4) GO TO 50
      DATA(IWP+K)=DATA(IWP+K)*DATA(IFACTO+K)
      GO TO 100
C
C     BEUS MIXING MODEL USED WHEN NSCBC=4
 50   WL=0.0035*UAVG*RE**0.9
      ARBAR=ABAR*0.5
      B1=0.04*(DATA(IGAP+K)/DAVG)**1.5
      XC=(0.4/GAVG*SQRT(32.2*RHOF*DAVG*(RHOF-RHOG))+0.6)/(SQRT(RHOF
     1/RHOG)+0.6)
C
C     SLIP RATIO, GAM, BASED ON SMITH CORRELATION
      GAM=1.
      IF(XAVG.LE.0.) GO TO 52
      GAM = 0.4 + 0.6*SQRT((0.4+XAVG*(RHOF/RHOG-0.4))/(0.4+0.6*XAVG))
      IF(XAVG.GT.XC) GO TO 55
 52   DATA(IWP+K)=WL+B1*ARBAR*GAVG/DAVG*RHOF/RHOG*(GAM-1.)/GAM*XAVG
      GO TO 100
 55   XOXC=0.57*RE**0.0417
      TK=0.5556*(TF+459.67)
C
C     ----------------------------------------------------------------
C     VISCOSITY OF SATURATED STEAM (KG/M SEC)
C     AS A FUNCTION OF TEMPERATURE (DEG K)
C
C     ERROR OF APPROXIMATION = 3 PERCENT FOR  373 < TV < 623 DE K
C     MAY ALSO BE USED FOR NON-SATURATED CONDITIONS AT SAME TV
C     THIS FIT HAS A SINGULARITY AT TW = 822 DEG K
C     VALUE AT 250 DEG C = .174E-4
C
      VISCG = 11.4 / (1.37E6 - TK*(844.+ TK))
      IF(TK.GT.623.) VISCG= 4.07E-8*TK-3.7E-7
      VISCG = 0.672 * VISCG
C     ----------------------------------------------------------------
      WG=0.0035*VISCG*(GAVG*GAM*DAVG/VISCG)**0.9
      WC=WL+B1*ARBAR*GAVG/DAVG*RHOF/RHOG*(GAM-1.)/GAM*XC
      DATA(IWP+K)=WG+(WC-WG)*((1.-XOXC)/(XAVG/XC-XOXC))
      GO TO 100
 80   CALL CURVE (XBETA,XAVG,BX,XQUAL,NBBC,IERROR,1)
      IF(IERROR.GT.1) GO TO 1000
```

```
        DATA(IWP+K) = GAVG*DAVG*XBETA *DATA(IFACTO+K)
 100    IF(J5.EQ.0) GO TO 240
        CAVG=0.5*(DATA(ICON+II)+DATA(ICON+JJ))
        IF(DATA(ILENGT+K).LE.0.0)  GO TO 1000
        DATA(ICOND+K)=CAVG*DATA(IGAP+K)/DATA(ILENGT+K)*GK*
     1  DATA(IFACTO+K)
 240    CONTINUE
      RETURN
1000  IERROR = 4
      RETURN
      END
```

```
C************************* SUBROUTINE MODEL *********************************
      SUBROUTINE MODEL(IPART,CARD,IPILE)
C
      IMPLICIT INTEGER (I)
      DIMENSION CARD(20),TAG(2)
      DATA TAG /4HW/GS, 4HW/GD /
      INTEGER IDAT(1)
      LOGICAL LDAT(1), GRID
      REAL KIJ, KF, KKF, KCLAD, KFUEL
C
      COMMON  DATA(1)
      EQUIVALENCE  (DATA(1),IDAT(1),LDAT(1))
C
      COMMON /COBRA1/  ABETA ,AFLUX ,ATOTAL,BBETA ,DIA   ,DT    ,DX    ,
     1   ELEV  ,FERROR,FLO   ,FTM   ,GC    ,GK    ,GRID  ,HSURF ,HF    ,
     2   HFG   ,HG    ,I2    ,I3    ,IERROR,IQP3  ,ITERAT,J1    ,J2    ,
     3   J3    ,J4    ,J5    ,J6    ,J7    ,KDEBUG,KF    ,KIJ   ,
     4   NAFACT,NARAMP,NAX   ,NAXL  ,NBBC  ,NCHAN ,NCHF  ,NDX   ,NF    ,
     5   NGAPS ,NGRID ,NGRIDT,NGTYPE,NGXL  ,NK    ,NODES ,NODESF,NPROP ,
     6   NRAMP ,NROD  ,NSCBC ,NV    ,NVISCW,PI    ,PITCH ,POWER ,PREF  ,
     7   QAX   ,RHOF  ,RHOG  ,SIGMA ,SL    ,TF    ,TFLUID,THETA ,THICK ,
     8   UF    ,VF    ,VFG   ,VG    ,Z
C
      COMMON /COBRA2/  AA(4), AF(7), AFACT(10,10), AV(7), AXIAL(30),
     1   AXL(10), BB(4), BX(30), CC(4), CCLAD(2), CFUEL(2), DFUEL(2),
     2   GAPXL(10), GFACT(9,10), GRIDXL(10), HGAP(2), HHF(30), HHG(30),
     3   IGRID(10), KCLAD(2), KFUEL(2), KKF(30), NCH(10), NGAP(9),
     4   PP(30), RCLAD(2),RFUEL(2),SSIGMA(30), TCLAD(2), UUF(30),
     5   VVF(30), VVG(30), XQUAL(30), Y(30), TT(30)
C
      COMMON /COBRA3/  MA    ,MC    ,MG    ,MN    ,MR    ,MS    ,MX    ,
     1          III   ,IA    ,IAAA  ,IAC   ,IALPHA,IAN   ,IANSWE,IB    ,
     1   ICCHAN,ICD   ,ICHFR ,ICON  ,ICOND ,ICP   ,ID    ,IDC   ,IDFDX ,
     2   IDHDX ,IDHYD ,IDHYDN,IDIST ,IDPDX ,IDPK  ,IDUR  ,IDR   ,IF    ,
     3   IFACTO,IFDIV ,IFINLE,IFLUX ,IFMULT,IFOLD ,IFSP  ,IFSPLI,IFXFLO,
     4   IGAP  ,IGAPN ,IGAPS ,IH    ,IHFILM,IHINLE,IHOLD ,IHPERI,IIDARE,
     5   IIDFUE,IIDGAP,IIK   ,IJBOIL,IJK   ,ILC   ,ILENGT,ILOCA ,ILR   ,
     6   IMCHFR,IMCFRC,IMCFRR,INTYPE,INWRAP,INWRPS,IP    ,IPERIM,IPH   ,
     7   IPHI  ,IPRNTC,IPRNTR,IPRNTN,IPW   ,IPWRF ,IQC   ,IQF   ,IQPRIM,
     8   IQUAL ,IRADIA,IRHO  ,IRHOOL,ISP   ,IT    ,ITDUMY,ITINLE,ITROD ,
     9   IU    ,IUH   ,IUSAVE,IUSTAR,IV    ,IVISC ,IVISCW,IVP   ,IVPA  ,
     A   IW    ,IWOLD ,IWP   ,IWSAVE,IX    ,IXCROS,IIA   ,IIB  ,IXPOLD
C
      COMMON/LINK3/DXX,ETIME,GIN,HIN,I8,IG,IN,ISAVE,JUMP,KASE,KT,MAXT,
     1 NDT,NDXP1,NFUELT,NG,NH,NJUMP,NOUT,NP,NPCHAN,NPNODE,NPROD,NQ,NR,
     2 NSKIPT,NSKIPX,NTRIES,PEXIT,PHTOT,SAVEDT,TIN,TTIME,ZZ
      COMMON/LINK9/ENEH(400)
      COMMON/SAVMOD/N1,N2,N3,N4,N5,N6,N7,N9
C-----------------------------------------------------------------------------
C
C     IPART=1  SET HYDRAULIC MODEL
C     IPART=2  PRINT HYDRAULIC MODEL
```

```
C
C     PRESET MODEL IS CODED FIRST AND IS USED IF ALL N1-N7=0
C     INDIVIDUAL PARTS OF MODEL MAY BE CHANGED BY
C     SETTING ANY OF N1-N7 POSITIVE NON-ZERO
C
      IF(IPART.EQ.2) GO TO 30
C     (N1) MIXING MODEL (CARD GROUP 10)
      NSCBC=1
      NBBC=1
      J5=0
      GK=0.0
      ABETA=0.02
      BBETA=0.0
      IF(IPILE.EQ.2) ABETA=0.0
C     (N2) SINGLE PHASE FRICTION (CARD GROUP 2)
         DO 4 I=1,4
         AA(I)=0.184
         BB(I)=-0.2
    4    CC(I)=0.0
      NVISCW=0
C     (N3) TWO PHASE FRICTION (CARD GROUP 2)
      J4=0
C     (N4) VOID FRACTION (CARD GROUP 2)
      J2=0
      J3=0
C     (N5) FLOW DIVISION AT INLET (CARD GROUP 11)
      IG = 0
C     (N6) CONSTANTS (CARD GROUP 9)
      NCHF = 0
      KIJ=0.5
      FTM=0.0
      SL=0.5
      THETA=0.0
      ELEV=1.0
C     (N7) ITERATION (CARD GROUP 9)
      NTRIES=20
      FERROR=0.01
C     (N8) PHYSICAL PROPERTIES (CARD GROUP 1)
      NPROP=0
C     (N9) COUPLING PARAMETER FOR ENTHALPY EXCHANGE
      IF(NK.EQ.0) GO TO 999
         DO 3201 K=1,NK
3201     ENEH(K)=1.0
 999  CONTINUE
C
      READ(I2,1001) CARD,N1,N2,N3,N4,N5,N6,N7,NPROP,N9
      WRITE(I3,1009) CARD
      IFLOWS=100
      IF((N1+N2+N3+N4+N5+N6+N7+NPROP+N9).EQ.0) RETURN
      IF(N1.EQ.0) GO TO 6
      IF (N1.EQ.2) NSCBC=2
      IF (N1.EQ.3) NSCBC=4
```

```
      IF(IPILE.EQ.2) WRITE(I3,1010)
      IF(N1.LT.3) READ(I2,1002) CARD,ABETA,BBETA
      IF(N1.EQ.1) WRITE(I3,1011) CARD
   6  IF(N2.EQ.0) GO TO 8
      READ(I2,1003) CARD,NVISCW,(AA(I),BB(I),CC(I),I=1,4)
      WRITE(I3,1012) CARD
   8  IF(N3.EQ.0) GO TO 10
      READ(I2,1001) CARD,J4
      WRITE(I3,1013) CARD
      IF(J4.LE.4) GO TO 10
      READ(I2,1003) CARD,NF,AF
      WRITE(I3,1014) CARD
  10  IF(N4.EQ.0) GO TO 12
      READ(I2,1001) CARD,J2,J3
      WRITE(I3,1015) CARD
      IF(J3.LE.4) GO TO 12
      READ(I2,1003) CARD,NV,AV
      WRITE(I3,1014) CARD
  12  IF(N5.EQ.0) GO TO 16
      READ(I2,1001) CARD,IG
      WRITE(I3,1016) CARD
      IF(IG.LE.1) GO TO 16
C
C     FOR IG=2 THE RELATIVE FLOW SPLITS ARE READ IN HERE, AND THE
C     ACTUAL FLOWS ARE CALCULATED IN SUBROUTINE PRECAL.
      CALL READIN(1,NCHAN ,DATA(IFINLE+1),CARD,CARD,1)
  16  IF(N6.EQ.0) GO TO 18
      READ(I2,1003) CARD,NCHF,KIJ,FTM,SL,THETA
      WRITE(I3,1017) CARD
      ELEV=COS(THETA*PI/180.0)
  18  IF(N7.EQ.0) GO TO 20
      READ(I2,1003) CARD,NTRIES,FERROR
      WRITE (I3,1018) CARD
  20  IF (NPROP.EQ.0) GO TO 22
      READ (I2,1004) CARD, NPROP, N, PH, PP(2)
      WRITE (I3,1019) CARD
      PP(1) = PH
      IF (N.LE.1) GO TO 22
      PP(1) = 10.0
      IF (PH.LT.200.0) GO TO 22
      R = 0.01*PH
      PP(1) = 6.0*R*R*R*(R-1.35)/(R-0.35)
  22  CONTINUE
      IF(N9.EQ.0) GO TO 3206
      M=1
3204  MM=MIN0((M+13),NK)
      READ (I2,3202) CARD,(ENEH(K),K=M,MM)
      WRITE(I3,3203) CARD
      M=MM+1
      IF (M.LE.NK) GO TO 3204
3206  CONTINUE
      RETURN
```

```
C
C     IPART = 2.  PRINT MODEL
 30   WRITE (I3,1061)
      IF ( (N1+N2+N3+N4+N5+N6+N7).EQ.0) WRITE (I3,1060)
      SIG=TAG(1)
      IF (NSCBC.EQ.2) SIG=TAG(2)
      IF(N1.LT.3) WRITE (I3,1062) SIG, ABETA, BBETA
      IF(N1.EQ.3) WRITE(I3,1084)
      WRITE (I3,1063) NVISCW, (I,AA(I),BB(I),CC(I),I=1,4)
      WRITE (I3,1064) J4
      IF (J4.GT.4) WRITE (I3,1065) (AF(I),I=1,NF)
      WRITE (I3,1066) J2,J3
      IF (J3.GT.4) WRITE (I3,1065) (AV(I),I=1,NV)
      WRITE (I3,1067) IG
      IF (IG.EQ.2) WRITE (I3,1068) (DATA(IFINLE+I),I=1,NCHAN )
      WRITE (I3,1069) NCHF,KIJ,FTM,SL,THETA
      WRITE (I3,1070) NTRIES,FERROR
      IF(N9.GT.0) GO TO 40
      WRITE(I3,1071)
      WRITE(I3,1072)
      GO TO 50
 40   WRITE (I3,1071)
      WRITE(I3,1080)
      WRITE(I3,1081)(K,ENEH(K),K=1,NK)
 50   CONTINUE
      RETURN
C
C------------------------------------------------------------------
1001  FORMAT(20A4, T1, 14I5)
1002  FORMAT(20A4, T1, 14E5.0)
1003  FORMAT(20A4, T1, I5, 13E5.0)
1004  FORMAT(20A4, T1, 2I5, 2E5.0)
1009  FORMAT('  HYDRAULIC MODEL INDICATORS',2X '***', 20A4, '*** MODEL')
1010  FORMAT(/, '  * * * * * * * * * *   IS CHANGED MIXING MODEL VALID F
     1OR BWR CASE?', /)
1011  FORMAT('  MIXING COEFFICIENTS', 9X, '***', 20A4, '*** MODEL')
1012  FORMAT('  SINGLE-PHASE FRICTION', 7X, '***', 20A4, '*** MODEL')
1013  FORMAT('  TWO-PHASE FRICTION (J4)', 5X, '***', 20A4, '*** MODEL')
1014  FORMAT('  POLYNOMIAL COEFFICIENTS', 5X, '***', 20A4, '*** MODEL')
1015  FORMAT('  VOID FRACTION (J2, J3)', 6X '***', 20A4, '*** MODEL')
1016  FORMAT('  INLET FLOW DIVISION (IG)', 4X '***', 20A4, '*** MODEL')
1017  FORMAT('  CONSTANTS', 19X, '***', 20A4, '*** MODEL')
1018  FORMAT('  ITERATION', 19X, '***', 20A4, '*** MODEL')
1019  FORMAT('  NPROP, N, PH, P2', 12X, '***', 20A4, '*** MODEL')
1060  FORMAT(///, '  PRESET HYDRAULIC MODEL USED')
1061  FORMAT(43X, 'THERMAL - HYDRAULIC MODEL', /, 43X,
     1 '-------------------------')
1062  FORMAT(///, '  (1) MIXING', /, 6X, '------', /,
     1 '  MIXING COEFFICIENT (',A4,') = ',F6.3,'* (RE**', F5.2, ')', /,
     2 '  TWO-PHASE MIXING SAME AS SINGLE PHASE (NBBC=1)', /,
     3 '  NO THERMAL CONDUCTION (GK=0.0)' )
1063  FORMAT(///, '  (2) SINGLE-PHASE FRICTION', 10X,
```

```
     1 'F = A*(RE**B) + C', /, 6X, '------ ----- --------', /,
     2 '  NVISCW = ', I2, 16X, '(=0 FOR NO WALL VISCOSITY CORRECTION, =1
     3 FOR INCLUSION)' /, '  FRIC TYPE', 5X, 'A',  9X, 'B',  9X, 'C', /,
     4 (I7, 3X, 3F10.4))
1064 FORMAT(///, '  (3) TWO-PHASE FRICTION', /, 6X,
     1 '--- ----- --------', /, '  J4 = ', I2, 20X,
     2 '(J4=0 HOMOGENEOUS,  =1 ARMAND,  =2 BAROCZY,  =5 POLYNOMIAL IN QU
     3ALITY)' )
1065 FORMAT('  POLYNOMIAL COEFF', 5X, 1P7E15.4)
1066 FORMAT(///, '  (4) VOID FRACTION', /, 6X, '---- --------', /,
     1 '  J2 = ', I2, 20X, '(J2=0 NO SUBCOOLED VOID,   =1 LEVY MODEL)'
     2 /, '  J3 = ', I2, 20X, '(J3=0 SLIP RATIO = 1,   =1 ARMAND,   =2 S
     3MITH,   =5 SLIP POLYNOMIAL,   =6 VOID = F(QUAL)' )
1067 FORMAT(///, '  (5) FLOW DIVISION AT INLET', /, 6X,          '----
     1 -------- -- -----', /, '  IG = ', I2, 20X, '(IG=0 SAME G,    =1 S
     2AME DP/DX,   =2 GIN/GAV RATIO GIVEN)' )
1068 FORMAT('  FLOW SPLIT = ', 5X, 10F10.3/ (20X, 10F10.3) )
1069 FORMAT(///, '  (6) CONSTANTS', /, 6X, '---------', /,
     1 '  CRITICAL HEAT FLUX (NCHF)', 8X, '=', I6, /,
     2 '  CROSS-FLOW RESISTANCE (KIJ)', 6X, '=', F10.3, /,
     3'  MOMENTUM TURBULENT FACTOR (FTM)', 2X, '=', F10.3, /,
     4 '  TRANSVERSE MOMENTUM FACTOR (S/L)', 1X, '=', F10.3, /,
     5 '  CHANNEL  ANGLE FROM VERTICAL', 5X, '=', F10.3, '   DEGREES')
1070 FORMAT(///, '  (7) ITERATION', /, 6X, '---------', /,
     1 '  MAX. ALLOWABLE NO. ITERATIONS', 4X, '=', I6, /,
     2 '  FLOW CONVERGENCE FACTOR', 10X, '=', 1PE12.3)
1071 FORMAT (///,'  (8) COUPLING PARAMETER FOR THE MIXING TERM',/,6X,'
     1--------------------------------------')
1072 FORMAT('  NO ENTHALPY COUPLING PARAMETER IS USED')
1080 FORMAT ('  BOUNDARY-COUPLING PARAMETER')
1081 FORMAT (8(2X,I5,'-',F7.3))
1084 FORMAT(///, '  (1) MIXING', /, 6X,'------', /,'      BEUS MODEL')
3202 FORMAT(20A4,T1,14E5.0)
3203 FORMAT('  COUPLING FACTOR NH',10X,'***' ,20A4,'*** MODEL')
C-----------------------------------------------------------------------
      END
```

```
C*********************** SUBROUTINE MPC ******************************
      SUBROUTINE MPC (TCL, RCP, COND)
C
C     CALCULATES HEAT CAPACITY AND CONDUCTIVITY OF ZIRCALOY AS A
C     FUNCTION OF TEMPERATURE
C
C     ARGUMENTS
C       INPUT       TCL       TEMPERATURE (DEG F)
C       RETURN      RCP       HEAT CAPACITY (BTU/FT**3-DEG F)
C                   COND      CONDUCTIVITY (BTU/SEC-FT-DEG F)
C
C     THIS SUBROUTINE IS BASED ON DATA IN TREE-NUREG-1005, APPENDIX B.
C     CONDUCTIVITY IS USED UNCHANGED. HEAT CAPACITY HAS BEEN FIT
C     LINEARLY IN THE ALPHA PHASE (TEM < 1190), BY A CONSTANT IN THE
C     BETA PHASE (TEM > 1254), AND BY AN INVERTED VEE IN THE TRANSITION.
C     ERROR IS 5 PER CENT IN THE ALPHA PHASE, 300 < TEM < 1190 DEG K.
C-----------------------------------------------------------------------
      DIMENSION CN(4)
      DATA CN /7.51, 2.09E-2, -1.45E-5, 7.67E-9 /
      DATA CVTC,CVTRC/1.61E-4, 1.49E-5/
C-----------------------------------------------------------------------
C
C     HEAT CAPACITY
C
C     CONVERT TO TEM (DEG K)
      TEM=.5556*(TCL+459.67)
      IF (TEM.GT.1090.)  GO TO 20
C
C     ALPHA PHASE:    (0 < TEM < 1090 DEG K, USUAL CASE)
      RCP = 1673456. + TEM * 721.6
      GO TO 50
C
 20   IF (TEM.GE.1254.)  GO TO 30
      RCP = 5346400. - 36080.*ABS(TEM-1170.)
      GO TO 50
 30   RCP = 2315680.
 50   CONTINUE
C
C     CONDUCTIVITY
      COND = CN(1)+ TEM*(CN(2)+ TEM*(CN(3)+ TEM*CN(4)))
C     CONVERT COND FROM (W/M-DEG K) TO (BTU/SEC-FT-DEG F)
      COND = COND*CVTC
C     CONVERT RCP FROM (J/M**3-DEG K) TO (BTU/FT**3-DEG F)
      RCP = RCP*CVTRC
      RETURN
      END
```

```
C*********************** SUBROUTINE MPF ******************************
      SUBROUTINE MPF (TFUEL, FTD, FPUO2, RCP, COND)
C
C     CALCULATES HEAT CAPACITY AND CONDUCTIVITY OF UO2 AND PUO2 FUELS
C     AS FUNCTIONS OF TEMPERATURE, FRACTION OF THEORETICAL DENSITY,
C     AND PLUTONIUM CONTENT.
C
C     ARGUMENTS
C       INPUT       TFUEL    TEMPERATURE (DEG F)
C                   FTD      FRACTION OF THEORETICAL DENSITY
C                   FPUO2    PLUTONIUM FRACTION BY VOLUME
C       RETURN      RCP     HEAT CAPACITY (BTU/FT**3-DEG F)
C                   COND    CONDUCTIVITY (BTU/SEC-FT-DEG F)
C
C     THIS SUBROUTINE IS BASED ON EXPRESSIONS USED IN MATPRO; SEE
C     TREE-NUREG-1005, APPENDIX A. THOSE EXPRESSIONS HAVE BEEN
C     APPROXIMATED BY POLYNOMIAL FITS WHOSE MAXIMUM ERRORS ARE ABOUT
C     ONE STANDARD DEVIATION IN EXPERIMENTAL DATA.
C        RCP ERROR =  2 PER CENT       300 < TEM < 3000 DEG K
C        COND ERROR = 10 PER CENT       400 < TEM < 2500 DEG K
C-----------------------------------------------------------------------
      DIMENSION RC(4), RCM(4), CN(3), CNM(3)
      DATA  RC /1.78E6, 3.62E3, -2.61, 6.59E-4/
      DATA RCM /1.81E6, 3.72E3, -2.57, 6.13E-4/
      DATA  CN /10.8, -8.84E-3, 2.25E-6/
      DATA CNM /9.88, -8.44E-3, 2.25E-6/
      DATA CVTC,CVTRC/1.61E-4, 1.49E-5/
C-----------------------------------------------------------------------
C
      TEM=.5556*(TFUEL+459.7)
      IF (FPUO2.GT.1.E-7)  GO TO 20
C
C     UO2 FUEL
 10   RCP = FTD*( RC(1)+ TEM*(RC(2) +TEM*(RC(3) +TEM*RC(4))) )
      BT = 2.74 - TEM * 5.8E-4
      POR = 1.- BT*(1.- FTD)
C     THE FACTOR  /(1.-BT*(1.-.95)) IS INCORPORATED IN THE FIT CN(3)
      COND = POR*( CN(1)+ TEM*(CN(2)+ TEM*CN(3)) )
      GO TO 100
C
C     MIXED OXIDE FUEL
 20   RCP=FTD*(1.+.045+FPUO2)*(RCM(1)+TEM*(RCM(2)+
     *TEM*(RCM(3)+TEM*RCM(4))))
      BT = 2.74 - TEM * 5.8E-4
      POR = FTD / (1.+ BT*(1.-FTD))
C     THE FACTOR (1.+BT*(1.-.96))/.96 IS INCORPORATED IN CNM(3)
      COND = POR*( CNM(1)+ TEM*(CNM(2)+ TEM*CNM(3)) )
 100  CONTINUE
C     COND CONVERTED FROM (W/M-DEG K) TO (BTU/SEC-FT-DEG F)
      COND=COND*CVTC
C     RCP CONVERTED FROM (J/M**3-DEG K) TO (BTU/FT**3-DEG F)
      RCP=RCP*CVTRC
```

```
      RETURN
      END
```

```
C********************** SUBROUTINE MPG *********************************
      SUBROUTINE  MPG (INIT, BURN, EFFB, FRAC, PRESS, CPR, EXPR, GRGH,
     1      THG, RADFU, PG, TG, GMIX, TF, TC, HGAP)
C
C     CALULATES GAP HEAT TRANSFER COEFFICIENT, IN THREE PARTS:
C     1. OPEN GAP COMPONENT, BASED ON CONDUCTIVITY OF A MIXTURE OF FOUR
C        NOBLE GASES; A SMALL GAP CORRECTION IS APPLIED IF PGAS > 0.
C     2. CONTRIBUTION FROM PARTIAL FUEL-CLAD CONTACT
C     3. RADIATION COMPONENT
C        IF RADFU > (RADFU+THG) - ROUGH, THEN IN ADDITION TO THE ABOVE:
C     4. CLOSED GAP LAW = CPR * (PRESS**EXPR)
C
C     PARTS 1 & 2 ARE BASED ON TREE-NUREG-1005, APPENDIX C, WITH CRACKED
C     PELLET MODEL; PART 4 IS USER-SUPPLIED.
C
C     MPG IS CALLED WITH INIT = .TRUE. TO PERFORM INITIALIZATION
C     NORMAL CALLS HAVE INIT = .FALSE.
C
C     ARGUMENTS: INIT = .TRUE.
C       INPUT      BURN     BURNUP (MWD/MTU)
C                  GRGH     ROOT MEAN SQUARE OF FUEL PELLET AND CLADDING
C                            SURFACE ROUGHNESSES (FT)
C                  THG      GAP THICKNESS (FT)
C       RETURN     GRGH     IF GRGH  = 0 ON INPUT, A DEFAULT VALUE OF
C                            1.34E-6 FEET IS RETURNED
C                  EFFB     FRACTIONAL EFFECT OF BURNUP, USED IN PARTIAL
C                            FUEL-CLAD CONTACT MODEL
C                  FRAC     FRACTION OF FUEL PERIMETER IN LIGHT CONTACT
C                            WITH CLAD
C
C     ARGUMENTS: INIT = .FALSE. (NORMAL ENTRY)
C       INPUT      FRAC     FRACTION OF FUEL PERIMETER TOUCHING CLAD
C                  PRESS    PRESSURE OF FUEL AGAINST CLAD FOR CLOSED GAP
C                  CPR      COEFFICIENT OF PRESS
C                  EXPR     EXPONENT OF PRESS
C                  GRGH     RMS OF FUEL AND CLAD GRGH NESSES (FT)
C                  THG      GAP THICKNESS (FT)
C                  PG       PRESSURE OF GAS MIXTURE IN GAP, FOR SMALL
C                           GAP CORRECTION FACTOR (PSIA)
C                  TG       TEMPERATURE OF GAS MIXTURE IN GAP (DEG F)
C                  GMIX     FOUR MOLE FRACTIONS OF NOBLE GASES
C                            1. HELIUM
C                            2. ARGON
C                            3. KRYPTON
C                            4. ZENON
C                            THE FOUR ELEMENTS OF GMIX MUST SUM TO 1
C                  TF       TEMPERATURE OF FUEL PELLET SURFACE (DEG F)
C                  TC       TEMPERATURE OF INNER CLAD SURFACE (DEG F)
C       RETURN     HGAP     GAP HEAT TRANSFER COEFFICIENT
C                           (BTU/FT**3-DEG F)
C-----------------------------------------------------------------------
      DIMENSION  GMIX(4), CC(4), EE(4), CON(4), CSR(4), AM(4,4), BM(4,4)
```

```
      LOGICAL  INIT
C
C     COMBINING FACTORS WHICH ARE FUNCTIONS ONLY OF THE MOLECULAR
C     WEIGHTS OF THE FOUR NOBLE GASES
      DATA AM / 0.,   .295, .232, .194,
     2          .362, 0.,   .309, .332,
     3          .413, .235, 0.,   .286,
     4          .435, .260, .232, 0.    /
      DATA BM / 0.,   1.78, 2.14, 2.39,
     2          .563, 0.,   1.20, 1.35,
     3          .467, .831, 0.,   1.12,
     4          .418, .743, .894, 0.    /
      DATA CC / 3.366E-3, 3.421E-4, 4.029E-5, 4.726E-5 /
      DATA EE / .668, .701, .872, .923 /
C-----------------------------------------------------------------------
C
C     MAKE THE NECESSARY UNIT CONVERSIONS
C     CONVERT TO DGAP(M)
      DGAP = THG*.3048
C     TEMPERATURES CONVERTED FROM (DEG F) TO (DEG K)
      TCLAD=.5556*(TC+459.67)
      TGAS=.5556*(TG+459.67)
      TFUEL=.5556*(TF+459.67)
      TGAS=.5556*(TG+459.67)
C     CONVERT TO PGAS(N/M**2)
      PGAS=PG*6.893E3
C     CONVERT TO ROUGH(M)
      ROUGH=GRGH*.3048
C
      IF (INIT) GO TO 200
C
C     NOBLE GAS CONDUCTIVITIES
      CON(1) = 0.
      DO  10  I = 1, 4
        IF (GMIX(I).LT.1.E-6)  GO TO 10
        CON(I) = CC(I) *(TGAS**EE(I))
        CSR(I) = SQRT(CON(I))
 10     CONTINUE
C     SMALL GAP CORRECTION FOR HELIUM:
      GAP = AMAX1  (ROUGH, DGAP)
      FAC = PGAS * GAP
      IF (FAC.LT.1.E-9)  GO TO 15
      CON(1) = CON(1) / (1.+ CON(1)*.2103*SQRT(TGAS)/FAC)
      CSR(1) = SQRT(CON(1))
 15   CONTINUE
C
C     MIXTURE CONDUCTIVITY
      GCOND = 0.
         DO  30  I = 1, 4
         IF (GMIX(I).LT.1.E-6) GO TO 30
         XSUM = GMIX(I)
            DO  20  J = 1, 4
```

```
            IF (J.EQ.I) GO TO 20
            IF (GMIX(J).LT.1.E-6) GO TO 20
            TS = CSR(J) + CSR(I)*BM(I,J)
            XSUM = XSUM + GMIX(J)*AM(I,J)*TS*TS/CON(J)
 20         CONTINUE
         GCOND = GCOND + CON(I)*GMIX(I)/XSUM
 30      CONTINUE
      HGAP = GCOND /(DGAP + ROUGH)
C     PARTIAL FUEL-CLAD CONTACT MODEL
      HGAP = (1.-FRAC)*HGAP + FRAC*GCOND/ROUGH
C
C     RADIATION HEAT TRANSFER CONTRIBUTION
      REMISF = AMAX1(1.1485, AMIN1(2.451, -.154+TFUEL*1.3025E-3 ))
      REMISC = 1.33
      RFVIEW = REMISF + (REMISC-1.)*RADFU/(RADFU+THG)
      HGAP=HGAP+5.279E-8*(TFUEL+TCLAD)*(TFUEL*TFUEL+TCLAD*TCLAD)/RFVIEW
C     CONVERT HGAP FROM (W/M**2-DEG K)) TO (BTU/SEC-FT**2-DEG F)
      HGAP=HGAP*4.89E-5
C
C     CLOSED GAP CONTACT HEAT TRANSFER
      IF (DGAP .GE. ROUGH)  RETURN
      HGAP = HGAP +  CPR * (PRESS **EXPR)
      RETURN
C
C     INITIALIZATION OF MPG, CALLED ONLY ONCE
 200  IF (GRGH.LE.0.)  GRGH = 1.34E-6
C
C     FRACTION OF FUEL IN LIGHT CONTACT WITH CLAD, A FUNCTION OF BURNUP
C     --FRACTIONAL EFFECT OF BURNUP, INDEPENDENT OF FUEL RADIUS
      IF (BURN-600.) 210,210,220
 210  EFFB = 0.
      GO TO 230
 220  CONTINUE
      TS = .001*BURN - .6
      TS = TS*TS
      EFFB = 1.- 1./(TS*TS + 1.)
 230  CONTINUE
C
C     --FRACTION OF CIRCUMFERENCE OF FUEL IN LIGHT CONTACT WITH CLAD
      A1 = 100. - 98.*EFFB
      A2 = 4. - .5*EFFB
      FRAC = 1./ (A1*(100.*DGAP/RADFU)**A2 + 1.42857) + .3
      RETURN
      END
```

```
C*********************** SUBROUTINE OPERA *******************************
      SUBROUTINE OPERA(IPART,CARD)
C
      IMPLICIT INTEGER (I)
      INTEGER IDAT(1)
      LOGICAL LDAT(1), GRID
      REAL KIJ, KF, KKF, KCLAD, KFUEL
C
      COMMON  DATA(1)
      EQUIVALENCE  (DATA(1),IDAT(1),LDAT(1))
C
      COMMON /COBRA1/  ABETA ,AFLUX ,ATOTAL,BBETA ,DIA   ,DT    ,DX    ,
     1   ELEV  ,FERROR,FLO   ,FTM   ,GC    ,GK    ,GRID  ,HSURF ,HF    ,
     2   HFG   ,HG    ,I2    ,I3    ,IERROR,IQP3  ,ITERAT,J1    ,J2    ,
     3   J3    ,J4    ,J5    ,J6    ,J7    ,KDEBUG,KF    ,KIJ   ,
     4   NAFACT,NARAMP,NAX   ,NAXL  ,NBBC  ,NCHAN ,NCHF  ,NDX   ,NF    ,
     5   NGAPS ,NGRID ,NGRIDT,NGTYPE,NGXL  ,NK    ,NODES ,NODESF,NPROP ,
     6   NRAMP ,NROD  ,NSCBC ,NV    ,NVISCW,PI    ,PITCH ,POWER ,PREF  ,
     7   QAX   ,RHOF  ,RHOG  ,SIGMA ,SL    ,TF    ,TFLUID,THETA ,THICK ,
     8   UF    ,VF    ,VFG   ,VG    ,Z
C
      COMMON /COBRA2/  AA(4), AF(7), AFACT(10,10), AV(7), AXIAL(30),
     1   AXL(10), BB(4), BX(30), CC(4), CCLAD(2), CFUEL(2), DFUEL(2),
     2   GAPXL(10), GFACT(9,10), GRIDXL(10), HGAP(2), HHF(30), HHG(30),
     3   IGRID(10), KCLAD(2), KFUEL(2), KKF(30), NCH(10), NGAP(9),
     4   PP(30), RCLAD(2),RFUEL(2),SSIGMA(30), TCLAD(2), UUF(30),
     5   VVF(30), VVG(30), XQUAL(30), Y(30), TT(30)
C
      COMMON /COBRA3/  MA    ,MC    ,MG    ,MN    ,MR    ,MS    ,MX    ,
     1         III   ,IA    ,IAAA  ,IAC   ,IALPHA,IAN   ,IANSWE,IB    ,
     1   ICCHAN,ICD   ,ICHFR ,ICON  ,ICOND ,ICP   ,ID    ,IDC   ,IDFDX ,
     2   IDHDX ,IDHYD ,IDHYDN,IDIST ,IDPDX ,IDPK  ,IDUR  ,IDR   ,IF    ,
     3   IFACTO,IFDIV ,IFINLE,IFLUX ,IFMULT,IFOLD ,IFSP  ,IFSPLI,IFXFLO,
     4   IGAP  ,IGAPN ,IGAPS ,IH    ,IHFILM,IHINLE,IHOLD ,IHPERI,IIDARE,
     5   IIDFUE,IIDGAP,IIK   ,IJBOIL,IJK   ,ILC   ,ILENGT,ILOCA ,ILR   ,
     6   IMCHFR,IMCFRC,IMCFRR,INTYPE,INWRAP,INWRPS,IP    ,IPERIM,IPH   ,
     7   IPHI  ,IPRNTC,IPRNTR,IPRNTN,IPW   ,IPWRF ,IQC   ,IQF   ,IQPRIM,
     8   IQUAL ,IRADIA,IRHO  ,IRHOOL,ISP   ,IT    ,ITDUMY,ITINLE,ITROD ,
     9   IU    ,IUH   ,IUSAVE,IUSTAR,IV    ,IVISC ,IVISCW,IVP   ,IVPA  ,
     A   IW    ,IWOLD ,IWP   ,IWSAVE,IX    ,IXCROS,IIA  ,IIB  ,IXPOLD
C
      COMMON/LINK2/CROSS(6),FG(30),FH(30),FP(30),FQ(30),IM(9),JM(9),
     1OUTPUT(10),PRINT(12),TEXT(17),YG(30),YH(30),YP(30),YQ(30)
      COMMON/LINK3/DXX,ETIME,GIN,HIN,I8,IG,IN,ISAVE,JUMP,KASE,KT,MAXT,
     1 NDT,NDXP1,NFUELT,NG,NH,NJUMP,NOUT,NP,NPCHAN,NPNODE,NPROD,NQ,NR,
     2 NSKIPT,NSKIPX,NTRIES,PEXIT,PHTOT,SAVEDT,TIN,TTIME,ZZ
      DIMENSION CARD(20)
C-----------------------------------------------------------------------
C
C     IPART=1  READ OPERATING CONDITIONS
C     IPART=2  PRINT OPERATING CONDITIONS
C     COBRA AND MEKIN SAME CODING EXCEPT IMEKIN = 0
```

```
C
      IMEKIN = 0
      IF(IPART.EQ.2) GO TO 10
      READ (I2,1001) CARD, IN, HIN, GIN, PEXIT
      WRITE(I3,1011) CARD
      IF ( (NDX.LE.0) .OR. (Z.LE.0.0) ) GO TO 30
      PREF = PEXIT
      IF(IN.EQ.0) TIN=0.0
      IF(IN.LT.2) GO TO 2
      IF(IN.EQ.2) CALL READIN(2,NCHAN ,DATA(IHINLE+1),CARD,CARD,1)
      IF(IN.EQ.3) CALL READIN(3,NCHAN ,DATA(IHINLE+1),CARD,CARD,1)
    2 READ(I2,1002) CARD,NP,NH,NG,NQ
      WRITE(I3,1012) CARD
      IF (NP.GT.1) CALL READIN(4,NP,YP,FP,CARD,2)
      IF (NH.GT.1) CALL READIN(5,NH,YH,FH,CARD,2)
      IF (NG.GT.1) CALL READIN(6,NG,YG,FG,CARD,2)
      IF (NQ.GT.1) CALL READIN(7,NQ,YQ,FQ,CARD,2)
      IF (NPROP.GT.0) GO TO 9
C
C     SET MAX AND MIN PRESSURES FOR PHYSICAL PROPERTIES IN FIZPRP.
      ZMIN = 1.0
      IF (NH.LE.1) GO TO 4
         DO 3 I=1,NH
         IF (FH(I).LT.ZMIN) ZMIN = FH(I)
    3    CONTINUE
    4 WV = HIN
      IF (IN.LT.2) GO TO 6
      WV = 1000.0
         DO 5 I=1,NCHAN
         IF (DATA(IHINLE+I).LT.WV) WV=DATA(IHINLE+I)
    5    CONTINUE
C     WV CORRESPONDS TO MIN HIN OR TIN AT STEADY STATE
    6 R = 0.01*WV*ZMIN
      IF (R.LT.4.5) R = R*(1.0-0.1*(4.5-R))
C
C     SET PP(1) TO PRESSURE LOWER THAN MIN IN PROBLEM FOR FIZPRP
C     SET PP(2) TO HIGHEST PRESSURE DURING TRANSIENT
      PP(1) = 10.0
      IF (R.GT.2.0) PP(1) = 6.0*R*R*R*(R-1.35)/(R-0.35)
      ZMAX = 1.0
      IF (NP.LE.1) GO TO 8
      ZMIN = 1.0E06
         DO 7 I=1,NP
         IF (FP(I).GT.ZMAX) ZMAX = FP(I)
         IF (FP(I).LT.ZMIN) ZMIN = FP(I)
    7    CONTINUE
      IF (ZMIN*PREF.LT.PP(1)) PP(1) = ZMIN*PREF
    8 PP(2) = ZMAX*PREF + 0.01
      NPROP = 30
    9 CONTINUE
C
C     SET TTIME AND NDT FOR MEKIN ONLY
```

```
      IF (IMEKIN.EQ.0) RETURN
      TTIME = 1.0
      NDT = 1
      IF ((NP+NH+NG+NQ).LE.0) NDT=0
      RETURN
C
 10   WRITE (I3,1020) PEXIT,GIN
C     SET HINLET = H OR T ACCORDING TO IN
      IF (IN-1) 12,14,20
 12   WRITE (I3,1021) IN,HIN
      GO TO 16
 14   WRITE (I3,1022) IN,HIN
 16      DO 18 I=1,NCHAN
 18      DATA(IHINLE+I) = HIN
      GO TO 22
 20   IF (IN.EQ.2) WRITE (I3,1023) IN,(I,DATA(IHINLE+I),I=1,NCHAN )
      IF (IN.EQ.3) WRITE (I3,1024) IN,(I,DATA(IHINLE+I),I=1,NCHAN )
 22   WRITE (I3,1025) Z,NDX
      Z = Z/12.0
      IF (NDT.GT.0) GO TO 24
      WRITE (I3,1026)
      GO TO 26
 24   IF (IMEKIN.EQ.0) WRITE (I3,1027) NDT,TTIME
      IF (NP.GT.1) WRITE(I3,1028) (YP(I),FP(I),I=1,NP)
      IF (NH.GT.1) WRITE(I3,1029) (YH(I),FH(I),I=1,NH)
      IF (NG.GT.1) WRITE(I3,1030) (YG(I),FG(I),I=1,NG)
      IF (NQ.GT.1) WRITE(I3,1031) (YQ(I),FQ(I),I=1,NQ)
 26   RETURN
 30   WRITE (I3,1040)
      STOP
C
C-----------------------------------------------------------------------
1001  FORMAT(20A4, T1, I5, 13E5.0)
1002  FORMAT(20A4, T1, 14I5)
1011  FORMAT('  IN H(OR T)IN GIN PEXIT', 6X, '***', 20A4, '*** OPERA')
1012  FORMAT('  TRANS INDIC FOR P H G Q',5X, '***', 20A4, '*** OPERA')
1020  FORMAT(43X, 'OPERATING CONDITIONS', /, 43X,
     1 '--------------------', //, '  PRESSURE', 20X, '(PSIA)', 9X, '=',
     2 F10.2, /, '  AV. INLET MASS VELOCITY', 5X, '(MLB/SQFT.HR)', 2X,
     3 '=', F12.4)
1021  FORMAT('  IN=', I2, '  INLET ENTHALPY',   7X, '(BTU/LB)', 7X, '=',
     1 F11.3)
1022  FORMAT('  IN=', I2, '  INLET TEMPERATURE',4X, '(DEG F)', 8X, '=',
     1 F11.3)
1023  FORMAT('  IN=', I2, '  INLET ENTHALPIES', 5X, '(BTU/LB)', 7X, '=',
     1/(5X,6(I5,5X,F10.3)/))
1024  FORMAT('  IN=', I2, '  INLET TEMPERATURES',3X, '(DEG F)', 8X, '=',
     1/(5X,6(I5,5X,F10.3)/))
1025  FORMAT(' *CHANNEL LENGTH', 14X, '(IN)', 11X, '=', F10.2, /,
     1 ' *NO. OF AXIAL INTERVALS', 21X, '=', I7)
1026  FORMAT('  NO TRANSIENT CALCULATION')
1027  FORMAT(' *NO. OF TIME STEPS', 26X, '=', I7, /,
```

```
     1 ' *TOTAL TIME OF TRANSIENT', 5X, '(SEC)', 10X, '=', F10.2)
1028  FORMAT (/, 33H   FORCING FUNCTION FOR PRESSURE /
     1        23H      TIME     PRESSURE /
     2        23H     (SEC)     FACTOR   /  (F10.4,F13.4))
1029  FORMAT (/, 38H   FORCING FUNCTION FOR INLET ENTHALPY/
     1        28H      TIME  INLET ENTHALPY          /
     2        23H     (SEC)     FACTOR   /  (F10.4,F13.4))
1030  FORMAT (/,38H   FORCING FUNCTION FOR INLET FLOW    /
     1        28H      TIME  INLET FLOW              /
     2        23H     (SEC)     FACTOR   /  (F10.4,F13.4))
1031  FORMAT (/, 38H   FORCING FUNCTION FOR HEAT FLUX     /
     1        38H      TIME   HEAT FLUX              /
     2        23H     (SEC)     FACTOR   /  (F10.4,F13.4))
1040  FORMAT('  INPUT DATA ERROR. NDX OR Z .LT.0.  STOP (OPERA)')
C-----------------------------------------------------------------------
      END
```

```
C********************** SUBROUTINE PRECAL ******************************
      SUBROUTINE PRECAL
C
      IMPLICIT INTEGER (I)
      INTEGER IDAT(1)
      LOGICAL LDAT(1), GRID
      REAL KIJ, KF, KKF, KCLAD, KFUEL
C
      COMMON  DATA(1)
      EQUIVALENCE  (DATA(1),IDAT(1),LDAT(1))
C
      COMMON /COBRA1/  ABETA ,AFLUX ,ATOTAL,BBETA ,DIA   ,DT    ,DX    ,
     1   ELEV  ,FERROR,FLO   ,FTM   ,GC    ,GK    ,GRID  ,HSURF ,HF    ,
     2   HFG   ,HG    ,I2    ,I3    ,IERROR,IQP3  ,ITERAT,J1    ,J2    ,
     3   J3    ,J4    ,J5    ,J6    ,J7    ,KDEBUG,KF    ,KIJ   ,
     4   NAFACT,NARAMP,NAX   ,NAXL  ,NBBC  ,NCHAN ,NCHF  ,NDX   ,NF    ,
     5   NGAPS ,NGRID ,NGRIDT,NGTYPE,NGXL  ,NK    ,NODES ,NODESF,NPROP ,
     6   NRAMP ,NROD  ,NSCBC ,NV    ,NVISCW,PI    ,PITCH ,POWER ,PREF  ,
     7   QAX   ,RHOF  ,RHOG  ,SIGMA ,SL    ,TF    ,TFLUID,THETA ,THICK ,
     8   UF    ,VF    ,VFG   ,VG    ,Z
C
      COMMON /COBRA2/  AA(4), AF(7), AFACT(10,10), AV(7), AXIAL(30),
     1   AXL(10), BB(4), BX(30), CC(4), CCLAD(2), CFUEL(2), DFUEL(2),
     2   GAPXL(10), GFACT(9,10), GRIDXL(10), HGAP(2), HHF(30), HHG(30),
     3   IGRID(10), KCLAD(2), KFUEL(2), KKF(30), NCH(10), NGAP(9),
     4   PP(30), RCLAD(2),RFUEL(2),SSIGMA(30), TCLAD(2), UUF(30),
     5   VVF(30), VVG(30), XQUAL(30), Y(30), TT(30)
C
      COMMON /COBRA3/  MA    ,MC    ,MG    ,MN    ,MR    ,MS    ,MX    ,
     1          III   ,IA    ,IAAA  ,IAC   ,IALPHA,IAN   ,IANSWE,IB    ,
     1   ICCHAN,ICD   ,ICHFR ,ICON  ,ICOND ,ICP   ,ID    ,IDC   ,IDFDX ,
     2   IDHDX ,IDHYD ,IDHYDN,IDIST ,IDPDX ,IDPK  ,IDUR  ,IDR   ,IF    ,
     3   IFACTO,IFDIV ,IFINLE,IFLUX ,IFMULT,IFOLD ,IFSP  ,IFSPLI,IFXFLO,
     4   IGAP  ,IGAPN ,IGAPS ,IH    ,IHFILM,IHINLE,IHOLD ,IHPERI,IIDARE,
     5   IIDFUE,IIDGAP,IIK   ,IJBOIL,IJK   ,ILC   ,ILENGT,ILOCA ,ILR   ,
     6   IMCHFR,IMCFRC,IMCFRR,INTYPE,INWRAP,INWRPS,IP    ,IPERIM,IPH   ,
     7   IPHI  ,IPRNTC,IPRNTR,IPRNTN,IPW   ,IPWRF ,IQC   ,IQF   ,IQPRIM,
     8   IQUAL ,IRADIA,IRHO  ,IRHOOL,ISP   ,IT    ,ITDUMY,ITINLE,ITROD ,
     9   IU    ,IUH   ,IUSAVE,IUSTAR,IV    ,IVISC ,IVISCW,IVP   ,IVPA  ,
     A   IW    ,IWOLD ,IWP   ,IWSAVE,IX    ,IXCROS,IIA  ,IIB  ,IXPOLD
C
      COMMON/LINK3/DXX,ETIME,GIN,HIN,I8,IG,IN,ISAVE,JUMP,KASE,KT,MAXT,
     1 NDT,NDXP1,NFUELT,NG,NH,NJUMP,NOUT,NP,NPCHAN,NPNODE,NPROD,NQ,NR,
     2 NSKIPT,NSKIPX,NTRIES,PEXIT,PHTOT,SAVEDT,TIN,TTIME,ZZ
C-----------------------------------------------------------------------
C
C     PREPARE TO START CALCULATION (IN CALC)
      CALL PROP(1,1)
      IF (IERROR.GT.0) GO TO 20
      NDXP1 = NDX + 1
      DX = Z/FLOAT(NDX)
      DXX = DX*12.0
```

```
      DT = 0.0
      IF ( (NDT.GT.0) .AND. (TTIME.LE.0.0) ) NDT=0
      IF (NDT.GT.0) DT = TTIME/FLOAT(NDT)
      SAVEDT = DT
C
C     SET HINLET
      HIN = DATA(IHINLE+1)
      IF ( (IN.EQ.0) .OR. (IN.EQ.2) ) GO TO 10
      IF (IN.GE.3) GO TO 6
      TIN = HIN
      CALL CURVE(HIN,TIN,HHF,TT,NPROP,IERROR,1)
      IF (IERROR.GT.0) GO TO 20
         DO 4 I=1,NCHAN
         DATA(ITINLE+I) = TIN
  4      DATA(IHINLE+I) = HIN
      GO TO 10
  6      DO 8 I=1,NCHAN
         DATA(ITINLE+I) = DATA(IHINLE+I)
         CALL CURVE(DATA(IHINLE+I),DATA(ITINLE+I),HHF,TT,NPROP,IERROR,1)
         IF (IERROR.GT.0) GO TO 20
  8      CONTINUE
C
C     SET FINLET
 10   WV = GIN/0.0036
      FLO = WV*ATOTAL
      WV1 = 1.0
         DO 12 I=1,NCHAN
         IF (IG.EQ.2) WV1 = DATA(IFINLE+I)
 12      DATA(IFINLE+I) = WV*WV1*DATA(IAN+I)
      IF (IG.EQ.1) CALL SPLIT
      RETURN
 20   WRITE (I3,1001)
      RETURN
C
C-----------------------------------------------------------------------
1001  FORMAT('  PRECAL    ERROR SIGNAL AFTER CALLING CURVE OR PROP')
C-----------------------------------------------------------------------
      END
```

```
C*********************** SUBROUTINE PROP ******************************
      SUBROUTINE PROP(IPART,J)
C
      IMPLICIT INTEGER (I)
      INTEGER  IDAT(1)
      LOGICAL  LDAT(1), GRID
      REAL KIJ, KF, KKF, KCLAD, KFUEL
C
      COMMON DATA(1)
      EQUIVALENCE  (DATA(1),IDAT(1),LDAT(1))
C
      COMMON /COBRA1/  ABETA ,AFLUX ,ATOTAL,BBETA ,DIA   ,DT    ,DX    ,
     1   ELEV  ,FERROR,FLO   ,FTM   ,GC    ,GK    ,GRID  ,HSURF ,HF    ,
     2   HFG   ,HG    ,I2    ,I3    ,IERROR,IQP3  ,ITERAT,J1    ,J2    ,
     3   J3    ,J4    ,J5    ,J6    ,J7    ,KDEBUG,KF    ,KIJ   ,
     4   NAFACT,NARAMP,NAX   ,NAXL  ,NBBC  ,NCHAN ,NCHF  ,NDX   ,NF    ,
     5   NGAPS ,NGRID ,NGRIDT,NGTYPE,NGXL  ,NK    ,NODES ,NODESF,NPROP ,
     6   NRAMP ,NROD  ,NSCBC ,NV    ,NVISCW,PI    ,PITCH ,POWER ,PREF  ,
     7   QAX   ,RHOF  ,RHOG  ,SIGMA ,SL    ,TF    ,TFLUID,THETA ,THICK ,
     8   UF    ,VF    ,VFG   ,VG    ,Z
C
      COMMON /COBRA2/  AA(4), AF(7), AFACT(10,10), AV(7), AXIAL(30),
     1   AXL(10), BB(4), BX(30), CC(4), CCLAD(2), CFUEL(2), DFUEL(2),
     2   GAPXL(10), GFACT(9,10), GRIDXL(10), HGAP(2), HHF(30), HHG(30),
     3   IGRID(10), KCLAD(2), KFUEL(2), KKF(30), NCH(10), NGAP(9),
     4   PP(30), RCLAD(2),RFUEL(2),SSIGMA(30), TCLAD(2), UUF(30),
     5   VVF(30), VVG(30), XQUAL(30), Y(30), TT(30)
C
      COMMON /COBRA3/  MA    ,MC    ,MG    ,MN    ,MR    ,MS    ,MX    ,
     1          III   ,IA    ,IAAA  ,IAC   ,IALPHA,IAN   ,IANSWE,IB    ,
     1   ICCHAN,ICD   ,ICHFR ,ICON  ,ICOND ,ICP   ,ID    ,IDC   ,IDFDX ,
     2   IDHDX ,IDHYD ,IDHYDN,IDIST ,IDPDX ,IDPK  ,IDUR  ,IDR   ,IF    ,
     3   IFACTO,IFDIV ,IFINLE,IFLUX ,IFMULT,IFOLD ,IFSP  ,IFSPLI,IFXFLO,
     4   IGAP  ,IGAPN ,IGAPS ,IH    ,IHFILM,IHINLE,IHOLD ,IHPERI,IIDARE,
     5   IIDFUE,IIDGAP,IIK   ,IJBOIL,IJK   ,ILC   ,ILENGT,ILOCA ,ILR   ,
     6   IMCHFR,IMCFRC,IMCFRR,INTYPE,INWRAP,INWRPS,IP    ,IPERIM,IPH   ,
     7   IPHI  ,IPRNTC,IPRNTR,IPRNTN,IPW   ,IPWRF ,IQC   ,IQF   ,IQPRIM,
     8   IQUAL ,IRADIA,IRHO  ,IRHOOL,ISP   ,IT    ,ITDUMY,ITINLE,ITROD ,
     9   IU    ,IUH   ,IUSAVE,IUSTAR,IV    ,IVISC ,IVISCW,IVP   ,IVPA  ,
     A   IW    ,IWOLD ,IWP   ,IWSAVE,IX    ,IXCROS,IIA   ,IIB   ,IXPOLD
C
      COMMON/LINK4/IFRM,IHTM,IPROP,NCC,NCF,NDM1,NDS,NGP
C-----------------------------------------------------------------------
C
      NPROP = NPROP
      IF(IPART.LT.1 .OR. IPART.GT.2) GO TO 1001
      GO TO (9,100),IPART
C
C     PART 1, CALCULATION OF SATURATATED PROPERTIES
  9      DO 10 I=1,NPROP
         IF(PREF.LT.PP(I)) GO TO 20
 10      CONTINUE
```

```
      GO TO 200
 20   IF(I.GT.1) GO TO 40
      GO TO 210
 40   VALUE = (PREF-PP(I-1))/(PP(I)-PP(I-1))
      HF    =    HHF(I-1) + VALUE*(   HHF(I)-   HHF(I-1))
      HG    =    HHG(I-1) + VALUE*(   HHG(I)-   HHG(I-1))
      VF    =    VVF(I-1) + VALUE*(   VVF(I)-   VVF(I-1))
      VG    =    VVG(I-1) + VALUE*(   VVG(I)-   VVG(I-1))
      UF    =    UUF(I-1) + VALUE*(   UUF(I)-   UUF(I-1))
      TF    =     TT(I-1) + VALUE*(    TT(I)-    TT(I-1))
      KF    =    KKF(I-1) + VALUE*(   KKF(I)-   KKF(I-1))
      SIGMA = SSIGMA(I-1) + VALUE*(SSIGMA(I)-SSIGMA(I-1))
      HFG = HG-HF
      VFG = VG-VF
      RHOG = 1./VG
      RHOF = 1./VF
      RETURN
C
C     PART 2, CALCULATE LIQUID PROPERTIES AND PARAMETERS
 100  NCHAN = NCHAN
      IF(J.GT.1) GO TO 102
         DO 101 I=1,NCHAN
 101     IDAT(IJBOIL+I)=0
 102     DO 150 I=1,NCHAN
         DATA(IVISCW+I)=UF
         DATA(IVISC +I)=UF
         DATA(IT    +I)=TF
         DATA(ICON  +I)=KF
         DATA(IV    +I)=VF
         HH=DATA(IH+I+MC*(J-1))
         IF(HH.GT.HF) GO TO 105
         CALL CURVE(DATA(IVISC+I),HH,UUF,HHF,NPROP,IERROR,1)
         IF(IERROR.GT.1) GO TO 1000
         CALL CURVE(DATA(IV   +I),HH,VVF,HHF,NPROP,IERROR,2)
         CALL CURVE(DATA(IT   +I),HH,TT ,HHF,NPROP,IERROR,2)
         CALL CURVE(DATA(ICON +I),HH,KKF,HHF,NPROP,IERROR,2)
 105     TM=DATA(IT    +I)-1.
         CALL CURVE (HM,TM,HHF,TT,NPROP,IERROR,1)
         IF(IERROR.GT.1) GO TO 1000
         DATA(ICP+I)=HH-HM
         IF(HH.GT.HF)  DATA(ICP+I)=HF-HM
         DATA(IVISC +I)=DATA(IVISC +I)/3600.
         DATA(ICON  +I)=DATA(ICON  +I)/3600.
         RE=DATA(IF+I+MC*(J-1))/DATA(IA+I)*DATA(IDHYD+I)/DATA(IVISC+I)
         IF(RE.LT.0.)WRITE(I3,1)I,J,RE,DATA(IF+I+MC*(J-1)),DATA(IVISC+I)
         IF(RE.LT.2000.) RE = 2000.
         PR=DATA(ICP+I)*DATA(IVISC+I)/DATA(ICON+I)
         IF(DATA(IH+I+MC*(J-1)).GT.HF.AND.IDAT(IJBOIL+I).NE.0)
     1   GO TO 120
         IF(IHTM.NE.0.AND.J.NE.1) GO TO 108
C        DATA(IHFILM+I)=0.023*DATA(ICON+I)/DATA(IDHYD+I)*RE**.8*PR**.4
         DATA(IHFILM+I) = HCOOL(-1,I,J)
```

```
         DTWALL=DATA(IQPRIM+I)/DATA(IHPERI+I)/DATA(IHFILM+I)
C        DETERMINE THE START OF NUCLEATE BOILING
         IF(IDAT(IJBOIL+I).GT.0)     GO TO 106
         IF(DATA(IQPRIM+I).LT.0.0)  GO TO 106
C        TLBOIL=TF-DTWALL+60.*EXP(-PREF/900.)*(DATA(IQPRIM+I)/
         TLBOIL=TF-DTWALL+ HCOOL(-2,I,J)
         IF(DATA(IT+I).GE.TLBOIL.AND.NCHF.NE.4) IDAT(IJBOIL+I)=J
         IF(NCHF.EQ.4.AND.DATA(IH+I+MC*(J-1)).GE.HF) IDAT(IJBOIL+I)=J
 106     TWALL=DATA(IT+I)+DTWALL
         GO TO 110
 108     SAVE=0.
         SUM=0.
            DO 109 NN=1,NROD
            DUMY=DATA(IPWRF+I+MC*(NN-1))
            IF(DUMY.LE.0.) GO TO 109
            SUM=SUM+DUMY*DATA(ITROD+NODESF+1+MN*(NN-1+MR*(J-1)))
            SAVE=SAVE+DATA(IPWRF+I+MC*(NN-1))
 109        CONTINUE
         IF(SAVE.EQ.0.) GO TO 120
         TWALL=SUM/SAVE
         IF(IDAT(IJBOIL+I).NE.0) GO TO 112
         IF(TWALL.GE.TF.AND.NCHF.NE.4) IDAT(IJBOIL+I)=J
         IF(DATA(IH+I+MC*(J-1)).GE.HF.AND.NCHF.EQ.4) IDAT(IJBOIL+I)=J
 110     CONTINUE
 112     IF(TWALL.LT.TF) CALL CURVE(DATA(IVISCW+I),TWALL,UUF,TT,NPROP,
     1   IERROR,1)
         IF(IERROR.GT.1) GO TO 1000
 120     L=IDAT(INTYPE+I)
         DATA(IFSP+I)=AA(L)*RE**BB(L)+CC(L)
         DATA(IVISCW+I)=DATA(IVISCW+I)/3600.
         IF(NVISCW.EQ.1)
     1   DATA(IFSP+I)=DATA(IFSP+I)*(1.+DATA(IHPERI+I)/DATA(IPERIM+I)*
     2   ((DATA(IVISCW+I)/DATA(IVISC+I))**0.6-1.0))
 150     CONTINUE
      RETURN
 200  WRITE(I3,6) PREF,PP
      GO TO 1001
 210  WRITE(I3,5) PREF,PP
      GO TO 1001
1000  WRITE(I3,7)
1001  IERROR = 11
      RETURN
C
C-----------------------------------------------------------------------
  1   FORMAT('  PROP.  REYNOLDS NO. IN CHAN ', I3, ' J = ', I3,
     1 ' IS TOO LOW. RE = ', 1PE10.3, 5X, 'F, VISC = ', 2E15.4)
  5   FORMAT(60H FAILURE OF SUBROUTINE PROP, PRESSURE TOO LOW FOR TABLE
     1P =    E12.5 /(10E10.4))
  6   FORMAT(61H FAILURE OF SUBROUTINE PROP, PRESSURE TOO HIGH FOR TABLE
     1 P =    E12.5 /(10E10.4))
  7   FORMAT(40H TABLE LOOKUP FAILED IN SUBROUTINE PROP   )
C-----------------------------------------------------------------------
```

```
      END
```

```
C*********************** SUBROUTINE QPR3 ******************************
      SUBROUTINE QPR3(TEXT)
C
      IMPLICIT INTEGER (I)
      DIMENSION  JB(10),TEXT(17)
      INTEGER IDAT(1)
      LOGICAL LDAT(1), GRID
      REAL KIJ, KF, KKF, KCLAD, KFUEL
C
      COMMON  DATA(1)
      EQUIVALENCE  (DATA(1),IDAT(1),LDAT(1))
C
      COMMON /COBRA1/  ABETA ,AFLUX ,ATOTAL,BBETA ,DIA   ,DT    ,DX    ,
     1   ELEV  ,FERROR,FLO   ,FTM   ,GC    ,GK    ,GRID  ,HSURF ,HF    ,
     2   HFG   ,HG    ,I2    ,I3    ,IERROR,IQP3  ,ITERAT,J1    ,J2    ,
     3   J3    ,J4    ,J5    ,J6    ,J7    ,KDEBUG,KF    ,KIJ   ,
     4   NAFACT,NARAMP,NAX   ,NAXL  ,NBBC  ,NCHAN ,NCHF  ,NDX   ,NF    ,
     5   NGAPS ,NGRID ,NGRIDT,NGTYPE,NGXL  ,NK    ,NODES ,NODESF,NPROP ,
     6   NRAMP ,NROD  ,NSCBC ,NV    ,NVISCW,PI    ,PITCH ,POWER ,PREF  ,
     7   QAX   ,RHOF  ,RHOG  ,SIGMA ,SL    ,TF    ,TFLUID,THETA ,THICK ,
     8   UF    ,VF    ,VFG   ,VG    ,Z
C
      COMMON /COBRA2/  AA(4), AF(7), AFACT(10,10), AV(7), AXIAL(30),
     1   AXL(10), BB(4), BX(30), CC(4), CCLAD(2), CFUEL(2), DFUEL(2),
     2   GAPXL(10), GFACT(9,10), GRIDXL(10), HGAP(2), HHF(30), HHG(30),
     3   IGRID(10), KCLAD(2), KFUEL(2), KKF(30), NCH(10), NGAP(9),
     4   PP(30), RCLAD(2),RFUEL(2),SSIGMA(30), TCLAD(2), UUF(30),
     5   VVF(30), VVG(30), XQUAL(30), Y(30), TT(30)
C
      COMMON /COBRA3/  MA    ,MC    ,MG    ,MN    ,MR    ,MS    ,MX    ,
     1          III   ,IA    ,IAAA  ,IAC   ,IALPHA,IAN   ,IANSWE,IB    ,
     1   ICCHAN,ICD   ,ICHFR ,ICON  ,ICOND ,ICP   ,ID    ,IDC   ,IDFDX ,
     2   IDHDX ,IDHYD ,IDHYDN,IDIST ,IDPDX ,IDPK  ,IDUR  ,IDR   ,IF    ,
     3   IFACTO,IFDIV ,IFINLE,IFLUX ,IFMULT,IFOLD ,IFSP  ,IFSPLI,IFXFLO,
     4   IGAP  ,IGAPN ,IGAPS ,IH    ,IHFILM,IHINLE,IHOLD ,IHPERI,IIDARE,
     5   IIDFUE,IIDGAP,IIK   ,IJBOIL,IJK   ,ILC   ,ILENGT,ILOCA ,ILR   ,
     6   IMCHFR,IMCFRC,IMCFRR,INTYPE,INWRAP,INWRPS,IP    ,IPERIM,IPH   ,
     7   IPHI  ,IPRNTC,IPRNTR,IPRNTN,IPW   ,IPWRF ,IQC   ,IQF   ,IQPRIM,
     8   IQUAL ,IRADIA,IRHO  ,IRHOOL,ISP   ,IT    ,ITDUMY,ITINLE,ITROD ,
     9   IU    ,IUH   ,IUSAVE,IUSTAR,IV    ,IVISC ,IVISCW,IVP   ,IVPA  ,
     A   IW    ,IWOLD ,IWP   ,IWSAVE,IX    ,IXCROS,IIA  ,IIB  ,IXPOLD
C
      COMMON/LINK3/DXX,ETIME,GIN,HIN,I8,IG,IN,ISAVE,JUMP,KASE,KT,MAXT,
     1 NDT,NDXP1,NFUELT,NG,NH,NJUMP,NOUT,NP,NPCHAN,NPNODE,NPROD,NQ,NR,
     2 NSKIPT,NSKIPX,NTRIES,PEXIT,PHTOT,SAVEDT,TIN,TTIME,ZZ
C-----------------------------------------------------------------------
C
      READ (I2,700) ZM
      WRITE (I3,1000) ZM
      IF (ZM.GE.0.0) GO TO 505
      IF (ZM.LT.-1.01) GO TO 500
      ZM = 3413.0/3.6
```

```
      GO TO 505
  500 ZM = 1000.0/3.6
  505 WRITE (I3,1001) ZM
      NDXP1=NDX+1
         DO 601 I=1,NCHAN
  601    READ(I2,700)  (DATA(IQF+I+MC*(J-1)),J=2,NDXP1)
      IF(IQP3.EQ.0) GO TO 705
         DO 602 I=1,NCHAN
  602    READ(I2,700)  (DATA(IQC+I+MC*(J-1)),J=2,NDXP1)
  705 CONTINUE
C
C     PRINT INPUT FUEL NODAL POWERS
      WRITE(I3,650)
         DO 621 I=1,NCHAN ,10
            DO 5 K=1,10
    5       JB(K)=I+K-1
         II=I+9
         IF(NCHAN .LE.II) II=NCHAN
         L=II-I+1
         WRITE(I3,655) (JB(K),K=1,L)
            DO 621 J=1,NDX
            WRITE(I3,30) J    ,(DATA(IQF+K+MC*(J  )),K=I,II)
  621       CONTINUE
C
C     MULTIPLY FUEL POWERS BY ZM
      SUMF = 0.0
         DO 630 I=1,NCHAN
         DATA(IRADIA+I) = 0.0
            DO 630 J=2,NDXP1
            DATA(IQF+I+MC*(J-1))=DATA(IQF+I+MC*(J-1))*ZM
            DATA(IRADIA+I) = DATA(IRADIA+I) + DATA(IQF+I+MC*(J-1))
  630       SUMF = SUMF + DATA(IQF+I+MC*(J-1))
      SUMC = 0.0
      IF(IQP3.EQ.0) GO TO 645
C
C     PRINT INPUT COOLANT NODAL POWERS
      WRITE(I3,660)
         DO 622 I=1,NCHAN ,10
            DO 6 K=1,10
    6       JB(K)=I+K-1
         II=I+9
         IF(NCHAN .LE.II) II=NCHAN
         L=II-I+1
         WRITE(I3,655) (JB(K),K=1,L)
            DO 622 J=1,NDX
            WRITE(I3,30) J    ,(DATA(IQC+K+MC*(J  )),K=I,II)
  622       CONTINUE
C
C     MULTIPLY COOLANT POWERS BY ZM
         DO 640 I=1,NCHAN
            DO 640 J=2,NDXP1
            DATA(IQC+I+MC*(J-1))=DATA(IQC+I+MC*(J-1))*ZM
```

```
            DATA(IRADIA+I) = DATA(IRADIA+I) + DATA(IQC+I+MC*(J-1))
 640        SUMC = SUMC + DATA(IQC+I+MC*(J-1))
C
C     PRINT FUEL AND COOLANT SUMMED POWERS.
 645  SUMT = SUMF+SUMC
      WV = FLOAT(NCHAN )/SUMT
         DO 647 I=1,NCHAN
 647     DATA(IRADIA+I) = DATA(IRADIA+I)*WV
      WRITE (I3,1004) (DATA(IRADIA+I),I=1,NCHAN )
      WV = 3.6/3413.0
      SUMF1 = WV*SUMF
      SUMC1 = WV*SUMC
      SUMT1 = WV*SUMT
      SUMF = 0.001*SUMF
      SUMC = 0.001*SUMC
      SUMT = 0.001*SUMT
      WRITE (I3,1002) SUMF1,SUMF, SUMC1,SUMC, SUMT1,SUMT
      AFLUX = SUMT1*3.413/(PHTOT*Z)
      WRITE(I3,1003) AFLUX
      RETURN
C
C-----------------------------------------------------------------------
 30   FORMAT(I5, 2X, 10F10.5)
 650  FORMAT( //,'  HEAT GENERATION IN    FUEL')
 655  FORMAT(//, '  NODE  ROD', I4, I9, 8I10, /)
 660  FORMAT( //,'  HEAT GENERATION IN COOLANT')
 700  FORMAT(8E10.0)
1000  FORMAT(1H1,    ' READ NODAL POWERS IN SUBROUTINE QPR3 AND MULTIPLY
     1 GIVEN VALUES BELOW BY ZM', //, '  ZM GIVEN AS', F10.4, 7X,
     2 '(.GE.0.0  USED AS MULTIPLIER TO CONVERT TO BTU/SEC)', /, 30X,
     3 '(.EQ.-1.0 TO CONVERT MW TO BTU/SEC)', /, 30X,
     4 '(.EQ.-2.0 TO CONVERT MBTU/HR TO BTU/SEC)' )
1001  FORMAT(/, '  ZM TAKEN TO BE ', F11.5)
1002  FORMAT(/, '  POWER IN FUEL    = ',  F9.2, ' MW  IE ', F9.2,
     1 ' KBTU/SEC', /, 8X, 'IN COOLANT = ', F9.2 , ' MW  IE ', F9.2,
     2 ' KBTU/SEC', /, 8X, 'TOTAL      = ', F9.2,  ' MW  IE ', F9.2,
     3 ' KBTU/SEC')
1003  FORMAT(/, '  AVERAGE HEAT FLUX = ', F10.4, ' MBTU/SQFT.HR')
1004  FORMAT(//, '  RADIAL POWER FACTORS FOR EACH CHANNEL', /,
     1 (6X, 10F10.4, 22X) )
C-----------------------------------------------------------------------
      END
```

```
C*********************** SUBROUTINE READIN ********************************
      SUBROUTINE READIN(IVAR,N,A,B,CARD,M)
C
C     READ AND PRINT CARD IMAGES.
C     IVAR IDENTIFIES A, B AND THUS PRINTING
C     IF M=1, READ (A(I),I=1,N). BY FORMAT 16E5.0
C     IF M=2, READ (A(I),B(I),I=1,N) BY FORMAT 16E5.0
C-----------------------------------------------------------------------
      DIMENSION A(1),B(1),CARD(20)
C-----------------------------------------------------------------------
C
      IDI = 14/M
      IVMAX = 9
         DO 20 I=1,N,IDI
         II = I + IDI-1
         IF (II.GT.N) II=N
         IF (M.EQ.1) READ (5,1000) CARD, (A(L),L=I,II)
         IF (M.EQ.2) READ (5,1000) CARD, (A(L),B(L),L=I,II)
         IF (I.GT.1) GO TO 11
         IF ( (IVAR.LT.1) .OR. (IVAR.GT.IVMAX) ) GO TO 30
         GO TO (1,2,3,4,5,6,7,8,9), IVAR
  1      WRITE (6,1001) CARD
         GO TO 20
  2      WRITE (6,1002) CARD
         GO TO 20
  3      WRITE (6,1003) CARD
         GO TO 20
  4      WRITE (6,1004) CARD
         GO TO 20
  5      WRITE (6,1005) CARD
         GO TO 20
  6      WRITE (6,1006) CARD
         GO TO 20
  7      WRITE (6,1007) CARD
         GO TO 20
  8      WRITE (6,1008) CARD
         GO TO 20
  9      WRITE (6,1009) CARD
         GO TO 20
 11      WRITE (6,1011) CARD
 20      CONTINUE
      RETURN
 30   WRITE (6,1030) IVAR,IVMAX,CARD
      RETURN
C
C-----------------------------------------------------------------------
1000  FORMAT(20A4, T1, 14E5.0)
1001  FORMAT('  INLET FLOW SPLIT', 12X, '***',20A4,'*** READIN (MODEL)')
1002  FORMAT('  INLET ENTHALPIES', 12X,'***',20A4, '*** READIN (OPERA)')
1003  FORMAT('  INLET TEMPERATURES',10X,'***',20A4,'*** READIN (OPERA)')
1004  FORMAT('  PRESSURE TRANSIENT', 10X, '***', 20A4, '*** READIN (OPER
     1A)')
```

```
1005  FORMAT('  INLET ENTHALPY TRANSIENT',4X, '***', 20A4, '*** READIN (
     1OPERA)')
1006  FORMAT('  INLET FLOW TRANSIENT', 8X, '***', 20A4, '*** READIN (OPE
     1RA)')
1007  FORMAT('  INLET POWER TRANSIENT', 7X, '***', 20A4, '*** READIN (OP
     1ERA)')
1008  FORMAT('  AXIAL HEAT FLUX',13X '***', 20A4, '*** READIN(CARD20)')
1009  FORMAT('  RADIAL POWERS', 15X, '***', 20A4, '*** READIN(CARD20)')
1011  FORMAT(30X, '***', 20A4, '*** CONTINUED')
1030  FORMAT('  IVAR = ', I3, ' NOT 0 - ', I3, 6X, '***', 20A4, '*** REA
     1DIN')
C-----------------------------------------------------------------------
      END
```

```
C********************** SUBROUTINE RPROP ********************************
      SUBROUTINE RPROP(TRN,NCF,NGP,NDM1,HGAP,IPROP)
C
C     GET MATERIAL AND GAP PROPERTIES FOR ROD CONDUCTION CALCULATION
C-----------------------------------------------------------------------
      DIMENSION TRN(NCF)
      COMMON /MCOND/ CND(22),RCP(22),RAD(22),RRDR(22),
     1  VM(22),VP(22),QPPP(22)
      COMMON/FRDATA/BURN,CPR,EFFB,EPSF,EXPR,FPRESS,FPUO2,FRAC,FTD,
     1  GMIX(4),GRGH,PGAS,RADR,RDELT,THC,THG
C-----------------------------------------------------------------------
C
C     COMPUTE FUEL PROPERTIES
         DO 100 K=1,NCF
         ATEMP=0.5*(TRN(K+1)+TRN(K))
         CALL MPF(ATEMP,FTD,FPUO2,RCP(K),CND(K))
  100    CONTINUE
C
C     COMPUTE CLAD PROPERTIES
      KSTART=NGP+1
         DO 200 K=KSTART,NDM1
         ATEMP=0.5*(TRN(K+1)+TRN(K))
         CALL MPC(ATEMP,RCP(K),CND(K))
  200    CONTINUE
C
C     CALCULATE GAP HEAT TRANSFER COEFFICIENT
C
      IF(IPROP.LT.2) GO TO 300
      TGAP=(TRN(NGP)+TRN(NGP+1))*0.5
      CALL MPG(.FALSE.,BURN,EFFB,FRAC,FPRESS,CPR,EXPR,GRGH,THG,
     1 RAD(NGP),PGAS,TGAP,GMIX,TRN(NGP),TRN(NGP+1),HGAP)
  300 CONTINUE
      CND(NGP)=HGAP
      RCP(NGP)=0.0
  305 RETURN
      END
```

```
C********************** SUBROUTINE RTEMPF *******************************
      SUBROUTINE RTEMPF (TR,RDT,RADR,HSURF,TFLUID,NODES,NDM1)
C
C     GAUSSIAN SOLUTION OF TRIDIAGONAL TEMPERATURE PROBLEM IN FUEL ROD
C-----------------------------------------------------------------------
      DIMENSION A1(23),A2(22),A3(22),B(22),TR(NODES)
      COMMON /MCOND/ CND(22),RCP(22),RAD(22),RRDR(22),
     1  VM(22),VP(22),QPPP(22)
C-----------------------------------------------------------------------
C
      FSS=1.
      FTR=1.-FSS
      RDELT=RDT
C
C     SET UP COEFFICIENTS OF TRIDIAGONAL MATRIX
      A1(1)=0.0
      A2(1)=RRDR(1)*CND(1)+RDELT*VP(1)*RCP(1)
      B(1)=VP(1)*QPPP(1)+RDELT*VP(1)*RCP(1)*TR(1)
         DO 100 K=2,NDM1
         A1(K)=-RRDR(K-1)*CND(K-1)
         A2(K)=-A1(K)+RRDR(K)*CND(K)+RDELT*(VP(K)*RCP(K)+VM(K)*RCP(K-1))
         B(K)=VP(K)*QPPP(K)+VM(K)*QPPP(K-1)+RDELT*(VP(K)*RCP(K)+VM(K)*
     1   RCP(K-1))*TR(K)
 100     CONTINUE
      A1(NODES)=-RRDR(NDM1)*CND(NDM1)
      A2(NODES) = -A1(NODES) + RDELT*VM(NODES)*RCP(NDM1) +
     1  RADR*FSS*HSURF
      B(NODES) = VM(NODES)*QPPP(NDM1) +
     1  RDELT*VM(NODES)*RCP(NDM1)*TR(NODES) +
     2  RADR*HSURF*(TFLUID-FTR*TR(NODES))
      A1(NODES+1)=0.0
C
C     FORWARD ELIMINATION
      A2(1)=1./A2(1)
      A3(1)=A1(2)*A2(1)
      B(1)=B(1)*A2(1)
         DO 200 K=2,NODES
         A2(K)=1./(A2(K)-A1(K)*A3(K-1))
         A3(K)=A1(K+1)*A2(K)
         B(K)=(B(K)-A1(K)*B(K-1))*A2(K)
 200     CONTINUE
C
C     BACKWARD SUBSTITUTION
      TR(NODES)=B(NODES)
         DO 250 K=1,NDM1
         KK = NODES-K
 250     TR(KK)=B(KK)-TR(KK+1)*A3(KK)
      RETURN
      END
```

```
C********************** SUBROUTINE SCHEME ******************************
      SUBROUTINE SCHEME(JUMP,AAA)
C
C     THIS SUBROUTINE SETS UP AND PERFORMS THE SOLUTION OF THE FINITE
C     DIFFERENCE SCHEME AT EACH SPATIAL LOCATION X AT A SELECTED TIME T.
C-----------------------------------------------------------------------
      IMPLICIT INTEGER (I)
      DIMENSION AAA(1)
      LOGICAL  GRID, LDAT(1)
      REAL KIJ, KF, KKF, KCLAD, KFUEL
      INTEGER IDAT(1)
C
      COMMON  DATA(1)
      EQUIVALENCE (DATA(1),IDAT(1),LDAT(1))
C
      COMMON /COBRA1/  ABETA ,AFLUX ,ATOTAL,BBETA ,DIA   ,DT    ,DX    ,
     1   ELEV  ,FERROR,FLO   ,FTM   ,GC    ,GK    ,GRID  ,HSURF ,HF    ,
     2   HFG   ,HG    ,I2    ,I3    ,IERROR,IQP3  ,ITERAT,J1    ,J2    ,
     3   J3    ,J4    ,J5    ,J6    ,J7    ,KDEBUG,KF    ,KIJ   ,
     4   NAFACT,NARAMP,NAX   ,NAXL  ,NBBC  ,NCHAN ,NCHF  ,NDX   ,NF    ,
     5   NGAPS ,NGRID ,NGRIDT,NGTYPE,NGXL  ,NK    ,NODES ,NODESF,NPROP ,
     6   NRAMP ,NROD  ,NSCBC ,NV    ,NVISCW,PI    ,PITCH ,POWER ,PREF  ,
     7   QAX   ,RHOF  ,RHOG  ,SIGMA ,SL    ,TF    ,TFLUID,THETA ,THICK ,
     8   UF    ,VF    ,VFG   ,VG    ,Z
C
      COMMON /COBRA2/  AA(4), AF(7), AFACT(10,10), AV(7), AXIAL(30),
     1   AXL(10), BB(4), BX(30), CC(4), CCLAD(2), CFUEL(2), DFUEL(2),
     2   GAPXL(10), GFACT(9,10), GRIDXL(10), HGAP(2), HHF(30), HHG(30),
     3   IGRID(10), KCLAD(2), KFUEL(2), KKF(30), NCH(10), NGAP(9),
     4   PP(30), RCLAD(2),RFUEL(2),SSIGMA(30), TCLAD(2), UUF(30),
     5   VVF(30), VVG(30), XQUAL(30), Y(30), TT(30)
C
      COMMON /COBRA3/  MA    ,MC    ,MG    ,MN    ,MR    ,MS    ,MX    ,
     1          III    ,IA    ,IAAA  ,IAC   ,IALPHA,IAN   ,IANSWE,IB    ,
     1   ICCHAN,ICD   ,ICHFR ,ICON  ,ICOND ,ICP   ,ID    ,IDC   ,IDFDX ,
     2   IDHDX ,IDHYD ,IDHYDN,IDIST ,IDPDX ,IDPK  ,IDUR  ,IDR   ,IF    ,
     3   IFACTO,IFDIV ,IFINLE,IFLUX ,IFMULT,IFOLD ,IFSP  ,IFSPLI,IFXFLO,
     4   IGAP  ,IGAPN ,IGAPS ,IH    ,IHFILM,IHINLE,IHOLD ,IHPERI,IIDARE,
     5   IIDFUE,IIDGAP,IIK   ,IJBOIL,IJK   ,ILC   ,ILENGT,ILOCA ,ILR   ,
     6   IMCHFR,IMCFRC,IMCFRR,INTYPE,INWRAP,INWRPS,IP    ,IPERIM,IPH   ,
     7   IPHI  ,IPRNTC,IPRNTR,IPRNTN,IPW   ,IPWRF ,IQC   ,IQF   ,IQPRIM,
     8   IQUAL ,IRADIA,IRHO  ,IRHOOL,ISP   ,IT    ,ITDUMY,ITINLE,ITROD ,
     9   IU    ,IUH   ,IUSAVE,IUSTAR,IV    ,IVISC ,IVISCW,IVP   ,IVPA  ,
     A   IW    ,IWOLD ,IWP   ,IWSAVE,IX    ,IXCROS,IIA   ,IIB   ,IXPOLD
C-----------------------------------------------------------------------
C
C     IPILE = 0,1,2 FOR STANDARD COBRA, PWR, BWR
      IPILE = J7
      FMIN = .0001
      NDXP1 = NDX+1
      IF(JUMP.EQ.3) GO TO 400
      JUMP = 2
```

```
C
C     BEGIN STEPPING THROUGH CHANNEL
 400     DO 450 J=1,NDXP1
         JP1 = J+1
         JM1 = J-1
         IF(J.GT.1) GO TO 405
C        SET CONDITIONS AT START OF CHANNEL
            DO 401 I=1,NCHAN
 401        DATA(IQPRIM+I)=0.
         CALL FORCE(1)
         IF(IERROR.GT.1) GO TO 440
         CALL AREA(1)
         IF(IERROR.GT.1) GO TO 440
         CALL PROP(2,1)
         IF(IERROR.GT.1) GO TO 440
         CALL VOID(1)
         IF(IERROR.GT.1) GO TO 440
         GO TO 428
  405    IF(JUMP.EQ.3) GO TO 420
         IF(NGRID.LT.1) GO TO 410
         GRID = .FALSE.
            DO 408 I=1,NGRID
            ZG = GRIDXL(I)*Z
            IF(ZG.GT.DATA(IX+JM1).AND.ZG.LE.DATA(IX+J))GO TO 409
 408        CONTINUE
         GO TO 410
 409     NGTYPE = IGRID(I)
         GRID = .TRUE.
C        CALCULATE PARAMETERS TO BE SAVED FROM PREVIOUS SPACE
 410        DO 411 I=1,NCHAN
            DATA(IVPA+I)=DATA(IVP+I)/DATA(IA+I)
 411        CONTINUE
 420     CALL HEAT(J)
         IF(IERROR.GT.1) GO TO 440
         IF (IPILE.EQ.2) GO TO 423
         CALL MIX(JM1)
         IF(IERROR.GT.1) GO TO 440
 423     CALL DIFFER(1,JM1)
         IF(IERROR.GT.1) GO TO 440
C
C        CALCULATE ENTHALPY AND ESTIMATE FLOW AT X.
            DO 425 I=1,NCHAN
            IF(ITERAT.EQ.1.AND.JUMP.NE.3.OR.IPILE.EQ.2)
      1     DATA(IF+I+MC*(J-1)) = DATA(IF+I+MC*(JM1-1))
            DATA(IH+I+MC*(J-1))=(DATA(IH+I+MC*(JM1-1))+DX/DT/
      1     DATA(IUH+I)*DATA(IHOLD+I+MC*(J-1))+DX*DATA(IDHDX+I))/
      2     (1.0+DX/DT/ DATA(IUH+I))
 425        CONTINUE
         IF(JUMP.EQ.3) GO TO 450
         CALL FORCE(J)
         IF(IERROR.GT.1) GO TO 440
         CALL AREA(J)
```

```
      IF(IERROR.GT.1) GO TO 440
      CALL PROP(2,J)
      IF(IERROR.GT.1) GO TO 440
      CALL VOID(J)
      IF(IERROR.GT.1) GO TO 440
      CALL DIFFER(3,J)
      IF(IERROR.GT.1) GO TO 440
      IF (IPILE.NE.2) GO TO 4255
      CALL SEPRAT(1,J,JUMP)
      IF(IERROR.GT.1) GO TO 440
      GO TO 435
 4255    DO 426 K=1,NK
         DATA(IWSAVE+K)=DATA(IW+K+MG*(J-1))
 426     CONTINUE
C     CALCULATE THE DIVERSION CROSSFLOW AT X.
      CALL DIVERT(J)
      IF(IERROR.GT.1) GO TO 440
C     CALCULATE THE FLOW AT X AND CHECK FOR CONVERGENCE.
      CALL DIFFER(2,J)
      IF(IERROR.GT.1) GO TO 440
         DO 4270 I=1,NCHAN
         FSAVE=DATA(IF+I+MC*(J-1))
         RHODIF=DATA(IRHO+I+MC*(J-1))-DATA(IRHOOL+I+MC*(J-1))
         IF(DT.LT.0.001.AND.ABS(RHODIF).LT.0.001) RHODIF=0.0
         DATA(IF+I+MC*(J-1))=DATA(IF+I+MC*(JM1-1))+DX*DATA(IDFDX+I)
     1   -DX/DT*RHODIF*DATA(IA+I)
C        THE FOLLOWING STATEMENT PROVIDES DAMPING FOR MORE RAPID
C        CONVERGENCE, ESPECIALLY WHEN USING THE SUBCOOLED VOID OPTION
C        USERS MAY WISH TO TRY OTHER COMBINATIONS OF CONSTANTS.
         DATA(IF+I+MC*(J-1))=0.2*FSAVE+0.8*DATA(IF+I+MC*(J-1))
         IF(ABS(DATA(IF+I+MC*(J-1))-FSAVE)/FSAVE.GT.FERROR)  JUMP=1
         IF(DATA(IF+I+MC*(J-1)).LT.FMIN)  DATA(IF+I+MC*(J-1))=FMIN
 4270    CONTINUE
C     CALCULATE SP AT X-DX.
      CALL DIFFER(4,J)
      IF(IERROR.GT.1) GO TO 440
C  THE FACTOR DAMPING WAS ADDED AFTER PUBLICATION.  A VALUE OF ZERO WAS
C  USED FOR THE SAMPLE PROBLEMS.  A VALUE OF 0.5 HAS BEEN FOUND TO SPEED
C  CONVERGENCE FOR MANY PROBLEMS.  USERS MAY WISH TO TRY OTHER VALUES.
      DAMPNG = 0.5
         DO 430 K=1,NK
         II=IDAT(IIK+K)
         JJ=IDAT(IJK+K)
         DATA(ISP+K+MG*(JM1-1))=DAMPNG*DATA(ISP+K+MG*(JM1-1))+
     1   (1.-DAMPNG)*(DATA(ISP+K+MG*(J-1))-(DATA(IDPDX+II)-
     2   DATA(IDPDX+JJ))*DX)
 430     CONTINUE
 435     DO 427 I=1,NCHAN
 427     DATA(IP+I+MC*(J-1))=DATA(IP+I+MC*(JM1-1))+DX*DATA(IDPDX+I)
 428  CONTINUE
      IF(KDEBUG.LT.1) GO TO 450
      GO TO 445
```

```
 440        WRITE(I3,1) J,DATA(IX+J)
            GO TO 446
 445        WRITE(I3,2)J,DATA(IX+J)
 446        WRITE(I3,3)
            WRITE(I3,52)(I,DATA(IH+I+MC*(J-1)),DATA(IF+I+MC*(J-1)),
     1      DATA(IP+I+MC*(J-1)),DATA(IH+I+MC*(JM1-1)),
     2      DATA(IF+I+MC*(JM1-1)),DATA(IP+I+MC*(JM1-1)),I=1,NCHAN )
            WRITE(I3,4)
            WRITE(I3,52)(I,DATA(IQUAL+I),DATA(IALPHA+I),
     1      DATA(IRHO+I+MC*(J-1)),DATA(IVP+I),DATA(IV+I),DATA(IFMULT+I),
     2      I=1,NCHAN )
            WRITE(I3,5)
            WRITE(I3,52)(K,DATA(IW+K+MG*(JM1-1)),DATA(IW+K+MG*(J-1)),
     1      DATA(IWP+K),DATA(IUSTAR+K),DATA(ISP+K+MG*(JM1-1)),
     2      DATA(ISP+K+MG*(J  -1)),K=1,NK)
            WRITE(I3,6)
            WRITE(I3,52)(I,DATA(IDHDX+I),DATA(IUH+I),DATA(IDPDX+I),
     1      DATA(IQPRIM+I),DATA(IFOLD+I+MC*(J-1)),DATA(IRHOOL+I+MC*(J-1)),
     2      I=1,NCHAN )
            IF(IERROR.GT.1) RETURN
 450        CONTINUE
      IF(JUMP.EQ.3) RETURN
C     CORRECT SUBCHANNEL PRESSURES TO ZERO EXIT PRESSURE.
C     PRESSURE P(I,J) IS THE PRESSURE ABOVE THE EXIT REFERENCE PRESSURE.
         DO 460 I=1,NCHAN
         PEXIT=DATA(IP+I+MC*(NDXP1-1))
         DO 460 J=1,NDXP1
 460     DATA(IP+I+MC*(J-1))=DATA(IP+I+MC*(J-1)) - PEXIT
      IF (IPILE.NE.2) RETURN
      CALL SEPRAT(2,J,JUMP)
      RETURN
C
C----------------------------------------------------------------------
   1  FORMAT('1ERROR DETECTED IN SUBROUTINE SCHEME AT NODE',I3,
     1 '   X =',E10.5,' FEET'/' CALCULATION FOR THIS CASE STOPPED')
   2  FORMAT(' NODE',I3,'   X =',E10.5)
   3  FORMAT('     I     H(I,J)      F(I,J)       P(I,J)    H(I,J-1)    F
     1(I,J-1)    P(I,J-1)')
   4  FORMAT('     I    QUAL(I)    ALPHA(I)    RHO(I,J)      VP(I)
     1 V(I)    FMULT(I)')
   5  FORMAT('    K    W(K,J-1)      W(K,J)       WP(K)    USTAR(K)    SP
     1(K,J-1)     SP(K,J)')
   6  FORMAT('     I    DHDX(I)       UH(I)     DPDX(I)    QPRIM(I)    FO
     1LD(I,J) RHOOLD(I,J)')
  16  FORMAT(3I5,4E12.6)
  52  FORMAT( I5,6E12.6)
C----------------------------------------------------------------------
      END
```

```
C*********************** SUBROUTINE SEPRAT ******************************
      SUBROUTINE SEPRAT(IPART,J,JUMP)
C
C     FLOW ITERATION FOR SEPARATED CHANNELS (EG BWR)
C     CALLED FROM SCHEME
C     SP USED FOR (1) DM/DP (2) DM (3) DP
C------------------------------------------------------------------------
      IMPLICIT INTEGER (I)
      INTEGER IDAT(1)
      LOGICAL LDAT(1),GRID
      REAL KIJ, KF, KKF, KCLAD, KFUEL
C
      COMMON  DATA(1)
      EQUIVALENCE  (DATA(1),IDAT(1),LDAT(1))
C
      COMMON /COBRA1/  ABETA ,AFLUX ,ATOTAL,BBETA ,DIA   ,DT    ,DX    ,
     1   ELEV  ,FERROR,FLO   ,FTM   ,GC    ,GK    ,GRID  ,HSURF ,HF    ,
     2   HFG   ,HG    ,I2    ,I3    ,IERROR,IQP3  ,ITERAT,J1    ,J2    ,
     3   J3    ,J4    ,J5    ,J6    ,J7    ,KDEBUG,KF    ,KIJ   ,
     4   NAFACT,NARAMP,NAX   ,NAXL  ,NBBC  ,NCHAN ,NCHF  ,NDX   ,NF    ,
     5   NGAPS ,NGRID ,NGRIDT,NGTYPE,NGXL  ,NK    ,NODES ,NODESF,NPROP ,
     6   NRAMP ,NROD  ,NSCBC ,NV    ,NVISCW,PI    ,PITCH ,POWER ,PREF  ,
     7   QAX   ,RHOF  ,RHOG  ,SIGMA ,SL    ,TF    ,TFLUID,THETA ,THICK ,
     8   UF    ,VF    ,VFG   ,VG    ,Z
C
      COMMON /COBRA2/  AA(4), AF(7), AFACT(10,10), AV(7), AXIAL(30),
     1   AXL(10), BB(4), BX(30), CC(4), CCLAD(2), CFUEL(2), DFUEL(2),
     2   GAPXL(10), GFACT(9,10), GRIDXL(10), HGAP(2), HHF(30), HHG(30),
     3   IGRID(10), KCLAD(2), KFUEL(2), KKF(30), NCH(10), NGAP(9),
     4   PP(30), RCLAD(2),RFUEL(2),SSIGMA(30), TCLAD(2), UUF(30),
     5   VVF(30), VVG(30), XQUAL(30), Y(30), TT(30)
C
      COMMON /COBRA3/  MA    ,MC    ,MG    ,MN    ,MR    ,MS    ,MX    ,
     1          III   ,IA    ,IAAA  ,IAC   ,IALPHA,IAN   ,IANSWE,IB    ,
     1   ICCHAN,ICD   ,ICHFR ,ICON  ,ICOND ,ICP   ,ID    ,IDC   ,IDFDX ,
     2   IDHDX ,IDHYD ,IDHYDN,IDIST ,IDPDX ,IDPK  ,IDUR  ,IDR   ,IF    ,
     3   IFACTO,IFDIV ,IFINLE,IFLUX ,IFMULT,IFOLD ,IFSP  ,IFSPLI,IFXFLO,
     4   IGAP  ,IGAPN ,IGAPS ,IH    ,IHFILM,IHINLE,IHOLD ,IHPERI,IIDARE,
     5   IIDFUE,IIDGAP,IIK   ,IJBOIL,IJK   ,ILC   ,ILENGT,ILOCA ,ILR   ,
     6   IMCHFR,IMCFRC,IMCFRR,INTYPE,INWRAP,INWRPS,IP    ,IPERIM,IPH   ,
     7   IPHI  ,IPRNTC,IPRNTR,IPRNTN,IPW   ,IPWRF ,IQC   ,IQF   ,IQPRIM,
     8   IQUAL ,IRADIA,IRHO  ,IRHOOL,ISP   ,IT    ,ITDUMY,ITINLE,ITROD ,
     9   IU    ,IUH   ,IUSAVE,IUSTAR,IV    ,IVISC ,IVISCW,IVP   ,IVPA  ,
     A   IW    ,IWOLD ,IWP   ,IWSAVE,IX    ,IXCROS,IIA   ,IIB  ,IXPOLD
C
      COMMON /REFP/ PO
C------------------------------------------------------------------------
C
      IF (IPART.EQ.2) GO TO 10
C     DO 2 I=1,NCHAN
C     DATA(IDFDX+I)=0.0
C  2  DATA(IF+I+MC*(J-1))=DATA(IF+I+MC*(J-2))-DX/DT*(DATA(IRHO+I+MC*(J-1
```

```
C     1    ))-DATA(IRHOOL+I+MC*(J-1)))*DATA(IA+I)
C      CALL DIFFER(3,J)
       RETURN
C
 10    PMIN=100000.0
       PMAX=-1000.0
          DO 12 I=1,NCHAN
          WV=DATA(IP+I)
          IF (WV.LT.PMIN) PMIN=WV
          IF (WV.GT.PMAX) PMAX=WV
 12       CONTINUE
       IF(ABS(1.-PMIN/PMAX).LT.FERROR)  RETURN
       JUMP=1
       IF(ITERAT.GT.1) GO TO 16
       FTOT=0.0
          DO 14 I=1,NCHAN
          FTOT=FTOT+DATA(IF+I)
          IF (DATA(ISP+I).GT.0.0) GO TO 14
          DATA(ISP+I)=0.7*DATA(IF+I)/(DATA(IP+I)-DATA(IRHO+I+MC*NDX)*
      1   ELEV*Z)
 14       CONTINUE
       GO TO 20
 16       DO 18 I=1,NCHAN
          DELTAP=    (DATA(IP+I) -DATA(ISP+I+2*MC))
          IF( ABS(DELTAP).LT..001)  GO TO 18
          DATA(ISP+I)=( DATA(IF+I)-DATA(ISP+I+MC))/DELTAP
 18       CONTINUE
 20    SUM1=0.0
       SUM13=0.0
          DO 22 I=1,NCHAN
          SUM1=SUM1+DATA(ISP+I)
          SUM13=SUM13+DATA(ISP+I)*DATA(IP+I)
          DATA(ISP+I+MC)=DATA(IF+I)
 22       DATA(ISP+I+MC*2)=DATA(IP+I)
       P113=SUM13/SUM1
       IF (ITERAT.EQ.1.AND.DT.GT.1000.) GO TO 23
       IF(P113.LE.0..OR.P113.GT.2*PO) P113=PO
 23    PO=P113
       IF(PO.LT.0.) PO=ABS(PO)
       SUMF=0.0
          DO 24 I=1,NCHAN
          DATA(IF+I)=DATA(IF+I)+DATA(ISP+I)*(PO-DATA(IP+I))
 24       SUMF=SUMF+DATA(IF+I)
          DO 26 I=1,NCHAN
 26       DATA(IF+I)=DATA(IF+I)*FTOT/SUMF
       RETURN
       END
```

```
C*********************** SUBROUTINE SOLVE ********************************
      SUBROUTINE SOLVE(NN,LMAX,MID,UL,X,B,NK)
C
C     STORE DIAGONAL BAND OF AAA MATRIX.  POSITION (K,L) IN SQUARE
C     ARRAY BECOMES (K,(MID-K+L) ) IN NEW ARRAY.
C-------------------------------------------------------------------------
      DIMENSION UL(NK,LMAX),X(NN),B(NN)
C-------------------------------------------------------------------------
C
      IF(NN.EQ.1) GO TO 5
      NP1 = NN+1
      X(1) = B(1)
         DO 2 I = 2,NN
         IM1 = I-1
         SUM = 0.0
         JMIN = MAX0(1,(I-MID+1) )
C        DOUBLE PRECISION MAY BE REQUIRED FOR INNER LOOP.
            DO 1 J = JMIN,IM1
            JJ = MID-I+J
  1         SUM = SUM + UL(I,JJ)*X(J)
  2      X(I) = B(I) - SUM
C
      X(NN) = X(NN)/UL(NN,MID)
         DO 4 IBACK = 2,NN
         I = NP1-IBACK
C        I GOES (NN-1),...,1
         IP1 = I+1
         SUM = 0.0
C        DOUBLE PRECISION MAY BE REQUIRED FOR INNER LOOP.
         JMAX = MIN0(NN,(I+MID-1) )
            DO 3 J = IP1,JMAX
            JJ = MID-I+J
  3         SUM = SUM + UL(I,JJ)*X(J)
  4      X(I) = (X(I)-SUM)/UL(I,MID)
      RETURN
  5   X(1) = B(1)/UL(1,MID)
      RETURN
      END
```

```
C********************** SUBROUTINE SPLIT *******************************
      SUBROUTINE SPLIT
C
C     CORRECT FLOW ESTIMATE BY ITERATION. THIS PROCEDURE ASSUMES
C     THERE IS NO DENSITY CHANGE WITH LENGTH AND THAT NO DIVERSION
C     CROSSFLOW IS OCCURRING CONVERGENCE TOLERANCE IS E.
C-----------------------------------------------------------------------
      IMPLICIT INTEGER (I)
      INTEGER IDAT(1)
      LOGICAL LDAT(1),GRID
      REAL KIJ, KF, KKF, KCLAD, KFUEL
C
      COMMON  DATA(1)
      EQUIVALENCE  (DATA(1),IDAT(1),LDAT(1))
C
      COMMON /COBRA1/  ABETA ,AFLUX ,ATOTAL,BBETA ,DIA   ,DT    ,DX    ,
     1   ELEV  ,FERROR,FLO   ,FTM   ,GC    ,GK    ,GRID  ,HSURF ,HF    ,
     2   HFG   ,HG    ,I2    ,I3    ,IERROR,IQP3  ,ITERAT,J1    ,J2    ,
     3   J3    ,J4    ,J5    ,J6    ,J7    ,KDEBUG,KF    ,KIJ   ,
     4   NAFACT,NARAMP,NAX   ,NAXL  ,NBBC  ,NCHAN ,NCHF  ,NDX   ,NF    ,
     5   NGAPS ,NGRID ,NGRIDT,NGTYPE,NGXL  ,NK    ,NODES ,NODESF,NPROP ,
     6   NRAMP ,NROD  ,NSCBC ,NV    ,NVISCW,PI    ,PITCH ,POWER ,PREF  ,
     7   QAX   ,RHOF  ,RHOG  ,SIGMA ,SL    ,TF    ,TFLUID,THETA ,THICK ,
     8   UF    ,VF    ,VFG   ,VG    ,Z
C
      COMMON /COBRA2/  AA(4), AF(7), AFACT(10,10), AV(7), AXIAL(30),
     1   AXL(10), BB(4), BX(30), CC(4), CCLAD(2), CFUEL(2), DFUEL(2),
     2   GAPXL(10), GFACT(9,10), GRIDXL(10), HGAP(2), HHF(30), HHG(30),
     3   IGRID(10), KCLAD(2), KFUEL(2), KKF(30), NCH(10), NGAP(9),
     4   PP(30), RCLAD(2),RFUEL(2),SSIGMA(30), TCLAD(2), UUF(30),
     5   VVF(30), VVG(30), XQUAL(30), Y(30), TT(30)
C
      COMMON /COBRA3/  MA    ,MC    ,MG    ,MN    ,MR    ,MS    ,MX    ,
     1          III   ,IA    ,IAAA  ,IAC   ,IALPHA,IAN   ,IANSWE,IB    ,
     1   ICCHAN,ICD   ,ICHFR ,ICON  ,ICOND ,ICP   ,ID    ,IDC   ,IDFDX ,
     2   IDHDX ,IDHYD ,IDHYDN,IDIST ,IDPDX ,IDPK  ,IDUR  ,IDR   ,IF    ,
     3   IFACTO,IFDIV ,IFINLE,IFLUX ,IFMULT,IFOLD ,IFSP  ,IFSPLI,IFXFLO,
     4   IGAP  ,IGAPN ,IGAPS ,IH    ,IHFILM,IHINLE,IHOLD ,IHPERI,IIDARE,
     5   IIDFUE,IIDGAP,IIK   ,IJBOIL,IJK   ,ILC   ,ILENGT,ILOCA ,ILR   ,
     6   IMCHFR,IMCFRC,IMCFRR,INTYPE,INWRAP,INWRPS,IP    ,IPERIM,IPH   ,
     7   IPHI  ,IPRNTC,IPRNTR,IPRNTN,IPW   ,IPWRF ,IQC   ,IQF   ,IQPRIM,
     8   IQUAL ,IRADIA,IRHO  ,IRHOOL,ISP   ,IT    ,ITDUMY,ITINLE,ITROD ,
     9   IU    ,IUH   ,IUSAVE,IUSTAR,IV    ,IVISC ,IVISCW,IVP   ,IVPA  ,
     A   IW    ,IWOLD ,IWP   ,IWSAVE,IX    ,IXCROS,IIA  ,IIB  ,IXPOLD
C-----------------------------------------------------------------------
C
      E=0.005
      SAVEDT = DT
      DT = 1.E+10
         DO 10 I=1,NCHAN
         DATA(IF+I)=DATA(IFINLE+I)
 10      DATA(IH+I)=DATA(IHINLE+I)
```

```
         DO 100 K=1,200
         CALL PROP(2,1)
         IF(IERROR.GT.1) GO TO 1000
         CALL VOID(1)
            DO 15 I=1,NCHAN
 15         DATA(IVPA+I)=DATA(IVP+I)/DATA(IA+I)
         IF(IERROR.GT.1) GO TO 1000
         IF(FTM.GT.0.) CALL MIX(1)
         IF(IERROR.GT.1) GO TO 1000
         CALL DIFFER(3,1)
         IF(IERROR.GT.1) GO TO 1000
         DPAVG = 0.
            DO 20 I=1,NCHAN
 20         DPAVG=DPAVG+DATA(IDPDX+I)*DATA(IA+I)
         DPAVG = DPAVG/ATOTAL
         J=2
         FTOT = 0.
            DO 30 I=1,NCHAN
            DELTAF=(DPAVG-DATA(IDPDX+I))*0.5/DATA(IDPDX+I)*DATA(IF+I)
            IF(FTM.GT.0.) DELTAF = DELTAF*0.5
            FSAVE     =DATA(IF+I)
            DATA(IF+I)=DATA(IF+I)+DELTAF
            IF(DATA(IF+I).LT.0.)  GO TO 1000
            IF( ABS(DATA(IF+I)-FSAVE)/FSAVE .GT. E)  J=1
            FTOT=FTOT+DATA(IF+I)
  30        CONTINUE
            DO 40 I=1,NCHAN
            DATA(IF    +I)=DATA(IF+I)*FLO/FTOT
 40         DATA(IFINLE+I)=DATA(IF+I)
         IF(J.GT.1) GO TO 120
 100     CONTINUE
1000  WRITE(I3,1)  (I,DATA(IF+I),DATA(IDPDX+I),I=1,NCHAN)
      IERROR = 8
 120  DT = SAVEDT
      RETURN
C-----------------------------------------------------------------------
  1   FORMAT(40H FLOW SPLIT TO GIVE EQUAL DP/DX FAILED   /(I5,2E14.6))
C-----------------------------------------------------------------------
      END
```

```
C*********************** SUBROUTINE STATE *********************************
      SUBROUTINE STATE(P,TV,TL,ROV,ROL,EV,EL,TSAT,DTSDP,
     1   DELDP,DEVDP,DELDT,DEVDT,DRLDP,DRVDP,DRLDT,DRVDT,IOP,IERR)
C
C     SUBROUTINE STATE CALCULATES THE STATE DYNAMIC PROPERTIES OF
C     WATER. THE PRESENT VERSION USES FITS DUE TO BILL RIVARD OF
C     GROUP T-3 OF THE LASL THEORETICAL DIVISION.
C     TAKEN FROM TRAC AND RECODED TO IMPROVE EFFICIENCY.
C     SI UNITS ARE USED
C
C     INPUT VARIABLES
C       1. P    PRESSURE
C       2. TL   TEMPERATURE OF THE LIQUID
C       3. TV   TEMPERATURE OF THE VAPOR
C       4. IOP OPTION SELECTOR - NOT IN PRESENT VERSION
C
C     OUTPUT VARIABLES
C       1. EV      INTERNAL ENERGY OF THE VAPOR
C       2. EL      INTERNAL ENERGY OF THE LIQUID
C       3. TSAT    SATURATION TEMPERATURE
C       4. ROL     DENSITY OF THE LIQUID
C       5. ROV     DENSITY OF THE VAPOR
C       6. DTSDP   DERIVATIVE OF TSAT WRT PRESSURE
C       7. DELDP   DERIVATIVE OF TL WRT PRESSURE
C       8. DEVDP   DERIVATIVE OF TV WRT PRESSURE
C       9. DELDT   DERIVATIVE OF EL WRT TL
C      10. DEVDT   DERIVATIVE OF EV WRT TV
C      11. DRLDP   DERIVATIVE OF ROL WRT PRESSURE
C      12. DRVDP   DERIVATIVE OF ROV WRT PRESSURE
C      13. DRLDT   DERIVATIVE OF ROL WRT TL
C      14. DRVDT   DERIVATIVE OF ROV WRT TV
C      15. IERR    ERROR FLAG (INPUT VARIABLE OUT OF RANGE)
C
C     FOR THE CALCULATION OF SATURATED PROPERTIES
C       1. TSAT     SATURATION TEMPERATURE
C       2. DTSDP     DERIVATIVE OF TSAT WRT PRESSURE
C       3. ES       SATURATION INTERNAL ENERGY
C       4. DPES     DERIVATIVE OF ES WRT PRESSURE
C       5. GAMS     GAMMA SUB S
C       6. DPGAMS   DERIVATIVE OF GAMS WRT PRESSURE
C       7. CPS      C SUB PS
C       8. DPCPS    DERIVATIVE OF CPS WRT PRESSURE
C       9. GAMSM    GAMS-ONE
C
C     FOR THE CALCULATION OF SUPERHEATED VAPOR PROPERTIES
C         1. BETA A WORKING PARAMETER
C         2. CAPK A WORKING PARAMETER
C         3. DBETAP  DERIVATIVE OF BETA WRT PRESSURE
C         4. DCAPKP  DERIVATIVE OF CAPK WRT PRESSURE
C         5. DEVDT
C         6. DEVDP
C         7. ROV
```

```
C        8. DRVDE
C        9. DRVDP
C-----------------------------------------------------------------------
C
C     CONSTANTS USED IN FITS
C
C     FOR TSAT, CPS
      DATA TSC1,TSC2, TSEXP  /9.0395, 255.2, 0.223/
      DATA CPS1,CPS2, CPSEXP  /9.5875E2, .132334E-2, -0.8566/
C     CPS2 = -CPSEXP * TCRINV
C     FOR ES, GAMS  IF P < 20 BARS
      DATA G11,G12,G13  /2.6194106E6, -4.995E10, 3.403E5/
      DATA G14,G15,G16  /1.0665544E+0, 1.02E-8, -2.548E-15/
C     G11,G14 ARE ADJUSTED SO THAT ES RESP. GAMS JUMPS LESS THAN
C     1 PART IN 1.E-8 ACROSS P = 20 BARS.
      DATA G17 /-5.096E-15/
C     G17 = 2.* G16
C     FOR ES, GAMS  IF P > 20 BARS
      DATA G21,G22,G23  /2.5896E6, 6.350E-3, -1.0582E-9/
      DATA G24,G25,G26  /1.0764, 3.625E-10, -9.063E-17/
      DATA G27,G28  /-2.1164E-9, -18.126E-17/
C     G27 = 2.* G23,   G28 = 2.* G26
C
      DATA P20B /2.0E6/
      DATA TCRIT /647.3/
      DATA TCRINV /.154488E-2/
      DATA CC,CCI,CCM  /1.3, .76923, 0.3/
C
      DATA RL0,RL1,RL2  /1.E3, -2.E-5, -.15E-9/
      DATA RL22  /-.3E-9/
C     RL22 = 2.*RL2
      DATA CL2I  /0.657E-6/
C
C     FOR EL  IF TL < 300 DEG C
      DATA SL0,SL1,SL2,SL3  /-1.4655677E+06, 6.9269554E+03,
     A  -7.7423067E0, 7.2803006E-03/
C     SL0 IS CHOSEN SO THE JUMP IN EL AT 300 DEG C IS AS
C     SMALL AS POSSIBLE
      DATA SL22,SL33 /-15.484613E+0, 2.1840901E-2/
C     SL22 = 2.* SL2,   SL33 = 3.* SL3
C     FOR EL  IF TL > 300 DEG C
      DATA SH0,SH1,SH2,SH3  /-8.9, 2.3639439E+04,
     1  -7.7434017E+01, 7.0215574E-02/
      DATA SH22,SH33 /-1.5486803E2, 2.1064672E-1/
C     SH22 = 2.* SH2,   SH33 = 3.* SH3
C
C     FOR VAPOR
      DATA A11,A12,A13  /1.2959E-3, 593.59, 1.6847E-3/
C
      DATA  HALF,ZERO,ONE,TWO  /0.5, 0., 1., 2./
C-----------------------------------------------------------------------
C
```

```
C     CHECK THAT P, TL, TV, ARE WITHIN RANGE OF FITS
C
      IF (P.GE.1.0E+3.AND.P.LE.190.0E+5) GO TO 5
      IERR = 1
      RETURN
  5   IF (TL.GE.280.0.AND.TL.LE.647.0) GO TO 10
      IERR = 2
      RETURN
 10   IF(TV.GE.280.0) GO TO 20
      IERR = 3
      RETURN
 20   IERR = 0
C
C     CALCULATE SATURATION PROPERTIES
      TSAT = TSC1* P**TSEXP
      PINV = ONE/ P
      DTSDP = TSAT*TSEXP*PINV
      TSAT = TSAT + TSC2
C
      T1 = ONE - TSAT*TCRINV
      CPS = CPS1* T1**CPSEXP
      DPCPS = CPS2*CPS/T1 *DTSDP
C
      IF (P.GT.P20B) GO TO 150
      T2 = ONE/ (G13+P)
      T1 = T2*G12
      ES = G11 + T1
      DPES = -T1*T2
      GAMS = G14 + P*(G15 + P*G16)
      DPGAMS = G15+G17*P
      GO TO 200
 150  CONTINUE
      ES = G21+(G23*P+G22)*P
      DPES = G22+G27*P
      GAMS = G24+(G26*P+G25)*P
      DPGAMS = G25 + G28*P
 200  GAMSM = GAMS - ONE
C
C     CALCULATE LIQUID PROPERTIES
C
C     1. INTERNAL ENERGY AND ITS DERIVATIVES
C
      DELDP = 0.
      IF (TL.GE.573.15) GO TO 220
      EL = SL0 + TL*(SL1 + TL*(SL2 + TL*SL3))
      DELDT = SL1 + TL*(SL22 + TL*SL33)
      GO TO 240
 220  CONTINUE
      EL = SH0 + TL*(SH1 + TL*(SH2 + TL*SH3))
      DELDT = SH1 + TL*(SH22 + TL*SH33)
 240  CONTINUE
C
```

```
C        2. DENSITY AND ITS DERIVATIVES
C
      ROL = RL0 + EL*(RL1 + EL*RL2)  + P*CL2I
      DRLDP = CL2I
      DRLDE = RL1 + EL*RL22
      DRLDT = DRLDE*DELDT
C
C     CALCULATE VAPOR PROPERTIES
C
      DT = TV-TSAT
      IF (DT.LE.ZERO) GO TO 250
C
C     CALCULATE SUPERHEATED VAPOR PROPERTIES
      T1 = ONE/(A11*CPS-ONE)
      T1SQ = T1*T1
      BETA = TSAT*TSAT*(ONE - T1SQ)
      T2 = TSAT*T1
      DE = A12*(DT+SQRT(TV*TV-BETA)-T2)
      EV = ES + DE
      CAPK = A13*DE+TSAT+T2
      DBETAP = TWO*(BETA*DTSDP+T2*T2*T2*A11*DPCPS)/TSAT
      DCAPKP = -A13*DPES + (ONE + T1)*DTSDP
     1  -TSAT*A11*T1SQ*DPCPS
      T3 = ONE-BETA/(CAPK*CAPK)
      DEVDT = ONE/(HALF*T3*A13)
      DEVDP = -HALF*(T3*DCAPKP+DBETAP/CAPK)*DEVDT
      T4 = ONE/(GAMSM*ES+CCM*DE)
      ROV = P*T4
      DRVDE = -ROV*CCM*T4
      DRVDT = DRVDE*DEVDT
      DRVDP = ROV*(PINV-(ES*DPGAMS+(GAMSM-CCM)*DPES)*T4)
     1   + DRVDE*DEVDP
      GO TO 300
 250  CONTINUE
C
C     SUBCOOLED VAPOR
C
      DEVDT = CPS * CCI
      DE = DT * DEVDT
      EV = ES + DE
      T1 = ONE/ CPS
      DEVDP = -(DTSDP -CC*T1*(DPES +DE*DPCPS*T1) )*DEVDT
      T1 = ONE/ GAMSM
      T2 = ONE/ EV
      ROV = P *T1*T2
      DRVDE = -ROV *T2
      DRVDT = DRVDE * DEVDT
      DRVDP = ROV *(PINV - DPGAMS*T1) + DRVDE*DEVDP
C
 300  CONTINUE
      RETURN
      END
```

```
C********************** SUBROUTINE SURTEN ******************************
      SUBROUTINE SURTEN(P,RL,RG,ST)
C
      X=RL-RG
      X=0.000001*X**4
      ST=X*(4.60+1.84/EXP(0.685*X)+0.232*EXP(1.56*(X-15.0)))
      ST=ST*6.8525E-05
      RETURN
      END
```

```
C*********************** SUBROUTINE TABLES ******************************
      SUBROUTINE TABLES(CARD)
C
      IMPLICIT INTEGER (I)
      DIMENSION CARD(20)
      INTEGER IDAT(1)
      LOGICAL LDAT(1),GRID,PRINT
      REAL KIJ, KF, KKF, KCLAD, KFUEL
C
      COMMON  DATA(1)
      EQUIVALENCE  (DATA(1),IDAT(1),LDAT(1))
C
      COMMON /COBRA1/  ABETA ,AFLUX ,ATOTAL,BBETA ,DIA   ,DT    ,DX    ,
     1   ELEV  ,FERROR,FLO   ,FTM   ,GC    ,GK    ,GRID  ,HSURF ,HF    ,
     2   HFG   ,HG    ,I2    ,I3    ,IERROR,IQP3  ,ITERAT,J1    ,J2    ,
     3   J3    ,J4    ,J5    ,J6    ,J7    ,KDEBUG,KF    ,KIJ   ,
     4   NAFACT,NARAMP,NAX   ,NAXL  ,NBBC  ,NCHAN ,NCHF  ,NDX   ,NF    ,
     5   NGAPS ,NGRID ,NGRIDT,NGTYPE,NGXL  ,NK    ,NODES ,NODESF,NPROP ,
     6   NRAMP ,NROD  ,NSCBC ,NV    ,NVISCW,PI    ,PITCH ,POWER ,PREF  ,
     7   QAX   ,RHOF  ,RHOG  ,SIGMA ,SL    ,TF    ,TFLUID,THETA ,THICK ,
     8   UF    ,VF    ,VFG   ,VG    ,Z
C
      COMMON /COBRA3/  MA    ,MC    ,MG    ,MN    ,MR    ,MS    ,MX    ,
     1          III   ,IA    ,IAAA  ,IAC   ,IALPHA,IAN   ,IANSWE,IB    ,
     1   ICCHAN,ICD   ,ICHFR ,ICON  ,ICOND ,ICP   ,ID    ,IDC   ,IDFDX ,
     2   IDHDX ,IDHYD ,IDHYDN,IDIST ,IDPDX ,IDPK  ,IDUR  ,IDR   ,IF    ,
     3   IFACTO,IFDIV ,IFINLE,IFLUX ,IFMULT,IFOLD ,IFSP  ,IFSPLI,IFXFLO,
     4   IGAP  ,IGAPN ,IGAPS ,IH    ,IHFILM,IHINLE,IHOLD ,IHPERI,IIDARE,
     5   IIDFUE,IIDGAP,IIK   ,IJBOIL,IJK   ,ILC   ,ILENGT,ILOCA ,ILR   ,
     6   IMCHFR,IMCFRC,IMCFRR,INTYPE,INWRAP,INWRPS,IP    ,IPERIM,IPH   ,
     7   IPHI  ,IPRNTC,IPRNTR,IPRNTN,IPW   ,IPWRF ,IQC   ,IQF   ,IQPRIM,
     8   IQUAL ,IRADIA,IRHO  ,IRHOOL,ISP   ,IT    ,ITDUMY,ITINLE,ITROD ,
     9   IU    ,IUH   ,IUSAVE,IUSTAR,IV    ,IVISC ,IVISCW,IVP   ,IVPA  ,
     A   IW    ,IWOLD ,IWP   ,IWSAVE,IX    ,IXCROS,IIA   ,IIB   ,IXPOLD
C
      COMMON/LINK2/CROSS(6),FG(30),FH(30),FP(30),FQ(30),IM(9),JM(9),
     1OUTPUT(10),PRINT(12),TEXT(17),YG(30),YH(30),YP(30),YQ(30)
      COMMON/LINK3/DXX,ETIME,GIN,HIN,I8,IG,IN,ISAVE,JUMP,KASE,KT,MAXT,
     1 NDT,NDXP1,NFUELT,NG,NH,NJUMP,NOUT,NP,NPCHAN,NPNODE,NPROD,NQ,NR,
     2 NSKIPT,NSKIPX,NTRIES,PEXIT,PHTOT,SAVEDT,TIN,TTIME,ZZ
C-----------------------------------------------------------------------
C
C     SET PRINTING PARAMETERS FOR INPRIN
      IF (J1.GT.1) GO TO 4
         DO 2 I=1,11
    2    PRINT(I) = .TRUE.
      PRINT(5) = .FALSE.
      PRINT(6) = .FALSE.
C
C     FOR CALC (CARD GROUP 9)
    4 READ (I2,1001) CARD, KDEBUG
      WRITE (I3,1002) CARD
```

```
C
C     FOR EXPRIN (CARD GROUPS 9, 12)
      READ (I2,1001) CARD,NSKIPX, NSKIPT, NOUT, NPCHAN, NPROD, NPNODE
      WRITE (I3,1003) CARD
C     NSKIPX.   EVERY NSKIPX AXIAL STEP PRINTED.      (0 = 1)
C     NSKIPT.   EVERY NSKIPT TIME  STEP PRINTED.      (0 = 1)
C     NOUT = 0-3 FOR PRINTING (0) CHANNEL ONLY, (1) CHAN + CROSS FLOWS,
C     (2) CHAN + FUEL TEMP,  (3) CHAN + C-F + FUEL TEMP
C     NPCHAN = 0, ALL CHAN PRINTED.   .GT.0 READ CHANS REQD.
C     NPROD, NPNODE AS NPCHAN BUT FOR RODS AND NODES.
      IF (NSKIPX.LT.1) NSKIPX = 1
      IF (NSKIPT.LT.1) NSKIPT = 1
      IF (NPCHAN.LT.1) GO TO 6
      MROSI=1
7209  MMJAVI=MINO((MROSI+13),NPCHAN)
      READ(I2,1001) CARD,(IDAT(IPRNTC+I),I=MROSI,MMJAVI)
      WRITE(I3,1004) CARD
      MROSI=MMJAVI+1
      IF(MROSI.LE.NPCHAN) GO TO 7209
  6   IF(NPROD.LT.1) GO TO 8
      MROSI=1
8209  MMJAVI=MINO ((MROSI+13),NPROD)
      READ (I2,1001)CARD,(IDAT(IPRNTR+I),I=MROSI,MMJAVI)
      WRITE (I3,1006) CARD
      MROSI=MMJAVI+1
      IF (MROSI.LE.NPROD) GO TO  8209
  8   IF(NPNODE.LT.1) GO TO 10
      MROSI=1
6209  MMJAVI=MINO((MROSI+13),NPNODE)
      READ(I2,1001) CARD,(IDAT(IPRNTN+I),I=MROSI,MMJAVI)
      WRITE(I3,1007)CARD
      MROSI=MMJAVI+1
      IF (MROSI.LE.NPNODE) GO TO 6209
C
 10   IF (NPCHAN.GT.0) GO TO 14
      NPCHAN = NCHAN
         DO 12 I=1,NCHAN
 12      IDAT(IPRNTC+I) = I
 14   IF (NPROD.GT.0) GO TO 18
      NPROD = NROD
         DO 16 I=1,NROD
 16      IDAT(IPRNTR+I) = I
 18   IF (NPNODE.GT.0) GO TO 22
      NPNODE = NODESF+1
         DO 20 I=1,NPNODE
 20      IDAT(IPRNTN+I) = I
 22   CONTINUE
C
      RETURN
C
C---------------------------------------------------------------------
1001  FORMAT(20A4, T1, 14I5)
```

```
1002  FORMAT('  KDEBUG', 22X, '***', 20A4, '*** TABLES')
1003  FORMAT('  PRINTING', 20X, '***', 20A4, '*** TABLES')
1004  FORMAT('  PRINT CHANNELS   ', 11X, '***', 20A4, '*** TABLES')
1005  FORMAT('  PLUS REMAINDER')
1006  FORMAT('  PRINT RODS       ', 11X, '***', 20A4, '*** TABLES')
1007  FORMAT('  PRINT NODES      ', 11X, '***', 20A4, '*** TABLES')
C-----------------------------------------------------------------------
      END
```

```
C*********************** SUBROUTINE TEMFR *********************************
      SUBROUTINE TEMFR(TDUMY,DT,N,TFLUID,HGAP,HSURF,QP,III,NT)
C
C     QP IS VOLUMETRIC HEAT GENERATION RATE IN FUEL(BTU/SEC-FT**3)
C-------------------------------------------------------------------------
      DIMENSION TDUMY(1)
C
      COMMON /MCOND/ CND(22),RCP(22),RAD(22),RRDR(22),
     1  VM(22),VP(22),QPPP(22)
      COMMON/FRDATA/BURN,CPR,EFFB,EPSF,EXPR,FPRESS,FPUO2,FRAC,FTD,
     1  GMIX(4),GRGH,PGAS,RADR,RDELT,THC,THG
      COMMON/LINK4/IFRM,IHTM,IPROP,NCC,NCF,NDM1,NDS,NGP
C-------------------------------------------------------------------------
C
         DO 20 JJ=1,NCF
 20      QPPP(JJ)=QP
      RDELT=1./DT
      IF(NT.EQ.1) RDELT=0.
      IF(NT.EQ.1.AND.III.EQ.1) GO TO 30
      IF (IPROP.EQ.0) GO TO 30
      CALL RPROP(TDUMY(1),NCF,NGP,NDM1,HGAP,IPROP)
 30   CALL RTEMPF(TDUMY(1),RDELT,RADR,HSURF,TFLUID,NDS,NDM1)
      RETURN
      END
```

```
C*********************** SUBROUTINE TEMP *******************************
      SUBROUTINE TEMP (T,DUM,N,JJ,A,B)
C
C     SUBROUTINE TEMP CALCULATES THE TRANSIENT TEMPERATURE DISTRIBUTION
C     IN A CYLINDERICAL OR PLATE NUCLEAR FUEL ELEMENT WHERE THE LARGEST
C     NUMBER NODE IS THE CLADDING.  FOR TRANSIENT CALCULATIONS, FLUID
C     DATA AT T IS USED TO CALCULATE THE TEMPERATURE AT T+DT BY USING
C     A STABLE IMPLICIT NUMERICAL TECHNIQUE.
C     SIMULTANEOUS EQUATIONS ARE SOLVED USING A COMPACT ELIMINATION
C     SCHEME FOR TRI-DIAGONAL MATRICES.
C
C     THE VALUE OF T UPON ENTRY IS THE TEMPERATURE AT ORIGINAL TIME.
C     AT EXIT T IS THE TEMPERATURE DELTA-T LATER IN TIME.
C-----------------------------------------------------------------------
      IMPLICIT INTEGER (I)
      DIMENSION  A(3,100),B(100),T(100)
      INTEGER IDAT(1)
      LOGICAL LDAT(1),GRID
      REAL KIJ, KF, KKF, KCLAD, KFUEL, KFDR2
C
      COMMON  DATA(1)
      EQUIVALENCE  (DATA(1),IDAT(1),LDAT(1))
C
      COMMON /COBRA1/  ABETA ,AFLUX ,ATOTAL,BBETA ,DIA   ,DT    ,DX    ,
     1   ELEV  ,FERROR,FLO   ,FTM   ,GC    ,GK    ,GRID  ,HSURF ,HF    ,
     2   HFG   ,HG    ,I2    ,I3    ,IERROR,IQP3  ,ITERAT,J1    ,J2    ,
     3   J3    ,J4    ,J5    ,J6    ,J7    ,KDEBUG,KF    ,KIJ   ,
     4   NAFACT,NARAMP,NAX   ,NAXL  ,NBBC  ,NCHAN ,NCHF  ,NDX   ,NF    ,
     5   NGAPS ,NGRID ,NGRIDT,NGTYPE,NGXL  ,NK    ,NODES ,NODESF,NPROP ,
     6   NRAMP ,NROD  ,NSCBC ,NV    ,NVISCW,PI    ,PITCH ,POWER ,PREF  ,
     7   QAX   ,RHOF  ,RHOG  ,SIGMA ,SL    ,TF    ,TFLUID,THETA ,THICK ,
     8   UF    ,VF    ,VFG   ,VG    ,Z
C
      COMMON /COBRA2/  AA(4), AF(7), AFACT(10,10), AV(7), AXIAL(30),
     1   AXL(10), BB(4), BX(30), CC(4), CCLAD(2), CFUEL(2), DFUEL(2),
     2   GAPXL(10), GFACT(9,10), GRIDXL(10), HGAP(2), HHF(30), HHG(30),
     3   IGRID(10), KCLAD(2), KFUEL(2), KKF(30), NCH(10), NGAP(9),
     4   PP(30), RCLAD(2),RFUEL(2),SSIGMA(30), TCLAD(2), UUF(30),
     5   VVF(30), VVG(30), XQUAL(30), Y(30), TT(30)
C
      COMMON /COBRA3/  MA    ,MC    ,MG    ,MN    ,MR    ,MS    ,MX    ,
     1         III   ,IA    ,IAAA  ,IAC   ,IALPHA,IAN   ,IANSWE,IB    ,
     1   ICCHAN,ICD   ,ICHFR ,ICON  ,ICOND ,ICP   ,ID    ,IDC   ,IDFDX ,
     2   IDHDX ,IDHYD ,IDHYDN,IDIST ,IDPDX ,IDPK  ,IDUR  ,IDR   ,IF    ,
     3   IFACTO,IFDIV ,IFINLE,IFLUX ,IFMULT,IFOLD ,IFSP  ,IFSPLI,IFXFLO,
     4   IGAP  ,IGAPN ,IGAPS ,IH    ,IHFILM,IHINLE,IHOLD ,IHPERI,IIDARE,
     5   IIDFUE,IIDGAP,IIK   ,IJBOIL,IJK   ,ILC   ,ILENGT,ILOCA ,ILR   ,
     6   IMCHFR,IMCFRC,IMCFRR,INTYPE,INWRAP,INWRPS,IP    ,IPERIM,IPH   ,
     7   IPHI  ,IPRNTC,IPRNTR,IPRNTN,IPW   ,IPWRF ,IQC   ,IQF   ,IQPRIM,
     8   IQUAL ,IRADIA,IRHO  ,IRHOOL,ISP   ,IT    ,ITDUMY,ITINLE,ITROD ,
     9   IU    ,IUH   ,IUSAVE,IUSTAR,IV    ,IVISC ,IVISCW,IVP   ,IVPA  ,
     A   IW    ,IWOLD ,IWP   ,IWSAVE,IX    ,IXCROS,IIA  ,IIB  ,IXPOLD
```

```
C-----------------------------------------------------------------------
C
C     SETUP A MATRIX OF THE FORM   A*T=B WHERE ONLY THE 3 DIAGONALS OF
C     A ARE STORED.
      NM1 = NODESF-1
      NP1 = NODESF+1
      IF(NODESF.LE.0) GO TO 1000
      J=IDAT(IIDFUE+N)
      DR = DFUEL(J)*.5/FLOAT(NM1)
      DR2 = DR**2
      RCFUEL = RFUEL(J)*CFUEL(J)/DT
      KFDR2  = KFUEL(J)/DR2
      HGAP1 = 1./(1./HGAP(J) + TCLAD(J)/KCLAD(J))
      QCLAD = 0.
C     J IS THE FUEL TYPE CODE. CYLINDERICAL FUEL, J=1.  PLATE FUEL, J=2.
      IF(J.EQ.2) GO TO 101
C
C     THIS SECTION FOR CYLINDRICAL FUEL RODS.
      QFUEL=DATA(IFLUX+N+MR*(JJ-1))*4.*DATA(ID+N)/DFUEL(J)**2
         DO 100 I=1,NP1
         IF(I.GT.1) GO TO 10
         A(2,I) = RCFUEL + 4.*KFDR2
         A(3,I) = -4.*KFDR2
         GO TO 80
 10      IF(I.GT.NM1) GO TO 20
         A(1,I) = -KFDR2*(1.-1./FLOAT(2*I-2))
         A(2,I) = RCFUEL + 2.*KFDR2
         A(3,I) = -KFDR2*(1.+1./FLOAT(2*I-2))
         GO TO 80
 20      IF(I.EQ.NP1) GO TO 30
         A(1,I) = -2.*KFDR2
         A(2,I) = RCFUEL + 2.*KFDR2 + 2.*HGAP1/DR + HGAP1/DR/FLOAT(I-1)
         A(3,I) = -(2.*HGAP1/DR + HGAP1/DR/FLOAT(I-1))
         GO TO 80
 30      A(1,I)=-HGAP1/TCLAD(J)*DFUEL(J)/DATA(ID+N)
         A(2,I)= RCLAD(J)*CCLAD(J)/DT+HGAP1/TCLAD(J) * DFUEL(J)/
     1   DATA(ID+N) + HSURF/TCLAD(J)
 80      IF(I.EQ.NP1) GO TO 90
         B(I) = QFUEL + RCFUEL*T(I)
         GO TO 100
 90      B(I) = QCLAD + RCLAD(J)*CCLAD(J)/DT*T(I) + HSURF/TCLAD(J)*
     1   TFLUID
 100     CONTINUE
         GO TO 300
C
C
C        THIS SECTION FOR FLAT PLATE FUEL.
 101     QFUEL=DATA(IFLUX+N+MR*(JJ-1))*2./DFUEL(J)
         DO 200 I=1,NP1
         IF(I.GT.1) GO TO 110
         A(2,I) = RCFUEL + KFDR2*2.
         A(3,I) = -2.*KFDR2
```

```
         GO TO 180
 110     IF(I.GT.NM1) GO TO 120
         A(1,I) = -KFDR2
         A(2,I) = RCFUEL + 2.*KFDR2
         A(3,I) = -KFDR2
         GO TO 180
 120     IF(I.EQ.NP1) GO TO 130
         A(1,I) = -2.*KFDR2
         A(2,I) = RCFUEL + 2.*KFDR2 + 2.*HGAP1/DR
         A(3,I) = -2.*HGAP1/DR
         GO TO 180
 130     A(1,I) = -HGAP1/TCLAD(J)
         A(2,I) =  RCLAD(J)*CCLAD(J)/DT + HGAP1/TCLAD(J) +
     1   HSURF/TCLAD(J)
 180     IF(I.EQ.NP1) GO TO 190
         B(I) = QFUEL + RCFUEL*T(I)
         GO TO 200
 190     B(I) = QCLAD + RCLAD(J)*CCLAD(J)/DT*T(I) + HSURF/TCLAD(J)*
     1   TFLUID
 200     CONTINUE
C
C
C     THIS SECTION CALCULATES THE TEMPERATURES FOR
C     WHICHEVER FUEL TYPE IS USED BY SOLVING THE
C     TRIDIAGONAL MATRIX USING GAUSS ELIMINATION.
 300  MM = NP1-1
         DO 310 K = 1,MM
         AK = A(1,K+1)/A(2,K)
         A(2,K+1) = A(2,K+1)-A(3,K)*AK
 310     B(K+1) = B(K+1)-B(K)*AK
      T(NP1) = B(NP1)/A(2,NP1)
         DO 320 K = 1,MM
         L = MM-K+1
 320     T(L) = (B(L)-A(3,L)*T(L+1))/A(2,L)
      RETURN
C
1000  IERROR = 15
      RETURN
      END
```

```
C********************** SUBROUTINE TIDY ******************************
      SUBROUTINE TIDY
C
      IMPLICIT INTEGER (I)
      DIMENSION NTHBOX(20,20)
      INTEGER IDAT(1)
      LOGICAL LDAT(1),GRID
      REAL KIJ, KF, KKF, KCLAD, KFUEL
C
      COMMON  DATA(1)
      EQUIVALENCE  (DATA(1),IDAT(1),LDAT(1))
C
      COMMON /COBRA1/  ABETA ,AFLUX ,ATOTAL,BBETA ,DIA   ,DT    ,DX    ,
     1   ELEV  ,FERROR,FLO   ,FTM   ,GC    ,GK    ,GRID  ,HSURF ,HF    ,
     2   HFG   ,HG    ,I2    ,I3    ,IERROR,IQP3  ,ITERAT,J1    ,J2    ,
     3   J3    ,J4    ,J5    ,J6    ,J7    ,KDEBUG,KF    ,KIJ   ,
     4   NAFACT,NARAMP,NAX   ,NAXL  ,NBBC  ,NCHAN ,NCHF  ,NDX   ,NF    ,
     5   NGAPS ,NGRID ,NGRIDT,NGTYPE,NGXL  ,NK    ,NODES ,NODESF,NPROP ,
     6   NRAMP ,NROD  ,NSCBC ,NV    ,NVISCW,PI    ,PITCH ,POWER ,PREF  ,
     7   QAX   ,RHOF  ,RHOG  ,SIGMA ,SL    ,TF    ,TFLUID,THETA ,THICK ,
     8   UF    ,VF    ,VFG   ,VG    ,Z
C
      COMMON /COBRA3/  MA    ,MC    ,MG    ,MN    ,MR    ,MS    ,MX    ,
     1         III   ,IA    ,IAAA  ,IAC   ,IALPHA,IAN   ,IANSWE,IB    ,
     1   ICCHAN,ICD   ,ICHFR ,ICON  ,ICOND ,ICP   ,ID    ,IDC   ,IDFDX ,
     2   IDHDX ,IDHYD ,IDHYDN,IDIST ,IDPDX ,IDPK  ,IDUR  ,IDR   ,IF    ,
     3   IFACTO,IFDIV ,IFINLE,IFLUX ,IFMULT,IFOLD ,IFSP  ,IFSPLI,IFXFLO,
     4   IGAP  ,IGAPN ,IGAPS ,IH    ,IHFILM,IHINLE,IHOLD ,IHPERI,IIDARE,
     5   IIDFUE,IIDGAP,IIK   ,IJBOIL,IJK   ,ILC   ,ILENGT,ILOCA ,ILR   ,
     6   IMCHFR,IMCFRC,IMCFRR,INTYPE,INWRAP,INWRPS,IP    ,IPERIM,IPH   ,
     7   IPHI  ,IPRNTC,IPRNTR,IPRNTN,IPW   ,IPWRF ,IQC   ,IQF   ,IQPRIM,
     8   IQUAL ,IRADIA,IRHO  ,IRHOOL,ISP   ,IT    ,ITDUMY,ITINLE,ITROD ,
     9   IU    ,IUH   ,IUSAVE,IUSTAR,IV    ,IVISC ,IVISCW,IVP   ,IVPA  ,
     A   IW    ,IWOLD ,IWP   ,IWSAVE,IX    ,IXCROS,IIA   ,IIB   ,IXPOLD
C
      COMMON/LINK3/DXX,ETIME,GIN,HIN,I8,IG,IN,ISAVE,JUMP,KASE,KT,MAXT,
     1 NDT,NDXP1,NFUELT,NG,NH,NJUMP,NOUT,NP,NPCHAN,NPNODE,NPROD,NQ,NR,
     2 NSKIPT,NSKIPX,NTRIES,PEXIT,PHTOT,SAVEDT,TIN,TTIME,ZZ
C-----------------------------------------------------------------------
C
C     TIDY UP FOR INPRIN.
      ZZ = 12.0*Z
         DO 4 I=1,NCHAN
         DATA(IAC+I) = 144.0*DATA(IA+I)
         DATA(IPW+I) = 12.0*DATA(IPERIM+I)
         DATA(IPH+I) = 12.0*DATA(IHPERI+I)
         DATA(IDC+I) = 12.0*DATA(IDHYD+I)
         DATA(IDR+I) = 12.0*DATA(ID+I)
            DO 4 L=1,4
            IDAT(ILC+I+MC*(L-1)) = 0
            DATA(IDIST+I+MC*(L-1)) = 0.0
            DATA(IGAPS+I+MG*(L-1)) = 0.0
```

```
  4         CONTINUE
C
      IF (NK.EQ.0) RETURN
         DO 12 K=1,NK
         I = IDAT(IIK+K)
         J = IDAT(IJK+K)
            DO 8 L=1,4
            IF (IDAT(ILC+I+MC*(L-1)).EQ.0) GO TO 10
  8         CONTINUE
         WRITE (6,2004) K,J,I
 10      IDAT(ILC+I+MC*(L-1)) = J
         DATA(IDIST+I+MC*(L-1)) = DATA(ILENGT+K)*12.0
 12      DATA(IGAPS+I+MG*(L-1)) = DATA(IGAP+K)*12.0
      RETURN
C-----------------------------------------------------------------------
2004  FORMAT(' CARDS4  GAP CONNECTION ', I3, '  CHANNEL ', I3,
     1 ' IS 5TH ADJACENT TO ', I3)
C-----------------------------------------------------------------------
      END
```

```
C********************** SUBROUTINE TIMING *******************************
      SUBROUTINE TIMING(ICPU)
C
C     THIS SUBROUTINE TIMING IS A DUMY ROUTINE FOR USE ON
C     SYSTEMS WHERE THE CPU TIME IS NOT READILY AVAILABLE.
C
      ICPU=0.
      RETURN
      END
```

```
C********************** SUBROUTINE VOID ******************************
      SUBROUTINE VOID (J)
C
      IMPLICIT INTEGER (I)
      INTEGER IDAT(1)
      LOGICAL LDAT(1),GRID
      REAL KIJ, KF, KKF, KCLAD, KFUEL
C
      COMMON  DATA(1)
      EQUIVALENCE  (DATA(1),IDAT(1),LDAT(1))
C
      COMMON /COBRA1/  ABETA ,AFLUX ,ATOTAL,BBETA ,DIA   ,DT    ,DX    ,
     1   ELEV  ,FERROR,FLO   ,FTM   ,GC    ,GK    ,GRID  ,HSURF ,HF    ,
     2   HFG   ,HG    ,I2    ,I3    ,IERROR,IQP3  ,ITERAT,J1    ,J2    ,
     3   J3    ,J4    ,J5    ,J6    ,J7    ,KDEBUG,KF    ,KIJ   ,
     4   NAFACT,NARAMP,NAX   ,NAXL  ,NBBC  ,NCHAN ,NCHF  ,NDX   ,NF    ,
     5   NGAPS ,NGRID ,NGRIDT,NGTYPE,NGXL  ,NK    ,NODES ,NODESF,NPROP ,
     6   NRAMP ,NROD  ,NSCBC ,NV    ,NVISCW,PI    ,PITCH ,POWER ,PREF  ,
     7   QAX   ,RHOF  ,RHOG  ,SIGMA ,SL    ,TF    ,TFLUID,THETA ,THICK ,
     8   UF    ,VF    ,VFG   ,VG    ,Z
C
      COMMON /COBRA2/  AA(4), AF(7), AFACT(10,10), AV(7), AXIAL(30),
     1   AXL(10), BB(4), BX(30), CC(4), CCLAD(2), CFUEL(2), DFUEL(2),
     2   GAPXL(10), GFACT(9,10), GRIDXL(10), HGAP(2), HHF(30), HHG(30),
     3   IGRID(10), KCLAD(2), KFUEL(2), KKF(30), NCH(10), NGAP(9),
     4   PP(30), RCLAD(2),RFUEL(2),SSIGMA(30), TCLAD(2), UUF(30),
     5   VVF(30), VVG(30), XQUAL(30), Y(30), TT(30)
C
      COMMON /COBRA3/  MA    ,MC    ,MG    ,MN    ,MR    ,MS    ,MX    ,
     1          III   ,IA    ,IAAA  ,IAC   ,IALPHA,IAN   ,IANSWE,IB    ,
     1   ICCHAN,ICD   ,ICHFR ,ICON  ,ICOND ,ICP   ,ID    ,IDC   ,IDFDX ,
     2   IDHDX ,IDHYD ,IDHYDN,IDIST ,IDPDX ,IDPK  ,IDUR  ,IDR   ,IF    ,
     3   IFACTO,IFDIV ,IFINLE,IFLUX ,IFMULT,IFOLD ,IFSP  ,IFSPLI,IFXFLO,
     4   IGAP  ,IGAPN ,IGAPS ,IH    ,IHFILM,IHINLE,IHOLD ,IHPERI,IIDARE,
     5   IIDFUE,IIDGAP,IIK   ,IJBOIL,IJK   ,ILC   ,ILENGT,ILOCA ,ILR   ,
     6   IMCHFR,IMCFRC,IMCFRR,INTYPE,INWRAP,INWRPS,IP    ,IPERIM,IPH   ,
     7   IDUM  ,IPRNTC,IPRNTR,IPRNTN,IPW   ,IPWRF ,IQC   ,IQF   ,IQPRIM,
     8   IQUAL ,IRADIA,IRHO  ,IRHOOL,ISP   ,IT    ,ITDUMY,ITINLE,ITROD ,
     9   IU    ,IUH   ,IUSAVE,IUSTAR,IV    ,IVISC ,IVISCW,IVP   ,IVPA  ,
     A   IW    ,IWOLD ,IWP   ,IWSAVE,IX    ,IXCROS,IIA  ,IIB  ,IXPOLD
C
      COMMON /PPSV/ PPI
C-----------------------------------------------------------------------
C
      IPHI=IFMULT
         DO 200 I=1,NCHAN
         PSI = 0.
         DPSIDH = 0.
         IF(J3.EQ.0) GO TO 40
         DATA(IH+I+MC*(J-1))=DATA(IH+I+MC*(J-1))-.1
         DATA(IQUAL+I)=(DATA(IH+I+MC*(J-1))-HF)/HFG
         IF(DATA(IQUAL+I).LE.1.0E-15)DATA(IQUAL+I)=0.
```

```
          IF(J2.EQ.1)DATA(IQUAL+I)=SCQUAL(I,J)
          IF(DATA(IQUAL+I).LE.1.0E-15)DATA(IQUAL+I)=0.
          DATA(IALPHA+I) = BVOID(I,J)
          PSI=RHOF*DATA(IQUAL+I)*(1.-DATA(IALPHA+I))-RHOG*DATA(IALPHA+I)
     1    *(1.-DATA(IQUAL+I))
          DATA(IH+I+MC*(J-1))=DATA(IH+I+MC*(J-1))+.1
 40       DATA(IQUAL+I)=(DATA(IH+I+MC*(J-1))-HF)/HFG
          IF(DATA(IQUAL+I).LE.1.0E-15)DATA(IQUAL+I)=0.
          IF(J2.EQ.1)DATA(IQUAL+I)=SCQUAL(I,J)
          IF(DATA(IQUAL+I).LE.1.0E-15)  GO TO 150
          XP=DATA(IQUAL+I)
          DATA(IALPHA+I)=BVOID(I,J)
C
C         CALCULATE TWO-PHASE DENSITY.
C******** THE FOLLOWING CARDS CORRECT THE CALCULATION OF RHO AND VP
          DATA(IRHO+I+MC*(J-1))=RHOG*DATA(IALPHA+I)+1./DATA(IV+I)
     1    *(1.-DATA(IALPHA+I))
C
C         CALCULATE TWO-PHASE SPECIFIC VOLUME FOR MOMENTUM.
          DATA(IVP+I)=DATA(IV+I)*(1.-XP)**2/(1.-DATA(IALPHA+I))+VG*XP**2/
     1    DATA(IALPHA+I)
          IF(J7.NE.2)  GO TO 3
          IF(J.EQ.1)  GO TO 3
          RHODIF = DATA(IRHO+I+MC*(J-1))-DATA(IRHOOL+I+MC*(J-1))
          DATA(IF+I+MC*(J-1))=DATA(IF+I+MC*(J-2))-DX/DT*RHODIF*DATA(IA+I)
  3       CONTINUE
C
C         TWO-PHASE FRICTIONAL PRESSURE GRADIENT MULTIPLIERS.
          DATA(IPHI+I)=1.
          IF(J4.EQ.0)   DATA(IPHI+I)=RHOF/DATA(IRHO+I+MC*(J-1))
          GWV = 3600.0*DATA(IF+I+MC*(J-1))/DATA(IA+I)
          IF (J4.EQ.2) CALL BAROC(2,PREF,XP,GWV,DATA(IPHI+I),PPI)
          IF(J4.NE.1) GO TO 50
          DATA(IPHI+I)=1.
          XA=DATA(IALPHA+I)
          IF(XA.GT.0.0.AND.XA.LE.0.6)XXX=(1.-XP)**2/(1.-XA)**1.42
          IF(XA.GT.0.6.AND.XA.LE.0.9)XXX=.478*(1.-XP)**2/(1.-XA)**2.2
          IF(XA.GT.0.9.AND.XA.LE.1.0)XXX=1.73*(1.-XP)**2/(1.-XA)**1.64
          DATA(IPHI+I)=XXX
 50       IF(J4.NE.5) GO TO 140
          DATA(IPHI+I)=AF(1)
          XX = DATA(IQUAL+I)
             DO 130 K=2,NF
             DATA(IPHI+I)=DATA(IPHI +I)+AF(K)*XX
 130         XX          =DATA(IQUAL+I)*XX
 140      DATA(IU  +I)=DATA(IF+I+MC*(J-1))/DATA(IA+I)*DATA(IVP+I)
          IF(J3.EQ.0) GO TO 145
          DPSIDH=-10.*(PSI-RHOF*DATA(IQUAL+I)*(1.-DATA(IALPHA+I))+RHOG*
     1    DATA(IALPHA+I)*(1.-DATA(IQUAL+I)))
 145      DATA(IUH+I)=DATA(IF+I+MC*(J-1))/DATA(IA+I)/
     1    (DATA(IRHO+I+MC*(J-1))-HFG*DPSIDH)
          GO TO 200
```

```
C
C        TWO-PHASE FLOW PARAMETERS WITHOUT BOILING.
 150     DATA(IALPHA+I)=0.0
         DATA(IRHO  +I+MC*(J-1))=1.0/DATA(IV+I)
         IF(J7.NE.2)  GO TO 4
         IF(J.EQ.1)  GO TO 4
         RHODIF = DATA(IRHO+I+MC*(J-1))-DATA(IRHOOL+I+MC*(J-1))
         DATA(IF+I+MC*(J-1))=DATA(IF+I+MC*(J-2))-DX/DT*RHODIF*DATA(IA+I)
  4      CONTINUE
         DATA(IVP   +I)=DATA(IV+I)
         DATA(IU    +I)=DATA(IF+I+MC*(J-1))/DATA(IA+I)*DATA(IVP+I)
         DATA(IUH   +I)=DATA(IU+I)
         DATA(IPHI  +I)=1.0
         DATA(IQUAL +I)=0.0
 200     CONTINUE
      RETURN
      END
```

```
C********************** SUBROUTINE WHEN *******************************
      SUBROUTINE WHEN(DATIM)
C
C     THIS WHEN SUBROUTINE IS A DUMMY FOR USE BY THE MULTICS
C     VERSION OF COBRA-IIIC/MIT
C
      DIMENSION DATIM(5)
      DATA BLANK/4H    /
         DO 5 I=1,5
         DATIM(I)=BLANK
C        DATIM(I)=4H
  5      CONTINUE
      RETURN
      END
```

```
C********************** FUNCTION BVOID ********************************
      FUNCTION BVOID(I,J)
C
C     BVOID CALCULATES THE BULK VOID FRACTION GIVEN A QUALITY.
C-----------------------------------------------------------------------
      IMPLICIT INTEGER (I)
      LOGICAL GRID
      REAL KIJ, KF, KKF, KCLAD, KFUEL
C
      COMMON  DATA(1)
C
      COMMON /COBRA1/  ABETA ,AFLUX ,ATOTAL,BBETA ,DIA   ,DT    ,DX    ,
     1   ELEV  ,FERROR,FLO   ,FTM   ,GC    ,GK    ,GRID  ,HSURF ,HF    ,
     2   HFG   ,HG    ,I2    ,I3    ,IERROR,IQP3  ,ITERAT,J1    ,J2    ,
     3   J3    ,J4    ,J5    ,J6    ,J7    ,KDEBUG,KF    ,KIJ   ,
     4   NAFACT,NARAMP,NAX   ,NAXL  ,NBBC  ,NCHAN ,NCHF  ,NDX   ,NF    ,
     5   NGAPS ,NGRID ,NGRIDT,NGTYPE,NGXL  ,NK    ,NODES ,NODESF,NPROP ,
     6   NRAMP ,NROD  ,NSCBC ,NV    ,NVISCW,PI    ,PITCH ,POWER ,PREF  ,
     7   QAX   ,RHOF  ,RHOG  ,SIGMA ,SL    ,TF    ,TFLUID,THETA ,THICK ,
     8   UF    ,VF    ,VFG   ,VG    ,Z
C
      COMMON /COBRA2/  AA(4), AF(7), AFACT(10,10), AV(7), AXIAL(30),
     1   AXL(10), BB(4), BX(30), CC(4), CCLAD(2), CFUEL(2), DFUEL(2),
     2   GAPXL(10), GFACT(9,10), GRIDXL(10), HGAP(2), HHF(30), HHG(30),
     3   IGRID(10), KCLAD(2), KFUEL(2), KKF(30), NCH(10), NGAP(9),
     4   PP(30), RCLAD(2),RFUEL(2),SSIGMA(30), TCLAD(2), UUF(30),
     5   VVF(30), VVG(30), XQUAL(30), Y(30), TT(30)
C
      COMMON /COBRA3/  MA    ,MC    ,MG    ,MN    ,MR    ,MS    ,MX    ,
     1          III   ,IA    ,IAAA  ,IAC   ,IALPHA,IAN   ,IANSWE,IB    ,
     1   ICCHAN,ICD   ,ICHFR ,ICON  ,ICOND ,ICP   ,ID    ,IDC   ,IDFDX ,
     2   IDHDX ,IDHYD ,IDHYDN,IDIST ,IDPDX ,IDPK  ,IDUR  ,IDR   ,IF    ,
     3   IFACTO,IFDIV ,IFINLE,IFLUX ,IFMULT,IFOLD ,IFSP  ,IFSPLI,IFXFLO,
     4   IGAP  ,IGAPN ,IGAPS ,IH    ,IHFILM,IHINLE,IHOLD ,IHPERI,IIDARE,
     5   IIDFUE,IIDGAP,IIK   ,IJBOIL,IJK   ,ILC   ,ILENGT,ILOCA ,ILR   ,
     6   IMCHFR,IMCFRC,IMCFRR,INTYPE,INWRAP,INWRPS,IP    ,IPERIM,IPH   ,
     7   IPHI  ,IPRNTC,IPRNTR,IPRNTN,IPW   ,IPWRF ,IQC   ,IQF   ,IQPRIM,
     8   IQUAL ,IRADIA,IRHO  ,IRHOOL,ISP   ,IT    ,ITDUMY,ITINLE,ITROD ,
     9   IU    ,IUH   ,IUSAVE,IUSTAR,IV    ,IVISC ,IVISCW,IVP   ,IVPA  ,
     A   IW    ,IWOLD ,IWP   ,IWSAVE,IX    ,IXCROS,IIA   ,IIB   ,IXPOLD
C-----------------------------------------------------------------------
C
      XP=DATA(IQUAL+I)
      BVOID = 0.
      IF(XP.LE.0.) RETURN
      DATA(IALPHA+I)=0.
      IF(J3.EQ.0) DATA(IALPHA+I)=XP*VG/((1.-XP)*VF+XP*VG)
      IF(J3.EQ.1)DATA(IALPHA+I)=(0.833+.167*XP)*XP*VG/((1.-XP)*VF+XP*VG)
      IF (J3.EQ.2) GO TO 85
      IF(J3.EQ.5) DATA(IALPHA+I)=XP*VG/((1.-XP)*VF*AV(1)+XP*VG)
      IF(J3.NE.6) GO TO 90
                  DATA(IALPHA+I)=AV(1)
```

```
      XX=DATA(IQUAL+I)
         DO 80 K=2,NV
         DATA(IALPHA+I)=DATA(IALPHA+I)+AV(K)*XX
 80      XX = DATA(IQUAL+I)*XX
      GO TO 90
C
C     SMITH SLIP CORRELATION
 85   SLP = 0.4 + 0.6*((0.4+XP*(VG/VF-0.4))/(0.4+0.6*XP))**0.5
      DATA(IALPHA+I) = XP*VG/(SLP*(1.0-XP)*VF+XP*VG)
 90   BVOID = DATA(IALPHA+I)
      RETURN
      END
```

```
C********************** FUNCTION CHF1 ********************************
      FUNCTION CHF1(N,I,J)
C
      IMPLICIT INTEGER (I)
      LOGICAL GRID
      REAL KIJ, KF, KKF, KCLAD, KFUEL, KD
C
      COMMON  DATA(1)
C
      COMMON /COBRA1/  ABETA ,AFLUX ,ATOTAL,BBETA ,DIA   ,DT    ,DX    ,
     1   ELEV  ,FERROR,FLO   ,FTM   ,GC    ,GK    ,GRID  ,HSURF ,HF    ,
     2   HFG   ,HG    ,I2    ,I3    ,IERROR,IQP3  ,ITERAT,J1    ,J2    ,
     3   J3    ,J4    ,J5    ,J6    ,J7    ,KDEBUG,KF    ,KIJ   ,
     4   NAFACT,NARAMP,NAX   ,NAXL  ,NBBC  ,NCHAN ,NCHF  ,NDX   ,NF    ,
     5   NGAPS ,NGRID ,NGRIDT,NGTYPE,NGXL  ,NK    ,NODES ,NODESF,NPROP ,
     6   NRAMP ,NROD  ,NSCBC ,NV    ,NVISCW,PI    ,PITCH ,POWER ,PREF  ,
     7   QAX   ,RHOF  ,RHOG  ,SIGMA ,SL    ,TF    ,TFLUID,THETA ,THICK ,
     8   UF    ,VF    ,VFG   ,VG    ,Z
C
      COMMON /COBRA3/  MA    ,MC    ,MG    ,MN    ,MR    ,MS    ,MX    ,
     1          III   ,IA    ,IAAA  ,IAC   ,IALPHA,IAN   ,IANSWE,IB    ,
     1   ICCHAN,ICD   ,ICHFR ,ICON  ,ICOND ,ICP   ,ID    ,IDC   ,IDFDX ,
     2   IDHDX ,IDHYD ,IDHYDN,IDIST ,IDPDX ,IDPK  ,IDUR  ,IDR   ,IFLOW ,
     3   IFACTO,IFDIV ,IFINLE,IFLUX ,IFMULT,IFOLD ,IFSP  ,IFSPLI,IFXFLO,
     4   IGAP  ,IGAPN ,IGAPS ,IH    ,IHFILM,IHINLE,IHOLD ,IHPERI,IIDARE,
     5   IIDFUE,IIDGAP,IIK   ,IJBOIL,IJK   ,ILC   ,ILENGT,ILOCA ,ILR   ,
     6   IMCHFR,IMCFRC,IMCFRR,INTYPE,INWRAP,INWRPS,IP    ,IPERIM,IPH   ,
     7   IPHI  ,IPRNTC,IPRNTR,IPRNTN,IPW   ,IPWRF ,IQC   ,IQF   ,IQPRIM,
     8   IQUAL ,IRADIA,IRHO  ,IRHOOL,ISP   ,IT    ,ITDUMY,ITINLE,ITROD ,
     9   IU    ,IUH   ,IUSAVE,IUSTAR,IV    ,IVISC ,IVISCW,IVP   ,IVPA  ,
     A   IW    ,IWOLD ,IWP   ,IWSAVE,IX    ,IXCROS,IIA   ,IIB   ,IXPOLD
C
C     BAW-2 CHF CORRELATION
      DATA A0, B0,A1,A2,A3,A4,A5,A6,A7,A8,A9 / 1.15509, 4.8844,
     1 0.3702E+8, 2.1289E-3, 0.83040, 0.68479E-3, 4.5756E+4, 1.0996E-2,
     2 0.71186, 0.20729E-3, 547.49/
      DATA  A21,A22,A23,KD /  2.9840, 7.82293, 0.45758, 1.02508 /
C-----------------------------------------------------------------------
C
      QA=DATA(IA +I)
      QP=DATA(IPERIM+I)
      QF=DATA(IFLOW+I+MC*(J-1))
      QH=DATA(IH+I+MC*(J-1))
      RAT=QF/QA
      DE=4.*QA/QP
      XX=(QH-HF)/HFG
      CHF1=(A0-B0*DE)*(A1*(A2*RAT)**(A3+A4*(PREF-2000.))
     1    -A9*RAT*XX*HFG)/(A5*(A6*RAT)**(A7+A8*(PREF-2000.)))
C
C     AXIAL FLUX CORRECTION FACTOR
      FAXIAL = 1.
      IF(J.EQ.1) GO TO 10
```

```
      C=A21*(1.-XX)**A22/(RAT*.0036)**A23
      SUM = 0.
      JS = 2
         DO 5 JJ=JS,J
 5       SUM=SUM+DATA(IFLUX+N+MR*(JJ-1))*(EXP(C*DATA(IX+JJ))-
     1                              EXP(C*DATA(IX+JJ-1)))
      FAXIAL=SUM*EXP(-C*DATA(IX+J))/DATA(IFLUX+N+MR*(J-1))/
     1    (1.-EXP(-C*(DATA(IX+J)-DATA(IX+JS-1))))*KD
 10   CHF1 = CHF1/FAXIAL
      RETURN
      END
```

```
C********************** FUNCTION CHF2 ********************************
      FUNCTION CHF2(N,I,J)
C
C     W-3 CORRELATION INCLUDING, SPACER FACTOR, UNHEATED WALL CORRECTION
C     AXIAL FLUX FACTOR
C     REFERENCE, LS TONG, BOILING CRISIS AND CRITICAL HEAT FLUX
C     AEC CRITICAL REVIEW SERI5S,TID-25887(1972).
C-----------------------------------------------------------------------
      IMPLICIT INTEGER (I)
      INTEGER IDAT(1)
      LOGICAL GRID
      REAL KIJ, KF, KKF, KCLAD, KFUEL
C
      COMMON  DATA(1)
      EQUIVALENCE  (DATA(1),IDAT(1))
C
      COMMON /COBRA1/  ABETA ,AFLUX ,ATOTAL,BBETA ,DIA   ,DT    ,DX    ,
     1    ELEV  ,FERROR,FLO   ,FTM   ,GC    ,GK    ,GRID  ,HSURF ,HF    ,
     2    HFG   ,HG    ,I2    ,I3    ,IERROR,IQP3  ,ITERAT,J1    ,J2    ,
     3    J3    ,J4    ,J5    ,J6    ,J7    ,KDEBUG,KF    ,KIJ   ,
     4    NAFACT,NARAMP,NAX   ,NAXL  ,NBBC  ,NCHAN ,NCHF  ,NDX   ,NF    ,
     5    NGAPS ,NGRID ,NGRIDT,NGTYPE,NGXL  ,NK    ,NODES ,NODESF,NPROP ,
     6    NRAMP ,NROD  ,NSCBC ,NV    ,NVISCW,PI    ,PITCH ,POWER ,PREF  ,
     7    QAX   ,RHOF  ,RHOG  ,SIGMA ,SL    ,TF    ,TFLUID,THETA ,THICK ,
     8    UF    ,VF    ,VFG   ,VG    ,Z
C
      COMMON /COBRA3/  MA    ,MC    ,MG    ,MN    ,MR    ,MS    ,MX    ,
     1          III   ,IA    ,IAAA  ,IAC   ,IALPHA,IAN   ,IANSWE,IB    ,
     1    ICCHAN,ICD   ,ICHFR ,ICON  ,ICOND ,ICP   ,ID    ,IDC   ,IDFDX ,
     2    IDHDX ,IDHYD ,IDHYDN,IDIST ,IDPDX ,IDPK  ,IDUR  ,IDR   ,IFLOW ,
     3    IFACTO,IFDIV ,IFINLE,IFLUX ,IFMULT,IFOLD ,IFSP  ,IFSPLI,IFXFLO,
     4    IGAP  ,IGAPN ,IGAPS ,IH    ,IHFILM,IHINLE,IHOLD ,IHPERI,IIDARE,
     5    IIDFUE,IIDGAP,IIK   ,IJBOIL,IJK   ,ILC   ,ILENGT,ILOCA ,ILR   ,
     6    IMCHFR,IMCFRC,IMCFRR,INTYPE,INWRAP,INWRPS,IP    ,IPERIM,IPH   ,
     7    IPHI  ,IPRNTC,IPRNTR,IPRNTN,IPW   ,IPWRF ,IQC   ,IQF   ,IQPRIM,
     8    IQUAL ,IRADIA,IRHO  ,IRHOOL,ISP   ,IT    ,ITDUMY,ITINLE,ITROD ,
     9    IU    ,IUH   ,IUSAVE,IUSTAR,IV    ,IVISC ,IVISCW,IVP   ,IVPA  ,
     A    IW    ,IWOLD ,IWP   ,IWSAVE,IX    ,IXCROS,IIA  ,IIB  ,IXPOLD
C-----------------------------------------------------------------------
C
      DE=4.*DATA(IA+I)/DATA(IPERIM+I)
      DH=4.*DATA(IA+I)/DATA(IHPERI+I)
      RU = 1.-DE/DH
      XX=(DATA(IH+I+MC*(J-1))-HF)/HFG
C
C     W-3 CORRELATION USING EQUILIBRIUM STEAM QUALITY
      CHF2     = ((2.022 - 0.0004302*PREF) + (0.1722 - 0.0000984*PREF)
     1 *EXP((18.2 - 0.004129*PREF)*XX))
     2 *((0.1484-1.596*XX+.1729*XX*ABS(XX))*DATA(IFLOW+I+MC*(J-1))/
     3 DATA(IA+I) * .0036 + 1.037) * (1.157 - 0.869*XX)
     4 *(0.2664 + 0.8357*EXP(-37.812*DH))
     5 *(0.8258+0.000794*(HF-DATA(IHINLE+I)))/.0036
```

```
C
C     UNHEATED WALL CORRECTION
      IF(RU.GT.0.) CHF2 = CHF2*(1. - RU*(13.76-1.372*EXP(1.78*XX)
     1 -4.732/(DATA(IFLOW+I+MC*(J-1))/DATA(IA+I)*0.0036)**.0535
     1 -0.0619*(PREF*0.001)**.14 - 11.101*DH**.1077))
C
C     SPACER FACTOR CORRECTION
C     USER SHOULD SELECT PROPER VALUE OF TDC
      TDC = .019
      IF(NGRID.GT.0)CHF2=CHF2*(1.+.03*DATA(IFLOW+I+MC*(J-1))/
     1DATA(IA+I)*.0036*(TDC/.019)**.35)
C
C     AXIAL FLUX PROFILE CORRECTION
      FAXIAL = 1.
      IF(J.LE.IDAT(IJBOIL+I))  GO TO 10
      C=1.8*(1.-XX)**4.31/(DATA(IFLOW+I+MC*(J-1))/
     1DATA(IA+I)*.0036)**.478
      SUM = 0.
      JS=IDAT(IJBOIL+I)+1
      CE=C/2.
         DO 5 JJ=JS,J
  5      SUM=SUM+DATA(IFLUX+N+MR*(JJ-1))*(EXP(CE*DATA(IX+JJ))+
     1   EXP(CE*DATA(IX+JJ-1)))*(EXP(CE*DATA(IX+JJ))
     2   -EXP(CE*DATA(IX+JJ-1)))
      FAXIAL=SUM*EXP(-CE*DATA(IX+J))/DATA(IFLUX+N+MR*(J-1))/
     1(1.-EXP(-C*(DATA(IX+J)-DATA(IX+JS-1))))
      FAXIAL=FAXIAL*EXP(-CE*DATA(IX+J))
   10 CHF2 = CHF2/FAXIAL
      RETURN
      END
```

```
C********************** FUNCTION CHF3 *********************************
      FUNCTION CHF3(N,I,J)
C
      IMPLICIT INTEGER (I)
      LOGICAL GRID
      REAL KIJ, KF, KKF, KCLAD, KFUEL
C
      COMMON  DATA(1)
C
      COMMON /COBRA1/  ABETA ,AFLUX ,ATOTAL,BBETA ,DIA   ,DT    ,DX    ,
     1   ELEV  ,FERROR,FLO   ,FTM   ,GC    ,GK    ,GRID  ,HSURF ,HF    ,
     2   HFG   ,HG    ,I2    ,I3    ,IERROR,IQP3  ,ITERAT,J1    ,J2    ,
     3   J3    ,J4    ,J5    ,J6    ,J7    ,KDEBUG,KF    ,KIJ   ,
     4   NAFACT,NARAMP,NAX   ,NAXL  ,NBBC  ,NCHAN ,NCHF  ,NDX   ,NF    ,
     5   NGAPS ,NGRID ,NGRIDT,NGTYPE,NGXL  ,NK    ,NODES ,NODESF,NPROP ,
     6   NRAMP ,NROD  ,NSCBC ,NV    ,NVISCW,PI    ,PITCH ,POWER ,PREF  ,
     7   QAX   ,RHOF  ,RHOG  ,SIGMA ,SL    ,TF    ,TFLUID,THETA ,THICK ,
     8   UF    ,VF    ,VFG   ,VG    ,Z
C
      COMMON /COBRA3/  MA    ,MC    ,MG    ,MN    ,MR    ,MS    ,MX    ,
     1          III   ,IA    ,IAAA  ,IAC   ,IALPHA,IAN   ,IANSWE,IB    ,
     1   ICCHAN,ICD   ,ICHFR ,ICON  ,ICOND ,ICP   ,ID    ,IDC   ,IDFDX ,
     2   IDHDX ,IDHYD ,IDHYDN,IDIST ,IDPDX ,IDPK  ,IDUR  ,IDR   ,IFLOW ,
     3   IFACTO,IFDIV ,IFINLE,IFLUX ,IFMULT,IFOLD ,IFSP  ,IFSPLI,IFXFLO,
     4   IGAP  ,IGAPN ,IGAPS ,IH    ,IHFILM,IHINLE,IHOLD ,IHPERI,IIDARE,
     5   IIDFUE,IIDGAP,IIK   ,IJBOIL,IJK   ,ILC   ,ILENGT,ILOCA ,ILR   ,
     6   IMCHFR,IMCFRC,IMCFRR,INTYPE,INWRAP,INWRPS,IP    ,IPERIM,IPH   ,
     7   IPHI  ,IPRNTC,IPRNTR,IPRNTN,IPW   ,IPWRF ,IQC   ,IQF   ,IQPRIM,
     8   IQUAL ,IRADIA,IRHO  ,IRHOOL,ISP   ,IT    ,ITDUMY,ITINLE,ITROD ,
     9   IU    ,IUH   ,IUSAVE,IUSTAR,IV    ,IVISC ,IVISCW,IVP   ,IVPA  ,
     A   IW    ,IWOLD ,IWP   ,IWSAVE,IX    ,IXCROS,IIA  ,IIB  ,IXPOLD
C-----------------------------------------------------------------------
C
C     HENCH-LEVY CORRELATION FOR CRITICAL HEAT FLUX
C
      G=DATA(IFLOW+I+MC*(J-1))*.0036/DATA(IA+I)
      XE=(DATA(IH+I+MC*(J-1))-HF)/HFG
      IF(DATA(IFLUX+N+MR*(J-1)).LE.0.) GO TO 10
      XC1=0.273-0.212*(TANH(3.*G))**2
      XC2=0.5-0.269*(TANH(3.*G))**2+0.0346*(TANH(2.*G))**2
      IF(XE.GE.XC2) Q=0.6-0.7*XE-0.09*(TANH(2.*G))**2
      IF(XE.GT.XC1.AND.XE.LT.XC2) Q=1.9-3.3*XE-0.7*(TANH(3.*G))**2
      IF(XE.LT.XC1) Q=1.0
      Q=Q*1.E6
      Q=Q*(1.1-0.1*((PREF-600.)/400.)**1.25)
      Q=Q/3600
      CHF3=Q
      RETURN
C
 10   CHF3=10.*DATA(IFLUX+N+MR*(J-1))
      RETURN
      END
```

```
C********************** FUNCTION CHF4 *********************************
      FUNCTION CHF4(N,I,J)
C
      IMPLICIT INTEGER (I)
      INTEGER IDAT(1)
      LOGICAL GRID
      REAL KIJ, KF, KKF, KCLAD, KFUEL
C
      COMMON  DATA(1)
      EQUIVALENCE  (DATA(1),IDAT(1))
C
      COMMON /COBRA1/  ABETA ,AFLUX ,ATOTAL,BBETA ,DIA   ,DT    ,DX    ,
     1   ELEV  ,FERROR,FLO   ,FTM   ,GC    ,GK    ,GRID  ,HSURF ,HF    ,
     2   HFG   ,HG    ,I2    ,I3    ,IERROR,IQP3  ,ITERAT,J1    ,J2    ,
     3   J3    ,J4    ,J5    ,J6    ,J7    ,KDEBUG,KF    ,KIJ   ,
     4   NAFACT,NARAMP,NAX   ,NAXL  ,NBBC  ,NCHAN ,NCHF  ,NDX   ,NF    ,
     5   NGAPS ,NGRID ,NGRIDT,NGTYPE,NGXL  ,NK    ,NODES ,NODESF,NPROP ,
     6   NRAMP ,NROD  ,NSCBC ,NV    ,NVISCW,PI    ,PITCH ,POWER ,PREF  ,
     7   QAX   ,RHOF  ,RHOG  ,SIGMA ,SL    ,TF    ,TFLUID,THETA ,THICK ,
     8   UF    ,VF    ,VFG   ,VG    ,Z
C
      COMMON /COBRA3/  MA    ,MC    ,MG    ,MN    ,MR    ,MS    ,MX    ,
     1         III   ,IA    ,IAAA  ,IAC   ,IALPHA,IAN   ,IANSWE,IB    ,
     1   ICCHAN,ICD   ,ICHFR ,ICON  ,ICOND ,ICP   ,ID    ,IDC   ,IDFDX ,
     2   IDHDX ,IDHYD ,IDHYDN,IDIST ,IDPDX ,IDPK  ,IDUR  ,IDR   ,IFLOW ,
     3   IFACTO,IFDIV ,IFINLE,IFLUX ,IFMULT,IFOLD ,IFSP  ,IFSPLI,IFXFLO,
     4   IGAP  ,IGAPN ,IGAPS ,IH    ,IHFILM,IHINLE,IHOLD ,IHPERI,IIDARE,
     5   IIDFUE,IIDGAP,IIK   ,IJBOIL,IJK   ,ILC   ,ILENGT,ILOCA ,ILR   ,
     6   IMCHFR,IMCFRC,IMCFRR,INTYPE,INWRAP,INWRPS,IP    ,IPERIM,IPH   ,
     7   IPHI  ,IPRNTC,IPRNTR,IPRNTN,IPW   ,IPWRF ,IQC   ,IQF   ,IQPRIM,
     8   IQUAL ,IRADIA,IRHO  ,IRHOOL,ISP   ,IT    ,ITDUMY,ITINLE,ITROD ,
     9   IU    ,IUH   ,IUSAVE,IUSTAR,IV    ,IVISC ,IVISCW,IVP   ,IVPA  ,
     A   IW    ,IWOLD ,IWP   ,IWSAVE,IX    ,IXCROS,IIA   ,IIB ,IXPOLD
C-----------------------------------------------------------------------
C
C     THE CISE CORRELATION IS USED TO ESTIMATE CRITICAL POWER
C
      IF(J.LE.IDAT(IJBOIL+I)) GO TO 100
C
      XLBL=.3048*DX*FLOAT(J-IDAT(IJBOIL+I))
      G=4.88*DATA(IFLOW+I+MC*(J-1))/DATA(IA+I)
      C1=(1.-PREF/3206.)
      GSTAR=3375.*C1**3
      DH=.3048*DATA(IDHYD+I)
      A=C1/(G*.001)**.333
      IF(G.LT.GSTAR) A=1./(1.+1.481E-4*C1**(-3)*G)
      B=0.199*(3206./PREF-1.)**0.4*G*DH**1.4
      XCR=(DATA(IHPERI+I)*A*XLBL)/(DATA(IPERIM+I)*(XLBL+B))
      XE=(DATA(IH+I+MC*(J-1))-HF)/HFG
      HSUB=HF-DATA(IH+I)
      CPR=(XCR*HFG+HSUB)/(XE*HFG+HSUB)
      CHF4=CPR
```

```
      RETURN
C
 100  CHF4=10.
      RETURN
      END
```

```
C*********************** FUNCTION CIJ *********************************
      FUNCTION CIJ(K,J)
C
      IMPLICIT INTEGER (I)
      INTEGER IDAT(1)
      REAL KIJ, KF, KKF, KCLAD, KFUEL
C
      COMMON  DATA(1)
      EQUIVALENCE  (DATA(1),IDAT(1))
C
      COMMON /COBRA1/  ABETA ,AFLUX ,ATOTAL,BBETA ,DIA   ,DT    ,DX    ,
     1   ELEV  ,FERROR,FLO   ,FTM   ,GC    ,GK    ,GRID  ,HSURF ,HF    ,
     2   HFG   ,HG    ,I2    ,I3    ,IERROR,IQP3  ,ITERAT,J1    ,J2    ,
     3   J3    ,J4    ,J5    ,J6    ,J7    ,KDEBUG,KF    ,KIJ   ,
     4   NAFACT,NARAMP,NAX   ,NAXL  ,NBBC  ,NCHAN ,NCHF  ,NDX   ,NF    ,
     5   NGAPS ,NGRID ,NGRIDT,NGTYPE,NGXL  ,NK    ,NODES ,NODESF,NPROP ,
     6   NRAMP ,NROD  ,NSCBC ,NV    ,NVISCW,PI    ,PITCH ,POWER ,PREF  ,
     7   QAX   ,RHOF  ,RHOG  ,SIGMA ,SL    ,TF    ,TFLUID,THETA ,THICK ,
     8   UF    ,VF    ,VFG   ,VG    ,Z
C
      COMMON /COBRA3/  MA    ,MC    ,MG    ,MN    ,MR    ,MS    ,MX    ,
     1          III   ,IA    ,IAAA  ,IAC   ,IALPHA,IAN   ,IANSWE,IB    ,
     1   ICCHAN,ICD   ,ICHFR ,ICON  ,ICOND ,ICP   ,ID    ,IDC   ,IDFDX ,
     2   IDHDX ,IDHYD ,IDHYDN,IDIST ,IDPDX ,IDPK  ,IDUR  ,IDR   ,IFLOW ,
     3   IFACTO,IFDIV ,IFINLE,IFLUX ,IFMULT,IFOLD ,IFSP  ,IFSPLI,IFXFLO,
     4   IGAP  ,IGAPN ,IGAPS ,IH    ,IHFILM,IHINLE,IHOLD ,IHPERI,IIDARE,
     5   IIDFUE,IIDGAP,IIK   ,IJBOIL,IJK   ,ILC   ,ILENGT,ILOCA ,ILR   ,
     6   IMCHFR,IMCFRC,IMCFRR,INTYPE,INWRAP,INWRPS,IP    ,IPERIM,IPH   ,
     7   IPHI  ,IPRNTC,IPRNTR,IPRNTN,IPW   ,IPWRF ,IQC   ,IQF   ,IQPRIM,
     8   IQUAL ,IRADIA,IRHO  ,IRHOOL,ISP   ,IT    ,ITDUMY,ITINLE,ITROD ,
     9   IU    ,IUH   ,IUSAVE,IUSTAR,IV    ,IVISC ,IVISCW,IVP   ,IVPA  ,
     A   IW    ,IWOLD ,IWP   ,IWSAVE,IX    ,IXCROS,IIA  ,IIB  ,IXPOLD
C------------------------------------------------------------------------
C
      GGG=DATA(IGAP+K)
      IF(GGG.LE.0.0)  GO TO 1000
      II=IDAT(IIK+K)
      JJ=IDAT(IJK+K)
      RSTAR=DATA(IRHO+II+MC*(J-1))
      IF(DATA(IW+K+MG*(J-1)).LT.0.0) RSTAR=DATA(IRHO+JJ+MC*(J-1))
      WMIN=ABS(DATA(IW+K+MG*(J-1)))
      IF(WMIN.LT..001) WMIN = .001
      CIJ=KIJ*WMIN*0.5/GC/RSTAR/GGG/GGG
      CIJ=CIJ/DATA(IFACTO+K)**2
      RETURN
 1000 IERROR = 18
      RETURN
      END
```

```
C********************** FUNCTION HCOOL ********************************
      FUNCTION HCOOL(N,I,JJ)
C
C     COMPUTES THE HEAT TRANSFER COEFFICIENT FOR ROD N FACING
C     SUBCHANNEL I AT AXIAL LOCATION J.
C     USING THOM/JENS/LOTTES SUBCOOLED BOILING HEAT TRANSFER COEFF.
C     PROC.I.M.E. VOL 180, PART 3C, PAGES 226-246 (1965-6)
C     HCOOL CALC BY FWD DIFFERENCING, IE FROM CONDITIONS IN LAST INTVL.
C     JJ = J-1 WHEN CALLED FROM HEAT   AND J FROM PROP.
C-----------------------------------------------------------------------
C
      IMPLICIT INTEGER (I)
      LOGICAL GRID
      REAL KIJ, KF, KKF, KCLAD, KFUEL
C
      COMMON  DATA(1)
C
      COMMON /COBRA1/  ABETA ,AFLUX ,ATOTAL,BBETA ,DIA   ,DT    ,DX    ,
     1   ELEV  ,FERROR,FLO   ,FTM   ,GC    ,GK    ,GRID  ,HSURF ,HF    ,
     2   HFG   ,HG    ,I2    ,I3    ,IERROR,IQP3  ,ITERAT,J1    ,J2    ,
     3   J3    ,J4    ,J5    ,J6    ,J7    ,KDEBUG,KF    ,KIJ   ,
     4   NAFACT,NARAMP,NAX   ,NAXL  ,NBBC  ,NCHAN ,NCHF  ,NDX   ,NF    ,
     5   NGAPS ,NGRID ,NGRIDT,NGTYPE,NGXL  ,NK    ,NODES ,NODESF,NPROP ,
     6   NRAMP ,NROD  ,NSCBC ,NV    ,NVISCW,PI    ,PITCH ,POWER ,PREF  ,
     7   QAX   ,RHOF  ,RHOG  ,SIGMA ,SL    ,TF    ,TFLUID,THETA ,THICK ,
     8   UF    ,VF    ,VFG   ,VG    ,Z
C
      COMMON /COBRA3/  MA    ,MC    ,MG    ,MN    ,MR    ,MS    ,MX    ,
     1          III   ,IA    ,IAAA  ,IAC   ,IALPHA,IAN   ,IANSWE,IB    ,
     1   ICCHAN,ICD   ,ICHFR ,ICON  ,ICOND ,ICP   ,ID    ,IDC   ,IDFDX ,
     2   IDHDX ,IDHYD ,IDHYDN,IDIST ,IDPDX ,IDPK  ,IDUR  ,IDR   ,IFLOW ,
     3   IFACTO,IFDIV ,IFINLE,IFLUX ,IFMULT,IFOLD ,IFSP  ,IFSPLI,IFXFLO,
     4   IGAP  ,IGAPN ,IGAPS ,IH    ,IHFILM,IHINLE,IHOLD ,IHPERI,IIDARE,
     5   IIDFUE,IIDGAP,IIK   ,IJBOIL,IJK   ,ILC   ,ILENGT,ILOCA ,ILR   ,
     6   IMCHFR,IMCFRC,IMCFRR,INTYPE,INWRAP,INWRPS,IP    ,IPERIM,IPH   ,
     7   IPHI  ,IPRNTC,IPRNTR,IPRNTN,IPW   ,IPWRF ,IQC   ,IQF   ,IQPRIM,
     8   IQUAL ,IRADIA,IRHO  ,IRHOOL,ISP   ,IT    ,ITDUMY,ITINLE,ITROD ,
     9   IU    ,IUH   ,IUSAVE,IUSTAR,IV    ,IVISC ,IVISCW,IVP   ,IVPA  ,
     A   IW    ,IWOLD ,IWP   ,IWSAVE,IX    ,IXCROS,IIA   ,IIB  ,IXPOLD
C-----------------------------------------------------------------------
C
      IF (N+1) 6,4,2
    2 IF (DATA(IQUAL+I).GT.0.0) GO TO 6
C
C     SINGLE PHASE AND ENTRY FROM PROP (N=-1)
    4 RE=DATA(IFLOW+I+MC*(JJ-1))/DATA(IA+I)*DATA(IDHYD+I)/DATA(IVISC+I)
      IF(RE.LT.2000.) RE = 2000.
      PR=DATA(ICP+I)*DATA(IVISC+I)/DATA(ICON+I)
C     HCOOL          =0.023*DATA(ICON+I)/DATA(IDHYD+I)*RE**.8*PR**.4
      HCOOL      = 0.134*DATA(ICON+I)/DATA(IDHYD+I)*RE**.65*PR**.4
      RETURN
C
```

```
C     TWO PHASE AND ENTRY FROM PROP(N=-2)
  6   FI = 3600.0*DATA(IQPRIM+I)/DATA(IHPERI+I)
      IF(FI.LT.0.) FI=ABS(FI)
      DTSAT = 0.072*(FI**0.5)*EXP(-PREF/1260.0)
      IF (N.GE.0) GO TO 8
      HCOOL = DTSAT
      RETURN
  8   DTTOT = DTSAT + TF - DATA(IT+I)
      HCOOL = FI/(3600.0*DTTOT)
      RETURN
      END
```

```
C********************** FUNCTION HLIQ ********************************
      FUNCTION HLIQ(P)
C
      U=ALOG(P)
      IF(P.LE.265.0) GO TO 2
      U=U-7.0
      HLIQ=((((((-0.58728711D00*U+0.11490811D01)*U+0.74153448D01)*U
     1+0.1080109D02)*U+0.13891584D02)*U+0.37492429D02)*U
     2+0.16078158D03)*U+0.55715337D03
      RETURN
    2 HLIQ=(((((((((-0.4771D-04*U+0.84618D-03)*U-0.533926D-02)*U
     1+0.12037370D-01)*U+0.908507D-02)*U-0.6628012D-01)*U
     2+0.41031089D-01)*U+0.28766511D-00)*U+0.22225855D01)*U
     3+0.33320422D02)*U+0.69795537D02
      RETURN
      END
```

```
C********************** FUNCTION HVAP ********************************
      FUNCTION HVAP(P)
C
      U=ALOG(P)
      IF(P.LE.450.0) GO TO 2
      U=U-7.0
      HVAP=(((((0.37170416D01*U-0.91118126D01)*U-0.2444781D02)*U
     1-0.27217176D02)*U-0.44206896D02)*U-0.46351642D02)*U
     2+0.11876082D04
      RETURN
  2   HVAP=((((((-0.3674D-04*U-0.5862D-03)*U+0.43507598D-02)*U
     1-0.14535040D-01)*U+0.22775919D-01)*U
     2+0.85550917D0)*U+0.14228318D02)*U+0.11059625D04
      RETURN
      END
```

```
C********************** FUNCTION ROLIQ **********************************
      FUNCTION ROLIQ(P)
C
      U=ALOG(P)
      IF(P.LE.450.0) GO TO 2
      U=U-7.0
      VLIQ=(((((-0.26381D-03*U+0.142678D-02)*U+0.21252D-02)*U
     1+0.119227D-02)*U+0.197421D-02)*U+0.404696D-02)*U
     2+0.21963280D-1
      ROLIQ=1.0/VLIQ
      RETURN
    2 VLIQ=(((((((0.468D-08*U-0.747D-07)*U+0.39696D-06)*U
     1-0.36945D-06)*U-0.204944D-05)*U+0.67462798D-05)*U
     2+0.33132739D-04)*U+0.10394514D-03)*U+0.16140836D-1
      ROLIQ=1.0/VLIQ
      RETURN
      END
```

```
C********************** FUNCTION ROVAP ********************************
      FUNCTION ROVAP(P)
C
      U=ALOG(P)
      IF(P.LE.450.0) GO TO 2
      U=U-7.0
      PVG=(((((0.47458752D01*U-0.65913524D01)*U-0.22430605D02)*U
     1-0.27967054D02)*U-0.53007282D02)*U-0.61514691D02)*U
     2+0.43997464D03
      ROVAP=P/PVG
      RETURN
    2 PVG=(((((((-0.186D-05*U-0.12008D-03)*U+0.67223D-03)*U
     1-0.307139D-02)*U-0.631126D-02)*U+0.60001629D-01)*U
     2+0.11039315D01)*U+0.19257401D02)*U+0.33360056D03
      ROVAP=P/PVG
      RETURN
      END
```

```
C*********************** FUNCTION S **********************************
      FUNCTION S(K,I)
C
      IMPLICIT INTEGER (I)
      INTEGER IDAT(1)
      COMMON  DATA(1)
      EQUIVALENCE  (DATA(1),IDAT(1))
C
      COMMON /COBRA3/  MA     ,MC     ,MG     ,MN     ,MR     ,MS     ,MX     ,
     1          III    ,IA     ,IAAA   ,IAC    ,IALPHA,IAN    ,IANSWE,IB     ,
     1    ICCHAN,ICD    ,ICHFR  ,ICON   ,ICOND  ,ICP    ,ID     ,IDC    ,IDFDX  ,
     2    IDHDX ,IDHYD  ,IDHYDN,IDIST  ,IDPDX  ,IDPK   ,IDUR   ,IDR    ,IFLOW  ,
     3    IFACTO,IFDIV  ,IFINLE,IFLUX  ,IFMULT,IFOLD  ,IFSP   ,IFSPLI,IFXFLO,
     4    IGAP  ,IGAPN  ,IGAPS  ,IH     ,IHFILM,IHINLE,IHOLD  ,IHPERI,IIDARE,
     5    IIDFUE,IIDGAP,IIK    ,IJBOIL,IJK    ,ILC    ,ILENGT,ILOCA  ,ILR    ,
     6    IMCHFR,IMCFRC,IMCFRR,INTYPE,INWRAP,INWRPS,IP     ,IPERIM,IPH    ,
     7    IPHI  ,IPRNTC,IPRNTR,IPRNTN,IPW    ,IPWRF  ,IQC    ,IQF    ,IQPRIM,
     8    IQUAL ,IRADIA,IRHO   ,IRHOOL,ISP    ,IT     ,ITDUMY,ITINLE,ITROD  ,
     9    IU    ,IUH    ,IUSAVE,IUSTAR,IV     ,IVISC  ,IVISCW,IVP    ,IVPA   ,
     A    IW    ,IWOLD  ,IWP    ,IWSAVE,IX     ,IXCROS,IIA   ,IIB   ,IXPOLD
C-----------------------------------------------------------------------
C
      S = 0.
      IF(I.EQ.IDAT(IIK+K))    S =  1.
      IF(I.EQ.IDAT(IJK+K))    S = -1.
      RETURN
      END
```

```
C********************** FUNCTION SATTEM ********************************
      FUNCTION SATTEM(P)
C
      REAL *8 U,XATTEM
C-----------------------------------------------------------------------
      XX=ALOG(P)
      U=DBLE(XX)
      IF(P.LE.450.0) GO TO 2
      U=U-7.0D0
      XATTEM=((((-0.16074225D-00*U-0.69678576D0)*U+0.61781119D0)*U
     1+0.14657783D02)*U+0.12405875D03)*U+0.55599496D03
      SATTEM=SNGL(XATTEM)
      RETURN
  2   XATTEM=(((-0.198D-05*U+0.1405D-04)*U-3.265D-5)*U+
     1 2.3907D-3)
      XATTEM=(((XATTEM*U+0.434618D-02)*U+0.17363004D0)*U+0.22808149D01)
      XATTEM=((XATTEM*U+0.33446776D02)*U+0.10182494D3)
      SATTEM=SNGL(XATTEM)
      RETURN
      END
```

```
C********************** FUNCTION SCQUAL ********************************
      FUNCTION SCQUAL(I,J)
C
C     LEVY SUBCOOLED MODEL.  CALCULATES TRUE QUALITY AS A CORRECTION TO
C     THE EQUILIBRIUM QUALITY.
C-----------------------------------------------------------------------
      IMPLICIT INTEGER (I)
      LOGICAL GRID
      REAL KIJ, KF, KKF, KCLAD, KFUEL
C
      COMMON  DATA(1)
C
      COMMON /COBRA1/  ABETA ,AFLUX ,ATOTAL,BBETA ,DIA   ,DT    ,DX    ,
     1   ELEV  ,FERROR,FLO   ,FTM   ,GC    ,GK    ,GRID  ,HSURF ,HF    ,
     2   HFG   ,HG    ,I2    ,I3    ,IERROR,IQP3  ,ITERAT,J1    ,J2    ,
     3   J3    ,J4    ,J5    ,J6    ,J7    ,KDEBUG,KF    ,KIJ   ,
     4   NAFACT,NARAMP,NAX   ,NAXL  ,NBBC  ,NCHAN ,NCHF  ,NDX   ,NF    ,
     5   NGAPS ,NGRID ,NGRIDT,NGTYPE,NGXL  ,NK    ,NODES ,NODESF,NPROP ,
     6   NRAMP ,NROD  ,NSCBC ,NV    ,NVISCW,PI    ,PITCH ,POWER ,PREF  ,
     7   QAX   ,RHOF  ,RHOG  ,SIGMA ,SL    ,TF    ,TFLUID,THETA ,THICK ,
     8   UF    ,VF    ,VFG   ,VG    ,Z
C
      COMMON /COBRA3/  MA    ,MC    ,MG    ,MN    ,MR    ,MS    ,MX    ,
     1          III   ,IA    ,IAAA  ,IAC   ,IALPHA,IAN   ,IANSWE,IB    ,
     1   ICCHAN,ICD   ,ICHFR ,ICON  ,ICOND ,ICP   ,ID    ,IDC   ,IDFDX ,
     2   IDHDX ,IDHYD ,IDHYDN,IDIST ,IDPDX ,IDPK  ,IDUR  ,IDR   ,IFLOW ,
     3   IFACTO,IFDIV ,IFINLE,IFLUX ,IFMULT,IFOLD ,IFSP  ,IFSPLI,IFXFLO,
     4   IGAP  ,IGAPN ,IGAPS ,IH    ,IHFILM,IHINLE,IHOLD ,IHPERI,IIDARE,
     5   IIDFUE,IIDGAP,IIK   ,IJBOIL,IJK   ,ILC   ,ILENGT,ILOCA ,ILR   ,
     6   IMCHFR,IMCFRC,IMCFRR,INTYPE,INWRAP,INWRPS,IP    ,IPERIM,IPH   ,
     7   IPHI  ,IPRNTC,IPRNTR,IPRNTN,IPW   ,IPWRF ,IQC   ,IQF   ,IQPRIM,
     8   IQUAL ,IRADIA,IRHO  ,IRHOOL,ISP   ,IT    ,ITDUMY,ITINLE,ITROD ,
     9   IU    ,IUH   ,IUSAVE,IUSTAR,IV    ,IVISC ,IVISCW,IVP   ,IVPA  ,
     A   IW    ,IWOLD ,IWP   ,IWSAVE,IX    ,IXCROS,IIA   ,IIB   ,IXPOLD
C-----------------------------------------------------------------------
C
      XP=DATA(IQUAL+I)
      DATA(IXPOLD+I)=0.
      SCQUAL = XP
      IF(DATA(IQPRIM+I).LE.0.)  RETURN
      CNC = 0.015
      JJ=J
C     ******* THE FOLLOWING CARDS CORRECT THE LEVY MODEL
      YB=CNC/UF   *3600.   *SQRT( SIGMA    *GC*DATA(IDHYD+I)/VF)
      TAUW= DATA(IFSP+I)*.125*VF*(DATA(IFLOW+MC*(J-1)+I)/
     1DATA(IA+I))**2/GC
      PR=DATA(ICP+I)*UF/KF
      Q=DATA(IQPRIM+I)/(DATA(IHPERI+I)/VF*DATA(ICP+I)*SQRT(TAUW*GC*VF))
      RE=DATA(IFLOW+I+MC*(J-1))/DATA(IA+I)*DATA(IDHYD+I)/DATA(IVISC+I)
      IF(RE.LT.2000.)  RE=2000.
      HTC=DATA(ICON+I) /DATA(IDHYD+I)*.023*RE**.8*PR**.4
      DELTAT=DATA(IQPRIM+I)/DATA(IHPERI +I)/HTC
```

```
C     *******
      IF(YB.GE.0..AND. YB.LT.5.) DELTAT = DELTAT - Q*PR*YB
      IF(YB.GE.5..AND. YB.LT.30.)DELTAT = DELTAT
     1 - 5.*Q*(PR+ALOG(1.+PR*(YB*.2-1.)))
      IF(YB.GE.30.) DELTAT = DELTAT - 5.*Q*(PR+ALOG(1.+5.*PR)
     1 + .5*ALOG(YB/30.))
      XD=-DATA(ICP+I)*DELTAT/HFG
      ARG=DATA(IQUAL+I)/XD-1.
      IF (ARG.LT.-15.0) GO TO 140
      IF(ARG.GT.0.) ARG = 0.
      XP =DATA(IQUAL+I)-XD*EXP(ARG)
C     ******* THE FOLLOWING CARDS CORRECT THE LEVY MODEL
      IF(DATA(IQUAL+I).LT.XD) XP=0.
      IF(J7.EQ.2)  GO TO 130
      IF(ITERAT.EQ.1) DATA(IXPOLD+I+MC*(J-1))=XP
      DUMY=DATA(IXPOLD+I+MC*(J-1))
      XP=.99*XP+.01*DUMY
 130  IF(JJ.EQ.1)  JJ=2
      XP=AMAX1(XP,DATA(IXPOLD+I+MC*(JJ-2)))
      DATA(IXPOLD+I+MC*(J-1))=XP
  140 SCQUAL = XP
      RETURN
      END
```

APPENDIX F
SUGGESTIONS FOR POSSIBLE IMPROVEMENTS TO COBRA IIIc/MIT

Following extensive work with the current version of COBRA IIIc/MIT-2, both in the production of this manual and in actual applications, The author wishes to make the following suggestions for improvement to the code. In general, the suggestions are designed to improve the usability without necessarily increasing the capabilities.

SUGGESTIONS

1) In the evolution of the current code, three input methods have been developed and incorporated into the coding. A major priority in the development of the various methods was preserving the code's compatibility with older data decks. Although admirable in intent, the duplication in the methods has added unnecessary length to the coding and excessively complicated the job of assembling new input files. A new input method should be developed to replace all three of the older methods. The new method should incorporate all of the options currently available in any of the other methods.

The format currently used in the card group 20 method holds the greatest promise for developing into the consolidated method suggested above. A few suggestions follow for alterations which could be made.

1.a The options currently available in the older methods which are not available in the Card Group 20 method should be added. These include the option to read in and print out multiple cards of text for use as a memory aid; the option to read in the fluid property table rather than calculate it internally; the option to use the IMAP = 4 channel map input scheme; and the wire wrap diversion crossflow option.

1.b The Card Group 20 Method should be simplified to eliminate the redundancy of reading in constants which are only used to indicate that a card follows which contains other constants. An example of this duplication is found on card 23-HM. By assigning values to the indicators N3 through N9 other than their current on/off options, several of the following "HM" type cards could be eliminated.

1.c The option to read in only selected portions of the input deck for additional cases should be preserved without resorting to the use of Group Control Cards. The selection of which groups would be read in could be accomplished through on/off flags read in on a single card at the start of the input for each case.

The following suggestions are possible independant of whether or not an entirely new input method is desired.

2) The current method for reading in nodal fuel and coolant powers is cumbersome and bulky. Through methods similar to those used to read in the channel data (ie. through the use of similar types of profiles) this portion of the input data could be greatly simplified and reduced. A suggested method would be to read in axial relative power profile types and then specify only the values of the radial power factors, and the average nodal power. The profiles, radial power factors, and average nodal powers for the coolant and fuel shoud be inputed seperately.

3) The formats of input read in subroutine READIN should be altered to provide additional length to the input fields. This alteration is necessary not for the additional accuracy it could provide (which would be negligible compared to the the inaccuracies of the code itself), but to allow for blank spaces between the input values. Such blank space would greatly simplify the process of debugging the input deck.

4) Add blank spaces between the columns of the debug and terminal error printouts. In their current form, the values run into one another making the printouts difficult if not impossible to read.

5) Add error checks to the input data which check that all input variables are within acceptable ranges. Due to the increases in run time which could result from such checks, an option should be provided to disable them. These input range checks could eliminate a little of the flexibility in the input, but enough is already available that the portion lost could be negligible. An example of the use of such checks would be variable PHI (fraction of rod power given to a specified channel) on card 15-RD. Currently PHI can even be given greater than 1.0 which is useful for the input of smeared rod powers. However, if PHI is greater than one due to an input error (say the ommision of a decimal point), the calculations would be severely erroneous. A data range check would eliminate the possibility that such an error would go un detected but would also eliminate the option to smear the rod power by specifing an artificially large value for PHI. Since other options are already available (such as giving a large value for either FRAC, HNR (The number of heated rods) or RADIA (The radial power factor) little would be lost in terms of actual capabilities, and nothing would be lost if the option to disarm the input range checking were provided.

6) Indicators should also be added to allow the user to select the heat transfer correlation used in subroutine HCOOL if desired. This would necessarily be unavailable if the BEEST heat transfer model were selected.

The following suggestions are for improvements which could make the code more efficient.

7) The problem dependent variable arrays FACSL(I) and FACSLK(I) are currently dimensioned to 100 each. This dimension wastes space for small cases and could be insufficient for large cases. To eliminate this problem, both variable arrays should be merged into the "DATA" array and variably dimensioned to the value of MG on card I1.

8) In many instances, the calculations of the subscript values for elements of the "DATA" array are repetitive. Values such as "J-1" could be calculated once and stored. Within the do loops over the channel, rod, and gap numbers elimination of such repetitive calculations could have beneficial effects on the run time.

9) Rather than repeatedly search through all the gaps in the problem looking for those which communicate with a specific channel, advantage could be taken of the data already stored in the LOCA array. Since the LOCA array contains lists of all the communicating gaps for each channel, excessive searching could be eliminated. This same method could also be applied to searches over all channels looking for which ones receive energy from a particular rod, since this information is already available in the LR array contained in the "DATA" array.

10) Several of the variables calculated and stored in the "DATA" array are redundant. Their elimination could reduce the storage requirements and run time for most jobs.

11) In the preparation of this manual it was noted that the W-3 correlation used in COBRA IIIc/MIT-2 does not agree with that given in reference 50. Since the version of the W-3 correlation in reference 50 has been thoroughly checked out by both Todreas and Westinghouse, it is suggested that the version of the correlation which is used by COBRA IIIc/MIT-2 be changed.

Some of the above suggestions could be simply implimented while others will require major efforts. It is the sincere wish of the authors of this code manual that the efforts will eventually be undertaken. To facilitate the updating and correction of this manual as the revisions are made, the entire text has been stored on magnetic tape. This tape is available from the computer code librarian of the Nuclear Engineering Department at The Massachusetts Institute of Technology.