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HETRAN — A COMPUTER PROGRAM TO SOLVE THE TWO-DIMENSIONAL STEADY-STATE HEAT CONDUCTION ON A CLADDED TUBE WITH A CONNECTING FIN

by Frank B. Molls

Lewis Research Center
Cleveland, Ohio 44135

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16. Abstract

HETRAN, a computer program, has been written in FORTRAN IV, version 13, for the IBM 7094/7044 DCS to solve the two-dimensional equation $\nabla \cdot [K(T)\nabla T] = 0$, with convective boundary conditions on a cladded tube with a connecting fin. The tube wall, cladding, and fin can be made of different materials. The required input consists of an initial guess to the solution, the parameters defining the region, the heat transfer coefficients on the boundaries, the coolant and gas temperatures, and the relaxation parameters. Temperature dependent thermal conductivity is handled by a user supplied subroutine.

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SUMMARY

HETRAN, a computer program, has been written in FORTRAN IV, version 13, for the IBM 7094/7044 DCS to solve the two-dimensional equation $\nabla \cdot [K(T)\nabla T] = 0$, with convective boundary conditions on a cladded tube with a connecting fin. The tube wall, cladding, and fin can be made of different materials. The required input consists of an initial guess to the solution, the parameters defining the region, the heat transfer coefficients on the boundaries, the coolant and gas temperatures, and the relaxation parameters. Temperature dependent thermal conductivity is handled by a user supplied subroutine.

INTRODUCTION

There are several programs available for solving the two-dimensional steady-state heat conduction on arbitrary regions. However, they require as input a large amount of detail concerning the grid that is superimposed on the region. This leads to an excessive amount of manual preparation, especially if solutions are desired for a varied set of configurations. HETRAN is designed to overcome this difficulty for a particular type of geometry since it is a computer program which generates the grid.

HETRAN was originally written to determine design criteria for rocket nozzle tubes. A detailed discussion of this problem may be found in reference 1.

Following the presentation of mathematical development, the FORTRAN IV program, HETRAN, is presented with a complete description of the required input and the output obtained. The input and output for an example case is also given.

SYMBOLS

A	one of subregions of tube
A_1	one of subregions of cladding
B	one of subregions of tube
B_1	one of subregions of fin
D	one of subregions of tube
D_1	one of subregions of cladding
f_k	thickness of fin measured between sides of rectangle, cm
h_c	heat transfer coefficient on coolant side of tube, W/m^2
h_g	heat transfer coefficient on cladded, heated gas side of tube, W/m^2
K_i	conductivity of i^{th} material (i = 1, 2, 3), J/(m)(sec)(K)
MAT_i	i^{th} material (i = 1, 2, 3)
P	one of rectangular subregions of tube
P_1	rectangular subregion of fin
Q	one of subregions of tube
Q_1	one of subregions of fin
r_1	radius to inner wall of tube (top arc), cm
r_2	radius to interface between outer wall of tube and inner arc of cladding, cm
r_3	radius to outer boundary of cladding, cm
r_{1b}	radius to inner wall of tube (bottom arc), cm
r_{2b}	radius to outer wall of tube (bottom arc), cm
T	temperature, K
$T(I,J)$	temperature at I^{th}, J^{th} grid point, K
T_c	temperature of coolant, K
T_g	temperature of gas, K
T_{ref_1}	reference temperature used as lower limit in Kirchoff Transform for material 1, K
T_{ref_2}	reference temperature used as lower limit in Kirchoff Transform for material 2, K

T_{ref_3} reference temperature used as lower limit in Kirchoff Transform for material 3, K

u_i dependent variable for i^{th} material obtained from Kirchoff Transform

$u_i(I, J)$ dependent variable for i^{th} material at I^{th}, J^{th} grid point

x_L length of bottom rectangular section of tube, cm

x_m length of middle rectangular section of tube and fin, cm

y_1 perpendicular distance from top of middle rectangular section of fin to interface of cladding and fin, cm

y_{1b} perpendicular distance from bottom of middle rectangular section of fin to lower end of fin, cm

ZL one of subregions of tube

ZR one of rectangular subregions of tube

∂_i i^{th} boundary (i = 1, 2, . . ., 8) of tube, cladding, and fin

θ_A angle corresponding to subregions A and A_1, rad

θ_B angle corresponding to subregions B and B_1, rad

θ_D angle corresponding to subregions D and D_1, rad

θ_{TOP} angle by which top circular arc of tube is less than $\pi/2$ radians, rad

θ_Q angle corresponding to subregions Q and Q_1, rad

θ_Z angle corresponding to subregions ZL, rad

STATEMENT OF THE PROBLEM

HETRAN solves the two-dimensional equation

$$\nabla \cdot [K(T)\nabla T] = 0 \tag{1}$$

with boundary conditions

$$-K(T)\frac{\partial T}{\partial n} = h_c(T_c - T) \qquad \text{on } \partial_3$$

$$-K(T)\frac{\partial T}{\partial n} = h_g(T_g - T) \qquad \text{on } \partial_8$$

$$\frac{\partial T}{\partial n} = 0 \qquad \text{on } \partial_1, \partial_2, \partial_4, \partial_5, \partial_6, \partial_7$$

for the geometry shown in figure 1. The geometry represents a tube with cladding and a connecting fin. The tube is convectively cooled on its interior boundary, convectively

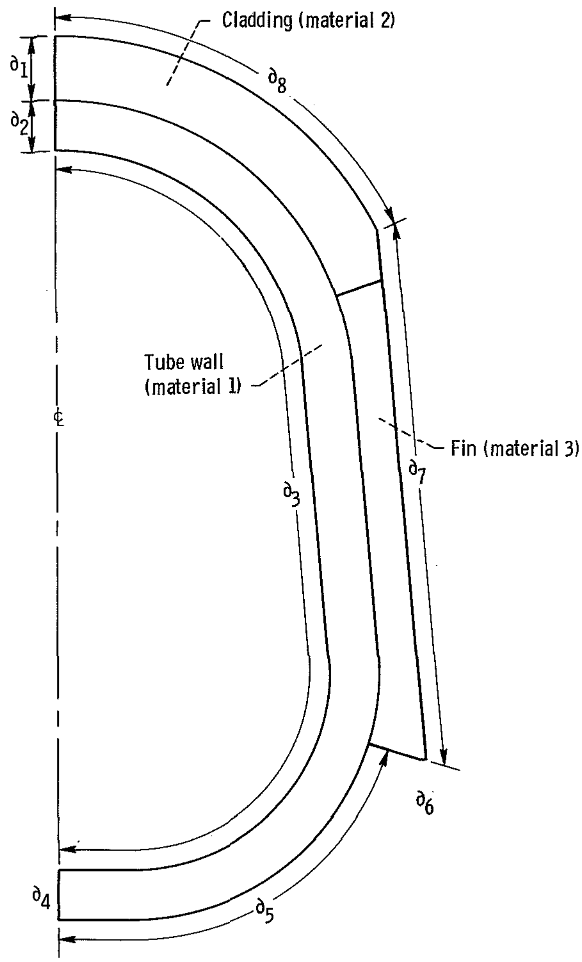

Figure 1. - Geometry on which equation (1) is solved.

heated on the outer boundary of the cladding, and insulated on the other boundaries. The tube wall, cladding, and connecting fin can be made of materials with different conductivities in which case equation (1) has discontinuous coefficients. We assume perfect thermal contact and continuity of heat flow at the interface of differing materials. Therefore, each point of the interface between different materials, say material 1 and material 2, satisfies

$$T_{MAT_1} = T_{MAT_2}$$

$$K_1 \left.\frac{\partial T}{\partial n}\right|_{MAT_1} = K_2 \left.\frac{\partial T}{\partial n}\right|_{MAT_2}$$

METHOD OF SOLUTION

Equation (1) and its associated boundary conditions are transformed by means of the Kirchoff transformation (ref. 2, sec. 2.1) leading to Laplace's equation on the interior of the region. Defining the following transformations:

$$u_1 = \int_{T_{ref_1}}^{T} K_1(z)dz \qquad (2a)$$

$$u_2 = \int_{T_{ref_2}}^{T} K_2(z)dz \qquad (2b)$$

$$u_3 = \int_{T_{ref_3}}^{T} K_3(z)dz \qquad (2c)$$

Applying these transformations to equation (1) and its boundary conditions results in a set of equations, one for each material region.

For material 1:

$$\nabla^2 u_1 = 0 \qquad (3)$$

$$-\frac{\partial u_1}{\partial n} = h_c(T_c - T) \qquad \text{on } \partial_3$$

$$\frac{\partial u_1}{\partial n} = 0 \qquad \text{on } \partial_2,\ \partial_4,\ \partial_5$$

For material 2:

$$\nabla^2 u_2 = 0$$

$$-\frac{\partial u_2}{\partial n} = h_g(T_g - T) \qquad \text{on } \partial_8$$

$$\frac{\partial u_2}{\partial n} = 0 \qquad \text{on } \partial_1 \tag{4}$$

For material 3:

$$\nabla^3 u_3 = 0$$

$$\frac{\partial u_3}{\partial n} = 0 \qquad \text{on } \partial_6, \ \partial_7$$

These equations are coupled along their interfaces by the assumptions of perfect heat contact and continuity of heat flow.

Next, the composite region of figure 1 is divided into 12 subregions (fig. 2). A grid, part of which is radial and part rectangular, is superimposed on these subregions in such a fashion that each of the boundaries and material interfaces lies on a grid line.

The Laplacian on the interior of each of the subregions is replaced by the regular five point difference formula and the resulting matrix solved by successive line overrelaxation (ref. 3, sec. 6.4). The points on the boundaries and along material interfaces are solved by point overrelaxation. Since the equations at these points are nonlinear, an iterative method for solution is required.

The derivation of the difference equations for these special points will be illustrated by taking typical points on the radial grid of regions A and A_1.

Let (I, J) be an ordered pair of integers where I refers to the radial position on the grid and J the angular position. Then the point (1, J) is on the inner boundary of region A at the J^{th} angular subdivision. Let a cell (cross-hatched area in fig. 3) be taken about this point in the manner of reference 3, page 11.

The difference equation at (1, J) is obtained in the following steps:

$$0 = \int_{\text{cell}} \nabla^2 u_1 \, dA = \oint_{\text{around cell}} \frac{\partial u_1}{\partial n} \, ds$$

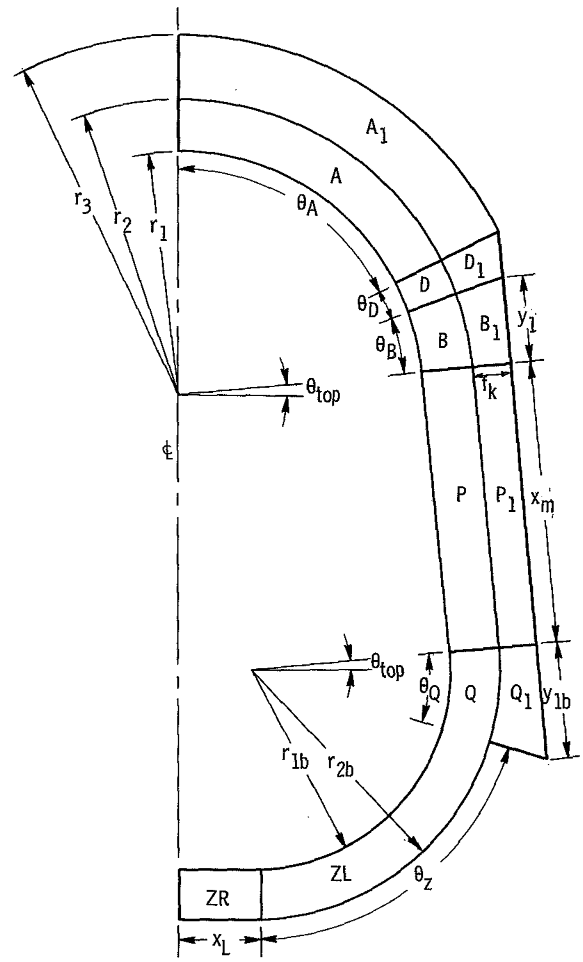

Figure 2. - Composite region divided into 12 subregions.

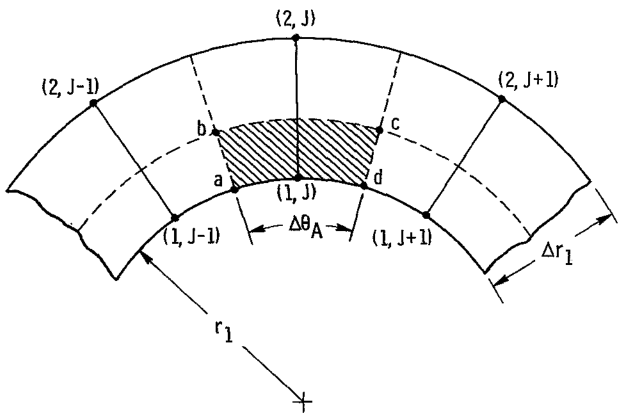

Figure 3. - Detail of grid for boundary point on region A.

$$0 = \int_{a-b} \frac{\partial u_1}{\partial_\theta} ds + \int_{b-c} \frac{\partial u_1}{\partial r} ds + \int_{c-d} - \frac{\partial u_1}{\partial_\theta} ds + \int_{d-a} \frac{\partial u_1}{\partial r} ds$$

$$0 \approx \frac{u_1(1,J) - u_1(1,J-1)}{2r_1 \sin \frac{\Delta\theta_A}{2}} \frac{\Delta r_1}{2} + \frac{u_1(1,J) - u_2(2,J)}{\Delta r_1}\left(r_1 + \frac{\Delta r_1}{2}\right)\Delta\theta_A$$

$$+ \frac{u_1(1,J) - u_1(1,J+1)}{2r_1 \sin \frac{\Delta\theta_A}{2}} \frac{\Delta r_1}{2} - h_c\left[T_c - T(1,J)\right] r_1 \, \Delta\theta_A \tag{5}$$

The temperature $T(1,J)$ is not known. But assuming a previous estimate of u_1 at $(1,J)$, say $\bar{u}_1(1,J)$ and a corresponding temperature $\bar{T}(1,J)$, it is possible to approximate $T(1,J)$. Let

$$f(T) = u_1 - \int_{T_{ref_1}}^{T} K_1(z)dz$$

$$\frac{df}{dT} = -K_1(T)$$

Expanding $f(T)$ in a Taylor's series about $\bar{T}(1,J)$ and truncating after the second term of the series result in

$$f(T) \approx f(\bar{T}) + (T - \bar{T}) \left.\frac{df}{dT}\right|_{T=\bar{T}} \tag{6}$$

$$0 \approx u_1 - \int_{T_{ref_1}}^{\bar{T}} K_1(z)dz - (T - \bar{T})K_1(\bar{T})$$

$$T(1,J) \approx \frac{u_1(1,J)}{K_1\left[\overline{T}(1,J)\right]} - \frac{\int_{T_{ref_1}}^{\overline{T}(1,J)} K_1(Z)dZ}{K_1\left[\overline{T}(1,J)\right]} + \overline{T}(1,J) \tag{7}$$

Substituting equation (7) into equation (5), rearranging, and solving for $u_1(1,J)$ give

$$u_1(1,J) = \frac{\Delta r_1}{4r_1 \sin \frac{\Delta\theta_A}{2}}\left[u_1(1,J-1) + u_1(1,J+1)\right] + \left(r_1 + \frac{\Delta r_1}{2}\right)\frac{\Delta\theta_A}{\Delta r_1}\, u_1(2,J) + h_c r_1 \,\Delta\theta_A$$

$$\times \left[T_c - \overline{T}(1,J) + \frac{\int_{T_{ref_1}}^{\overline{T}(1,J)} K_1(z)dz}{K_1\left[\overline{T}(1,J)\right]}\right] \frac{\Delta r_1}{2r_1 \sin \frac{\Delta\theta_A}{2}} + \left(r_1 + \frac{\Delta r_1}{2}\right)\frac{\Delta\theta_A}{\Delta r_1} + \frac{h_c r_1\, \Delta\theta_A}{K_1\left[\overline{T}(1,J)\right]}$$

Let $Z = u_1(1,J)$; then the new guess for $u_1(1,J)$ is obtained from

$$u_1(1,J) = \overline{u}_1(1,J) + w\left[Z - \overline{u}_1(1,J)\right]$$

where w is the relaxation parameter. The temperature $T(1,J)$ corresponding to $u_1(1,J)$ is obtained from equation (7).

The difference equations for a material interface point are obtained in a similar fashion. The cells about the point (N, J) of region A and the corresponding point (1, J) of region A_1 have a common boundary (path b → c of fig. 4). The cell for (N, J), say

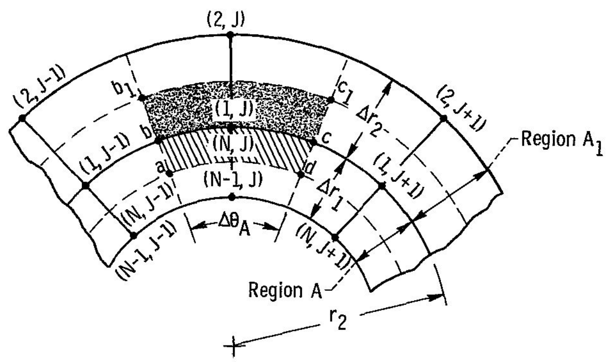

Figure 4. - Detail of grid for material interface point regions A and A_1.

$cell_1$, is cross-hatched area in figure 4, and the cell for $(1, J)$, say $cell_2$, is the stippled area in figure 4.

Again using the divergence theorem results in

$$0 = \int_{cell_1} \nabla^2 u_1 \, dA + \int_{cell_2} \nabla^2 u_2 \, dA$$

$$= \oint_{\text{around } cell_1} \frac{\partial u_1}{\partial n} ds + \oint_{\text{around } cell_2} \frac{\partial u_2}{\partial n} ds$$

$$0 = \int_{a \to b} \frac{\partial u_1}{\partial \theta} ds + \int_{b \to c} - \frac{\partial u_1}{\partial r} ds + \int_{c \to d} - \frac{\partial u_1}{\partial \theta} ds + \int_{d \to a} \frac{\partial u_1}{\partial r} ds + \int_{b \to b_1} \frac{\partial u_2}{\partial \theta} ds$$

$$+ \int_{b_1 \to c_1} - \frac{\partial u_2}{\partial r} ds + \int_{c_1 \to c} - \frac{\partial u_2}{\partial \theta} ds + \int_{c \to b} \frac{\partial u_2}{\partial r} ds \tag{8}$$

The assumption of continuity of heat flow implies

$$\int_{b \to c} - \frac{\partial u_1}{\partial r} ds + \int_{c \to b} \frac{\partial u_2}{\partial r} ds = 0$$

Dropping these integrals out of equation (8) and continuing with the approximation lead to

$$0 \approx \frac{u_1(N,J) - u_1(N,J-1)}{2r_2 \sin \frac{\Delta\theta_A}{2}} \frac{\Delta r_1}{2} + \frac{u_1(N,J) - u_1(N,J+1)}{2r_2 \sin \frac{\Delta\theta_A}{2}} \frac{\Delta r_1}{2} + \frac{u_1(N,J) - u_1(N-1,J)}{\Delta r_1}$$

$$\times \left(r_2 - \frac{\Delta r_1}{2}\right)\Delta\theta_A + \frac{u_2(1,J) - u_2(1,J-1)}{2r_2 \sin \frac{\Delta\theta_A}{2}} \frac{\Delta r_2}{2} + \frac{u_2(1,J) - u_2(2,J)}{\Delta r_2} \left(r_2 + \frac{\Delta r_2}{2}\right)\Delta\theta_A$$

$$+ \frac{u_2(1,J) - u_2(1,J+1)}{2r_2 \sin \frac{\Delta\theta_A}{2}} \frac{\Delta r_2}{2} \left[\frac{\Delta r_1}{2r_2 \sin \frac{\Delta\theta_A}{2}} + \left(r_2 - \frac{\Delta r_1}{2}\right)\Delta\theta_A\right] u_1(N,J)$$

$$+ \left[\frac{\Delta r_2}{2r_2 \sin \frac{\Delta\theta_A}{2}} + \left(r_2 + \frac{\Delta r_2}{2}\right)\Delta\theta_A\right] u_2(1,J)$$

$$= \frac{\Delta r_1}{4r_2 \sin \frac{\Delta\theta_A}{2}} \left[u_1(N,J-1) + u_1(N,J+1)\right] + \left(r_2 - \frac{\Delta r_1}{2}\right)\frac{\Delta\theta_A}{\Delta r_1} u_1(N-1,J)$$

$$+ \frac{\Delta r_2}{4r_2 \sin \frac{\Delta\theta_A}{2}} \left[u_2(1,J-1) + u_2(1,J+1)\right] + \left(r_2 + \frac{\Delta r_2}{2}\right)\frac{\Delta\theta_A}{\Delta r_2} u_2(2,J) \tag{9}$$

Letting TI(J) be the temperature associated with $u_2(1,J)$ and T(J) the temperature associated with $u_1(N,J)$ and using the same approximation as in equation (7) give

$$T(J) \approx \frac{u_1(N,J)}{K_1\left[\overline{T}(J)\right]} - \frac{\int_{T_{ref_1}}^{\overline{T}(J)} K_1(z)dz}{K_1\left[\overline{T}(J)\right]} + \overline{T}(J) \tag{10}$$

$$TI(J) \approx \frac{u_2(1, J)}{K_2\left[\overline{TI}(J)\right]} - \frac{\int_{T_{ref_2}}^{\overline{TI}(J)} K_2(z)dz}{K_2\left[\overline{TI}(J)\right]} + \overline{TI}(J) \tag{11}$$

However, the assumption of perfect thermal contact at a material interface implies that $T(J) = TI(J)$. Subtracting equation (10) from equation (11) results in

$$\left.\begin{aligned}
0 &= -\frac{u_1(N, J)}{K_1\left[\overline{T}(J)\right]} + \frac{u_2(1, J)}{K_2\left[\overline{T}(J)\right]} - \frac{\int_{T_{ref_2}}^{\overline{T}(J)} K_2(z)dz}{K_2\left[\overline{T}(J)\right]} + \frac{\int_{T_{ref_1}}^{\overline{T}(J)} K_1(z)dz}{K_1\left[\overline{T}(J)\right]} \\
-\frac{u_1(N, J)}{K_1\left[\overline{T}(J)\right]} &+ \frac{u_2(1, J)}{K_2\left[\overline{T}(J)\right]} = \frac{\int_{T_{ref_2}}^{\overline{T}(J)} K_2(z)dz}{K_2\left[\overline{T}(J)\right]} - \frac{\int_{T_{ref_1}}^{\overline{T}(J)} K_1(z)dz}{K_1\left[\overline{T}(J)\right]}
\end{aligned}\right\} \tag{12}$$

Equations (9) and (12) are solved simultaneously for $u_1(N, J)$ and $u_2(1, J)$. A new estimate for $T(J)$ is then obtained by adding equations (10) and (11) to give

$$T(J) = \overline{T}(J) + \frac{\dfrac{u_2(1, J)}{K_2\left[\overline{T}(J)\right]} + \dfrac{u_1(N, J)}{K_1\left[\overline{T}(J)\right]} - \left\{\dfrac{\int_{T_{ref_2}}^{\overline{T}(J)} K_2(z)dz}{K_2\left[\overline{T}(J)\right]} + \dfrac{\int_{T_{ref_1}}^{\overline{T}(J)} K_1(z)dz}{K_1\left[\overline{T}(J)\right]}\right\}}{2}$$

Convergence of the iteration process is assumed to occur when

$$\left|\frac{\text{heat in - heat out}}{\text{heat in}}\right| \leq \text{tol} \tag{13}$$

where tol is some preassumed number and

$$
\left.
\begin{aligned}
\text{heat in} &= -\int_{\text{gas side}} \frac{\partial u}{\partial n}\,ds \\
\text{heat out} &= -\int_{\text{coolant side}} \frac{\partial u}{\partial n}\,ds
\end{aligned}
\right\} \tag{14}
$$

Trapezoidal integration is used to approximate these integrals so as to be consistent with the difference equations.

When convergence has occurred, the temperatures corresponding to the u_i functions are determined by iterating on equations of the same type as equation (7).

The program was converted to double precision after it was found that the large aspect ratios of the cells of the grid led to an appreciable loss of significance. The program takes less than 1 minute to do 175 iterations for 1030 grid points.

PROGRAM PROCEDURE

The main program is HETRAN. There are 17 subroutines: CONSA, CONSB, RINIT, COMPA, COMPB, RCOL, CIRCOL, CIRCOT, RLINE, CLINE, OUTPUT, CON1, CON2, CON3, SUBT1, SUBT2, and SUBT3. The subroutines CON1, CON2, CON3, SUBT1, SUBT2, SUBT3, and part of RINIT must be supplied by the user. For more information on these subroutines, see the section labeled USER SUPPLIED SUBROUTINES. The calling relation of all subroutines is shown in figure 5.

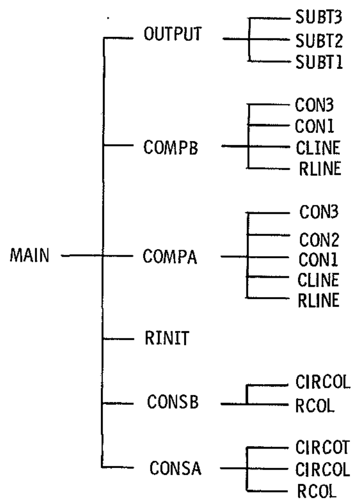

Figure 5. - Calling relation of subroutines.

HETRAN reads and prints all input data and controls the calls to the subroutines.

Subroutines CONSA calculates the grid constants for subregions A, A1, D, D1, B, and B1 and the point relaxation coefficients for the interfaces and boundaries of these regions. Through calls to RCOL, CIRCOL, and CIRCOT, it obtains the line relaxation coefficients for the aforementioned regions.

Subroutine CONSB calculates the grid constants for subregions P, P_1, Q, Q_1, ZR, and ZL and the point relaxation coefficients for the interfaces and boundaries of these regions. Through calls to RCOL and CIRCOL it obtains the line relaxation coefficients for the aforementioned regions.

Subroutine COMPA calculates the u_i's at each point of the grid for subregions A, A_1, D, D_1, B, and B_1 and the temperatures at interface and boundary points of these regions.

Subroutine COMPB calculates the u_i's at each point of the grid for subregions P, P_1, Q, Q_1, ZL, and ZR and the temperatures at interface and boundary points of these regions.

Subroutine RCOL factors a tridiagonal matrix with constant off-diagonal elements into a product of an upper and lower triangular matrix.

Subroutine CIRCOL computes the five point difference coefficients for Laplace's equation on an annulus where the increments in the radial direction are constant. Next, it factors the tridiagonal matrix of coefficients (coupling the variables along a radial) into a product of upper and lower triangular matrices.

Subroutine CIRCOT computes the five point difference coefficients for Laplace's equation on an annulus where the increments in the radial direction are variable. Next it factors the tridiagonal matrix of coefficients (coupling the variables along a radial) into a product of upper and lower triangular matrices.

Subroutine OUTPUT prints the points of the machine generated grid and the temperatures at each point of the grid. The temperatures are obtained through calls to SUBT1, SUBT2, and SUBT3. In addition, if IPUNCH is set equal to one in the input data, OUTPUT will punch 414 BCD cards which contain the last computed u_i's at each point of the grid and temperatures at each point of the interfaces and boundaries. The number of cards punched is a fixed quantity that can only be changed by changing the BCD dump statements in the section OUTPUT.

INPUT

Figure 6 shows the input variables as they are punched on data cards. The first input card is for a title which serves as problem identification. The remaining cards are for input variables. Fixed point variables must be punched in a five column field and floating point variables (decimal point must be punched) in an eight column field. In

1 — 72	73 — 80
TITLE	

1 — 5	6 — 10	11 — 15	16 — 20	21 — 25	26 — 30	31 — 35	36 — 40	41 — 45	46 — 50	51 — 55	56 — 60	61 — 65	66 — 70	71 — 80
NRA	NTA	NRB	NTB	NTD	NXP	NTQ	NZ	NZX	IPUNCH	IREAD	NCOUNT	MCOUNT	ICOS	

1 — 8	9 — 16	17 — 24	25 — 32	33 — 40	41 — 48	49 — 56	57 — 64	65 — 72	73 — 80
R1	R2	R3	YFINT	FINTHK	ANGTOP	HCOOL	TCOOL	HGAS	TGAS
XLONGM	R2B	YFINB	TOL						
WMEGA	WMEGA1	WMEGD	WMEGD1	WMEGB	WMEGB1				
WMEGP	WMEGP1	WMEGQ	WMEGQ1						

Figure 6. - Input form.

addition to the data cards, the user must supply a subroutine for an initial guess. For an explanation see the section labeled USER SUPPLIED SUBROUTINES.

Input Variables and Definitions

NRA number of division points for radius, $r_2 - r_1$ (see fig. 2), ≤ 15

NTA number of division points for angle θ_A (see fig. 2), ≤ 24

NRB number of division points for length f_k (see fig. 2), $4 \leq \text{NRB} \leq 5$

NTB number of division points for angle θ_B (see fig. 2), $\text{NRB} + \text{NTB} + \text{NTD} - 2 \leq 35$

NTD number of division points for angle θ_D (see fig. 2)

NXP number of division points for middle rectangular length x_m (see fig. 2), ≤ 20

NTQ number of division points for angle θ_Q (see fig. 2), ≤ 20

NZ number of division points for angle θ_Z (see fig. 2), ≤ 20

NZX number of division points for lower rectangular length x_L (see fig. 2), ≤ 19

IPUNCH trigger to OUTPUT subroutine:

= 0 No cards punched

= 1 414 BCD cards punched containing u's at each point of grid and temperatures along boundaries and interfaces. The number of cards punched is fixed by the dimension statements in the program

IREAD — trigger to RINIT subroutine:

= 0 — User must set initial guess for u's

= 1 — RINIT reads 414 BCD cards containing u's and temperatures along boundaries and interfaces

NCOUNT — maximum number of iterations program will be cycled. After NCOUNT iterations, output is printed and next case is processed.

MCOUNT — after MCOUNT iteration, heat in, heat out, and relative error are printed (see eqs. (13) and (14))

ICOS — trigger to activate a cosine variation for the heat transfer coefficient on the cladding:

= 0 — HGAS = HGAS

= 1 — HGAS = HGAS COS θ

R1 — radius to inner tube wall (top arc) (see fig. 2)

R2 — radius to interface of outer tube wall and inner radius of cladding (see fig. 2)

R3 — radius to outer boundary of cladding (see fig. 2)

YFINT — perpendicular distance from top of middle rectangle to interface of cladding and fin (see y_1 in fig. 2)

FINTHK — fin thickness measured between sides of rectangle (see f_k in fig. 2)

ANGTOP — angle in radians by which top circular arc of tube is less than 90° (see θ_{TOP} in fig. 2)

HCOOL — heat transfer coefficient on inner radius of tube

TCOOL — temperature of environment of inner radius of tube

HGAS — heat transfer coefficient on outer boundary of cladding

TGAS — temperature of environment on outer boundary of cladding

XLONGM — length of middle rectangular section of tube (see x_m in fig. 2)

R2B — radius to outer wall of tube (lower arc) (see r_{2b} in fig. 2)

TOL — trigger to stop iterations. If heat balance (eq. (13)) $\leq$ TOL, iterations are stopped and output is printed.

WMEGA — relaxation factor for subregion A (see fig. 2)

WMEGA1 — relaxation factor for subregion A1 (see fig. 2)

WMEGD — relaxation factor for subregion D (see fig. 2)

WMEGD1	relaxation factor for subregion D1 (see fig. 2)
WMEGB	relaxation factor for subregion B (see fig. 2)
WMEGB1	relaxation factor for subregion B1 (see fig. 2)
WMEGP	relaxation factor for subregion P (see fig. 2)
WMEGP1	relaxation factor for subregion P1 (see fig. 2)
WMEGQ	relaxation factors for subregions Q, ZL, and ZR (see fig. 2)
WMEGQ1	relaxation factors for subregion Q1 (see fig. 2)

Instructions for Preparing Input

Units of measurement. - Any compatible system of units may be used for linear and thermal input data. In the example problem the English system was used with lengths given in inches and temperatures in degrees Rankine. The one angle that is input, ANGTOP, must be in radians.

Relaxation factors. - The optimum relaxation factors are dependent upon the geometry and material. They will generally have to be found by experimentation. Provisions have been made for different relaxation factors in the various subregions.

Case of no cladding. - It is possible, by inputing R3 = R2, to run a case without cladding on the tube. The outer tube wall and the top boundary of the fin are then considered to be the heated surfaces.

Format for input data. - All fixed point variables are punched in a right-adjusted five column field; all floating point variables (punch decimal point) are in an eight column field.

USER SUPPLIED SUBROUTINES

The user must supply the following subroutines: CON1, CON2, CON3, SUBT1, SUBT2, and SUBT3. If an initial guess is not available on BCD cards, then an initial guess to the u_i's at each point of the grid and the corresponding temperatures at interface and boundary points must be supplied in RINIT.

Subroutines CON1, CON2, and CON3 have the same variable list. The subroutines perform the same function, but for different materials; CON1 refers to material 1, CON2 to material 2, and CON3 to material 3. Consequently, a description of CON1 is sufficient for all three routines.

The purpose of CON1 is to return to the calling program the conductivity of material 1 at a given temperature and the variable

$$\frac{\int_{T_{ref}}^{T} K_1(x)dx}{K_1(T)}$$

Usage: Subroutine CON1(TOLD, U, NTIM, COND) where

TOLD vector of temperatures supplied by calling program

U vector $\int_{T_{ref_1}}^{T} K_1(x)dx \Big/ K_1(T)$ computed in CON1

NTIM number of elements in vector TOLD supplied by calling program

COND vector of conductivities for material 1, computed in CON1, corresponding to vector of TOLD's

TOLD, U, and COND must be declared double precision and dimensional variables of at least dimension one in CON1.

Method: The subroutine must have a "DO LOOP" to calculate from I = 1, NTIM the conductivities, COND(I), for material 1, corresponding to the given temperatures TOLD(I). It must also calculate the variables

$$U(I) = \frac{\int_{T_{ref_1}}^{T} K_1(x)dx}{TOLD(I)}$$

The subroutines SUBT1, SUBT2, and SUBT3 must return the temperatures corresponding to a given vector of u_i's for materials 1, 2, and 3, respectively. Since the variable list of these three subroutines is identical and their function is the same, a description of SUBT1 is sufficient to describe all three subroutines.

The purpose of SUBT1 is to calculate a vector of temperatures for material 1, given the corresponding u_i's. The method which is useful for this calculation, is the Newton method of equation (7).

Usage: Subroutine SUBT1(U, T1, TEMP, N1, N2) where

U vector of u_1's, supplied by calling program

T1 initial guess to TEMP(N1) supplied by calling program

TEMP vector of temperatures, calculated by SUBT1, corresponding to vector of u's

N1 initial point of "DO LOOP" supplied by calling program

N2 final point of "DO LOOP" supplied by calling program

U and TEMP must be declared dimensioned variables in SUBT1 with dimension of at least one.

Method: The subroutine must have a "DO LOOP" to calculate from I = N1, N2 the temperatures, TEMP(I), for material 1, corresponding to the given U(I). Newton's method as given by equation (7) is an effective method for performing this calculation.

Subroutine RINIT sets the initial guess for the u_i at each grid point and the initial guess for the temperatures at each grid point of the boundaries and interfaces. These temperatures must correspond to the u_i at the given points.

There are two ways to set the initial guess in RINIT. If IREAD is set equal to 1 on the input data, then RINIT will attempt to read 414 BCD cards. These cards are generated by subroutine OUTPUT and contain the complete field of u_i and the temperatures along the boundaries and interfaces from the last iteration. If IREAD is set equal to 0 as the input data, then the user must supply the appropriate initial guess.

A constant temperature field can be inserted as a first guess by changing four cards in RINIT. First, card 22 of the listing for RINIT must be changed to the given temperature. Then, cards 26, 28, and 40 must be changed to the u_1, u_2, and u_3 corresponding to the temperature on card 22. For any other type of initial guess, cards 21 to 66 must be deleted and the appropriate guess inserted.

OUTPUT

Sample output is given in the appendix together with sample input. The units for linear and temperature output are the same as for input. The sample input used inches and degrees Rankine; the output units are also in these units. All angular output is given in degrees.

In addition to the sample output given in the appendix, 414 BCD cards can be obtained by setting IPUNCH equal to one. This output is suitable for restarting the program from the last iteration, or as an initial guess for a similar case in which the geometric parameters have been varied.

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, July 21, 1971,
132-80.

APPENDIX - COMPUTER LISTING WITH SAMPLE INPUT AND OUTPUT

Sample Input

SAMPLE CASE--STAINLESS TUBE,NICKEL CLADDING,COPPER FIN--NO COS VAR.

NRA	NTA	NRB	NTB	NTD	NXP	NTQ	NZ	NZX	IPUNCH	IREAD	NCCUNT	MCOUNT	ICOS
9	20	4	5	5	10	10	10	10	0	0	3000	250	-0

R1	R2	R3	Y-FIN-TOP	FIN-THICK	ANGLE-TOP
0.40500000E-01	0.52500000E-01	0.72500000E-01	0.12600000E-01	0.99999999E-03	0

H-COOLANT	TEMP-COOLANT	H-GAS	TEMP-GAS
0.14805000E-01	70.0000000	0.19429000E-02	5897.00000

X-MID-RECT	R2-BOT	Y-FIN-BOTTOM	TOLERANCE
0.32500000E-01	0.40000000E-01	0.94999999E-02	0.99999999E-04

OMEGA(A)	OMEGA(A1)	OMEGA(D)	OMEGA(D1)	OMEGA(B)	OMEGA(B1)
1.91999999	1.91999999	1.91999999	1.91999999	1.91999999	1.91999999

OMEGA(P)	OMEGA(P1)	OMEGA(Q)	OMEGA(Q1)
1.91999999	1.91999999	1.91999999	1.91999999

Sample Output

```
ITERATION =  250    HEAT IN =  0.52211515    HEAT OUT = -0.60466291    RELATIVE ERR =  0.15810259

ITERATION =  500    HEAT IN =  0.52490184    HEAT OUT = -0.54039369    RELATIVE ERR =  0.29513791E-01

ITERATION =  750    HEAT IN =  0.52544611    HEAT OUT = -0.52846774    RELATIVE ERR =  0.57506089E-02

ITERATION = 1000    HEAT IN =  0.52555250    HEAT OUT = -0.52615677    RELATIVE ERR =  0.11497699E-02

ITERATION = 1250    HEAT IN =  0.52557338    HEAT OUT = -0.52570379    RELATIVE ERR =  0.24812427E-03

ITERATION = 1421    HEAT IN =  0.52557682    HEAT OUT = -0.52562915    RELATIVE ERR =  0.99558095E-04
```

TEMPERATURES ON THE TOP RADIAL SECTION OF TUBE

THET = 0.

R	T	R	T	R	T	R	T
0.405000E-01	0.770166E+03	0.420000E-01	0.838638E+03	0.435000E-01	0.903183E+03	0.450000E-01	0.964230E+03
0.465000E-01	0.102212E+04	0.480000E-01	0.107715E+04	0.495000E-01	0.112956E+04	0.510000E-01	0.117954E+04
0.525000E-01	0.122742E+04						
0.525000E-01	0.122742E+04	0.528333E-01	0.123210E+04	0.531667E-01	0.123677E+04	0.535000E-01	0.124144E+04
0.535896E-01	0.124270E+04	0.538598E-01	0.124649E+04	0.543152E-01	0.125288E+04	0.549637E-01	0.126197E+04
0.571359E-01	0.129236E+04	0.605076E-01	0.133917E+04	0.654288E-01	0.140611E+04	0.725000E-01	0.149903E+04

THET = 0.250292E+01

R	T	R	T	R	T	R	T
0.405000E-01	0.769639E+03	0.420000E-01	0.838079E+03	0.435000E-01	0.902596E+03	0.450000E-01	0.963618E+03
0.465000E-01	0.102149E+04	0.480000E-01	0.107650E+04	0.495000E-01	0.112889E+04	0.510000E-01	0.117886E+04
0.525000E-01	0.122672E+04						
0.525000E-01	0.122672E+04	0.528333E-01	0.123139E+04	0.531667E-01	0.123607E+04	0.535000E-01	0.124074E+04
0.535896E-01	0.124199E+04	0.538598E-01	0.124578E+04	0.543152E-01	0.125216E+04	0.549637E-01	0.126125E+04
0.571359E-01	0.129163E+04	0.605076E-01	0.133843E+04	0.654288E-01	0.140537E+04	0.725000E-01	0.149832E+04

THET = 0.500584E+01

R	T	R	T	R	T	R	T
0.405000E-01	0.768057E+03	0.420000E-01	0.836401E+03	0.435000E-01	0.900833E+03	0.450000E-01	0.961780E+03
0.465000E-01	0.101959E+04	0.480000E-01	0.107454E+04	0.495000E-01	0.112688E+04	0.510000E-01	0.117681E+04
0.525000E-01	0.122463E+04						
0.525000E-01	0.122463E+04	0.528333E-01	0.122929E+04	0.531667E-01	0.123395E+04	0.535000E-01	0.123861E+04
0.535896E-01	0.123987E+04	0.538598E-01	0.124365E+04	0.543152E-01	0.125002E+04	0.549637E-01	0.125909E+04
0.571359E-01	0.128944E+04	0.605076E-01	0.133621E+04	0.654288E-01	0.140317E+04	0.725000E-01	0.149619E+04

THET = 0.750876E+01

R	T	R	T	R	T	R	T
0.405000E-01	0.765418E+03	0.420000E-01	0.833601E+03	0.435000E-01	0.897890E+03	0.450000E-01	0.958710E+03
0.465000E-01	0.101641E+04	0.480000E-01	0.107126E+04	0.495000E-01	0.112352E+04	0.510000E-01	0.117339E+04
0.525000E-01	0.122112E+04						
0.525000E-01	0.122112E+04	0.528333E-01	0.122577E+04	0.531667E-01	0.123041E+04	0.535000E-01	0.123506E+04
0.535896E-01	0.123631E+04	0.538598E-01	0.124008E+04	0.543152E-01	0.124644E+04	0.549637E-01	0.125549E+04
0.571359E-01	0.128577E+04	0.605076E-01	0.133250E+04	0.654288E-01	0.139948E+04	0.725000E-01	0.149262E+04

THET = 0.100117E+02

R	T	R	T	R	T	R	T
0.405000E-01	0.761716E+03	0.420000E-01	0.829673E+03	0.435000E-01	0.893760E+03	0.450000E-01	0.954401E+03
0.465000E-01	0.101194E+04	0.480000E-01	0.106666E+04	0.495000E-01	0.111880E+04	0.510000E-01	0.116857E+04
0.525000E-01	0.121619E+04						
0.525000E-01	0.121619E+04	0.528333E-01	0.122082E+04	0.531667E-01	0.122544E+04	0.535000E-01	0.123007E+04
0.535896E-01	0.123132E+04	0.538598E-01	0.123507E+04	0.543152E-01	0.124140E+04	0.549637E-01	0.125042E+04
0.571359E-01	0.128061E+04	0.605076E-01	0.132728E+04	0.654288E-01	0.139428E+04	0.725000E-01	0.148760E+04

THET = 0.125146E+02

R	T	R	T	R	T	R	T
0.405000E-01	0.756947E+03	0.420000E-01	0.824610E+03	0.435000E-01	0.888434E+03	0.450000E-01	0.948841E+03
0.465000E-01	0.100617E+04	0.480000E-01	0.106071E+04	0.495000E-01	0.111270E+04	0.510000E-01	0.116234E+04
0.525000E-01	0.120983E+04						
0.525000E-01	0.120983E+04	0.528333E-01	0.121442E+04	0.531667E-01	0.121902E+04	0.535000E-01	0.122362E+04
0.535896E-01	0.122486E+04	0.538598E-01	0.122859E+04	0.543152E-01	0.123489E+04	0.549637E-01	0.124386E+04
0.571359E-01	0.127393E+04	0.605076E-01	0.132051E+04	0.654288E-01	0.138754E+04	0.725000E-01	0.148108E+04

THET = 0.150175E+02

R	T	R	T	R	T	R	T
0.405000E-01	0.751104E+03	0.420000E-01	0.818404E+03	0.435000E-01	0.881902E+03	0.450000E-01	0.942017E+03
0.465000E-01	0.999090E+03	0.480000E-01	0.105340E+04	0.495000E-01	0.110519E+04	0.510000E-01	0.115466E+04
0.525000E-01	0.120199E+04						
0.525000E-01	0.120199E+04	0.528333E-01	0.120655E+04	0.531667E-01	0.121111E+04	0.535000E-01	0.121568E+04
0.535896E-01	0.121691E+04	0.538598E-01	0.122061E+04	0.543152E-01	0.122686E+04	0.549637E-01	0.123578E+04
0.571359E-01	0.126570E+04	0.605076E-01	0.131214E+04	0.654288E-01	0.137921E+04	0.725000E-01	0.147303E+04

THET = 0.175204E+02

R	T	R	T	R	T	R	T
0.405000E-01	0.744179E+03	0.420000E-01	0.811046E+03	0.435000E-01	0.874152E+03	0.450000E-01	0.933915E+03
0.465000E-01	0.990675E+03	0.480000E-01	0.104471E+04	0.495000E-01	0.109626E+04	0.510000E-01	0.114552E+04
0.525000E-01	0.119266E+04						
0.525000E-01	0.119266E+04	0.528333E-01	0.119717E+04	0.531667E-01	0.120169E+04	0.535000E-01	0.120622E+04
0.535896E-01	0.120743E+04	0.538598E-01	0.121111E+04	0.543152E-01	0.121730E+04	0.549637E-01	0.122615E+04
0.571359E-01	0.125587E+04	0.605076E-01	0.130215E+04	0.654288E-01	0.136924E+04	0.725000E-01	0.146338E+04

THET = 0.200234E+02

R	T	R	T	R	T	R	T
0.405000E-01	0.736168E+03	0.420000E-01	0.802527E+03	0.435000E-01	0.865172E+03	0.450000E-01	0.924521E+03
0.465000E-01	0.980908E+03	0.480000E-01	0.103461E+04	0.495000E-01	0.108587E+04	0.510000E-01	0.113487E+04
0.525000E-01	0.118180E+04						
0.525000E-01	0.118180E+04	0.528333E-01	0.118625E+04	0.531667E-01	0.119072E+04	0.535000E-01	0.119519E+04
0.535896E-01	0.119639E+04	0.538598E-01	0.120003E+04	0.543152E-01	0.120616E+04	0.549637E-01	0.121492E+04
0.571359E-01	0.124440E+04	0.605076E-01	0.129045E+04	0.654288E-01	0.135755E+04	0.725000E-01	0.145208E+04

THET = 0.225263E+02

R	T	R	T	R	T	R	T
0.405000E-01	0.727064E+03	0.420000E-01	0.792839E+03	0.435000E-01	0.854952E+03	0.450000E-01	0.913818E+03
0.465000E-01	0.969771E+03	0.480000E-01	0.102309E+04	0.495000E-01	0.107399E+04	0.510000E-01	0.112269E+04
0.525000E-01	0.116935E+04						
0.525000E-01	0.116935E+04	0.528333E-01	0.117375E+04	0.531667E-01	0.117815E+04	0.535000E-01	0.118256E+04
0.535896E-01	0.118375E+04	0.538598E-01	0.118733E+04	0.543152E-01	0.119339E+04	0.549637E-01	0.120204E+04
0.571359E-01	0.123123E+04	0.605076E-01	0.127701E+04	0.654288E-01	0.134407E+04	0.725000E-01	0.143904E+04

THET = 0.250292E+02

R	T	R	T	R	T	R	T
0.405000E-01	0.716863E+03	0.420000E-01	0.781975E+03	0.435000E-01	0.843482E+03	0.450000E-01	0.901794E+03
0.465000E-01	0.957244E+03	0.480000E-01	0.101011E+04	0.495000E-01	0.106061E+04	0.510000E-01	0.110895E+04
0.525000E-01	0.115529E+04						
0.525000E-01	0.115529E+04	0.528333E-01	0.115961E+04	0.531667E-01	0.116394E+04	0.535000E-01	0.116828E+04
0.535896E-01	0.116945E+04	0.538598E-01	0.117298E+04	0.543152E-01	0.117894E+04	0.549637E-01	0.118747E+04
0.571359E-01	0.121631E+04	0.605076E-01	0.126173E+04	0.654288E-01	0.132870E+04	0.725000E-01	0.142416E+04

THET = 0.275321E+02

R	T	R	T	R	T	R	T
0.405000E-01	0.705565E+03	0.420000E-01	0.769932E+03	0.435000E-01	0.830752E+03	0.450000E-01	0.888435E+03
0.465000E-01	0.943310E+03	0.480000E-01	0.995649E+03	0.495000E-01	0.104568E+04	0.510000E-01	0.109359E+04
0.525000E-01	0.113956E+04						
0.525000E-01	0.113956E+04	0.528333E-01	0.114379E+04	0.531667E-01	0.114804E+04	0.535000E-01	0.115230E+04
0.535896E-01	0.115344E+04	0.538598E-01	0.115691E+04	0.543152E-01	0.116277E+04	0.549637E-01	0.117116E+04
0.571359E-01	0.119958E+04	0.605076E-01	0.124456E+04	0.654288E-01	0.131134E+04	0.725000E-01	0.140733E+04

THET = 0.300350E+02

R	T	R	T	R	T	R	T
0.405000E-01	0.693171E+03	0.420000E-01	0.756708E+03	0.435000E-01	0.816759E+03	0.450000E-01	0.873732E+03
0.465000E-01	0.927955E+03	0.480000E-01	0.979696E+03	0.495000E-01	0.102918E+04	0.510000E-01	0.107660E+04
0.525000E-01	0.112213E+04						
0.525000E-01	0.112213E+04	0.528333E-01	0.112626E+04	0.531667E-01	0.113041E+04	0.535000E-01	0.113458E+04
0.535896E-01	0.113570E+04	0.538598E-01	0.113909E+04	0.543152E-01	0.114483E+04	0.549637E-01	0.115305E+04
0.571359E-01	0.118099E+04	0.605076E-01	0.122541E+04	0.654288E-01	0.129189E+04	0.725000E-01	0.138842E+04

THET = 0.325380E+02

R	T	R	T	R	T	R	T
0.405000E-01	0.679689E+03	0.420000E-01	0.742307E+03	0.435000E-01	0.801502E+03	0.450000E-01	0.857681E+03
0.465000E-01	0.911167E+03	0.480000E-01	0.962230E+03	0.495000E-01	0.101109E+04	0.510000E-01	0.105794E+04
0.525000E-01	0.110295E+04						
0.525000E-01	0.110295E+04	0.528333E-01	0.110697E+04	0.531667E-01	0.111101E+04	0.535000E-01	0.111507E+04
0.535896E-01	0.111616E+04	0.538598E-01	0.111947E+04	0.543152E-01	0.112507E+04	0.549637E-01	0.113311E+04
0.571359E-01	0.116047E+04	0.605076E-01	0.120422E+04	0.654288E-01	0.127023E+04	0.725000E-01	0.136724E+04

THET = 0.350409E+02

R	T	R	T	R	T	R	T
0.405000E-01	0.665131E+03	0.420000E-01	0.726738E+03	0.435000E-01	0.784988E+03	0.450000E-01	0.840282E+03
0.465000E-01	0.892945E+03	0.480000E-01	0.943240E+03	0.495000E-01	0.991390E+03	0.510000E-01	0.103758E+04
0.525000E-01	0.108198E+04						
0.525000E-01	0.108198E+04	0.528333E-01	0.108588E+04	0.531667E-01	0.108980E+04	0.535000E-01	0.109374E+04
0.535896E-01	0.109480E+04	0.538598E-01	0.109802E+04	0.543152E-01	0.110346E+04	0.549637E-01	0.111129E+04
0.571359E-01	0.113799E+04	0.605076E-01	0.118092E+04	0.654288E-01	0.124625E+04	0.725000E-01	0.134360E+04

THET = 0.375438E+02

R	T	R	T	R	T	R	T
0.405000E-01	0.649515E+03	0.420000E-01	0.710017E+03	0.435000E-01	0.767228E+03	0.450000E-01	0.821545E+03
0.465000E-01	0.873290E+03	0.480000E-01	0.922725E+03	0.495000E-01	0.970071E+03	0.510000E-01	0.101551E+04
0.525000E-01	0.105922E+04						
0.525000E-01	0.105922E+04	0.528333E-01	0.106298E+04	0.531667E-01	0.106676E+04	0.535000E-01	0.107057E+04
0.535896E-01	0.107160E+04	0.538598E-01	0.107470E+04	0.543152E-01	0.107998E+04	0.549637E-01	0.108756E+04
0.571359E-01	0.111350E+04	0.605076E-01	0.115545E+04	0.654288E-01	0.121984E+04	0.725000E-01	0.131722E+04

THET = 0.400467E+02

R	T	R	T	R	T	R	T
0.405000E-01	0.632867E+03	0.420000E-01	0.692168E+03	0.435000E-01	0.748243E+03	0.450000E-01	0.801486E+03
0.465000E-01	0.852216E+03	0.480000E-01	0.900693E+03	0.495000E-01	0.947135E+03	0.510000E-01	0.991728E+03
0.525000E-01	0.103463E+04						
0.525000E-01	0.103463E+04	0.528333E-01	0.103824E+04	0.531667E-01	0.104188E+04	0.535000E-01	0.104554E+04
0.535896E-01	0.104653E+04	0.538598E-01	0.104952E+04	0.543152E-01	0.105460E+04	0.549637E-01	0.106191E+04
0.571359E-01	0.108700E+04	0.605076E-01	0.1[illegible]779E+04	0.654288E-01	0.119091E+04	0.725000E-01	0.128781E+04

THET = 0.425496E+02

R	T	R	T	R	T	R	T
0.405000E-01	0.615220E+03	0.420000E-01	0.673222E+03	0.435000E-01	0.728062E+03	0.450000E-01	0.780132E+03
0.465000E-01	0.829747E+03	0.480000E-01	0.877164E+03	0.495000E-01	0.922599E+03	0.510000E-01	0.966235E+03
0.525000E-01	0.100823E+04						
0.525000E-01	0.100823E+04	0.528333E-01	0.101168E+04	0.531667E-01	0.101516E+04	0.535000E-01	0.101866E+04
0.535896E-01	0.101961E+04	0.538598E-01	0.102247E+04	0.543152E-01	0.102734E+04	0.549637E-01	0.103435E+04
0.571359E-01	0.105849E+04	0.605076E-01	0.109793E+04	0.654288E-01	0.115538E+04	0.725000E-01	0.125500E+04

THET = 0.450525E+02

R	T	R	T	R	T	R	T
0.405000E-01	0.596615E+03	0.420000E-01	0.653219E+03	0.435000E-01	0.706724E+03	0.450000E-01	0.757520E+03
0.465000E-01	0.805917E+03	0.480000E-01	0.852171E+03	0.495000E-01	0.896493E+03	0.510000E-01	0.939063E+03
0.525000E-01	0.980035E+03						
0.525000E-01	0.980035E+03	0.528333E-01	0.983313E+03	0.531667E-01	0.986619E+03	0.535000E-01	0.989954E+03
0.535896E-01	0.990854E+03	0.538598E-01	0.993583E+03	0.543152E-01	0.998222E+03	0.549637E-01	0.100492E+04
0.571359E-01	0.102802E+04	0.605076E-01	0.106592E+04	0.654288E-01	0.112525E+04	0.725000E-01	0.121820E+04

THET = 0.475555E+02

R	T	R	T	R	T	R	T
0.405000E-01	0.577104E+03	0.420000E-01	0.632207E+03	0.435000E-01	0.684277E+03	0.450000E-01	0.733696E+03
0.465000E-01	0.780773E+03	0.480000E-01	0.825759E+03	0.495000E-01	0.868863E+03	0.510000E-01	0.910259E+03
0.525000E-01	0.950089E+03						
0.525000E-01	0.950089E+03	0.528333E-01	0.953184E+03	0.531667E-01	0.956309E+03	0.535000E-01	0.959464E+03
0.535896E-01	0.960316E+03	0.538598E-01	0.962901E+03	0.543152E-01	0.967299E+03	0.549637E-01	0.973654E+03
0.571359E-01	0.995651E+03	0.605076E-01	0.103189E+04	0.654288E-01	0.108870E+04	0.725000E-01	0.117650E+04

THET = 0.548535E+02

R	T	R	T	R	T	R	T
0.405000E-01	0.515288E+03	0.420000E-01	0.565424E+03	0.435000E-01	0.612706E+03	0.450000E-01	0.657505E+03
0.465000E-01	0.700125E+03	0.480000E-01	0.740820E+03	0.495000E-01	0.779799E+03	0.510000E-01	0.817240E+03
0.525000E-01	0.853291E+03						
0.525000E-01	0.853291E+03	0.528333E-01	0.855837E+03	0.531667E-01	0.858417E+03	0.535000E-01	0.861031E+03
0.535896E-01	0.861738E+03	0.538598E-01	0.863887E+03	0.543152E-01	0.867558E+03	0.549637E-01	0.872888E+03
0.571359E-01	0.891536E+03	0.605076E-01	0.922724E+03	0.654288E-01	0.971913E+03		

THET = 0.621515E+02

R	T	R	T	R	T	R	T
0.405000E-01	0.448128E+03	0.420000E-01	0.492439E+03	0.435000E-01	0.534000E+03	0.450000E-01	0.573174E+03
0.465000E-01	0.610275E+03	0.480000E-01	0.645575E+03	0.495000E-01	0.679319E+03	0.510000E-01	0.711730E+03
0.525000E-01	0.743008E+03						
0.525000E-01	0.743008E+03	0.528333E-01	0.744986E+03	0.531667E-01	0.747013E+03	0.535000E-01	0.749089E+03
0.535896E-01	0.749655E+03	0.538598E-01	0.751381E+03	0.543152E-01	0.754361E+03	0.549637E-01	0.758754E+03
0.571359E-01	0.774606E+03	0.605076E-01	0.802346E+03				

THET = 0.694495E+02

R	T	R	T	R	T	R	T
0.405000E-01	0.379172E+03	0.420000E-01	0.416770E+03	0.435000E-01	0.451640E+03	0.450000E-01	0.483948E+03
0.465000E-01	0.513976E+03	0.480000E-01	0.541990E+03	0.495000E-01	0.568268E+03	0.510000E-01	0.593130E+03
0.525000E-01	0.616984E+03						
0.525000E-01	0.616984E+03	0.528333E-01	0.618316E+03	0.531667E-01	0.619737E+03	0.535000E-01	0.621246E+03
0.535896E-01	0.621665E+03	0.538598E-01	0.622969E+03	0.543152E-01	0.625298E+03	0.549637E-01	0.628905E+03
0.571359E-01	0.643292E+03						

THET = 0.767475E+02

R	T	R	T	R	T	R	T
0.405000E-01	0.316821E+03	0.420000E-01	0.346894E+03	0.435000E-01	0.374293E+03	0.450000E-01	0.399052E+03
0.465000E-01	0.420946E+03	0.480000E-01	0.439565E+03	0.495000E-01	0.454496E+03	0.510000E-01	0.464991E+03
0.525000E-01	0.469765E+03						
0.525000E-01	0.469765E+03	0.528333E-01	0.469840E+03	0.531667E-01	0.470033E+03	0.535000E-01	0.470340E+03
0.535896E-01	0.470439E+03	0.538598E-01	0.470788E+03	0.543152E-01	0.471540E+03	0.549637E-01	0.472967E+03

THET = 0.767475E+02

R	T	R	T	R	T	R	T
0.405000E-01	0.316821E+03	0.420000E-01	0.346894E+03	0.435000E-01	0.374293E+03	0.450000E-01	0.399052E+03
0.465000E-01	0.420946E+03	0.480000E-01	0.439565E+03	0.495000E-01	0.454496E+03	0.510000E-01	0.464991E+03
0.525000E-01	0.469765E+03						
0.525000E-01	0.469765E+03	0.528333E-01	0.469840E+03	0.531667E-01	0.470033E+03	0.535000E-01	0.470340E+03
0.535896E-01	0.470439E+03	0.538598E-01	0.470788E+03	0.543152E-01	0.471540E+03	0.549637E-01	0.472967E+03

THET = 0.800607E+02

R	T	R	T	R	T	R	T
0.405000E-01	0.293392E+03	0.420000E-01	0.320861E+03	0.435000E-01	0.345886E+03	0.450000E-01	0.368606E+03
0.465000E-01	0.389100E+03	0.480000E-01	0.407429E+03	0.495000E-01	0.423603E+03	0.510000E-01	0.437937E+03
0.525000E-01	0.451197E+03						
0.525000E-01	0.451197E+03	0.528333E-01	0.451330E+03	0.531667E-01	0.451518E+03	0.535000E-01	0.451761E+03
0.535896E-01	0.451834E+03	0.538598E-01	0.452077E+03	0.543152E-01	0.452561E+03		

THET = 0.833738E+02

R	T	R	T	R	T	R	T
0.405000E-01	0.272676E+03	0.420000E-01	0.297927E+03	0.435000E-01	0.321061E+03	0.450000E-01	0.342284E+03
0.465000E-01	0.361788E+03	0.480000E-01	0.379792E+03	0.495000E-01	0.396577E+03	0.510000E-01	0.412509E+03
0.525000E-01	0.428020E+03						
0.525000E-01	0.428020E+03	0.528333E-01	0.428163E+03	0.531667E-01	0.428353E+03	0.535000E-01	0.428590E+03
0.535896E-01	0.428661E+03	0.538598E-01	0.428895E+03				

THET = 0.866869E+02

R	T	R	T	R	T	R	T
0.405000E-01	0.254074E+03	0.420000E-01	0.277344E+03	0.435000E-01	0.298777E+03	0.450000E-01	0.318591E+03
0.465000E-01	0.336990E+03	0.480000E-01	0.354183E+03	0.495000E-01	0.370398E+03	0.510000E-01	0.385891E+03
0.525000E-01	0.400941E+03						
0.525000E-01	0.400941E+03	0.528333E-01	0.401062E+03	0.531667E-01	0.401202E+03	0.535000E-01	0.401361E+03
0.535896E-01	0.401406E+03						

THET = 0.900000E+02

R	T	R	T	R	T	R	T
0.405000E-01	0.237058E+03	0.420000E-01	0.258486E+03	0.435000E-01	0.278285E+03	0.450000E-01	0.296657E+03
0.465000E-01	0.313770E+03	0.480000E-01	0.329777E+03	0.495000E-01	0.344813E+03	0.510000E-01	0.358992E+03
0.525000E-01	0.372384E+03						
0.525000E-01	0.372384E+03	0.528333E-01	0.372466E+03	0.531667E-01	0.372522E+03	0.535000E-01	0.372554E+03

TEMPERATURES ON THE MIDDLE RECTANGULAR SECTION

X = 0.

Y	T	Y	T	Y	T	Y	T
0.	0.237058E+03	0.150000E-02	0.258486E+03	0.300000E-02	0.278285E+03	0.450000E-02	0.296657E+03
0.600000E-02	0.313770E+03	0.750000E-02	0.329777E+03	0.900000E-02	0.344813E+03	0.105000E-01	0.358992E+03
0.120000E-01	0.372384E+03						
0.120000E-01	0.372384E+03	0.123333E-01	0.372466E+03	0.126667E-01	0.372522E+03	0.130000E-01	0.372554E+03

X = 0.361111E-02

Y	T	Y	T	Y	T	Y	T
0.	0.215722E+03	0.150000E-02	0.235020E+03	0.300000E-02	0.253149E+03	0.450000E-02	0.270184E+03
0.600000E-02	0.286201E+03	0.750000E-02	0.301273E+03	0.900000E-02	0.315466E+03	0.105000E-01	0.328836E+03
0.120000E-01	0.341430E+03						
0.120000E-01	0.341430E+03	0.123333E-01	0.341504E+03	0.126667E-01	0.341549E+03	0.130000E-01	0.341564E+03

X = 0.722222E-02

Y	T	Y	T	Y	T	Y	T
0.	0.198638E+03	0.150000E-02	0.216085E+03	0.300000E-02	0.232605E+03	0.450000E-02	0.248240E+03
0.600000E-02	0.263028E+03	0.750000E-02	0.277004E+03	0.900000E-02	0.290196E+03	0.105000E-01	0.302626E+03
0.120000E-01	0.314304E+03						
0.120000E-01	0.314304E+03	0.123333E-01	0.314371E+03	0.126667E-01	0.314411E+03	0.130000E-01	0.314424E+03

X = 0.108333E-01

Y	T	Y	T	Y	T	Y	T
0.	0.184523E+03	0.150000E-02	0.200386E+03	0.300000E-02	0.215473E+03	0.450000E-02	0.229814E+03
0.600000E-02	0.243434E+03	0.750000E-02	0.256353E+03	0.900000E-02	0.268587E+03	0.105000E-01	0.280148E+03
0.120000E-01	0.291044E+03						
0.120000E-01	0.291044E+03	0.123333E-01	0.291104E+03	0.126667E-01	0.291140E+03	0.130000E-01	0.291152E+03

X = 0.144444E-01

Y	T	Y	T	Y	T	Y	T
0.	0.172691E+03	0.150000E-02	0.187192E+03	0.300000E-02	0.201025E+03	0.450000E-02	0.214215E+03
0.600000E-02	0.226780E+03	0.750000E-02	0.238737E+03	0.900000E-02	0.250094E+03	0.105000E-01	0.260863E+03
0.120000E-01	0.271051E+03						
0.120000E-01	0.271051E+03	0.123333E-01	0.271106E+03	0.126667E-01	0.271138E+03	0.130000E-01	0.271149E+03

X = 0.180556E-01

Y	T	Y	T	Y	T	Y	T
0.	0.162703E+03	0.150000E-02	0.176027E+03	0.300000E-02	0.188768E+03	0.450000E-02	0.200946E+03
0.600000E-02	0.212576E+03	0.750000E-02	0.223669E+03	0.900000E-02	0.234233E+03	0.105000E-01	0.244275E+03
0.120000E-01	0.253799E+03						
0.120000E-01	0.253799E+03	0.123333E-01	0.253849E+03	0.126667E-01	0.253880E+03	0.130000E-01	0.253890E+03

X = 0.216667E-01

Y	T	Y	T	Y	T	Y	T
0.	0.154249E+03	0.150000E-02	0.166555E+03	0.300000E-02	0.178348E+03	0.450000E-02	0.189645E+03
0.600000E-02	0.200455E+03	0.750000E-02	0.210787E+03	0.900000E-02	0.220644E+03	0.105000E-01	0.230028E+03
0.120000E-01	0.238941E+03						
0.120000E-01	0.238941E+03	0.123333E-01	0.238988E+03	0.126667E-01	0.239016E+03	0.130000E-01	0.239025E+03

X = 0.252778E-01

Y	T	Y	T	Y	T	Y	T
0.	0.147088E+03	0.150000E-02	0.158517E+03	0.300000E-02	0.169496E+03	0.450000E-02	0.180038E+03
0.600000E-02	0.190147E+03	0.750000E-02	0.199826E+03	0.900000E-02	0.209073E+03	0.105000E-01	0.217886E+03
0.120000E-01	0.226262E+03						
0.120000E-01	0.226262E+03	0.123333E-01	0.226305E+03	0.126667E-01	0.226331E+03	0.130000E-01	0.226340E+03

X = 0.288889E-01

Y	T	Y	T	Y	T	Y	T
0.	0.141006E+03	0.150000E-02	0.151683E+03	0.300000E-02	0.161977E+03	0.450000E-02	0.171894E+03
0.600000E-02	0.181433E+03	0.750000E-02	0.190587E+03	0.900000E-02	0.199344E+03	0.105000E-01	0.207691E+03
0.120000E-01	0.215620E+03						
0.120000E-01	0.215620E+03	0.123333E-01	0.215661E+03	0.126667E-01	0.215685E+03	0.130000E-01	0.215693E+03

X = 0.325000E-01

Y	T	Y	T	Y	T	Y	T
0.	0.135739E+03	0.150000E-02	0.145778E+03	0.300000E-02	0.155523E+03	0.450000E-02	0.164971E+03
0.600000E-02	0.174113E+03	0.750000E-02	0.182921E+03	0.900000E-02	0.191356E+03	0.105000E-01	0.199366E+03
0.120000E-01	0.206911E+03						
0.120000E-01	0.206911E+03	0.123333E-01	0.206949E+03	0.126667E-01	0.206972E+03	0.130000E-01	0.206979E+03

TEMPERATURES ON THE LOWER RADIAL SECTION OF TUBE

THET = 0.

R	T	R	T	R	T	R	T
0.280000E-01	0.135739E+03	0.295000E-01	0.145778E+03	0.310000E-01	0.155523E+03	0.325000E-01	0.164971E+03
0.340000E-01	0.174113E+03	0.355000E-01	0.182921E+03	0.370000E-01	0.191356E+03	0.385000E-01	0.199366E+03
0.400000E-01	0.206911E+03						
0.400000E-01	0.206911E+03	0.403333E-01	0.206949E+03	0.406667E-01	0.206972E+03	0.410000E-01	0.206979E+03

THET = 0.144952E+01

R	T	R	T	R	T	R	T
0.280000E-01	0.134680E+03	0.295000E-01	0.144559E+03	0.310000E-01	0.154145E+03	0.325000E-01	0.163449E+03
0.340000E-01	0.172468E+03	0.355000E-01	0.181176E+03	0.370000E-01	0.189522E+03	0.385000E-01	0.197429E+03
0.400000E-01	0.204789E+03						
0.400000E-01	0.204789E+03	0.403333E-01	0.204822E+03	0.406667E-01	0.204836E+03	0.410131E-01	0.204829E+03

THET = 0.289903E+01

R	T	R	T	R	T	R	T
0.280000E-01	0.133521E+03	0.295000E-01	0.143238E+03	0.310000E-01	0.152669E+03	0.325000E-01	0.161839E+03
0.340000E-01	0.170752E+03	0.355000E-01	0.179387E+03	0.370000E-01	0.187691E+03	0.385000E-01	0.195562E+03
0.400000E-01	0.202850E+03						
0.400000E-01	0.202850E+03	0.403333E-01	0.202880E+03	0.406667E-01	0.202889E+03	0.410525E-01	0.202872E+03

THET = 0.434855E+01

R	T	R	T	R	T	R	T
0.280000E-01	0.132269E+03	0.295000E-01	0.141818E+03	0.310000E-01	0.151093E+03	0.325000E-01	0.160132E+03
0.340000E-01	0.168953E+03	0.355000E-01	0.177546E+03	0.370000E-01	0.185860E+03	0.385000E-01	0.193781E+03
0.400000E-01	0.201124E+03						
0.400000E-01	0.201124E+03	0.403333E-01	0.201155E+03	0.406667E-01	0.201161E+03	0.411184E-01	0.201136E+03

THET = 0.579806E+01

R	T	R	T	R	T	R	T
0.280000E-01	0.130925E+03	0.295000E-01	0.140298E+03	0.310000E-01	0.149412E+03	0.325000E-01	0.158319E+03
0.340000E-01	0.167057E+03	0.355000E-01	0.175633E+03	0.370000E-01	0.184012E+03	0.385000E-01	0.192081E+03
0.400000E-01	0.199625E+03						
0.400000E-01	0.199625E+03	0.403333E-01	0.199657E+03	0.406667E-01	0.199664E+03	0.412108E-01	0.199638E+03

THET = 0.724758E+01

R	T	R	T	R	T	R	T
0.280000E-01	0.129492E+03	0.295000E-01	0.138677E+03	0.310000E-01	0.147619E+03	0.325000E-01	0.156387E+03
0.340000E-01	0.165040E+03	0.355000E-01	0.173617E+03	0.370000E-01	0.182113E+03	0.385000E-01	0.190436E+03
0.400000E-01	0.198350E+03						
0.400000E-01	0.198350E+03	0.403333E-01	0.198384E+03	0.406667E-01	0.198397E+03	0.413302E-01	0.198377E+03

THET = 0.869709E+01

R	T	R	T	R	T	R	T
0.280000E-01	0.127970E+03	0.295000E-01	0.136952E+03	0.310000E-01	0.145707E+03	0.325000E-01	0.154320E+03
0.340000E-01	0.162875E+03	0.355000E-01	0.171452E+03	0.370000E-01	0.180102E+03	0.385000E-01	0.188789E+03
0.400000E-01	0.197281E+03						
0.400000E-01	0.197281E+03	0.403333E-01	0.197321E+03	0.406667E-01	0.197342E+03	0.414769E-01	0.197347E+03

THET = 0.101466E+02

R	T	R	T	R	T	R	T
0.280000E-01	0.126359E+03	0.295000E-01	0.135123E+03	0.310000E-01	0.143671E+03	0.325000E-01	0.152101E+03
0.340000E-01	0.160527E+03	0.355000E-01	0.169083E+03	0.370000E-01	0.177889E+03	0.385000E-01	0.187037E+03
0.400000E-01	0.196382E+03						
0.400000E-01	0.196382E+03	0.403333E-01	0.196432E+03	0.406667E-01	0.196472E+03	0.416514E-01	0.196546E+03

THET = 0.115961E+02

R	T	R	T	R	T	R	T
0.280000E-01	0.124661E+03	0.295000E-01	0.133191E+03	0.310000E-01	0.141505E+03	0.325000E-01	0.149716E+03
0.340000E-01	0.157963E+03	0.355000E-01	0.166429E+03	0.370000E-01	0.175346E+03	0.385000E-01	0.184994E+03
0.400000E-01	0.195563E+03						
0.400000E-01	0.195563E+03	0.403333E-01	0.195648E+03	0.406667E-01	0.195734E+03	0.418543E-01	0.195994E+03

THET = 0.130456E+02

R	T	R	T	R	T	R	T
0.280000E-01	0.122882E+03	0.295000E-01	0.131159E+03	0.310000E-01	0.139209E+03	0.325000E-01	0.147154E+03
0.340000E-01	0.155152E+03	0.355000E-01	0.163426E+03	0.370000E-01	0.172308E+03	0.385000E-01	0.182326E+03
0.400000E-01	0.194382E+03						
0.400000E-01	0.194382E+03	0.403333E-01	0.194839E+03	0.406667E-01	0.195120E+03	0.420862E-01	0.195764E+03

THET = 0.215961E+02

R	T	R	T	R	T	R	T
0.280000E-01	0.110818E+03	0.295000E-01	0.117222E+03	0.310000E-01	0.123049E+03	0.325000E-01	0.128317E+03
0.340000E-01	0.133007E+03	0.355000E-01	0.137053E+03	0.370000E-01	0.140330E+03	0.385000E-01	0.142622E+03
0.400000E-01	0.143583E+03						

THET = 0.301466E+02

R	T	R	T	R	T	R	T
0.280000E-01	0.996175E+02	0.295000E-01	0.104311E+03	0.310000E-01	0.108361E+03	0.325000E-01	0.111794E+03
0.340000E-01	0.114615E+03	0.355000E-01	0.116820E+03	0.370000E-01	0.118398E+03	0.385000E-01	0.119337E+03
0.400000E-01	0.119643E+03						

THET = 0.386971E+02

R	T	R	T	R	T	R	T
0.280000E-01	0.908152E+02	0.295000E-01	0.941695E+02	0.310000E-01	0.969903E+02	0.325000E-01	0.993073E+02
0.340000E-01	0.101146E+03	0.355000E-01	0.102529E+03	0.370000E-01	0.103481E+03	0.385000E-01	0.104028E+03
0.400000E-01	0.104200E+03						

THET = 0.472476E+02

R	T	R	T	R	T	R	T
0.280000E-01	0.844081E+02	0.295000E-01	0.867710E+02	0.310000E-01	0.887387E+02	0.325000E-01	0.903359E+02
0.340000E-01	0.915868E+02	0.355000E-01	0.925161E+02	0.370000E-01	0.931482E+02	0.385000E-01	0.935082E+02
0.400000E-01	0.936211E+02						

THET = 0.557981E+02

R	T	R	T	R	T	R	T
0.280000E-01	0.799075E+02	0.295000E-01	0.815566E+02	0.310000E-01	0.829264E+02	0.325000E-01	0.840342E+02
0.340000E-01	0.848983E+02	0.355000E-01	0.855377E+02	0.370000E-01	0.859712E+02	0.385000E-01	0.862174E+02
0.400000E-01	0.862946E+02						

THET = 0.643485E+02

R	T	R	T	R	T	R	T
0.280000E-01	0.768027E+02	0.295000E-01	0.779480E+02	0.310000E-01	0.788994E+02	0.325000E-01	0.796683E+02
0.340000E-01	0.802676E+02	0.355000E-01	0.807106E+02	0.370000E-01	0.810107E+02	0.385000E-01	0.811811E+02
0.400000E-01	0.812345E+02						

THET = 0.728990E+02

R	T	R	T	R	T	R	T
0.280000E-01	0.746864E+02	0.295000E-01	0.754820E+02	0.310000E-01	0.761434E+02	0.325000E-01	0.766781E+02
0.340000E-01	0.770949E+02	0.355000E-01	0.774031E+02	0.370000E-01	0.776118E+02	0.385000E-01	0.777303E+02
0.400000E-01	0.777674E+02						

THET = 0.814495E+02

R	T	R	T	R	T	R	T
0.280000E-01	0.732625E+02	0.295000E-01	0.738195E+02	0.310000E-01	0.742830E+02	0.325000E-01	0.746580E+02
0.340000E-01	0.749505E+02	0.355000E-01	0.751667E+02	0.370000E-01	0.753131E+02	0.385000E-01	0.753961E+02
0.400000E-01	0.754221E+02						

THET = 0.900000E+02

R	T	R	T	R	T	R	T
0.280000E-01	0.723253E+02	0.295000E-01	0.727233E+02	0.310000E-01	0.730552E+02	0.325000E-01	0.733245E+02
0.340000E-01	0.735348E+02	0.355000E-01	0.736900E+02	0.370000E-01	0.737943E+02	0.385000E-01	0.738525E+02
0.400000E-01	0.738698E+02						

TEMPERATURES ON THE LOWER RECTANGULAR SECTION

X = 0.

Y	T	Y	T	Y	T	Y	T
0.	0.723253E+02	0.150000E-02	0.727233E+02	0.300000E-02	0.730552E+02	0.450000E-02	0.733245E+02
0.600000E-02	0.735348E+02	0.750000E-02	0.736903E+02	0.900000E-02	0.737943E+02	0.105000E-01	0.738525E+02
0.120000E-01	0.738698E+02						

X = 0.138889E-02

Y	T	Y	T	Y	T	Y	T
0.	0.721021E+02	0.150000E-02	0.724681E+02	0.300000E-02	0.727802E+02	0.450000E-02	0.730379E+02
0.600000E-02	0.732428E+02	0.750000E-02	0.733971E+02	0.900000E-02	0.735034E+02	0.105000E-01	0.735650E+02
0.120000E-01	0.735848E+02						

X = 0.277778E-02

Y	T	Y	T	Y	T	Y	T
0.	0.719211E+02	0.150000E-02	0.722587E+02	0.300000E-02	0.725511E+02	0.450000E-02	0.727963E+02
0.600000E-02	0.729939E+02	0.750000E-02	0.731449E+02	0.900000E-02	0.732507E+02	0.105000E-01	0.733130E+02
0.120000E-01	0.733335E+02						

X = 0.416667E-02

Y	T	Y	T	Y	T	Y	T
0.	0.717741E+02	0.150000E-02	0.720876E+02	0.300000E-02	0.723622E+02	0.450000E-02	0.725950E+02
0.600000E-02	0.727847E+02	0.750000E-02	0.729312E+02	0.900000E-02	0.730350E+02	0.105000E-01	0.730967E+02
0.120000E-01	0.731171E+02						

X = 0.555556E-02

Y	T	Y	T	Y	T	Y	T
0.	0.716558E+02	0.150000E-02	0.719495E+02	0.300000E-02	0.722087E+02	0.450000E-02	0.724303E+02
0.600000E-02	0.726124E+02	0.750000E-02	0.727541E+02	0.900000E-02	0.728551E+02	0.105000E-01	0.729155E+02
0.120000E-01	0.729356E+02						

X = 0.694444E-02

Y	T	Y	T	Y	T	Y	T
0.	0.715628E+02	0.150000E-02	0.718406E+02	0.300000E-02	0.720872E+02	0.450000E-02	0.722992E+02
0.600000E-02	0.724745E+02	0.750000E-02	0.726116E+02	0.900000E-02	0.727099E+02	0.105000E-01	0.727689E+02
0.120000E-01	0.727885E+02						

X = 0.833333E-02

Y	T	Y	T	Y	T	Y	T
0.	0.714925E+02	0.150000E-02	0.717584E+02	0.300000E-02	0.719951E+02	0.450000E-02	0.721995E+02
0.600000E-02	0.723692E+02	0.750000E-02	0.725024E+02	0.900000E-02	0.725982E+02	0.105000E-01	0.726559E+02
0.120000E-01	0.726751E+02						

X = 0.972222E-02

Y	T	Y	T	Y	T	Y	T
0.	0.714434E+02	0.150000E-02	0.717008E+02	0.300000E-02	0.719305E+02	0.450000E-02	0.721294E+02
0.600000E-02	0.722949E+02	0.750000E-02	0.724253E+02	0.900000E-02	0.725192E+02	0.105000E-01	0.725758E+02
0.120000E-01	0.725947E+02						

X = 0.111111E-01

Y	T	Y	T	Y	T	Y	T
0.	0.714144E+02	0.150000E-02	0.716667E+02	0.300000E-02	0.718923E+02	0.450000E-02	0.720878E+02
0.600000E-02	0.722508E+02	0.750000E-02	0.723793E+02	0.900000E-02	0.724720E+02	0.105000E-01	0.725279E+02
0.120000E-01	0.725466E+02						

X = 0.125000E-01

Y	T	Y	T	Y	T	Y	T
0.	0.714047E+02	0.150000E-02	0.716554E+02	0.300000E-02	0.718796E+02	0.450000E-02	0.720740E+02
0.600000E-02	0.722362E+02	0.750000E-02	0.723641E+02	0.900000E-02	0.724563E+02	0.105000E-01	0.725121E+02
0.120000E-01	0.725307E+02						

REC= 00000 FIL= 00002

Main Program

```
      COMMON /FORMA/R1,R2,R3,YFINT,FINTHK,ANGTOP,HCOOL,TCOOL,HGAS,TGAS,
     1XLONGM,R2B,YFINB,ANGBOT,SUMAO,SUMAI
      DOUBLE PRECISION R1,R2,R3,YFINT,FINTHK,ANGTOP,HCOOL,TCOOL,HGAS,
     1TGAS,XLONGM,R2B,YFINB,ANGBOT,SUMAO,SUMAI,TOL
      COMMON /FORAN/NRA,NRAM,NTA,NTAP,NRA1,NRA1M,NRA1X,NRA1XM,
     1NRB,NRBM,NTB,NTBM,NTD,NTDM
      COMMON  /FORCN/ NXP,NXP1,NTQ,NTQ1,NZ,NZ1,NZX,NZX1
      COMMON  /FORWA/WMEGA,WMEGA1,WMEGD,WMEGD1,WMEGB,WMEGB1
      DOUBLE PRECISION WMEGA,WMEGA1,WMEGD,WMEGD1,WMEGB,WMEGB1
      COMMON/FORWC/ WMEGP,WMEGP1,WMEGQ,WMEGQ1
      DOUBLE PRECISION WMEGP,WMEGP1,WMEGQ,WMEGQ1
      DIMENSION DENT(12)
      EXTERNAL DUBIO
C
C     IPUNCH = 0  NO CARDS PUNCHED
C     IPUNCH = 1  PUNCH 414 BCD CARDS
C     IREAD = 0   SET INITIAL GUESS FOR U,S AND TEMPS IN RINIT
C     IREAD = 1   RINIT READS 414 BCD CARDS FOR INITIAL GUESS
C     NCOUNT      MAXIMUM NUMBER OF ITERATIONS PROGRAM WILL CYCLE
C     MCOUNT      HEAT BALANCE PRINTED AFTER EVERY MCOUNT ITERATIONS
C     ICOS = 0    HGAS = HGAS
C     ICOS = 1    HGAS(I) = HGAS * COS(THETA(I))
C     R2 = R3     CASE WITH NO CLADDING
C
   10 READ(5,103) (DENT(I),I=1,12)
      READ(5,100) NRA,NTA,NRB,NTB,NTD,NXP,NTQ,NZ,NZX,IPUNCH,IREAD,
     1NCOUNT,MCOUNT,ICOS
      READ(5,101) R1,R2,R3,YFINT,FINTHK,ANGTOP,HCOOL,TCOOL,HGAS,TGAS
      READ(5,101) XLONGM,R2B,YFINB,TOL
      READ(5,101) WMEGA,WMEGA1,WMEGD,WMEGD1,WMEGB,WMEGB1
      READ(5,101) WMEGP,WMEGP1,WMEGQ,WMEGQ1
      WRITE(6,200) (DENT(I),I=1,12)
      WRITE(6,205) NRA,NTA,NRB,NTB,NTD,NXP,NTQ,NZ,NZX,IPUNCH,IREAD,NCOUN
     1T,MCOUNT,ICOS
      WRITE(6,201) R1,R2,R3,YFINT,FINTHK,ANGTOP
      WRITE(6,203) HCOOL,TCOOL,HGAS,TGAS
      WRITE(6,202) XLONGM,R2B,YFINB,TOL
      WRITE(6,206) WMEGA,WMEGA1,WMEGD,WMEGD1,WMEGB,WMEGB1
      WRITE(6,207) WMEGP,WMEGP1,WMEGQ,WMEGQ1
      ANGBOT = ANGTOP
      ICOUNT = 1
      CALL CONSA(ICOS)
      CALL CONSB
      CALL RINIT(IREAD)
    1 SUMAI = 0.0
      SUMAO = 0.0
      CALL COMPA(ICOS)
       CALL COMPB
      REL = ABS((ABS(SUMAI)-ABS(SUMAO))/ABS(SUMAI))
      IF(REL .LE. TOL) GO TO 2
      IF(MOD(ICOUNT,MCOUNT) .EQ. 0) WRITE(6,204) ICOUNT,SUMAI,SUMAO,REL
      ICOUNT = ICOUNT + 1
      IF (ICOUNT .GT. NCOUNT) GO TO 2
      GO TO 1
    2 ICOUNT = ICOUNT - 1
      WRITE(6,204) ICOUNT,SUMAI,SUMAO,REL
      CALL OUTPUT(IPUNCH)
      GO TO 10
  100 FORMAT (14I5)
  101 FORMAT (10D8.5)
  103 FORMAT(12A6)
  200 FORMAT(1HK,25X12A6//1H )
  201 FORMAT(1HK,11X2HR1,18X2HR2,18X2HR3,15X9HY-FIN-TOP,11X9HFIN-THICK,
     110X9HANGLE-TOP/6(5XG15.8)/1H )
  202 FORMAT(1HK,8X10HX-MID-RECT,12X6HR2-BOT,11X12HY-FIN-BOTTOM,9X12HTOL
     1ERANCE    /4(5XG15.8)/1H )
  203 FORMAT(1HK,8X9HH-COOLANT,11X12HTEMP-COOLANT,12X5HH-GAS,14X8HTEMP-G
     1AS/4(5XG15.8)/1H )
  204 FORMAT(1HK,5X12HITERATION = I5,5X10HHEAT IN = G15.8,5X11HHEAT OUT
     1= G15.8,5X15HRELATIVE ERR = G15.8//1H )
  205 FORMAT(1HK,4X3HNRA,5X3HNTA,5X3HNRB,5X3HNTB,5X3HNTD,5X3HNXP,5X3HNTQ
     1,5X2HNZ,
     16X3HNZX,3X6HIPUNCH,3X5HIREAD,2X6HNCOUNT,2X6HMCOUNT,4X4HICOS/14(3XI
     25)/1H )
  206 FORMAT(1HK,8X8HOMEGA(A),12X9HOMEGA(A1),11X8HOMEGA(D),12X9HOMEGA(D1
     1),11X8HOMEGA(B),12X9HOMEGA(B1)/6(5XG15.8)/1H )
  207 FORMAT(1HK,8X8HOMEGA(P),12X9HOMEGA(P1),11X8HOMEGA(Q),12X9HOMEGA(Q1
     1)/4(5XG15.8)/1H )
      END
```

```
      SUBROUTINE CONSA(ICOS)
      COMMON /FORAN/NRA,NRAM,NTA,NTAP,NRA1,NRA1M,NRA1X,NRA1XM,
     1NRB,NRBM,NTB,NTBM,NTD,NTDM
      COMMON /FORCN/ NXP,NXP1,NTQ,NTQ1,NZ,NZ1,NZX,NZX1
      COMMON /FORA1/DRB,HCA,A1X,A2X,A3X,A4X,A5X,A6X,HGA,HCD,
     1HCAD,HGAD,HCB,HCAB,D1X,D2X,D3X,AE,BE,DEX,DEY,EC,DENAD,
     2DENBZ
      DOUBLE PRECISION DRB,HCA,A1X,A2X,A3X,A4,A5X,A6X,HGA,HCD,
     1HCAD,HGAD,HCB,HCAB,D1X,D2X,D3X,AE,BE,DEX,DEY,EC,DENAD,DENBZ
      COMMON /FORA2/AA(15),AB(15),AC(15),A1A(35),A1B(35),A1C(35),AD(15),
     1BD(15),CD(15),A1D(35),B1D(35),C1D(35),BAD(15),CAD(15),
     2B1AD(35),C1AD(35),BA(15),BB(15),BC(15),B1A(20),B1B(20),B1C(20),
     3BBD(15),CBD(15),B1BD(20),C1BD(20),AP(15),BP(15),A1P(5),B1P(5),
     4D1BX(15),D2BX(15)
      DOUBLE PRECISION AA,AB,AC,A1A,A1B,A1C,AD,BD,CD,A1D,B1D,C1D,
     1BAD,CAD,B1AD,C1AD,BA,BB,BC,B1A,B1B,B1C,BBD,CBD,B1BD,C1BD,
     2AP,BP,A1P,B1P,D1BX,D2BX
      COMMON /FOUTA/THETA(25),RA(15),RA1X(35),RA1(35),THETD(15),
     1THETB(15)
      DOUBLE PRECISION THETA,RA,RA1X,RA1,THETD,THETB
      DIMENSION DRAX(35)
      DATA PI2/1.5707963268/
      DOUBLE PRECISION DRAX,PI2
      COMMON /FORMA/R1,R2,RA2,Y1,RAH,PT,HC,TC,HG,TG,PX,R2B,BY1,PTL,SUMAO,
     1SUMAI
      DOUBLE PRECISION R1,R2,RA2,RAH,PT,HC,TC,HG,TG,PX,R2B,PTL,SUMAO,
     1SUMAI,BY1
      DOUBLE PRECISION A4X,Y1,DRA,DTD,STA,DTDDRA,DTBDRA,CUTA1,ENTA,AY,
     1CUTA2,THEB,X1,DRA2,DTDRA,DTB2,YA,THA1,DTA,ENR,THED,DTB,X2,DTA2,
     2R1DR,STB
      COMMON /CLA/ UA(15),UA1(35),UD(15),UD1(35),UB(15),UB1(20)
      DOUBLE PRECISION UA,UA1,UD,UD1,UB,UB1
      COMMON /FORANN/NRA11,NRAM1,NRBM1
      DOUBLE PRECISION XA
C
C     GRID CONSTANTS FOR REGIONS A,A1,D,D1,B,B1
C
      XA = R2 + RAH
      CUTA2 = DATAN(Y1/XA)
       IF(RA2 .EQ. R2) GO TO 200
      YA = DSQRT(RA2*RA2 - XA*XA)
      CUTA1 = DATAN(YA/XA)
      GO TO 201
  200 THA1 = PI2-PT-CUTA2
      CUTA1 = CUTA2 + THA1 * .25
  201 THA1 = PI2 - PT - CUTA1
      NTA1 = NTA-1
      ENTA = NTA1
      NTAP = NTA+1
      DTA = THA1/ENTA
      DO 1I = 1,NTA
      AY = I-1
    1 THETA (I) = AY*DTA
      NRAM = NRA-1
      ENR = NRAM
      DRA = (R2-R1)/ENR
      DO 20 I=1,NRA
      AY=I-1
   20 RA(I) = R1+AY*DRA
      THED = CUTA1 - CUTA2
      NTDM = NTD - 1
      ENTA = NTDM
      DTD = THED/ENTA
      DO 10 I = 1,NTD
      AY = I - 1
   10 THETD(I) = AY * DTD
      THEB = CUTA2
      NRBM=NRB-1
      NTBM=NTB-1
      ENTA = NTBM
      ENR= NRBM
      DTB = THEB/ENTA
      DRB = RAH/ENR
      DO 30 I=1,NTB
      AY=I-1
   30 THETB(I)=AY*DTB
      DO 40 I=1,NRB
      AY = I-1
```

```
   40 RA1(I)=R2 + AY*DRB
      NRA1 = NTB + NRBM
      NRA1M=NRA1-1
      DO 50 I=1,NTB
      J=NRA1+1-I
   50 RA1(J) = XA/DCOS (THEB -THETB(I))
      RA1X (1)=R2 + DRB/2.0
      DO 60 I=2,NRBM
   60 RA1X(I)=RA1X(I-1)+DRB
      X1=THETB(NTB)-DTB/2.0
      DO 70 I=NRB,NRA1M
      RA1X(I) = XA/DCOS(THEB -X1)
   70 X1=X1-DTB
      NRA1X = NRA1 + NTDM
      IF(R2 .EQ. RA2) NRA1X = NRA1
      IF(R2 .EQ. RA2) GO TO 202
      X2 = CUTA2 + DTD/2.0
      DO 100 I = 1,NTDM
      J = NRA1 + I
      K = NTD-I
       RA1(J) = XA/DCOS(CUTA1 - THETD(K))
      J1 = J -1
      RA1X(J1) = XA/DCOS(X2)
  100 X2 = X2 + DTD
  202 NRA1XM = NRA1X-1
      NRA11 = NRA1XM-1
      NRAM1 = NRAM-1
      NRBM1 = NRBM - 1
      DRAX(1)=DRB/2.0
      DO 80I =2,NRA1XM
   80 DRAX(I)=RA1X(I)-RA1X (I-1)
      DRAX(NRA1X) = RA1(NRA1X) - RA1X(NRA1XM)
C
C     ITERATION CONSTANTS FOR REGIONS A,A1
C
      CALL CIRCOL(DRA,DTA,RA,AA,AB,AC,UA,NRA)
      HCA = HC * R1* DTA
      IF(R2 .EQ. RA2) GO TO 203
      CALL CIRCOT(DRAX,DTA,RA1,RA1X,A1A,A1B,A1C,UA1,NRA1X)
      A2X = A1C(1)
  203 A1X = AA(NRA) + AB(NRAM)
      A1C(NRA1X) = 2.0*A1A(NRA1X) + A1B(NRA1XM)
      HGA =  HG * RA2 * DTA
C
C     ITERATION CONSTANTS FOR REGIONS D,D1
C
      CALL CIRCOL(DRA,DTD,RA,AD,BD,CD,UD,NRA)
      HCD = HC * R1 * DTD
      IF(R2 .EQ. RA2) GO TO 204
      CALL CIRCOT(DRAX,DTD,RA1,RA1X,A1D,B1D,C1D,UD1,NRA1XM)
      A6X = 2.0 * A1D(1) + B1D(1)
  204 IF(R2 .EQ. RA2) A6X = HG * R2 * DTD
      A5X = AD(NRA) + BD(NRAM)
      AD(NRA) = AD(NRA)/2.0
C
C     ITERATION CONSTANTS FOR BOUNDARY BETWEEN REGIONS A,D AND A1,D1
C
      DO 103 I = 1,NRA
      BAD(I) = (AB(I) + BD(I))/2.0
  103 CAD(I) = AA(I) + AD(I) + RA(I) * (DTA + DTD)/DRA
      CAD(NRA) = AA(NRA)/2.0 + AD(NRA) + BAD(NRAM)
      CAD(1) = AA(1) + AD(1) + BAD(1)
      IF(R2 .EQ. RA2) GO TO 205
      B1AD(1) = (A1B(1) + B1D(1))/2.0
      DO 104 I = 2,NRA1XM
      B1AD(I) = (A1B(I) + B1D(I))/2.0
  104 C1AD(I) = A1A(I) + A1D(I) + B1AD(I) + B1AD(I-1)
      C1AD(1) = A1A(1) + A1D(1) + B1AD(1)
  205 HCAD = (HCA + HCD)/2.0
      HGAD = HGA/2.0
      IF(R2 .EQ. RA2) HGAD = HGAD+A6X/2.0
      C1AD(NRA1X) = A1A(NRA1X) + B1AD(NRA1XM)
C
C     ITERATION CONSTANTS FOR REGIONS B,B1
C
      CALL CIRCOL(DRA,DTB,RA,BA,BB,BC,UB,NRA)
      CALL CIRCOT(DRAX,DTB,RA1,RA1X,B1A,B1B,B1C,UB1,NRA1M)
      A4X = B1C (1)
      X1 = 2.0*DSIN(DTA/2.0)
```

```
      A4X = 2.0* B1A(1)+ B1B(1)
      A3X = BA(NRA) + BB(NRAM)
      BA(NRA) = BA(NRA)/2.0
      HCB = HC*R1*DTB
      DO 92 I=1,NRA
      BBD(I)= (BD(I) + BB(I))/2.0
   92 CBD(I) = AD(I) + BA(I) + RA(I)*(DTD+DTB)/DRA
      CBD(NRA) = AD(NRA)/2.0 + BA(NRA) + BBD(NRAM)
      CBD(1) = AD(1) + BA(1) + BBD(1)
C
C     ITERATION CONSTANTS FOR BOUNDARY BETWEEN REGIONS D,B AND D1,B1
      B1BD(1) = (B1D(1)+B1B(1))/2.0
      DO 93 I=2,NRA1M
      B1BD(I) = (B1D(I)+B1B(I))/2.0
   93 C1BD(I) = A1D(I) + B1D(I) + B1BD(I)+ B1BD(I-1)
      C1BD(1) = A1D(1) + B1D(1) + B1BD(1)
      C1BD(NRA1) = A1D(NRA1) + B1BD(NRA1M)
      HCAB = (HCD + HCB)/2.0
      D1X = AD(NRA) + BBD(NRAM) +BA(NRA)
      D2X = A1D(1) + B1D(1)/2.0
      D3X = B1A(1) +   B1B(1)/2.0
      DTD = DEY
      DO  110  I= 2,NRA1M
      D1BX (I) = A1D(I)+ (B1D(I)+B1D(I-1))/2.0
  110 D2BX(I) = B1A (I) +(B1B(I)+ B1B(I-1))/2.0
      D1BX (NRA1) = A1D(NRA1) + B1D(NRA1M)/2.0
      D2BX (NRA1) = B1B(NRA1M)/2.0
      IF(RA2 .NE. R2) GO TO 206
      D2X = A6X/2.0
      D1BX(1) = HG * DRAX(1) * THA1
      IF( ICOS .NE. 1) GO TO 207
      X1 = DCOS(THA1 +THED)
      D2X = D2X *X1
      D1BX(1) = D1BX(1) * X1
  207 D3X = A4X/2.0
      DO 208 I = 2,NRA1
      D1BX(I) = HG * DRAX(I) * THA1
  208 IF(ICOS .EQ. 1) D1BX(I) = D1BX(I) * X1
C
C     ITERATION CONSTANTS FOR BOUNDARY BETWEEN REGIONS B,P AND B1,P1
C
  206 NXP1 = NXP - 1
      ENTA = NXP1
      X1= PX/ENTA
      AE = X1/DRA
      BE = DRA/X1
      DTBDRA = DTB/DRA
      DO 31 I=1,NRA
      AP(I) = (BB(I) + AE)/2.0
   31 BP(I) = BA(I) + BE + AE + RA(I)*DTBDRA
      BP(1) = BA(1)+ AP(1)+ BE/2.0
      DEX = BA(NRA) + BE/2.0+ AP(NRAM)
      DENAD = X1/DRB
      DENBZ = DRB/X1
      DO 32 I=1,NRB
      A1P(I) = (B1B(I)+DENAD)/2.0
   32 B1P(I) = B1A(I) + DENBZ + (RA1(I)*DTB + X1)/DRB
      DEY = B1A(1) + DENBZ/2.0 + A1P(1)
      B1P(NRB) = B1A(NRB)+ DENBZ/2.0 + A1P(NRBM)
      EC = (HCB+X1*HC)/2.0
      RETURN
      END
```

```
      SUBROUTINE CONSB
      COMMON/FORAN/NRA,NRAM,NTA,NTAP,NRA1,NRA1M,NRA1X,NRA1XM,
     1NRB,NRBM,NTB,NTBM,NTD,NTDM
      COMMON /FORCN/ NXP,NXP1,NTQ,NTQ1,NZ,NZ1,NZX,NZX1
      COMMON/FORC1/PX22,HCP,PX2,PX1,PX4,P2X,P1X4,P1X3,HCPQ,S1P,S2P,
     1HCQ,Q1X,Q2X,HCQZ,QZ1,QZ2,HCZ,ZR3,HCRL,ZR1,ZR2,ZR4,ZR5,HCZR,PX3,
     1P1X2,P1X1
      DOUBLE PRECISION PX22,HCP,PX2,PX1,PX4,P2X,P1X4,P1X3,HCPQ,S1P,S2P,
     1HCQ,Q1X,Q2X,HCQZ,QZ1,QZ2,HCZ,ZR3,HCRL,ZR1,ZR2,ZR4,ZR5,HCZR,PX3
     2,P1X2,P1X1
      COMMON/FORC2/AQ(15),BQ(15),CQ(15),A1Q(5),B1Q(5),C1Q(5),PQA(15),
     1PQB(15),PQA1(15),PQB1(15),AQT(21),BQT(21),CQT(21),ZA(15),ZB (15),
     2ZC(15), AQZ (15),CQZ(15),ZARL(15),ZBRL(15)
      DOUBLE PRECISION AQ,BQ,CQ,A1Q,B1Q,C1Q,PQA,PQB,PQA1,PQB1,
     1AQT,BQT,CQT,ZA,ZB,ZC,AQZ,CQZ,ZARL,ZBRL
      COMMON /FOUTC/THETQ(20), XP(20),RQA(15),RQ(5),THETZ(20),
     1 XZ (20),QT (20),YP(20),YP1(5)
      DOUBLE PRECISION THETQ,XP,RQA,RQ,THETZ,XZ,QT,YP,YP1
      DATA PI2/1.570796328/
      COMMON/FORMA/R1,R2,RA2,Y1,RAH,PT,HC,TC,HG,TG,PX,R2B,BY1,PTL,SUMAO,
     1SUMAI
      DOUBLE PRECISION R1,R2,RA2,RAH,PT,HC,TC,HG,TG,PX,R2B,PTL,SUMAO,
     1SUMAI,Y1
      DOUBLE PRECISION BY1,DRA,DXP,DQR,X2,THEZ,DELZ,X3,THEQ,DRB,CTQ,DQL,
     1R1DR,PI2,DZX,SUM1,ENT,DRA2,AY,STA,X1,R2DR,ENZ,DP1X2,XQR,R1B,XQT,ZX
      COMMON/CLB/UQ(15),UZ(15),CP(15),UP(15),CP1(5),UP1(5),CZ(15),
     1UZR(15)
      DOUBLE PRECISION UQ,UZ,CP,UP,CP1,UP1,CZ,UZR
      COMMON /CLAB/ PXA,PXAP,PXA1,PXA1P,ZRA,ZRP
      DOUBLE PRECISION PXA,PXAP,PXA1,PXA1P,ZRA,ZRP
C
C     GRID CONSTANTS FOR REGIONS P,P1,Q,Q1,ZL,ZR
C
      R1B= R2B - R2 + R1
      THEQ= DATAN(BY1/(R2B+RAH))
      ENT = NRAM
      DRA = (R2-R1)/ENT
      ENT = NRBM
      DRB = RAH/ENT
      DRA2 = DRA/2.0
      NXP1= NXP-1
      ENT= NXP1
      DXP = PX/ENT
      DO 7 I=1,NXP
      AY= I-1
    7 XP(I)= AY*DXP
      DO 200 I = 1,NRA
      AY = I - 1
  200 YP(I) = AY * DRA
      DO 201 I = 1,NRB
      AY = I - 1
  201 YP1(I) = AY * DRB + YP(NRA)
      NTQ1= NTQ-1
      ENT= NTQ-1
      DTQ= THEQ/ENT
      DO 2  I=1,NTQ
      AY= I-1
    2 THETQ(I)= AY*DTQ
      DO 3  I=1,NRA
      AY= I-1
    3 RQA(I)= R1B+ AY * DRA
      R2DR = R2B + DRB/2.0
      RQ(1) = RQA(NRA)
      DO 5  I=2,NRB
    5 RQ(I) = RQ(I-1) + DRB
      THEZ= PI2 + PTL - THEQ
      NZ1= NZ-1
      ENZ= NZ1
      DELZ= THEZ/ENZ
      DO 30  I=1,NZ
      AY= I-1
   30 THETZ(I)= AY*DELZ
      ZX= R1-R1B
      NZX1= NZX-1
      ENZ= NZX1
      DZX= ZX/ENZ
      DO 32  I=1,NZX
      AY= I-1
   32 XZ(I)= AY*DZX
C
```

```
C     ITERATION CONSTANTS FOR REGIONS P,P1
C
      PX1 = DXP/DRA
      PX2 = DRA/DXP
      P1X1 = DRB/DXP
      P1X2 = DXP/DRB
      PX22= PX2/2.0
      HCP= HC*DXP
      PX3= PX1+PX2
      PX4= 2.0*PX3
      P1X3= 2.0*(P1X1+P1X2)
      P1X4= P1X1/2.0
      P2X= P1X1+P1X2
      PXA = -PX1/PX4
      PXAP = PX2/PX4
      PXA1 = -P1X2/P1X3
      PXA1P = P1X1/P1X3
      CALL RCOL(PXA,CP,UP,NRAM)
      CALL RCOL(PXA1,CP1,UP1,NRBM)
C
C     ITERATION CONSTANTS FOR REGIONS Q,Q1
C
      CALL CIRCOL(DRA,DTQ,RQA,AQ,BQ,CQ,UQ,NRA)
      HCQ= HC*R1B*DTQ
      DQR= DTQ/DRB
      STA= DSIN(DTQ/2.0)
      X2= DRB/(2.0*STA)
      A1Q(1)= X2/(2.0*R2B)
      B1Q(1)= R2DR*DQR
      C1Q(1)= X2/R2B + B1Q(1)
      DO 6 I = 2,NRB
      A1Q(I)= X2/RQ(I)
      B1Q(I) = B1Q(I-1) + DTQ
    6 C1Q(I)= 2.0*(A1Q(I) + RQ(I)*DQR)
      Q1X= AQ(NRA) + BQ(NRAM)
      Q2X= 2.0*A1Q(1) + B1Q(1)
C
C     ITERATION CONSTANTS FOR REGION ZL
C
      CALL CIRCOL(DRA,DELZ,RQA,ZA,ZB,ZC,UZ,NRA)
      ZC(NRA)= ZA(NRA) + ZB(NRAM)
      ZA(NRA)= ZA(NRA)/2.0
      HCZ= HC*R1B*DELZ
C
C     ITERATION CONSTANTS FOR REGION ZR
C
      ZR1= DRA/(2.0*DZX)
      ZR2= DZX/DRA
      ZR3= 2.0*ZR1
      ZR4= ZR3 + ZR2
      ZR5= 2.0*ZR4
      ZRA = -ZR2/ZR5
      ZRP = ZR3/ZR5
      CALL RCOL(ZRA,CZ,UZR,NRAM)
      HCZR= HC*DZX
C
C     ITERATION CONSTANTS FOR BOUNDARY BETWEEN REGIONS P,Q AND P1,Q1
C
      DO  55  I =1,NRA
      PQA(I) = (PX1+BQ(I))/2.0
   55 PQB(I) = PX2+ AQ(I) + PX1+ RQA(I)*DTQ/DRA
      PQB(1) = PX22   + AQ(1) + PQA(1)
      DO 56 I=1,NRB
      PQA1(I) = (P1X2  + B1Q (I))/2.0
   56 PQB1(I) =  P1X1  + A1Q(I) +  P1X2 + RQ (I)* DTQ/DRB
      X2 =  DTQ/2.0
      X1 =  R2B + RAH
      X3 =  X1-DRB/2.0
      SUM1 = 0.0
      DO  90 I= 2,NTQ
      QT (I) = X1/DCOS(THETQ(I))
      XQT = QT(I) * DSIN(THETQ(I)) - SUM1
      SUM1 = SUM1 + XQT
      AQT(I) = X1 -X3* DCOS(X2)
      AQT (I) = AQT(I)/XQT
      X2=  X2 + DTQ
   90 BQT (I) =  X3 * DTQ/( QT(I) - RQ(NRBM))
      AQT (NTQ +1)  =0.0
      DO 91  I = 2,NTQ
```

```
   91 CQT(I) = AQT(I) + AQT(I+1) + BQT(I)
      CQT(1) = P1X4 +PQA1(NRBM) + AQT(2)
      QT(1) = X1
      BQT(NTQ) = BQT(NTQ)/2.0
      S1P =  PX22   + AQ(NRA)/2.0 + PQA(NRAM)
      S2P =  P1X4      +A1Q(1) + PQA1(1)
      HCPQ = (HCP +HCQ)/2.0
C
C     ITERATION CONSTANTS FOR BOUNDARY BETWEEN REGIONS Q,ZL
      DO 92  I = 1,NRA
      AQZ(I) =  (BQ(I) + ZB(I))/2.0
   92 CQZ(I) = AQ(I) + ZA(I) +  RQA(I)*(DTQ+ DELZ)/DRA
      CQZ(1) = AQ(1) + ZA(1) + AQZ(1)
      HCQZ = (HCQ +HCZ)/2.0
      QZ1 = AQ(NRA)/2.0 + ZA(NRA) + AQZ(NRAM)
      QZ2 = A1Q (1)  +  B1Q(1)/2.0
C
C     ITERATION CONSTANTS FOR BOUNDARY BETWEEN REGIONS ZL,ZR
C
      DQR = DELZ/DRA
      DO  33  I= 1,NRA
      ZARL (I)  =  (ZB(I) + ZR2)/2.0
   33 ZBRL (I) = ZA(I) + ZR4 + RQA(I)* DQR
      ZBRL(1)  =  ZARL(1) +ZA(1)   +ZR1
      ZBRL(NRA) = ZA(NRA) + ZR1 + ZARL(NRAM)
      HCRL = (HCZ + HCZR)/2.0
      RETURN
      END
```

```
      SUBROUTINE RCOL(A,EL,U,N)
C
C     ROUTINE TO TRIANGULARIZE MATRIX CF COEFFICIENTS IN RECT. REGIONS
C
      DIMENSION EL(1),U(1)
      DOUBLE PRECISION A,EL,U
      EL(2) = 1.0
      U(2) = A
      DO 1 I = 3,N
      EL(I) = 1.0 - A * U(I-1)
    1 U(I) = A/EL(I)
      RETURN
      END
```

```
      SUBROUTINE CIRCOL(DRA,DTA,RA,AA,AB,AC,AD,N)
C
C     ROUTINE TO COMPUTE COEFFICIENTS AND TRIANGULARIZE MATRIX FOR
C     RADIAL REGIONS OF TUBE WALL
C
      DIMENSION RA(1),AA(1),AB(1),AC(1),AD(1)
      DOUBLE PRECISION RA,AA,AB,AC,AD,DRA2,DTA2,STA,DTDRA,X1,R1DR
     1,DRA,DTA
      DRA2 = DRA/2.0
      DTA2 = DTA/2.0
      N1 = N-1
      STA = DSIN(DTA2)
      DTDRA = DTA/DRA
      X1 = DRA2/STA
      R1DR = RA(1) + DRA2
      AA(1) = X1/(2.0 * RA(1))
      AB(1) = R1DR * DTDRA
      AC(1) = X1/RA(1) + AB(1)
      DO 1 I = 2,N
      AA(I) = X1/RA(I)
      AB(I) = AB(I-1) + DTA
    1 AC(I) = 2.0 * (AA(I) + RA(I) * DTDRA)
      AD(2) =-AB(2)/AC(2)
      DO 2 I = 3,N1
      AC(I) = AC(I) + AB(I-1) * AD(I-1)
    2 AD(I) =-AB(I)/AC(I)
      RETURN
      END
```

```
      SUBROUTINE CIRCOT(DRAX,DTA,RA1,RA1X,A1A,A1B,A1C,A1D,N)
C
C     ROUTINE TO COMPUTE COEFFICIENTS AND TRIANGULARIZE MATRIX FOR
C     RADIAL REGIONS OF CLADDING AND FIN
C
      DIMENSION DRAX(1),DMAX(1),RA1(1),RA1X(1),A1A(1),A1B(1),A1C(1),
     1A1D(1)
      DOUBLE PRECISION DRAX,RA1,RA1X,A1A,A1B,A1C,A1D,X1,DTA
      N1 = N-1
      X1 = 2.0 * DSIN(DTA/2.0)
      A1A(1) = DRAX(1)/(X1 * RA1(1))
      A1B(1) = RA1X(1) * DTA/(RA1(2) - RA1(1))
      A1C(1) = 2.0 * A1A(1) + A1B(1)
      DO 1 I = 2,N
      A1A(I) = DRAX(I)/(X1 * RA1(I))
      A1B(I) = RA1X(I) * DTA/(RA1(I+1) - RA1(I))
    1 A1C(I) = 2.0 * A1A(I) + A1B(I-1) + A1B(I)
      A1D(2) =-A1B(2)/A1C(2)
      DO 2 I = 3,N1
      A1C(I) = A1C(I) + A1B(I-1) * A1D(I-1)
    2 A1D(I) =-A1B(I)/A1C(I)
      RETURN
      END
```

```
      SUBROUTINE RINTI(IREAD)
      COMMON/FORAN/NRA,NRAM,NTA,NTAP,NRA1,NRA1M,NRA1X,NRA1XM,
     1NRB,NRBM,NTB,NTBM,NTD,NTDM
      COMMON /FORCN/ NXP,NXP1,NTQ,NTQ1,NZ,NZ1,NZX,NZX1
      COMMON/FORA/ A(15,25),A1(35,25),B(15,15),BZ(20,15),D(15,15),
     1 D1(35,15),TBA(25),TAI(25),TTA(25),TBB(15),TBI(15),TBD(15),
     2TDI(15),TDD(15)
      DOUBLE PRECISION A,A1,B,B1,D,D1,TBA,TAI,TTA,TBB,TBI,TBD,
     1TDI,TDD
      COMMON /FORC/ P(20,15),P1(20,5),Q(15,20),Q1(15,20),ZL(15,20),
     1ZR (20,15),TPB(20),TPI(20),TBQ(20),TQI(20),TZB(20),TZBR(20)
      DOUBLE PRECISION P,P1,Q,Q1,ZL,ZR,TPB,TPI,TBQ,TQI,TZB,TZBR
      DOUBLE PRECISION BZ
      IF (IREAD.EQ.1) GO TO 600
C
C     IREAD = 1   READ BCD CARDS CONTAINING U,S FOR ALL REGIONS
C                 AND TEMPS ON BOUNDARIES AND INTERFACES
C
C     INITIAL CONSTANT GUESS OF 1000 DEGREES FOR SAMPLE PROBLEM
C
      DO 1 I = 1,NTAP
      TBA(I) = 1000.0
      TAI(I) = 1000.0
      TTA(I) = 1000.0
      DO 2 J = 1,NRA
    2 A(J,I) = .1802084
      DO 1 J = 1,NRA1X
    1 A1(J,I) = .75271
      DO 4 J=1,NTD
      DO 5 I=1,NRA
    5 D(I,J) = A(I,1)
      DO 6 I=1,NRA1X
    6 D1(I,J) = A1(I,1)
      TBD(J) = TBA(1)
    4 TDI(J) = TAI(1)
      DO 7 J=1,NTB
      DO 8 I=1,NRA
    8 B(I,J) = A(I,1)
      DO 9 I=1,NRA1
      BZ(I,J) = 4.7233244
      TBB(I) = TDI(1)
    9 TDD(I) = TDI(1)
      TBD(J) = TBA(1)
    7 TBI(J) = TAI(1)
      DO 10 J=1,NXP
      DO 11 I=1,NRA
   11 P(J,I) = A(I,1)
      DO 12 I=1,NRB
   12 P1(J,I) = BZ(I,1)
      TPB(J) = TBA(1)
```

```
   10 TPI(J) = TAI(1)
      DO 13 J=1,NTQ
      DO 14 I=1,NRA
   14 Q(I,J) = A(I,1)
      DO 15 I= 1,NRB
   15 Q1(I,J) = BZ(I,1)
      TBQ(J) = TBA(1)
   13 TQI(J) = TAI(1)
      DO 16 J=1,NZ
      DO 17 I=1,NRA
   17 ZL(I,J) = A(I,1)
   16 TZB(J) = TBA(1)
      DO 18 J=1,NZX
      DO 19 I=1,NRA
   19 ZR(J,I) = A(I,1)
   18 TZBR(J) = TBA(1)
      GO TO 601
C
C     READ INITIAL GUESS FROM BCD CARDS
C
  600 CALL BCREAD (A(1,1),A(15,25))
      CALL BCREAD (A1(1,1),A1(35,25))
      CALL BCREAD (D(1,1),D(15,15))
      CALL BCREAD (D1(1,1),D1(35,15))
      CALL BCREAD (B(1,1),B(15,15))
      CALL BCREAD (BZ(1,1),BZ(20,15))
      CALL BCREAD (TBA(1),TBA(25))
      CALL BCREAD (TAI(1),TAI(25))
      CALL BCREAD (TTA(1),TTA(25))
      CALL BCREAD (TBD(1),TBD(15))
      CALL BCREAD (TDI(1),TDI(15))
      CALL BCREAD (TDD(1),TDD(15))
      CALL BCREAD (TBB(1),TBB(15))
      CALL BCREAD (TBI(1),TBI(15))
      CALL BCREAD (P(1,1),P(20,15))
      CALL BCREAD (P1(1,1),P1(20,5))
      CALL BCREAD (Q(1,1),Q(15,20))
      CALL BCREAD (Q1(1,1),Q1(15,20))
      CALL BCREAD (ZL(1,1),ZL(15,20))
      CALL BCREAD (ZR(1,1),ZR(20,15))
      CALL BCREAD (TPB(1),TPB(20))
      CALL BCREAD (TPI(1),TPI(20))
      CALL BCREAD (TBQ(1),TBQ(20))
      CALL BCREAD (TQI(1),TQI(20))
      CALL BCREAD (TZB(1),TZB(20))
      CALL BCREAD (TZBR(1),TZBR(20))
  601 CONTINUE
      RETURN
      END
```

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      SUBROUTINE COMPA(ICOS)
      COMMON /FORAN/NRA,NRAM,NTA,NTAP,NRA1,NRA1M,NRA1X,NRA1XM,
     1NRB,NRBM,NTB,NTBM,NTD,NTDM
      COMMON /FORA1/DRB,HCA,A1X,A2X,A3X,A4X,A5X,A6X,HGA,HCD,
     1HCAD,HGAD,HCB,HCAB,D1X,D2X,D3X,AE,BE,DEX,DEY,EC,DENAD,
     2DENBZ
      DOUBLE PRECISION DRB,HCA,A1X,A2X,A3X,A4,A5X,A6X,HGA,HCD,
     1HCAD,HGAD,HCB,HCAB,D1X,D2X,D3X,AE,BE,DEX,DEY,EC,DENAD,DENBZ
      COMMON /FORA2/AA(15),AB(15),AC(15),A1A(35),A1B(35),A1C(35),AD(15),
     1BD(15),CD(15),A1D(35),B1D(35),C1D(35),BAD(15),CAD(15),
     2B1AD(35),C1AD(35),BA(15),BB(15),BC(15),B1A(20),B1B(20),B1C(20),
     3BBD(15),CBD(15),B1BD(20),C1BD(20),AP(15),BP(15),A1P(5),B1P(5),
     4D1BX(15),D2BX(15)
      DOUBLE PRECISION AA,AB,AC,A1A,A1B,A1C,AD,BD,CD,A1D,B1D,C1D,
     1BAD,CAD,B1AD,C1AD,BA,BB,BC,B1A,B1B,B1C,BBD,CBD,B1BD,C1BD,
     2AP,BP,A1P,B1P,D1BX,D2BX
      COMMON /FORA/ A(15,25),A1(35,25),B(15,15),BZ(20,15),D(15,15),
     1 D1(35,15),TBA(25),TAI(25),TTA(25),TBB(15),TBI(15),TBD(15),
     2TDI(15),TDD(15)
      COMMON /FOUTA/THETA(25),RA(15),RA1X(35),RA1(35),THETD(15),
     1THETB(15)
      DOUBLE PRECISION A,A1,B,B1,D,D1,TBA,TAI,TTA,TBB,TBI,TBD,
     1TDI,TDD
      DOUBLE PRECISION THETA,RA,RA1X,RA1,THETD,THETB
      DIMENSION COAA(25),CONA1(25),CONAI(25),CONA1I(25),
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     1TB1(25),TT1(25),TAI1(25),TAI2(25),TAI3(25),CONBB(15),
     2CONBI(15),CONBII(15),CONBC(15),CONBD(15),CONDI(15),CONDD
     3(15),CONDII(15),X(35),F(35)
      DOUBLE PRECISION COAA,CONA1,CONAI,CONAII,TB1,TT1,TAI1,
     1TAI2,TAI3,CONBB,CONBI,CONBII,CONBC,CONBD,CONDI,
     2CONDD,CONDII,X,F
      COMMON /FORC/ P(20,15),P1(20,5),Q(15,20),Q1(15,20),ZL(15,20),
     1ZR (20,15),TPB(20),TPI(20),TBQ(20),TQI(20),TZB(20),TZBR(20)
      DOUBLE PRECISION P,P1,Q,Q1,ZL,ZR,TPB,TPI,TBQ,TQI,TZB,TZBR
      DATA PI2/1.5707963268/
      COMMON/FORMA/R1,R2,RA2,Y1,RAH,PT,HC,TC,HG,TG,PX,R2B,BY1,PTL,SUMAO,
     1SUMAI
      DOUBLE PRECISION R1,R2,RA2,RAH,PT,HC,TC,HG,TG,PX,R2B,PTL,SUMAO,
     1SUMAI,Y1,BY1
      COMMON /FORWA/WMEGA,WMEGA1,WMEGD,WMEGD1,WMEGB,WMEGB1
      DOUBLE PRECISION WMEGA,WMEGA1,WMEGD,WMEGD1,WMEGB,WMEGB1
      DOUBLE PRECISION A4X,BZ,B2,HGA1,HGAD1,BIX,X1,DTD,DET,X2,B3,X3,PI2
     1,X4,X5,X6
      COMMON /CLA/ UA(15),UA1(35),UD(15),UD1(35),UB(15),UB1(20)
      DOUBLE PRECISION UA,UA1,UD,UD1,UB,UB1
      COMMON /FORANN/NRA11,NRAM1,NRBM1
C
C     COMPUTE U'S ON REGION A
C
      DO 1 I = 1,NRA
    1 A(I,1) = A(I,3)
      DO 2 I = 1,NRA1X
    2 A1(I,1) =  A1(I,3)
      TAI(1) = TAI(3)
      TTA(1) = TTA(3)
      TBA(1) = TBA(3)
      CALL CON1(TBA,TB1,NTAP,COAA)
      CALL CON2(TTA,TT1,NTAP,CONA1)
      CALL CON1(TAI,TAI1,NTAP,CONAI)
      CALL CON2(TAI,TAI2,NTAP,CONAII)
      DO  4  J = 2,NTA
      JP = J+1
      J1 = J-1
      BIX = HCA * (TC - TBA(J) + TB1(J))
      A(1,J)=A(1,J)+WMEGA*((AA(1)*(A(1,J1)+A(1,JP))+AB(1)*A(2,J)+BIX)/
     1(AC(1)+HCA/COAA(J))-A(1,J))
      TBA(J) = TBA(J) - TB1(J) + A(1,J)/COAA(J)
      SUMAO = SUMAO +HCA *(TC - TBA(J))
      IF(J.EQ. 2) SUMAO = SUMAO/2.0
      F(2) = AB(1) *A(1,J) +AA(2)*(A(2,JP) +A(2,J1))
      DO 5 I = 3,NRAM1
    5 F(I) = AA(I) * (A(I,JP)+ A(I,J1))
      F(NRAM) = AB(NRAM) * A(NRA,J) + AA(NRAM) * (A(NRAM,JP)+A(NRAM,J1))
      CALL CLINE(AB,AC,UA,F,X,NRAM)
      DO 20 I = 2,NRAM
   20 A(I,J) = A(I,J) + WMEGA * (X(I) - A(I,J))
C
C     COMPUTE U'S ON MATERIAL INTERFACE BETWEEN REGOONS A AND A1
C
      IF(R2.NE.RA2)  GO TO 101
      HGA1 = HGA
      IF(ICOS.EQ.1)  HGA1= HGA * DCOS(THETA(J1))
      BIX= HGA1 * (TG-TAI(J) + TAI1(J))
      A(NRA,J)= A(NRA,J) + WMEGA* ((AA(NRA)*(A(NRA,J1)+ A(NRA,JP))/2.0
     1+ AB(NRAM) * A(NRAM,J) +BIX)/(A1X + HGA1/CONAI(J))-A(NRA,J))
      TAI(J)= TAI(J) - TAI1(J) + A(NRA,J)/CONAI(J)
      SUMAI = SUMAI + HGA1 * (TG-TAI(J))
      IF(J.EQ.2)  SUMAI= SUMAI/2.0
      GO TO 4
  101 DET = A1X/CONA1I(J)+  A2X/CONAI(J)
      B1=AA(NRA)*(A(NRA,JP)+A(NRA,J1))/2.+AB(NRAM)*A(NRAM,J)+A1A(1)*
     1(A1(1,JP)+A1(1,J1))+A1B(1)*A1(2,J)
      B2 = TAI2(J) - TAI1(J)
      X1 = (-A2X * B2 + B1/CONA1I(J))/DET
      X2 =(A1X * B2 + B1/CONAI(J))/DET
      A (NRA,J) = A (NRA,J) + WMEGA*( X1-A(NRA,J))
      A1(1,J) = A1(1,J)+ WMEGA1*(X2-A1 (1,J))
      TAI(J) = TAI(J) + (A(NRA,J)/CONAI(J) + A1(1,J)/CONA1I(J) - (TAI1(J
     1) + TAI2(J)))/2.0
C
C     COMPUTE U'S ON REGION A1
C
      F(2) = A1B(1)*A1(1,J) +A1A(2) *(A1(2,JP) +A1(2,J1))
      DO 8 I = 3,NRA11
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    8 F(I) = A1A(I) *(A1(I,JP) + A1(I,J1))
      F(NRA1XM) =A1B(NRA1XM) *A1(NRA1X,J) +A1A(NRA1XM)*(A1(NRA1XM,JP) +
     1A1(NRA1XM,J1))
      CALL CLINE(A1B,A1C,UA1,F,X,NRA1XM)
      DO 21 I = 2,NRA1XM
   21 A1(I,J) = A1(I,J) + WMEGA1 * (X(I) - A1(I,J))
      HGA1 = HGA
      IF(ICOS .EQ. 1) HGA1 = HGA * DCOS(THETA(J1))
      BIX = HGA1* (TG - TTA(J) + TT1(J))
      A1(NRA1X,J)=A1(NRA1X,J)+WMEGA1*((A1A(NRA1X)*(A1(NRA1X,J1)+A1(NRA1X
     1,JP))+A1B(NRA1XM)*A1(NRA1XM,J)+BIX)/(A1C(NRA1X)+HGA1/CONA1(J))-
     2A1(NRA1X,J))
      TTA(J) = TTA(J) -TT1(J)+A1(NRA1X,J)/CONA1(J)
      SUMAI = SUMAI + HGA1 *(TG-TTA(J))
      IF(J.EQ. 2) SUMAI = SUMAI/2.0
    4 CONTINUE
C
C     COMPUTE U'S ON BOUNDARY BETWEEN REGIONS A AND D
C
      BIX = HCAD * (TC - TBA(NTAP) + TB1(NTAP))
      A(1,NTAP) =A(1,NTAP) +WMEGA*((AA(1)*A(1,NTA)+AD(1)*D(1,2)+BAD(1) *
     1A(2,NTAP) + BIX)/(CAD(1) + HCAD/COAA(NTAP))-A(1,NTAP))
      TBA(NTAP) = TBA(NTAP) - TB1(NTAP) + A(1,NTAP)/COAA(NTAP)
      SUMAD = SUMAD + HCAD *(TC-TBA(NTAP))
      DO 70  I=2,NRAM
      I1 = I-1
   70 A(I,NTAP) =A(I,NTAP)+WMEGA*((AA(I)*A(I,NTA)+AD(I)*D(I,2)+BAD(I1 )*
     1A(I1 ,NTAP) +BAD(I)*A(I+1,NTAP))/CAD(I) -A(I,NTAP))
      IF(R2.EQ. RA2)  GO TO 110
      DET = CAD(NRA)/CONAI1(NTAP) + C1AD(1)/CONAI(NTAP)
      B2 = AA(NRA)*A(NRA,NTA)/2.0+AD(NRA)*D(NRA,2)+BAD(NRAM)*A(NRAM,NTAP
     1)+A1A(1)*A1(1,NTA)+A1D(1)*D1(1,2)+B1AD(1)*A1(2,NTAP)
      B3 = TAI2 (NTAP) - TAI1(NTAP)
      X1 = (-C1AD(1) * B3 + B2/CONA1I(NTAP)) / DET
      X2 = (CAD(NRA) * B3 + B2/CONAI(NTAP)) / DET
      A(NRA,NTAP) = A(NRA,NTAP) + WMEGA * (X1-A(NRA,NTAP))
      A1(1,NTAP) = A1(1,NTAP) + WMEGA1 * (X2-A1(1,NTAP))
      TAI(NTAP) = TAI(NTAP) + (A(NRA,NTAP)/CONAI(NTAP) + A1(1,NTAP)
     2/CONA1I(NTAP) - (TAI1(NTAP) +TAI2(NTAP)))/ 2.0
C
C     COMPUTE U'S ON BOUNDARY BETWEEN REGIONS A1 AND D1
C
      DO 71  I = 2,NRA1XM
      I1 = I-1
   71 A1(I,NTAP) =A1(I,NTAP)+WMEGA1*((A1A(I)*A1(I,NTA)+A1D(I)*D1(I,2)+
     1B1AD(I1 )*A1(I1 ,NTAP)+B1AD(I)*A1(I+1,NTAP))/C1AD(I)-A1(I,NTAP))
      HGAD1 = HGAD
      IF(ICOS .EQ. 1) HGAD1 = HGAD * DCOS(THETA(NTA))
      BIX = HGAD1* (TG - TTA(NTAP) + TT1(NTAP))
      A1(NRA1X,NTAP)= A1(NRA1X,NTAP)+WMEGA1*((A1A(NRA1X)*A1(NRA1X,NTA)+
     1B1AD(NRA1XM)*A1(NRA1XM,NTAP)+BIX)/(HGAD1/CONA1(NTAP) +C1AD(NRA1X))
     2-A1(NRA1X,NTAP))
      TTA(NTAP) = TTA(NTAP) - TT1(NTAP) + A1(NRA1X,NTAP)/CONA1(NTAP)
      SUMAI = SUMAI+HGAD1 *( TG -TTA(NTAP))
C
C     COMPUTE U'S ON REGION D
C
      GO TO 201
  110 HGAD1 = HGAD
      IF(ICOS.EQ.1)  HGAD1 = HGAD * DCOS(THETA(NTA))
      BIX= HGAD1 * (TG-TAI(NTAP) + TAI1(NTAP))
      A(NRA,NTAP)= A(NRA,NTAP) + WMEGA * ((AA(NRA)*A(NRA,NTA)/2.0 +
     1AD(NRA) * D(NRA,2) + BAD(NRAM)*A(NRAM,NTAP)+BIX)/(CAD(NRA)
     2 + HGAD1/CONAI(NTAP)) - A(NRA,NTAP))
      TAI(NTAP)= TAI(NTAP) - TAI1(NTAP) + A(NRA,NTAP)/CONAI(NTAP)
      SUMAI = SUMAI + HGAD1 * (TG-TAI(NTAP))
  201 DO   190 I =1,NRA
  190 D(I,1) = A(I,NTAP)
      DO 191 I=1,NRA1X
  191 D1(I,1) = A1(I,NTAP)
      CALL CON1(TBD,TB1,NTD,CONBD)
      CALL CONI(TDI,TAI1,NTD,CONDI)
      CALL CON2(TDI,TAI2,NTD,CONDI1)
      DO 112 J=2,NTDM
      J1 = J -1
      JP = J + 1
      BIX = HCD*(TC-TBD(J)+TB1(J))
      D(1,J)= D(1,J)+WMEGD*((AD(1)*(D(1,JP) +D(1,J1)) +BD(1)*
```

```
     1D(2,J)+BIX)/(CD(1)+HCD/CONBD(J))-D(1,J))
      TBD(J) = TBD(J) - TB1(J) + D(1,J)/CONBD(J)
      SUMAD = SUMAD + HCD *(TC -TBD(J))
      F(2) = BD(1) *D(1,J) +AD(2) *(D(2,JP) +D(2,J1))
      DO 113 I = 3,NRAM1
  113 F(I) = AD(I) * (D(I,JP) + D(I,J1))
      F(NRAM) = BD(NRAM) *D(NRA,J) + AD(NRAM) *(D(NRAM,JP) +D(NRAM,J1))
      CALL CLINE(BD,CD,UD,F,X,NRAM)
      DO 26 I = 2,NRAM
   26 D(I,J) = D(I,J) + WMEGD*(X(I) - D(I,J))
C
C     COMPUTE U'S ON MATERIAL INTERFACE BETWEEN REGOONS D AND D1
C
      IF(R2.NE.RA2)  GO TO 203
      HGAD1 = A6X
      IF(ICOS .EQ. 1) HGAD1 = A6X * DCOS(THETD(J) + THETA(NTA))
      BIX= HGAD1 * (TG- TDI(J) + TAI1(J))
      D(NRA,J) = D(NRA,J) +WMEGD*((AD(NRA)*(D(NRA,J1)+D(NRA,JP)
     1) + BD(NRAM) * D(NRAM,J) + BIX)/(A5X + HGAD1/CONDI(J)) -
     2D(NRA,J))
      TDI(J) = TDI(J) - TAI1(J) + D(NRA,J)/CONDI(J)
      SUMAI= SUMAI + HGAD1 * (TG-TDI(J))
      GO TO 112
  203 DET = A5X/COND1I(J) + A6X/CONDI(J)
      B1=AD(NRA)*(D(NRA,JP)+D(NRA,J1))+BD(NRAM)*D(NRAM,J)+A1D(1)*(D1(1,
     1JP)+D1(1,J1))+B1D(1)*D1(2,J)
      B2 = TAI2(J) - TAI1(J)
      X1 = (- B2 * A6X + B1/COND1I(J))/DET
      X2 = (B2 * A5X + B1/CONDI(J))/DET
      D(NRA,J)= D(NRA,J)+WMEGD*(X1-D(NRA,J))
      D1(1,J) = D1(1,J) + WMEGD1 * (X2 - D1(1,J))
      TDI(J) = TDI(J) + (D(NRA,J)/CONDI(J) + D1(1,J)/COND1I(J) -
     1 (TAI1(J) + TAI2(J)))/2.0
C
C     COMPUTE U'S ON REGION D1
C
      K = NRA1X - J
      K1 = K-1
      F(2) = B1D(1)*D1(1,J) +A1D(2) *(D1(2,JP) +D1(2,J1))
      DO 114 I = 3,K1
  114 F(I) = A1D(I) * (D1(I,JP) + D1(I,J1))
      F(K) = B1D(K)*D1(K+1,J) +A1D(K) *(D1(K,JP) +D1(K,J1))
      CALL CLINE(B1D,C1D,UD1,F,X,K)
      DO 23 I = 2,K
   23 D1(I,J) = D1(I,J) + WMEGD1* (X(I) - D1(I,J))
      K=K+1
      D1(K,J)=D1(K,J)+WMEGD1*((A1D(K)*D1(K,J-1)+B1D(K-1)*D1(K-1,J))/(A1D
     1(K)+B1D(K-1))-D1(K,J))
  112 CONTINUE
C
C     COMPUTE U'S ON BOUNDARY BETWEEN REGIONS D AND B
C
      BIX = HCAB * (TC - TBD(NTD) + TB1(NTD))
      D(1,NTD ) =D(1,NTD ) +WMEGD*((AD(1)*D(1,NTDM)+BA(1)*B(1,2)+BBD(1)*
     1D(2,NTD ) + BIX)/(CBD(1) + HCAB/CONBD(NTD ))-D(1,NTD ))
      TBD(NTD) = TBD(NTD) - TB1(NTD) + D(1,NTD)/CONBD(NTD)
      SUMAD = SUMAD + HCAB*(TC -TBD(NTD))
      DO 170 I = 2,NRAM
  170 D(I,NTD) = D(I,NTD)+WMEGD*((AD(I)*D(I,NTDM)+BA(I)*B(I,2)+BBD(I-1)*
     1D(I-1,NTD)+BBD(I)*D(I+1,NTD))/CBD(I)-D(I,NTD))
      TDD(1) = TDI(NTD)
C
C     COMPUTE U AT MATERIAL INTERFACE POINT BETWEEN REGIONS D,D1,B1
C
      CALL  CON3( TDD, TAI3,NRA1 , CONBC)
      IF(R2.NE.RA2)  GO TO 204
      X3 = D1X+D2X/CONDI(NTD)
      HGAD1 = D3X +D1BX(1)/CONBC(1)
      DET = X3/CONBC(1) +HGAD1/CONDI(NTD)
      BIX= D2X * (TG - TDI(NTD) + TAI1(NTD))
      B3 = D1BX(1)*(TG - TDI(NTD) +TAI3(1))
      B1 = AD(NRA) * D(NRA,NTDM) + BA(NRA) * B(NRA,2) + BBD(NRAM) *
     1D(NRAM,NTD)+BIX + B1A(1) * BZ(1,2) + B1B(1)*BZ(2,1)/2.0 + B3
      B2 = TAI3(1) - TAI1(NTD)
      X1 = (B1/CONBC(1) -B2 *HGAD1)/DET
      X2 = (B2 *X3 + B1/CONDI(NTD))/DET
      D(NRA,NTD)= D(NRA,NTD) + WMEGD* (X1-D(NRA,NTD))
      BZ(1,1)= BZ(1,1) + WMEGB1 * (X2 - BZ(1,1))
      TDI(NTD) = TDI(NTD) +(D(NRA,NTD)/CONDI(NTD) + BZ(1,1)/CONBC(1)
```

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     1 - (TAI1(NTD) + TAI3(1)))/2.0
      SUMAI = SUMAI + (D2X +D1BX(1))*(TG -TDI(NTD))
      DO 205  I=2,NRA1M
      BIX= D1BX(I)* (TG + TAI3(I) - TDD(I))
      BZ(I,1)= BZ(I,1) + WMEGB1 * ((B1A(I) * BZ(I,2) + (B1B(I-1)*BZ(I-1,
     11) + B1B(I)*BZ(I+1,1))/2.0 + BIX)/(D2BX(I) + D1BX(I)/CONBC(I))-BZ(
     2I,1))
      TDD(I)= TDD(I) - TAI3(I) + BZ(I,1)/CONBC(I)
  205 SUMAI= SUMAI + D1BX(I) * (TG-TDD(I))
      BIX= D1BX(NRA1) * (TG + TAI3(NRA1) - TDD(NRA1))
      BZ(NRA1,1)= BZ(NRA1,1) + WMEGB1 * ((B1B(NRA1M)*BZ(NRA1M,1)/2.0 +
     1BIX)/(B1B(NRA1M)/2.0 + D1BX(NRA1)/CONBC(NRA1))-BZ(NRA1,1))
      TDD(NRA1 )= TDD(NRA1 )- TAI3(NRA1 ) + BZ(NRA1,1)/CONBC(NRA1)
      SUMAI = SUMAI + D1BX(NRA1 ) *(TG-TDD(NRA1))
      DO 206  I=1,NRA
  206 B(I,1)= D(I,NTD)
      GO TO 207
  204 DET=D3X/(CONDI(NTD)*CONDII(NTD))+(D1X/CONDII(NTD)+D2X/CONDI(NTD))/
     1CONBC(1)
      B1=AD(NRA)*D(NRA,NTDM) + BBD(NRAM)*D(NRAM,NTD)+BA(NRA)*B(NRA,2)
     1+A1D(1)* D1(1,NTDM)+B1D(1)*D1(2,NTD)/2.0 + B1A(1)*BZ(1,2)+B1B(1)*B
     2Z(2,1)/2.0
      B2= TAI2(NTD)-TAI1(NTD)
      B3 = TAI3(1) - TAI1(NTD)
      X1= (-B3 * D3X/CONDII(NTD)+(B1/CONDII(NTD)-B2*D2X)/CONBC(1))
     1/DET
      X2= (D3X*(B2-B3)/CONDI(NTD)+(D1X*B2 + B1/CONDI(NTD))/CONBC(1))
     1/ DET
      X3 =  (- (D2X* B2-B1/CONDII(NTD))/CONDI(NTD) + B3*(D1X/CONDII
     1(NTD) + D2X/CONDI(NTD)))/DET
      D(NRA,NTD)= D(NRA,NTD) + WMEGD* (X1-D(NRA,NTD))
      D1(1,NTD) = D1(1,NTD) + WMEGD1*(X2- D1(1,NTD))
      BZ(1,1) = BZ(1,1)+ WMEGB1*(X3- BZ(1,1))
      TDI(NTD)= TDI(NTD)+(D(NRA,NTD)/CONDI(NTD) + D1(1,NTD)/CONDII(NTD)
     1+ BZ(1,1)/CONBC(1)- (TAI1(NTD) + TAI2(NTD)+ TAI3(1)))/3.0
      TDD(1) =  TDI(NTD)
      DO   90 I =1,NRA
   90 B(I,1) =  D(I,NTD)
C
C     COMPUTE U'S ON MATERIAL INTERFACE BETWEEN REGOCNS D1 AND B1
C
      CALL  CON2 (TDD, TAI2,NRA1,CONDD)
      DO 200 I =2,NRA1
      I1 = I-1
      DET = D1BX(I)/CONBC(I) + D2BX(I)/CONDD(I)
      X3= 1.0
      IF (I.EQ. NRA1) X3=0.0
      B1 = A1D(I) * D1(I,NTDM) + B1D(I1 )* D1(I1 ,NTD)/2.0 + B1B(I1 )*
     1 BZ (I1 ,1)/2.0 + X3*(B1D(I   )*D1(I+1,NTD)/2.0+ B1A(I)* BZ(I,2) +
     2 B1B(I   ) * BZ(I+1,1)/2.0)
      B2 = TAI3(I) - TAI2(I)
      X1 = (-B2*D2BX(I) + B1/CONBC(I))/DET
      X2= (B2* D1BX (I)+ B1/CONDD(I))/DET
      D1(I,NTD)=D1(I,NTD)+WMEGD1*(X1 -D1(I,NTD))
      BZ(I,1) = BZ (I,1)+ WMEGB1* (X2- BZ(I,1))
  200 TDD(I) = TDD(I) +(D1(I,NTD)/CONDD(I)+ BZ(I,1)/CONBC(I)- (TAI2
     1(I) + TAI3(I)))/2.0
C
C     COMPUTE U'S ON REGION B
  207 CALL CON1(TBB,TB1,NTB,CONBB)
      CALL CON3(TBI,TAI2,NTB,CONBII)
      CALL CON1(TBI,TAI1,NTB,CONBI)
      DO 12 J=2,NTBM
      JP = J + 1
      J1 = J -1
      BIX = HCB*(TC-TBB(J)+TB1(J))
      B(1,J)= B(1,J)+WMEGB*((BA(1)*(B(1,JP) +B(1,J1)) +BB(1)*
     1B(2,J)+BIX)/(BC(1)+HCB/CONBB(J))-B(1,J))
      TBB(J) = TBB(J) - TB1(J) + B(1,J)/CONBB(J)
      SUMAO = SUMAO + HCB*(TC -TBB(J))
      F(2) = BB(1) *B(1,J) +BA(2) *(B(2,JP) +B(2,J1))
      DO 13 I = 3,NRAM1
   13 F(I) = BA(I) * (B(I,JP) + B(I,J1))
      F(NRAM) =BB(NRAM)*B(NRA,J) +BA(NRAM) *(B(NRAM,JP)+B(NRAM,J1))
      CALL CLINE(BB,BC,UB,F,X,NRAM)
      DO 24 I = 2,NRAM
   24 B(I,J) = B(I,J) + WMEGB *(X(I) - B(I,J))
C
```

```
C     COMPUTE U'S ON MATERIAL INTERFACE BETWEEN REGIONS B AND B1
      DET = A3X/CONB1I(J) + A4X/CONBI(J)
      B1=BA(NRA)*(B(NRA,JP)+B(NRA,J1))+BB(NRAM)*B(NRAM,J)+B1A(1)*(BZ(1,
     1JP)+BZ(1,J1))+B1B(1)*BZ(2,J)
      B2 = TAI2(J) - TAI1(J)
      X1 = (- B2 * A4X + B1/CONB1I(J))/DET
      X2 = (B2 * A3X + B1/CONBI(J))/DET
      B(NRA,J)= B(NRA,J)+WMEGB*(X1-B(NRA,J))
      BZ(1,J) = BZ(1,J) + WMEGB1 * (X2 - BZ(1,J))
      TBI(J) = TBI(J) + (B(NRA,J)/CONBI(J) + BZ(1,J)/CONB1I(J) -
     1 (TAI1(J) + TAI2(J)))/2.0
C
C     COMPUTE U'S ON REGION B1
C
      K = NRA1-J
          K1 = K-1
      F(2) = B1B(1) *BZ(1,J) +B1A(2) *(BZ(2,JP) +BZ(2,J1))
       DO 14 I = 3,K1
   14 F(I) = B1A(I) *(BZ(I,JP) + BZ(I,J1))
      F(K) = B1B(K)*BZ(K+1,J) +B1A(K) *(BZ(K,JP) +BZ(K,J1))
      CALL CLINE(B1B,B1C,UB1,F,X,K)
      DO 25 I = 2,K
   25 BZ(I,J) = BZ(I,J) + WMEGB1 *(X(I) - BZ(I,J))
      K1 = K
      K=K+1
      BZ(K,J)=BZ(K,J)+ WMEGA1*((B1A(K)*BZ(K,J1 )+B1B(K1 )*BZ(K1 ,J))
     1/ (B1A(K) + B1B(K1 ))-BZ(K,J))
   12 CONTINUE
C
C     COMPUTE U'S ON BOUNDARY BETWEEN REGIONS B AND P
C
      BIX = EC*(TC-TBB(NTB) + TB1(NTB))
      B(1,NTB) = B(1,NTB) + WMEGB*((BA(1)*B(1,NTBM)+ BE*P(2,1)/2.0
     1+ AP(1)* B(2,NTB) + BIX)/(BP(1) + EC/CONBB(NTB)) - B(1,NTB))
      P(1,1) = B(1,NTB)
      TBB(NTB) = TBB(NTB)-TB1(NTB)+B(1,NTB)/CONBB(NTB)
      SUMAD = SUMAD + EC *(TC -TBB(NTB))
      DO 40 I=2,NRAM
      I1 = I-1
      B(I,NTB) = B(I,NTB)+WMEGB*((BA(I)*B(I,NTBM)+BE*P(2,I)+
     1AP(I1 )*B(I1 ,NTB)+ AP(I)*B(I+1,NTB))/BP(I)- B(I,NTB))
   40 P(1,I) = B(I,NTB)
      DET = DEX/CONB1I(NTB) + DEY/CONBI(NTB)
      B1= BA(NRA) * B(NRA,NTBM)+ BE*P(2,NRA)/2.0 + AP(NRAM)*
     1B(NRAM,NTB) + B1A(1)*BZ(1,NTBM)+DENBZ*P1(2,1)/2.0+A1P(1)*BZ(2,NTB)
      B2 = TAI2(NTB)-TAI1(NTB)
      X1 = (-B2*DEY + B1/CONB1I(NTB))/DET
      X2 = (B2*DEX + B1/CONBI(NTB))/DET
      B(NRA,NTB) = B(NRA,NTB)+WMEGB*(X1-B(NRA,NTB))
      BZ(1,NTB) = BZ(1,NTB) + WMEGB1*(X2-BZ(1,NTB))
      P(1,NRA) = B(NRA,NTB)
      P1(1,1) = BZ(1,NTB)
      TBI(NTB) = TBI(NTB)+(B(NRA,NTB)/CONBI(NTB)+ BZ(1,NTB)/CONB1I(
     1NTB) - (TAI1(NTB) + TAI2(NTB)))/2.0
C
C     COMPUTE U'S ON BOUNDARY BETWEEN REGIONS B1 AND P1
C
      DO 41 I=2,NRBM
      I1 = I-1
      BZ(I,NTB)= BZ(I,NTB)+WMEGB1*((B1A(I)*BZ(I,NTBM) + DENBZ*P1(2,I)+
     1A1P(I1 )*BZ(I1 ,NTB)+A1P(I)*BZ(I+1,NTB))/B1P(I)- BZ(I,NTB))
   41 P1(1,I)= BZ(I,NTB)
      BZ(NRB,NTB)=BZ(NRB,NTB)+ WMEGB1*((B1A(NRB)*BZ(NRB,NTBM)+DENBZ
     1*P1(2,NRB)/2.0 + A1P(NRBM)*BZ(NRBM,NTB))/B1P(NRB)-BZ(NRB,NTB))
      P1(1,NRB)= BZ(NRB,NTB)
      RETURN
      END
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      SUBROUTINE COMPB
      COMMON/FORAN/NRA,NRAM,NTA,NTAP,NRA1,NRA1M,NRA1X,NRA1XM,
     1NRB,NRBM,NTB,NTBM,NTD,NTDM
      COMMON /FORCN/ NXP,NXP1,NTQ,NTQ1,NZ,NZ1,NZX,NZX1
      COMMON /FORC/ P(20,15),P1(20,5),Q(15,20),Q1(15,20),ZL(15,20),
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     1ZR (20,15),TP3(20),TPI(20),TBQ(20),TQI(20),TZB(20),TZBR(20)
      DOUBLE PRECISION P,P1,Q,Q1,ZL,ZR,TPB,TPI,TBQ,TQI,TZB,TZBR
      COMMON/FORC1/PX22,HCP,PX2,PX1,PX4,P2X,P1X4,P1X3,HCPQ,S1P,S2P,
     1HCQ,Q1X,Q2X,HCQZ,QZ1,QZ2,HCZ,ZR3,HCRL,ZR1,ZR2,ZR4,ZR5,HCZR,PX3,
     1P1X2,P1X1
      DOUBLE PRECISION PX22,HCP,PX2,PX1,PX4,P2X,P1X4,P1X3,HCPQ,S1P,S2P,
     1HCQ,Q1X,Q2X,HCQZ,QZ1,QZ2,HCZ,ZR3,HCRL,ZR1,ZR2,ZR4,ZR5,HCZR,PX3
     2,P1X2,P1X1
      COMMON/FORC2/AQ(15),BQ(15),CQ(15),A1Q(5),B1Q(5),C1Q(5),PQA(15),
     1PQB(15),PQA1(15),PQB1(15),AQT(21),BQT(21),CQT(21),ZA(15),ZB (15),
     2ZC(15), AQZ (15),CQZ(15),ZARL(15),ZBRL(15)
      DOUBLE PRECISION AQ,BQ,CQ,A1Q,B1Q,C1Q,PQA,PQB,PQA1,PQB1,
     1AQT,BQT,CQT,ZA,ZB,ZC,AQZ,CQZ,ZARL,ZBRL
      COMMON /FOUTC/THETQ(20), XP(20),RQA(15),RQ(5),THETZ(20),
     1 XZ (20),QT (20),YP(20),YP1(5)
      DOUBLE PRECISION THETQ,XP,RQA,RQ,THETZ,XZ,QT,YP,YP1
      DIMENSION TB1(20),TAI1(20),TAI2(20),CONP(20),CONPI(20),CONP1I(20),
     1CONQ(20),CONQI(20),CONQ1I(20),CONZ(20),CONZR(20),X(15),F(15)
      DOUBLE PRECISION TB1,TAI1,TAI2,CONP,CONPI,CONP1I,CONQ,CONQI,
     1CONQ1I,CONZ,CONZR,X,F
      COMMON/FORMA/R1,R2,RA2,Y1,RAH,PT,HC,TC,HG,TG,PX,R2B,BY1,PTL,SUMAO,
     1SUMAI
      DOUBLE PRECISION R1,R2,RA2,RAH,PT,HC,TC,HG,TG,PX,R2B,PTL,SUMAO,
     1SUMAI,Y1,BY1
      COMMON/FORWC/ WMEGP,WMEGP1,WMEGQ,WMEGQ1
      DOUBLE PRECISION WMEGP,WMEGP1,WMEGQ,WMEGQ1
      DOUBLE PRECISION    B2,DET,X1,BIX,B1,X2,X4,X5
      COMMON/CLB/UQ(15),UZ(15),CP(15),UP(15),CP1(5),UP1(5),CZ(15),
     1UZR(15)
      DOUBLE PRECISION UQ,UZ,CP,UP,CP1,UP1,CZ,UZR
      COMMON /CLAB/ PXA,PXAP,PXA1,PXA1P,ZRA,ZRP
      DOUBLE PRECISION PXA,PXAP,PXA1,PXA1P,ZRA,ZRP
      COMMON /FORANN/NRA11,NRAM1,NRBM1
C
C     COMPUTE U'S IN RECTANGULAR REGION P
C
      CALL CON1(TPB,TB1,NXP,CONP)
      CALL CON1 (TPI,TAI1,NXP,CONPI)
      CALL CON3 (TPI,TAI2,NXP,CONP1I)
      DO 4  J=2,NXP1
      JP  = J+1
      J1  = J-1
      BIX= HCP*(TC-TPB(J) + TB1(J))
      P(J,1)= P(J,1) + WMEGP*((PX22*(P(J1 ,1) + P(JP ,1))+PX1*P(J,2) +
     1BIX)/(PX3 + HCP/CONP(J))-P(J,1))
      TPB(J)= TPB(J) - TB1(J) + P(J,1)/CONP(J)
      F(2) = -PXA* P(J,1) + PXAP * (P(JP,2) + P(J1,2))
      DO 5 I = 3,NRAM1
    5 F(I) = PXAP *(P(JP,I) + P(J1,I))
      F(NRAM) = -PXA * P(J,NRA ) +PXAP *(P(JP,NRAM) + P(J1,NRAM))
      CALL RLINE(PXA,CP,UP,F,X,NRAM)
      DO 25 I = 2,NRAM
   25 P(J,I) = P(J,I) + WMEGP * (X(I) - P(J,I))
C
C     COMPUTE U'S ON MATERIAL INTERFACE BETWEEN REGIONS P,P1
C
      DET = PX3/CONP1I(J) + P2X/CONPI(J)
      B1= PX1 * P(J,NRAM) + PX22*(P(J1 ,NRA) + P(JP ,NRA)) + P1X2 *
     1P1(J,2) + P1X4 * (P1(J1 ,1) + P1(JP ,1))
      B2 = TAI2(J) - TAI1(J)
      X1= (B1/CONP1I(J) - B2*P2X)/DET
      X2= (PX3*B2 + B1/CONPI(J))/DET
      P(J,NRA)= P(J,NRA) + WMEGP *(X1-P(J,NRA))
      P1(J,1)= P1(J,1) + WMEGP1 * (X2-P1(J,1))
      TPI(J)= TPI(J) + (P(J,NRA)/CONPI(J) + P1(J,1)/CONP1I(J) -
     1 (TAI1(J) + TAI2(J)))/2.0
C
C     COMPUTE U'S ON RECTANGULAR REGION P1
C
      F(2) = -PXA1 *P1(J,1) +PXA1P*(P1(JP,2) +P1(J1,2))
      DO 6 I = 3,NRBM1
    6 F(I) = PXA1P *(P1(JP,I) + P1(J1,I))
      F(NRBM) = -PXA1* P1(J,NRB ) +PXA1P*(P1(JP,NRBM) +P1(J1,NRBM))
      CALL RLINE(PXA1,CP1,UP1,F,X,NRBM)
      DO 26 I = 2,NRBM
   26 P1(J,I) = P1(J,I) + WMEGP1 * (X(I) - P1(J,I))
      P1(J,NRB) = P1(J,NRB) +WMEGP1 *((P1X2*P1(J,NRBM) +P1X4*(P1(J1,NRB)
     1+P1(JP,NRB)))/P2X - P1(J,NRB))
    4 SUMAO = SUMAO +HCP *(TC - TPB(J))
```

```
C
C     COMPUTE U'S ON BOUNDARY BETWEEN REGIONS P AND Q
C
      BIX = HCPQ*(TC- TPB(NXP) + TB1(NXP))
      P(NXP,1)= P(NXP,1)+ WMEGP*((PX22 *P(NXP1,1)+AQ(1) *Q(1,2)+ PQA(1)
     1 * P(NXP,2) + BIX)/(PQB(1)+ HCPQ/CONP(NXP))- P(NXP,1))
      TPB(NXP)= TPB(NXP)-TB1(NXP)+P(NXP,1)/CONP(NXP)
      SUMAO = SUMAO + HCPQ *(TC - TPB(NXP))
      Q(1,1)= P(NXP,1)
      DO 50 I=2,NRAM
      I1 = I-1
      P(NXP,I)= P(NXP,I) + WMEGP*((PX2*P(NXP1,I)+AQ(I)*Q(I,2)+
     1PQA(I1 )*P(NXP,I1 ) + PQA(I)*P(NXP,I+1))/PQB(I)-P(NXP,I))
   50 Q(I,1)= P(NXP,I)
      DET = S1P/CONP1I(NXP) + S2P/CONPI(NXP)
      B1 = PX22 *P(NXP1,NRA)+ AQ(NRA)*Q(NRA,2)/2.0+PQA(NRAM)*
     1P(NXP,NRAM)+P1X4*P1(NXP1,1)+A1Q(1)*Q1(1,2)+PQA1(1) *P1(NXP,2)
      B2 = TAI2(NXP)- TAI1(NXP)
      X1 = (-S2P*B2 + B1/CONP1I(NXP))/DET
      X2 = ( S1P *B2 + B1/CONPI(NXP))/DET
      P(NXP,NRA)= P(NXP,NRA)+ WMEGP*(X1-P(NXP,NRA))
      P1(NXP,1)= P1(NXP,1) + WMEGP1*(X2-P1(NXP,1))
      Q(NRA,1) = P(NXP,NRA)
      TPI(NXP) = TPI(NXP) + (P(NXP,NRA) /CONPI(NXP) + P1(NXP,1)/CONP1I
     1(NXP) - (TAI1(NXP) + TAI2(NXP)))/2.0
C
C     COMPUTE U'S ON BOUNDARY BETWEEN REGIONS P1 AND Q1
C
      Q1(1,1)= P1(NXP,1)
      DO 51 I=2,NRBM
      I1 = I-1
      P1(NXP,I)= P1(NXP,I)+WMEGP1*((P1X1*P1(NXP1,I)+A1Q(I)*Q1(I,2)
     1+PQA1(I1 )*P1(NXP,I1 )+ PQA1(I)*P1(NXP,I+1))/ PQB1(I) - P1(NXP,I))
   51 Q1(I,1)= P1(NXP,I)
      P1(NXP,NRB)=P1(NXP,NRB)+WMEGP1*((P1X4*P1(NXP1,NRB)+PQA1(NRBM) *
     1P1(NXP,NRBM)+AQT(2)* Q1(NRB,2))/CQT(1)-P1(NXP,NRB))
      Q1(NRB,1)= P1(NXP,NRB)
C
C     COMPUTE U'S ON REGION Q
C
      CALL CON1(TBQ,TB1,NTQ,CONQ)
      CALL CON1 (TQI,TAI1,NTQ,CONQI)
      CALL CON3(TQI,TAI2,NTQ,CONQ1I)
      DO 1 J=2,NTQ1
      JP = J + 1
      J1 = J -1
      BIX= HCQ*(TC-TBQ(J)+TB1(J))
      Q(1,J)= Q(1,J)+WMEGQ*((AQ(1)*(Q(1,J1 )+Q(1,JP ))+BQ(1)*
     1Q(2,J)+BIX)/(CQ(1)+HCQ/CONQ(J))-Q(1,J))
      TBQ(J)= TBQ(J)-TB1(J)+Q(1,J)/CONQ(J)
      SUMAO = SUMAO + HCQ *(TC - TBQ(J))
      F(2) = BQ(1) *Q(1,J)+AQ(2)*(Q(2,JP) + Q(2,J1))
      DO 2 I = 3,NRAM1
    2 F(I) = AQ(I) * (Q(I,JP) + Q(I,J1))
      F(NRAM) =BQ(NRAM) *Q(NRA,J)+AQ(NRAM)*(Q(NRAM,JP)+Q(NRAM,J1))
      CALL CLINE(BQ,CQ,UQ,F,X,NRAM)
      DO 20 I = 2,NRAM
   20 Q(I,J) = Q(I,J) + WMEGQ *(X(I) - Q(I,J))
C
C     COMPUTE U'S ON MATERIAL INTERFACE BETWEEN REGIONS Q AND Q1
C
      DET = Q1X/CONQ1I(J)+Q2X/CONQI(J)
      B1= AQ(NRA)*(Q(NRA,JP )+Q(NRA,J1 ))/2.0+BQ(NRAM)*Q(NRAM,
     1J) +A1Q(1)*(Q1(1,JP )+Q1(1,J1 ))+B1Q(1)*Q1(2,J)
      B2= TAI2(J)-TAI1(J)
      X1= (-Q2X*B2+B1/CONQ1I(J))/DET
      X2= (Q1X*B2+B1/CONQI(J))/DET
      Q(NRA,J)= Q(NRA,J)+WMEGQ*(X1-Q(NRA,J))
      Q1(1,J)= Q1(1,J)+WMEGQ1*(X2-Q1(1,J))
      TQI(J)= TQI(J)+(Q(NRA,J)/CONQI(J)+Q1(1,J)/CONQ1I(J)-
     1(TAI1(J)+TAI2(J)))/2.0
C
C     COMPUTE U'S ON REGION Q1
C
      DO 3 I = 2,NRBM1
      I1 = I-1
    3 Q1(I,J)= Q1(I,J)+WMEGQ1*((A1Q(I)*(Q1(I,J1 )+Q1(I,JP ))+
     1B1Q(I1 )*Q1(I1 ,J)+B1Q(I)*Q1(I+1,J))/C1Q(I)-Q1(I,J))
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      Q1(NRBM,J)=Q1(NRBM,J)+WMEGQ1*((A1Q(NRBM)*(Q1(NRBM,J1 )+Q1(NRBM,JP
     1))+B1Q(NRBM1)*Q1(NRBM1,J)+BQT(J)*Q1(NRB,J))/(A1Q(NRBM)*2.0+B1Q(NRB
     2M1)+BQT(J))-Q1(NRBM,J))
      Q1(NRB,J)= Q1(NRB,J) + WMEGQ1*((AQT(J)*Q1(NRB,J1 ) + AQT(JP )*
     1Q1(NRB,JP )  + BQT(J)* Q1(NRBM,J))/CQT(J) - Q1(NRB,J))
    1 CONTINUE
C
C     COMPUTE U'S ON BOUNDARY BETWEEN REGIONS Q AND ZL
C
      BIX = HCQZ*(TC-TBQ(NTQ) + TB1(NTQ))
      Q(1,NTQ) = Q(1,NTQ)+WMEGQ*((AQ(1)*Q(1,NTQ1)+ZA(1)*ZL(1,2)
     1+ AQZ(1) * Q(2,NTQ) + BIX)/(CQZ(1) + HCQZ/CONQ(NTQ))-Q(1,NTQ))
      ZL(1,1) = Q(1,NTQ)
      TBQ(NTQ) = TBQ(NTQ) - TB1(NTQ) + Q(1,NTQ)/CONQ(NTQ)
      SUMAO = SUMAO + HCQZ *(TC - TBQ(NTQ))
      DO 200 I=2,NRAM
      I1 = I-1
      Q(I,NTQ) = Q(I,NTQ)+WMEGQ*((AQ(I)*Q(I,NTQ1)+ZA(I)*ZL(I,2)+
     1AQZ(I1 )*Q(I1 ,NTQ)+AQZ(I)*Q(I+1,NTQ))/CQZ(I)-Q(I,NTQ))
  200 ZL(I,1) = Q(I,NTQ)
      DET = QZ1/CONQ1I(NTQ) + QZ2/CONQI(NTQ)
      B1 = AQ(NRA) * Q(NRA,NTQ1)/2.0+ AQZ(NRAM)*Q(NRAM,NTQ)+ZA(NRA)
     1* ZL(NRA,2)+ A1Q(1)*Q1(1,NTQ1)+ B1Q(1)*Q1(2,NTQ)/2.0
      B2 = TAI2(NTQ)-TAI1(NTQ)
      X1 = (-QZ2*B2 + B1/CONQ1I(NTQ))/DET
      X2 = (QZ1*B2 + B1/CONQI(NTQ))/DET
      Q(NRA,NTQ)=Q(NRA,NTQ)+WMEGQ*(X1-Q(NRA,NTQ))
      Q1(1,NTQ) = Q1(1,NTQ)+WMEGQ1*(X2-Q1(1,NTQ))
      TQI(NTQ)=TQI(NTQ)+(Q(NRA,NTQ)/CONQI(NTQ)+Q1(1,NTQ)/CONQ1I(NTQ)
     1-(TAI1(NTQ)+TAI2(NTQ)))/2.0
      ZL(NRA,1)=Q(NRA,NTQ)
C
C     COMPUTE U'S ON BOUNDARY OF REGION Q1
C
      DO 201 I = 2,NRBM1
      I1 = I-1
  201 Q1(I,NTQ)=Q1(I,NTQ)+WMEGQ1*((A1Q(I)*Q1(I,NTQ1)+B1Q(I1 )*Q1(I1 ,NTQ
     1)/2.0+B1Q(I)*Q1(I+1,NTQ)/2.0)/(A1Q(I)+(B1Q(I)+B1Q(I1 ))/2.0)-
     2Q1(I,NTQ))
      Q1(NRBM,NTQ)=Q1(NRBM,NTQ)+WMEGQ1*((A1Q(NRBM)*Q1(NRBM,NTQ1)+B1Q(NRB
     1M1)*Q1(NRBM1,NTQ)/2.0+BQT(NTQ)*Q1(NRB,NTQ))/(A1Q(NRBM)+B1Q(NRBM1)/
     22.0+BQT(NTQ))-Q1(NRBM,NTQ))
      Q1(NRB,NTQ)=Q1(NRB,NTQ)+WMEGQ1*((AQT(NTQ)*Q1(NRB,NTQ1)+
     1BQT(NTQ)*Q1(NRBM,NTQ))/(AQT(NTQ)+BQT(NTQ))-Q1(NRB,NTQ))
C
C     COMPUTE U'S ON REGION ZL
C
      CALL CON1 (TZB,TB1,NZ,CONZ)
      DO 30 J=2,NZ1
      JP = J + 1
      J1 = J -1
      BIX = HCZ*(TC-TZB(J)+ TB1(J))
      ZL(1,J)= ZL(1,J)+WMEGQ*((ZA(1)*(ZL(1,J1 )+ZL(1,JP ))+ZB(1)*ZL(2,J)
     1+BIX)/(ZC(1)+HCZ/CONZ(J)) - ZL(1,J))
      TZB(J)= TZB(J) - TB1(J)+ZL(1,J)/CONZ(J)
      SUMAO = SUMAO + HCZ *(TC - TZB(J))
      F(2) = ZB(1) *ZL(1,J)+ZA(2) *(ZL(2,JP)+ZL(2,J1))
      DO 31 I = 3,NRAM1
   31 F(I) = ZA(I) *(ZL(I,JP) + ZL(I,J1))
      F(NRAM) = ZB(NRAM)*ZL(NRA,J) +ZA(NRAM) *(ZL(NRAM,JP) +ZL(NRAM,J1))
      CALL CLINE(ZB,ZC,UZ,F,X,NRAM)
      DO 22 I = 2,NRAM
   22 ZL(I,J) = ZL(I,J) +WMEGQ *(X(I) - ZL(I,J))
      ZL(NRA,J) = ZL(NRA,J) + WMEGQ *((ZA(NRA) * (ZL(NRA,J1 ) + ZL(NRA,
     1JP )) + ZB(NRAM) * ZL(NRAM,J))/ZC(NRA) - ZL(NRA,J))
   30  CONTINUE
C
C     COMPUTE U'S ON BOUNDARY BETWEEN REGIONS ZL AND ZR
C
      BIX = HCRL *(TC-TZB(NZ)+ TB1(NZ))
      ZL(1,NZ) = ZL(1,NZ ) + WMEGQ * ((ZARL(1)*ZL(2,NZ)+ZA(1)*
     1ZL(1,NZ1)+ ZR1*ZR(2,1) + BIX)/(ZBRL(1)+HCRL/CONZ(NZ)) -
     2ZL(1 ,NZ))
      TZB(NZ)= TZB(NZ) - TB1(NZ) + ZL(1,NZ)/CONZ(NZ)
       SUMAO = SUMAO + HCRL * (TC -  TZB(NZ))
      DO 34 I=2,NRAM
      I1 = I-1
```

```
34 ZL(I,NZ)= ZL(I,NZ)+WMEGQ*((ZARL(I)*ZL(I+1 ,NZ)+
  1ZARL(I1 ) *ZL(I1 ,NZ) + ZR3*ZR(2,I)+ZA(I)*ZL(I,NZ1))/
  2ZBRL(I) - ZL(I,NZ))
   ZL(NRA,NZ) = ZL(NRA,NZ) + WMEGQ * ((ZA(NRA) * ZL(NRA,NZ1) +
  1ZR1 * ZR(2,NRA) + ZARL(NRAM) * ZL(NRAM,NZ))/ZBRL(NRA) - ZL(NRA,NZ)
  2)
   DO 35 I=1,NRA
35 ZR(1,I)= ZL(I,NZ)
C
C     COMPUTE U'S ON REGION ZR
C
   CALL CON1 (TZBR,TB1,NZX,CONZR)
   DO 32 J=2,NZX
   J1 = J-1
   JP = J+1
   IF(J .LT. NZX) GO TO 28
   DO 29 I = 1,NRA
29 ZR(JP,I) = ZR(J1,I)
28 BIX = HCZR *(TC - TZBR(J) + TB1(J))
   ZR(J,1)= ZR(J,1)+WMEGQ*((ZR1*(ZR(J1 ,1)+ZR(JP ,1)) +
  1 ZR2*ZR(J,2) + BIX)/(ZR4 + HCZR/CONZR(J))-ZR(J,1))
   TZBR(J)= TZBR(J)-TB1(J) + ZR(J,1)/CONZR(J)
    SUMAO = SUMAO + HCZR *(TC - TZBR(J))
   F(2) = -ZRA *ZR(J,1) +ZRP *(ZR(JP,2) +ZR(J1,2))
   DO 33 I = 3,NRAM1
33 F(I) = ZRP * (ZR(JP,I) + ZR(J1,I))
   F(NRAM) = -ZRA *ZR(J,NRA ) +ZRP *(ZR(JP,NRAM) +ZR(J1,NRAM))
   CALL RLINE(ZRA,CZ,UZR,F,X,NRAM)
   DO 27 I = 2,NRAM
27 ZR(J,I) = ZR(J,I) + WMEGQ *(X(I) - ZR(J,I))
   ZR(J,NRA) = ZR(J,NRA) +WMEGQ*((ZR2*ZR(J,NRAM) +ZR1*(ZR(J1,NRA) +
  1 ZR(JP,NRA)))/ZR4 - ZR(J,NRA))
32 CONTINUE
   RETURN
   END
```

```
   SUBROUTINE CON1(TOLD,U,NTIM,COND)
C
C     CONDUCTIVITY  FOR STAINLESS STEEL
C     TREF1 = 70.0 FOR SAMPLE PROBLEM
C
   DIMENSION TOLD(1),U(1),COND(50),B(6,5),TK(6),TEG(6)
   DOUBLE PRECISION TOLD,U,COND,B,TK,TEG,SUM,TNEW
   DATA (B(1,J),J =1,5)/.80380307D-4,.63751499D-6,-.14201613D-8,.1083
  17124D-11,0.D0/
   DATA (B(2,J), J=1,5)/.11520489D-3,.19479961D-6,-.1240770D-9,.624877
  11D-13,0.D0/
   DATA (B(3,J), J =1,5)/.40113088D-3,-.38485987D-6,.33912452D-9,-.99
  12039140D-13,.10638424D-16/
   DATA (TK(J),J = 1,3)/70.D0,400.D0,1200.D0/
   DATA IN/1/
   IF (IN .EQ. 1) GO TO 6
 4 DO 1 J=1,NTIM
   IF (TOLD(J) .GT. 70.D0) GO TO 20
   TOLD(J) = 70.D0
   COND(J) = .11841930-3
   U(J) = 0.0
   GO TO 1
20 K= 1
   DO 2 L = 1,2
   L1 = L + 1
 2 IF(TOLD(J) .GT. TK( L1)) K = L1
 8 COND(J)= B(K,1) + TOLD(J) * (B(K,2) + TOLD(J) * (B(K,3) + TOLD(J)*
  1(B(K,4) + TOLD(J) * B(K,5))))
   N = K
   SUM = 0.0
   DO 7 I = 1,N
 7 SUM = SUM + TEG(I)
   TNEW = SUM + TOLD(J) * (B(K,1) + TOLD(J) *(B(K,2)/2.0 + TOLD(J) *
  1 (B(K,3)/3.0 + TOLD(J) * (B(K,4)/4.0 + TOLD(J) * B(K,5)/5.0)))) -
  2 TK(N) * (B(K,1) + TK(N) * (B(K,2)/2.0 + TK(N) * (B(K,3)/3.0 + TK
  3 (N) * (B(K,4)/4.0 + TK(N) * B(K,5)/5.0))))
   U(J) = TNEW/COND(J)
 1 CONTINUE
   RETURN
```

```
    6 TEG(1) = 0.0
      DO 5 I = 1,2
      II = I + 1
    5 TEG(II) = TK(II) * (B(I ,1) + TK(II) * (B(I ,2)/2.0 + TK(II) * (
     1B(I ,3)/3.0 + TK(II) * (B(I ,4)/4.0 + TK(II) * B(I ,5)/5.0)))) -
     2TK(I) * (B(I ,1) + TK(I) * (B(I ,2)/2.0 + TK(I) * (B(I ,3)/3.0 +
     3 TK(I) * (B(I ,4)/4.0 + TK(I) * B(I ,5)/5.0))))
      IN = 2
      GO TO 4
      END
```

```
      SUBROUTINE CON2(TOLD,U,NTIM,COND)
C
C     CONDUCTIVITY NICKEL
C     TREF2 = 230.0 FOR SAMPLE PROBLEM
C
      DIMENSION TOLD(1),U(1),COND(50),B(6,5),TK(6),TEG(6)
      DOUBLE PRECISION TOLD,U,COND,B,TK,TEG,SUM,TNEW
      DATA (B(1,J),J=1,5)/ .40450270-2,-.13443105D-4,.19014014D-7,-.8813
     14126D-11,-.63860967D-15/
      DATA(B(2,J),J=1,5)/ .16581257D-2,-.27299411D-5,.34458597D-8,-.238
     150469D-11,.67843954D-15/
      DATA (B(3,J),J=1,5)/.43294101D-3,.22290446D-6,-.1714753D-9,.120048
     178D-12,-.2365019D-16/
      DATA (TK(J),J=1,3)/230.D0, 660.D0, 1360.D0/
      DATA IN/1/
      IF (IN .EQ. 1) GO TO 6
    4 DO 1 J=1,NTIM
   20 K= 1
      DO 2 L=1,2
      L1 = L + 1
    2 IF (TOLD(J).GT.TK(L1)) K=L1
    8 COND(J)= B(K,1) + TOLD(J) * (B(K,2) + TOLD(J) * (B(K,3) + TOLD(J)*
     1(B(K,4) + TOLD(J) * B(K,5))))
      N = K
      SUM = 0.0
      DO 7 I = 1,N
    7 SUM = SUM + TEG(I)
      TNEW = SUM + TOLD(J) * (B(K,1) + TOLD(J) *(B(K,2)/2.0 + TOLD(J) *
     1 (B(K,3)/3.0 + TOLD(J) * (B(K,4)/4.0 + TOLD(J) * B(K,5)/5.0)))) -
     2 TK(N) * (B(K,1) + TK(N) * (B(K,2)/2.0 + TK(N) * (B(K,3)/3.0 + TK
     3 (N) * (B(K,4)/4.0 + TK(N) * B(K,5)/5.0))))
         U(J) = TNEW/COND(J)
    1 CONTINUE
      RETURN
    6 TEG(1) = 0.0
      DO 5 I=1,2
      II = I + 1
    5 TEG(II) = TK(II) * (B(I ,1) + TK(II) * (B(I ,2)/2.0 + TK(II) * (
     1B(I ,3)/3.0 + TK(II) * (B(I ,4)/4.0 + TK(II) * B(I ,5)/5.0)))) -
     2TK(I) * (B(I ,1) + TK(I) * (B(I ,2)/2.0 + TK(I) * (B(I ,3)/3.0 +
     3 TK(I) * (B(I ,4)/4.0 + TK(I) * B(I ,5)/5.0))))
      IN = 2
      GO TO 4
      END
```

```
      SUBROUTINE CON3(TOLD,U,NTIM,COND)
C
C     CONDUCTIVITY COPPER
C     TREF3 = 120.0 FOR SAMPLE PROBLEM
C
      DIMENSION TOLD(1),U(1),COND(50),B(6,5),TK(6),TEG(6)
      DOUBLE PRECISION TOLD,U,COND,B,TK,TEG,SUM,TNEW
      DATA (B(1,J),J=1,5)/1.26923200,-.66746332D-1,.1422934D-2,-.1399347
     19D-4,.52471424D-7/
      DATA (B(2,J),J=1,5)/.44088491D0,-.12795533D-1,.13751066D-3,-.60595
     1948D-6,.82357513D-9/
      DATA (B(3,J),J=1,5)/.49401865D-1,-.667958510-3,.37770900D-5,-.9341
     13869D-8,.84968007D-11/
      DATA (B(4,J),J=1,5)/.70182202D-2,-.1002119D-4,.21603633D-7,-.21689
```

```
     1429D-10,.816627650-14/
      DATA (B(5,J),J=1,5)/.52029382D-2,.19183180D-5,-.55433799D-9,.14533
     1748D-12,0.D0/
      DATA (B(6,J), J = 1,5)/ .46D-2,0.D0,0.D0,0.D0,0.D0/
      DATA (TK(J),J = 1,5)/80.D0,120.D0,350.D0,860.D0,1660.D0/
      DATA IN/1/
      IF (IN .EQ. 1) GO TO 6
    4 DO 1 J=1,NTIM
   20 K= 1
      DO 2 L = 1,5
      L1 = L + 1
    2 IF(TOLD(J) .GT. TK( L )) K = L1
    8 COND(J)= B(K,1) + TOLD(J) * (B(K,2) + TOLD(J) * (B(K,3) + TOLD(J)*
     1(B(K,4) + TOLD(J) * B(K,5))))
      N = K-1
      IF(TOLD(J) .LE. 120.D0) N = 2
      SUM = 0.0
      DO 7 I = 1,N
    7 SUM = SUM + TEG(I)
      TNEW = SUM + TOLD(J) * (B(K,1) + TOLD(J) *(B(K,2)/2.0 + TOLD(J) *
     1 (B(K,3)/3.0 + TOLD(J) * (B(K,4)/4.0 + TOLD(J) * B(K,5)/5.0)))) -
     2 TK(N) * (B(K,1) + TK(N) * (B(K,2)/2.0 + TK(N) * (B(K,3)/3.0 + TK
     3 (N) * (B(K,4)/4.0 + TK(N) * B(K,5)/5.0))))
         U(J) = TNEW/COND(J)
    1 CONTINUE
      RETURN
    6 TEG(1) = 0.0
      TEG(2) = 0.0
      DO 5 I = 2,4
      II = I + 1
    5 TEG(II) = TK(II) * (B(II,1) + TK(II) * (B(II,2)/2.0 + TK(II) * (
     1B(II,3)/3.0 + TK(II) * (B(II,4)/4.0 + TK(II) * B(II,5)/5.0)))) -
     2TK(I) * (B(II,1) + TK(I) * (B(II,2)/2.0 + TK(I) * (B(II,3)/3.0 +
     3 TK(I) * (B(II,4)/4.0 + TK(I) * B(II,5)/5.0))))
      TEG(6) = 0.0
      IN = 2
      GO TO 4
      END
```

```
      SUBROUTINE RLINE(A,EL,U,F,X,N)
C
C     ROUTINE TO SOLVE AX = F WHERE A IS TRI-DIAGONAL WITH CONSTANT OFF
C     DIAGONAL ELEMENTS AND A = LU WHERE L AND U ARE LOWER AND UPPER
C     TRIANGULAR MATRICES
C
      DIMENSION EL(1),U(1),F(1),X(1),Y(15)
      DOUBLE PRECISION A,EL,U,F,X,Y
      N1 = N-1
      Y(2) = F(2)/EL(2)
      DO 1 I = 3,N
    1 Y(I) = (F(I) - A * Y(I-1))/EL(I)
      X(N) = Y(N)
      DO 2 J = 2,N1
      I = N+1 - J
    2 X(I) = Y(I) - U(I) * X(I+1)
      RETURN
      END
```

```
      SUBROUTINE CLINE(EM,EL,U,F,X,N)
C
C     ROUTINE TO SOLVE AX = F WHERE A IS TRI-DIAGONAL AND A = LU,L AND U
C     ARE LOWER AND UPPER TRIANGULAR MATRICES
C
      DIMENSION EM(1),EL(1),U(1),F(1),X(1),Y(35)
      DOUBLE PRECISION EM,EL,U,F,X,Y
      N1 = N-1
      Y(2) = F(2)/EL(2)
      DO 1 I = 3,N
    1 Y(I) = (F(I) + EM(I-1) * Y(I-1))/EL(I)
      X(N) = Y(N)
      DO 2 J = 2,N1
      I = N-J +1
    2 X(I) = Y(I) - U(I) * X(I+1)
      RETURN
      END
```

```
      SUBROUTINE OUTPUT(IPUNCH)
      COMMON /FORMA/R1,R2,RA2,YFINT,FINTHK,ANGTOP,HCOOL,TCOOL,HGAS,TGAS,
     1XLONGM,R2B,YFINB,ANGBOT,SUMAO,SUMAI
      DOUBLE PRECISION R1,R2,RA2,YFINT,FINTHK,ANGTOP,HCOOL,TCOOL,HGAS,
     1TGAS,XLONGM,R2B,YFINB,ANGBOT,SUMAO,SUMAI,TOL
      COMMON/FORA/ A(15,25),A1(35,25),B(15,15),BZ(20,15),D(15,15),
     1 D1(35,15),TBA(25),TAI(25),TTA(25),TBB(15),TBI(15),TBD(15),
     2TDI(15),TDD(15)
      DOUBLE PRECISION A,A1,B,BZ,D,D1,TBA,TAI,TTA,TBB,TBI,TBD,
     1TDI,TDD
      COMMON /FORC/ P(20,15),P1(20,5),Q(15,20),Q1(15,20),ZL(15,20),
     1ZR (20,15),TPB(20),TPI(20),TBQ(20),TQI(20),TZB(20),TZBR(20)
      DOUBLE PRECISION P,P1,Q,Q1,ZL,ZR,TPB,TPI,TBQ,TQI,TZB,TZBR
      COMMON /FORCN/ NXP,NXP1,NTQ,NTQ1,NZ,NZ1,NZX,NZX1
      COMMON/FOUTA/THETA(25),RA(15),RA1X(35),RA1(35),THETD(15),
     1THETB(15)
      DOUBLE PRECISION THETA,RA,RA1X,RA1,THETD,THETB
      COMMON /FOUTC/THETQ(20), XP(20),RQA(15),RQ(5),THETZ(20),
     1 XZ (20),QT (20),YP(20),YP1(5)
      DOUBLE PRECISION THETQ,XP,RQA,RQ,THETZ,XZ,QT,YP,YP1
      COMMON/FORAN/NRA,NRAM,NTA,NTAP,NRA1,NRA1M,NRA1X,NRA1XM,
     1NRB,NRBM,NTB,NTBM,NTD,NTDM
      DATA CONV/57.2957795/
      DIMENSION U(80),TEMP(80)
C
C     IPUNCH = 1  PUNCH BCD CARDS WITH U DISTRIBUTION FOR ALL
C                 SUBREGIONS AND TEMPS ON BOUNDARIES AND INTERFACES
C
      IF(IPUNCH .NE. 1) GO TO 600
      CALL BCDUMP (A(1,1),A(15,25),0)
      CALL BCDUMP (A1(1,1),A1(35,25),0)
      CALL BCDUMP (D(1,1),D(15,15),0)
      CALL BCDUMP (D1(1,1),D1(35,15),0)
      CALL BCDUMP (B(1,1),B(15,15),0)
      CALL BCDUMP (BZ(1,1),BZ(20,15),0)
      CALL BCDUMP (TBA(1),TBA(25),0)
      CALL BCDUMP (TAI(1),TAI(25),0)
      CALL BCDUMP (TTA(1),TTA(25),0)
      CALL BCDUMP (TBD(1),TBD(15),0)
      CALL BCDUMP (TDI(1),TDI(15),0)
      CALL BCDUMP (TDD(1),TDD(15),0)
      CALL BCDUMP (TBB(1),TBB(15),0)
      CALL BCDUMP (TBI(1),TBI(15),0)
      CALL BCDUMP (P(1,1),P(20,15),0)
      CALL BCDUMP (P1(1,1),P1(20,5),0)
      CALL BCDUMP (Q(1,1),Q(15,20),0)
      CALL BCDUMP (Q1(1,1),Q1(15,20),0)
      CALL BCDUMP (ZL(1,1),ZL(15,20),0)
      CALL BCDUMP (ZR(1,1),ZR(20,15),0)
      CALL BCDUMP (TPB(1),TPB(20),0)
      CALL BCDUMP (TPI(1),TPI(20),0)
      CALL BCDUMP (TBQ(1),TBQ(20),0)
      CALL BCDUMP (TQI(1),TQI(20),0)
      CALL BCDUMP (TZB(1),TZB(20),0)
      CALL BCDUMP (TZBR(1),TZBR(20),0)
  600 CONTINUE
C
```

```
C      REGION A
C
       T1 = TBA(1)
       WRITE(6,100)
       DO 1 I=2,NTAP
       THETA(I) = THETA(I) * CONV
       WRITE(6,101) THETA(I-1)
       DO 2 J=1,NRA
     2 U(J) = A(J,I)
       CALL SUBT1(U,T1,TEMP,1,NRA)
       T1 = TEMP(1)
       T2 = TEMP(NRA)
       WRITE(6,102) (RA(J),TEMP(J),J=1,NRA)
C
C      REGION A1
C
       IF(R2 .EQ. RA2) GO TO 1
       DO 4 J=1,NRA1X
     4 U(J) = A1(J,I)
       CALL SUBT2(U,T2,TEMP,1,NRA1X)
       WRITE(6,102) (RA1(J),TEMP(J),J=1,NRA1X)
     1 CONTINUE
C
C      REGION D
C
       DO 14 I = 2,NTD
       THB = THETD(I) * CONV + THETA(NTA)
       WRITE (6,101) THB
       DO 15 J = 1,NRA
    15 U(J) = D(J,I)
        CALL SUBT1(U,T1,TEMP,1,NRA)
       T1 = TEMP(1)
       T2 = TEMP(NRA)
       WRITE(6,102) (RA(J),TEMP(J), J= 1,NRA)
       IF(R2 .EQ. RA2) GO TO 14
C
C      REGION D1
C
       JJ = NRA1X + 1 - I
       DO 16 J = 1,JJ
    16 U(J) = D1(J,I)
       CALL SUBT2(U,T2,TEMP,1,JJ)
       WRITE(6,102) (RA1(J),TEMP(J),J=1,JJ)
    14 CONTINUE
C
C      REGION B
C
       THBL = THB
       DO 5 I = 1,NTB
       THB = THETB(I) * CONV + THBL
       WRITE (6,101) THB
       DO 6 J = 1,NRA
     6 U(J) = B(J,I)
        CALL SUBT1(U,T1,TEMP,1,NRA)
       T1 = TEMP(1)
       T2 = TEMP(NRA)
       WRITE(6,102) (RA(J),TEMP(J), J= 1,NRA)
C
C      REGION B1
C
       JJ = NRA1  + 1 - I
       DO 7 J = 1,JJ
     7 U(J) = BZ(J,I)
       CALL SUBT3(U,T2,TEMP,1,JJ)
       WRITE(6,102) (RA1(J),TEMP(J), J= 1,JJ)
     5 CONTINUE
C
C      REGION P
C
       WRITE(6,120)
       DO 30 I=1,NXP
       WRITE(6,105) XP(I)
       DO 31 J=1,NRA
    31 U(J)= P(I,J)
       CALL SUBT1(U,T1,TEMP,1,NRA)
       WRITE(6,102) (YP(J), TEMP(J), J=1,NRA)
C
C      REGION P1
C
```

```
      T1 = TEMP(1)
      T2 = TEMP(NRA)
      DO 32 J=1,NRB
   32 U(J)= P1(I,J)
      CALL SUBT3(U,T2,TEMP,1,NRB)
      WRITE(6,102) (YP1(J), TEMP(J), J=1,NRB)
   30 CONTINUE
C
C     REGION Q
C
      WRITE (6,122)
      DO 33 I=1,NTQ
      THB = THETQ(I)* CONV
      WRITE(6,101) THB
      DO 34 J=1,NRA
   34 U(J)= Q(J,I)
      CALL SUBT1(U,T1,TEMP,1,NRA)
      WRITE(6,102) (RQA(J), TEMP(J), J=1,NRA)
C
C     REGION Q1
C
      T1 = TEMP(1)
      T2 = TEMP(NRA)
      DO 35 J=1,NRB
   35 U(J)= Q1(J,I)
      CALL SUBT3(U,T2,TEMP,1,NRB)
      WRITE(6,102) (RQ(J), TEMP(J), J=1,NRBM),QT(I),TEMP(NRB)
   33 CONTINUE
C
C     REGION ZL
C
      THBL = THB
      DO 38 I=2,NZ
      THB = THETZ(I) *CONV + THBL
      WRITE(6,101) THB
      DO 39 J=1, NRA
   39 U(J)= ZL(J,I)
      CALL SUBT1(U,T1,TEMP,1,NRA)
      T1 = TEMP(1)
      WRITE(6,102) (RQA(J), TEMP(J), J=1,NRA)
   38 CONTINUE
C
C     REGION ZR
C
      WRITE(6,123)
      DO 40 I = 1,NZX
      WRITE(6,105) XZ(I)
      DO 41 J=1,NRA
   41 U(J)= ZR(I,J)
      CALL SUBT1(U,T1,TEMP,1,NRA)
      T1 = TEMP(1)
      WRITE(6,102) (YP(J), TEMP(J), J=1,NRA)
   40 CONTINUE
  100 FORMAT(1H1,37X46HTEMPERATURES ON THE TOP RADIAL SECTION OF TUBE//1
     1H )
  101 FORMAT(1HK,50X7HTHET = E13.6//9X1HR,15X1HT,15X1HR,15X1HT,
     115X1HR,15X1HT,15X1HR,15X1HT/1H )
  102 FORMAT(8(3XE13.6))
  105 FORMAT(1HK,53X4HX = E13.6//9X1HY,15X1HT,15X1HY,15X1HT,
     115X1HY,15X1HT,15X1HY,15X1HT/1H )
  120 FORMAT(1HK,37X46HTEMPERATURES ON THE MIDDLE RECTANGULAR SECTION//1
     1H )
  122 FORMAT(1HK,37X48HTEMPERATURES ON THE LOWER RADIAL SECTION OF TUBE/
     1/1H )
  123 FORMAT(1HK,37X45HTEMPERATURES ON THE LOWER RECTANGULAR SECTION//1H
     1 )
      RETURN
      END
```

```
      SUBROUTINE SUBT1(U,T1,TEMP,N1,N2)
C
C     SUBROUTINE TO TRANSFORM U FOR STAINLESS TO TEMPERATURE
C     TREF1 = 70.0 FOR SAMPLE PROBLEM
C
      DATA (B(1,J),J =1,5)/.80380307D-4,.63751499D-6,-.14201613D-8,.1083
```

```
     171240D-11,0.D0/
      DATA (B(2,J), J=1,5)/.11520489D-3,.19479961D-6,-.124077D-9,.624877
     11D-13,0.D0/
      DATA (B(3,J), J =1,5)/.40113088D-3,-.38485987D-6,.33912452D-9,-.99
     1203914D-13,.10638424D-16/
      DATA (TK(J),J = 1,3)/70.D0,400.D0,1200.D0/
      DIMENSION U(80),TEMP(80),B(6,5),TK(5),TEG(6)
      DOUBLE PRECISION B,TK
      DATA IN/1/
      IF (IN .EQ. 1) GO TO 6
    4 DO 1 I=N1,N2
    3 K = 1
      DO 2 L = 1,2
      L1= L+1
    2 IF(T1        .GT. TK( L1)) K = L1
      COND    = B(K,1) + T1         * (B(K,2) +  T1       * (B(K,3) + T1       *
     1(B(K,4) + T1         * B(K,5))))
      N = K
      SUM = 0.0
      DO 7 M = 1,N
    7 SUM = SUM + TEG(M)
      TNEW = SUM + T1 *        (B(K,1) + T1        *(B(K,2)/2.0 + T1        *
     1 (B(K,3)/3.0 + T1        * (B(K,4)/4.0 + T1        * B(K,5)/5.0)))) -
     2 TK(N) * (B(K,1) + TK(N) * (B(K,2)/2.0 + TK(N) * (B(K,3)/3.0 + TK
     3 (N) * (B(K,4)/4.0 + TK(N) * B(K,5)/5.0))))
      TNEW = T1 - (-U(I) + TNEW)/COND
      REL = ABS((T1-TNEW)/TNEW)
      T1=TNEW
      IF (REL.LE.1.0E-6) GO TO 1
      GO TO 3
    1 TEMP(I) = TNEW
      RETURN
    6 TEG(1) = 0.0
      DO 5 I = 1,2
      II = I + 1
    5 TEG(II) = TK(II) * (B(I ,1) + TK(II) * (B(I ,2)/2.0 + TK(II) * (
     1B(I ,3)/3.0 + TK(II) * (B(I ,4)/4.0 + TK(II) * B(I ,5)/5.0)))) -
     2TK(I) * (B(I ,1) + TK(I) * (B(I ,2)/2.0 + TK(I) * (B(I ,3)/3.0 +
     3 TK(I) * (B(I ,4)/4.0 + TK(I) * B(I ,5)/5.0))))
      IN = 2
      GO TO 4
      END
```

```
      SUBROUTINE SUBT2(U,T1,TEMP,N1,N2)
C
C     SUBROUTINE TO TRANSFORM U FOR NICKEL TO TEMPERATURE
C     TREF2 = 230.0 FOR SAMPLE PROBLEM
C
      DATA (B(1,J),J=1,5)/ .40450270D-2,-.13443105D-4,.19014014D-7,-.8813
     14126D-11,-.63860967D-15/
      DATA(B(2,J),J=1,5)/  .16581257D-2,-.27299411D-5,.34458597D-8,-.238
     150469D-11,.67843954D-15/
      DATA (B(3,J),J=1,5)/.43294101D-3,.22290446D-6,-.1714753D-9,.120048
     178D-12,-.2365019D-16/
      DATA (TK(J),J=1,3)/230.D0, 660.D0, 1360.D0/
      DIMENSION U(80),TEMP(80),B(6,5),TK(5),TEG(6)
      DOUBLE PRECISION B,TK
      DATA IN/1/
      IF (IN .EQ. 1) GO TO 6
    4 DO 1 I=N1,N2
    3 K = 1
      DO 2 L=1,2
      L1= L+1
    2 IF(T1 .GT. TK(L1)) K = L1
      COND    = B(K,1) + T1         * (B(K,2) +  T1       * (B(K,3) + T1       *
     1(B(K,4) + T1         * B(K,5))))
      N = K
      SUM = 0.0
      DO 7 M = 1,N
    7 SUM = SUM + TEG(M)
      TNEW = SUM + T1 *        (B(K,1) + T1        *(B(K,2)/2.0 + T1        *
     1 (B(K,3)/3.0 + T1        * (B(K,4)/4.0 + T1        * B(K,5)/5.0)))) -
     2 TK(N) * (B(K,1) + TK(N) * (B(K,2)/2.0 + TK(N) * (B(K,3)/3.0 + TK
     3 (N) * (B(K,4)/4.0 + TK(N) * B(K,5)/5.0))))
      TNEW = T1 - (-U(I) + TNEW)/COND
```

```
      REL = ABS((T1-TNEW)/TNEW)
      T1=TNEW
      IF (REL.LE.1.0E-6) GO TO 1
      GO TO 3
    1 TEMP(I) = TNEW
      DEBUG (U(I), I = N1,N2)
      RETURN
    6 TEG(1) = 0.0
      DO 5 I=1,2
      II = I + 1
    5 TEG(II) = TK(II) * (B(I ,1) + TK(II) * (B(I ,2)/2.0 + TK(II) * (
     1B(I ,3)/3.0 + TK(II) * (B(I ,4)/4.0 + TK(II) * B(I ,5)/5.0)))) -
     2TK(I) * (B(I ,1) + TK(I) * (B(I ,2)/2.0 + TK(I) * (B(I ,3)/3.0 +
     3 TK(I) * (B(I ,4)/4.0 + TK(I) * B(I ,5)/5.0))))
      IN = 2
      GO TO 4
      END
```

```
      SUBROUTINE SUBT3(U,T1,TEMP,N1,N2)
C
C     SUBROUTINE TO TRANSFORM U FOR COPPER TO TEMPERATURE
C     TREF3 = 120.0 FOR SAMPLE PROBLEM
C
      DATA (B(1,J),J=1,5)/1.269232D0,-.66746332D-1,.1422934D-2,-.1399347
     19D-4,.52471424D-7/
      DATA (B(2,J),J=1,5)/.44088491D0,-.12795533D-1,.13751066D-3,-.60595
     1948D-6,.82357513D-9/
      DATA (B(3,J),J=1,5)/.49401865D-1,-.66795851D-3,.37770900D-5,-.9341
     13869D-8,.84968007D-11/
      DATA (B(4,J),J=1,5)/.70182202D-2,-.1002119D-4,.21603633D-7,-.21689
     1429D-10,.81662765D-14/
      DATA (B(5,J),J=1,5)/.52029382D-2,.19183180D-6,-.55433799D-9,.14533
     1748D-12,0.D0/
      DATA (B(6,J), J = 1,5)/ .46D-2,0.D0,0.D0,0.D0,0.D0/
      DATA (TK(J),J = 1,5)/80.D0,120.D0,360.D0,860.D0,1660.D0/
      DIMENSION U(80),TEMP(80),B(6,5),TK(5),TEG(6)
      DOUBLE PRECISION B,TK
      DATA IN/1/
      IF (IN .EQ. 1) GO TO 6
    4 DO 1 I=N1,N2
    3 K = 1
      DO 2 L = 1,5
      L1= L+1
    2 IF (T1.GT.TK(L )) K=L1
      COND   = B(K,1) + T1      * (B(K,2) +  T1      * (B(K,3) + T1     *
     1(B(K,4) + T1      * B(K,5))))
      N = K-1
      SUM = 0.0
      IF(T1 .LE. 120.D0) N = 2
      DO 7 M = 1,N
    7 SUM = SUM + TEG(M)
      TNEW = SUM + T1 *       (B(K,1) + T1      *(B(K,2)/2.0 + T1      *
     1 (B(K,3)/3.0 + T1      * (B(K,4)/4.0 + T1      * B(K,5)/5.0)))) -
     2 TK(N) * (B(K,1) + TK(N) * (B(K,2)/2.0 + TK(N) * (B(K,3)/3.0 + TK
     3 (N) * (B(K,4)/4.0 + TK(N) * B(K,5)/5.0))))
      TNEW = T1 - (-U(I) + TNEW)/COND
      REL = ABS((T1-TNEW)/TNEW)
      T1=TNEW
      IF (REL.LE.1.0E-6) GO TO 1
      GO TO 3
    1 TEMP(I) = TNEW
      DEBUG (U(I), I = N1,N2)
      RETURN
    6 TEG(1) = 0.0
      TEG(2) = 0.0
      DO 5 I = 2,4
      II = I + 1
    5 TEG(II) = TK(II) * (B(II,1) + TK(II) * (B(II,2)/2.0 + TK(II) * (
     1B(II,3)/3.0 + TK(II) * (B(II,4)/4.0 + TK(II) * B(II,5)/5.0)))) -
     2TK(I) * (B(II,1) + TK(I) * (B(II,2)/2.0 + TK(I) * (B(II,3)/3.0 +
     3 TK(I) * (B(II,4)/4.0 + TK(I) * B(II,5)/5.0))))
      TEG(6) = 0.0
      IN = 2
      GO TO 4
      END
```

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