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A METHOD OF CALCULATING TRANSIENT TEMPERATURES IN A MULTIREGION, AXISYMMETRIC, CYLINDRICAL CONFIGURATION. THE ARGUS PROGRAM, 1089/RE248, WRITTEN IN FORTRAN II.

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D. F. Schoeberle
Reactor Physics Division

J. Heestand
Applied Mathematics Division

and

L. B. Miller
Reactor Physics Division

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TABLE OF CONTENTS

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

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ABSTRACT

A detailed description is given of ARGUS, a FORTRAN II computer program for calculating transient temperatures in any concentric cylindrical configuration. Included are an explanation of the mathematical methods, a discussion of special features and restrictions, input and output descriptions, operating instructions, several sample problems, and the code listing.

The program allows up to 25 concentric regions, each containing either a stationary or turbulently flowing material with temperature-dependent properties. Any stationary material can have spatial- and time-dependent heat generation. Temperatures are calculated at node points which are equally spaced within a region. The number of radial node points in a stationary material region is specified by input. Up to 100 node points per radial row and up to 16 radial rows are allowed.

Material properties of flowing materials are approximated by second-order polynomials, and the thermal properties of stationary materials are considered to be constant within a temperature phase. There may be up to 9 phase changes in stationary materials, with heats of transformation added to the material at the transformation temperatures. Thermal resistances at stationary region interfaces are considered by means of input coefficients of heat transfer. Film coefficients on flowing region boundaries are calculated by the program, and time-dependent coolant velocities are permitted.

NOMENCLATURE

Roman Letters

Physical Symbol	FORTRAN Symbol	Definition
A_F	AF(L)	Flow area of coolant channel
A_{ij}	-	Heat-conduction area for an element surrounding node point i in nodal row j
a_1,a_2,a_3 b_1,b_2	A1(N),A2(N),A3(N) B1(N),B2(N)	Exponents in film coefficient equations
$B_{i,j};C_{i,j};D_{i,j};$ $E_{i,j};G_{i,j}$	B(I,J),C(I,J), D(I,J),E(N,J), G(I,J)	Coefficients in the finite-difference temperature equation for radial point i in nodal row j
c_p	-	Specific heat of a material
d	WIDAN(N)	Width of a coolant annulus: $d = R_0 - R_1$
De	DE(N)	Equivalent heat-transfer diameter, used only in film-coefficient equations
DUMP NUMBER	NDUMP	The number of the tape dump to be used to restart the problem if it is a continuation of a previous problem
H(B,L,J),h,etc.	H(B,L,J)	Film coefficient on boundary of coolant annulus
$h_{1,j},h_{1,L,J}$,etc.	H(1,N,J)	Film coefficient on inner wall of the annulus
$h_{2,j},h_{2,L,J}$,etc.	H(2,N,J)	Film coefficient on outer wall of the annulus
$H_1,H_2,\ldots H_6$	H1(N),H2(N),...H6(N)	Coefficients in the film-coefficient equations
I	I	Nodal point number ($1 \le I \le IMAX$)
i	-	Nodal point number ($1 \le i \le NI_L$)
IMAX	IMAX	Number of radial node points ($3 \le IMAX \le 100$)
ICS	ICS(N)	Parameter to designate source of coolant
IH	IH(N)	Parameter to select a set of equations for calculation of film coefficients at the boundaries of each region of flowing coolant
IPT	IPT(N)	Parameter to select velocity function $[\phi(\tau)]$ for each region of flowing coolant
ITEMP	ITEMP	Parameter to designate form of initial temperature input
J,j	J	Nodal row number ($1 \le J,j < JMAX$)
JMAX	JMAX	The number of nodal rows
k(M)	CAY(ML,NP)	Thermal conductivity of material M
K(L)	K(L)	A parameter to specify type of region L: K = 1 for thick region with heat generation; K = 2 for thick region without heat generation; K = 3 for thin region with heat generation; K = 4 for thin region without heat generation; K = 5 for flowing coolant
$k_{M,NP}$	CAY(ML,NP)	Thermal conductivity of the NP^{th} phase of material M
k_0,k_1,k_2	CAY(ML,1...3)	Parameters in the thermal conductivity equation for a flowing coolant material: $k = k_0 + k_1T + k_2T^2$
L	L	Region number (L = 1,2,...,LMAX)
ℓ_J	DZ or DZ2	The length of a segment of a channel containing flowing coolant
LMAX	LMAX	The number of regions in the configuration ($LMAX \le 25$)
M	M(L),MM(L),ML	Material number
M	EM	A modified FOURIER modulus: $M = \overline{\Delta r}^2/\alpha\overline{\Delta\tau}$
MMAX	MMAX	The number of materials whose properties are given as input ($1 \le MMAX \le 10$)
$N(\tau,\Delta\tau)$	CURREN	$[n(\tau)+n(\tau+\Delta\tau)]/2 \approx \frac{1}{\Delta\tau}\int_{\tau}^{\tau+\Delta\tau} n\,d\tau$
N_1,N_2	EN	A modified Biot modulus: $N_1 = (h_2\overline{\Delta r}/k)[8R_1/(4R_1+\Delta r)]$; $N_2 = (h_1\overline{\Delta r}/k)[8R_0/(4R_0-\Delta r)]$
$n(\tau)$	ENTAU(NENTAU)	Point values of the time-dependent part of the power function
NH	NH(IX)	Initial number of time intervals between h computations
NI(L)	NI(L)	Number of radial node points per nodal row in region L
NN	NN	The number of pointwise values of $n(\tau)$ to be given in the input
NPMAX	NPMAX	Number of temperature ranges (phases) for which material properties of solid materials are specified ($1 \le NPMAX \le 10$)
NPHI	NPHI(N)	The number of pointwise values of a time-dependent velocity function, $\phi(\tau)$, to be given in the input
NPR	NPR	Number of time intervals between print-outs
NPT	NPT	Number of sets of time-dependent coolant-velocity factors $[\phi(\tau)]$ to be input ($1 \le NPT \le 4$)
Nu	-	Nusselt's number, used only in film-coefficient equations
$N\beta$	NBETA	Number of values of β to be given as input
$N\gamma$	NGAMMA	Number of values of γ to be specified for a $\phi(\tau)$ set
P	P	Period of exponential function if $n(\tau) = e^{\tau/P}$
PR	PR	Prandtl number (used in film-coefficient equations)
Q,q''',etc.	QMUZ(I,J)	Rate of heat generation per unit volume: $q''' = q_0\mu(r)\zeta(z)n(\tau)$
$q_0(L)$	QO(L)	Power normalization coefficient for region L with heat generation
r	-	Radius
$R_1(L)$	R(L-1)	Inner radius of region L
$R_0(L),R(L)$	R(L)	Outer radius of region L
Re	RE	Reynolds number (used in film-coefficient equations)
$T_1,T_2,\ldots,T_{LMAX}$ or $T_{ij}(0)$	T(I,J)	Initial temperatures at time $\tau = 0$
$T_{i,j}(\tau)$	T(I,J)	The temperature of radial node point i, located in nodal row j, at time τ
$T_f(\tau)$	-	A fluid temperature
$T_{i,j}(\tau')$	TDT(I,J)	The temperature of radial node point i of nodal row j at time $\tau + \Delta\tau$
$TT_{M,NP}$	TT(ML,NP)	Transformation temperature of solid material M between phase NP and NP + 1
U(n)	U(L)	Surface-contact conductance on outer boundary of the n'th solid region. This value is not used to calculate heat transfer from a region bounded by a flowing coolant. U = 0 for last region if it contains a solid material
$v_J(\tau),v,v_z$,etc.	V(N)	Coolant velocity
$V_{i,j}$	-	The volume associated with node point i of nodal row j
$V_0(L)$	VO(N)	The velocity normalization factor for a flowing coolant region L. V_0 is negative if the flow is directed from row J=JMAX to J=1
Z,z	Z	Axial length of the configuration

Greek Letters

Physical Symbol	FORTRAN Symbol	Definition
α	-	Thermal diffusivity of a material; $\alpha = k/(\rho c_p)$
β	S2(temporary)	Coefficient of volumetric expansion (used only in film-coefficient equations)
β_i	BETA(NBET)	The number of time intervals ($\Delta\tau$) between specified (input) values of $n(\tau)$ for $\tau_{n_{i-1}} \le \tau \le \tau_{n_i}$
γ_i	GAMMA(N,N1)	The number of $\Delta\tau$ intervals between given input values of $\phi(\tau)$ for $\tau_{p_{i-1}} \le \tau \le \tau_{p_i}$
ΔH	-	Heat of transformation, per unit mass, of a solid material M
$\overline{\Delta r}_L, \Delta r_L$	DR(L)	An increment of radial length inside region L
$\overline{\Delta Z}, \Delta Z, \Delta z$	DZ	The axial distance between nodal rows of mesh points
$\overline{\Delta\tau}', \Delta\tau$	DT(1)	Initial unit time interval
$\overline{\Delta\tau}_1, \Delta\tau_1$	DT(1)	Unit time interval for coolant and thick stationary regions
$\overline{\Delta\tau}_2, \Delta\tau_2$	DT(2)	Unit time interval for thin stationary regions
ϵ_d	EPSD(IX)	The minimum fractional change in h before doubling the parameter NH
ϵ_h	EPSH(IX)	The maximum fractional change in h before halving the parameter NH
$\zeta(j)$	ZETA(L,J)	Axially dependent power factors for a region L with heat generation
$\mu(r)$	AMU(I)	Radially dependent power factors for a region L with heat generation
ν	ANEW	Kinematic viscosity of a flowing coolant material; used only in film-coefficient equations

Physical Symbol	FORTRAN Symbol	Definition
ν_0, ν_1, ν_2	ANU(ML,1...3)	Parameters in the equation for the kinematic viscosity for phases 1 and 2 of a flowing coolant material: $\nu = \nu_0 + \nu_1 T_f + \nu_2 T_f^2$
ρ	RO	Density of a material M
ρ_0, ρ_1, ρ_2	RHO(ML,1...3) ROW(N)(inlet only)	Parameters in the equation for the density for phases 1 and 2 of a flowing coolant material: $\rho = \rho_0 + \rho_1 T_f + \rho_2 T_f^2$
$\rho\Delta H_1, \rho\Delta H_2, \ldots$	RHODH(N,NP)	Initial density times the heat of transformation for a solid material
ρc_p	RHOC(ML,NP) ROC(N,J)	Initial density times the specific heat of a solid material
	RHOC(ML,4)	Also, the density times specific heat for phase 3 (bulk boiling) of a flowing coolant
$\rho c_0, \rho c_1, \rho c_2$	RHOC(ML,1...3)	Parameters in the equation for the volumetric heat capacity for phases 1 and 2 of a flowing coolant: $\rho c_p = \rho c_0 + \rho c_1 T_f + \rho c_2 T_f^2$
τ	TAU	The time variable
τ_F	TAUF	The final time or termination time of a problem
τ_{n_i}	TAUN(NBET)	The value of time τ at which β_{i+1} replaces β_i
τ_{p_i}	TAUP(N,N1)	The value of time τ at which γ_{i+1} replaces γ_i
$\phi(\tau)$	PHI(N,N2)	A time-dependent coolant-velocity function. Values of the function are given pointwise in the input, and up to four functions may be given
Ψ_s	PSIS(N)	The coolant saturation (boiling) temperature for a flowing coolant
$\Psi_0(L)$	PSIO(N)	The inlet coolant temperature

I. MATHEMATICAL ANALYSIS

A. General Problem Description

As part of the continuing Fast Reactor Safety Program, an interest has developed in calculating transient temperatures in various experimental configurations. These configurations usually consist of combinations of flowing and stationary materials confined within concentric cylindrical regions. The number of regions varies, depending upon the purpose of the experiment to be performed.

In order to automate the procedure for calculating transient temperatures in such experiments, a new FORTRAN II code, ARGUS, has been written. This program will calculate transient temperatures in any cylindrical configuration consisting of up to 25 concentric regions, and supersedes the more restricted program 524/RE147 (CYCLOPS).[(1)*]

In the following sections of this report, the equations for calculating transient temperature distributions in concentric cylindrical regions are derived. Any region may contain either a stationary or a flowing material, with heat generation permitted in any stationary material region. A stationary material can be either a solid or a nonflowing liquid; a flowing material can be a liquid or gas moving at any velocity. For the stationary materials, thermal properties are represented as step functions of temperature within prescribed temperature ranges. Second-order polynomials are used to approximate the temperature dependence of the properties of flowing materials.

The regions are assumed to be very long compared with their thickness, so that axial heat conduction may be neglected. However, axial transport of heat due to material motion is considered in the regions with flowing materials.

The temperature field in any region containing a stationary material will obey the general diffusion equation

$$\rho c_p \frac{\partial T}{\partial \tau} = \mathrm{div}(k \text{ grad } T) + Q(\overline{R}, \tau), \tag{1}$$

where

$T(\overline{R}, \tau)$ = temperature;

$k(T)$ = thermal conductivity;

(ρc_p) = volumetric heat capacity;

$Q(\overline{R}, \tau)$ = rate of heat generation.

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*Raised numbers in parentheses refer to references at the end of this report.

Assuming that only radial heat conduction occurs and that the heat source is not angular dependent, Eq. (1) reduces to

$$\rho c_p \frac{\partial T}{\partial \tau} = \frac{1}{r}\left[\frac{\partial}{\partial r}\left(kr \frac{\partial T}{\partial r}\right)\right] + q_1(r,z,\tau), \tag{2}$$

where $q_1(r,z,\tau)$ is the rate of heat generation.

Assuming that thermal properties have a constant value within prescribed temperature ranges, Eq. (2) can be further reduced to

$$\rho c_p \frac{\partial T}{\partial \tau} = k\left(\frac{\partial^2 T}{\partial r^2} + \frac{1}{r}\frac{\partial T}{\partial r}\right) + q_1(r,z,\tau), \tag{3}$$

where Eq. (3) holds within a temperature range.

The differential equation of heat conduction in a flowing material region can be approximated as

$$\rho c_p\left(\frac{\partial T}{\partial \tau} + v_z \frac{\partial T}{\partial z}\right) = q_2(z,\tau), \tag{5}$$

where v_z is the axial velocity of the flowing material and $q_2(z,\tau)$ the rate of heat addition to the material.

Equations (3) and (5) are reduced to finite difference form and the difference equations are solved by the ARGUS program.

At boundaries between stationary materials, the following condition is used:

$$q'' = U(T_1 - T_2),$$

where

q'' = heat flux per unit area;

U = boundary conductance;

T_1 and T_2 = temperatures on opposite sides of the boundary.

At boundaries between stationary and flowing materials, heat transfer is characterized by a film coefficient computed by the code from input material properties and fluid velocities.

The outer boundary of the outer region is assumed to be perfectly insulated.

B. Mesh Layout and Description

The axial length Z and the radial width $R_0(L) - R_0(L-1)$ of a typical region L are divided into finite increments ΔZ and Δr, and then nodal points are assigned to give a mesh layout as illustrated in Figs. 1 and 2. The input parameter NI(L) gives the total number of node points

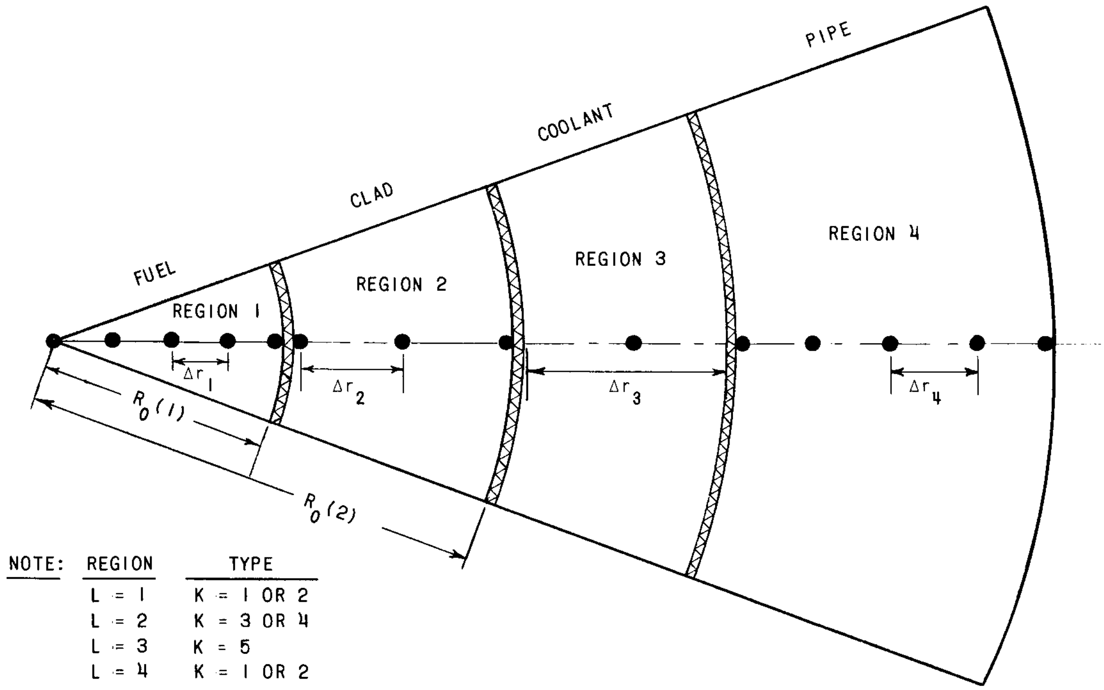

Fig. 1. Example of Mesh Layout for a Typical Radial Row (No Scale)

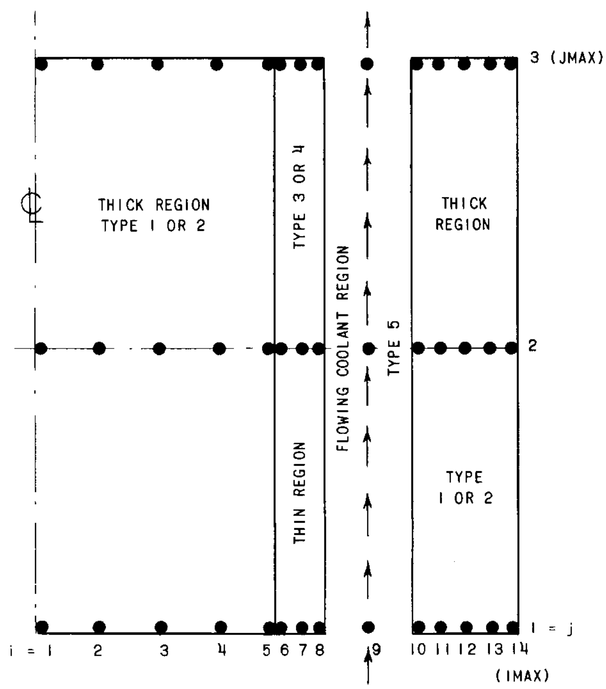

Fig. 2. Examples of Axial Mesh Point Layout

in a typical radial row within a region L. For stationary regions, there is a node point, in each radial row, infinitesimally close to each boundary, and the remaining points are equally spaced in between. A coolant (flowing material) region has only one nodal point per radial row, located at the central radius of the region.

In order to use the program to approximate two-dimensional problems, there is a radial row of node points on each end of the configuration and (JMAX - 2) radial rows equally spaced between the end rows. For one-dimensional problems, the parameter JMAX can be taken as unity to give one radial row of node points at the half-height of the configuration. In this case, Eq. (5) is not used, and the program holds the coolant temperature, in any flowing material region, constant at the input source temperature Ψ_0.

The subscript i locates any node point along a radial path, and the parameter IMAX denotes the total number of node points per radial row. The subscript j locates the radial row of node points in the axial direction, and the parameter JMAX denotes the total number of radial rows. Note that the first node point in a row, $i = 1$, is always on the centerline of the configuration, regardless of which type of region represents the central region.

In subsequent sections, the differential Eqs. (3) and (5) are expanded into difference equations in terms of the temperatures at appropriate discrete node points.

C. Finite Difference Equations for Thick Regions

1. Introduction

A thick region will be defined as a stationary material region in which there are three or more node points per radial row. This type of region is selected by using the input parameter $K = 1$ (if heat generation occurs in the material) or $K = 2$ (if no heat generation occurs). The boundary node points are treated by using a new method developed by L. H. Back.[3] Equation (3) is now expanded into finite difference forms, where the boundary node points and the interior node points are treated separately.

2. The Difference Equation for the First Node Point of the First Region

The finite difference equation for the first node point $(i = 1)$ of the first region $(L = 1)$ has been derived in Reference 1, p. 15, and also is given by Dusinberre.[4] The details will not be repeated here.

These references show that Eq. (3) can be transformed into

$$T_1(\tau + \Delta\tau_1) = \left(1 - \frac{4}{M}\right)T_1(\tau) + \frac{4}{M}T_2(\tau) + \frac{Q(r,z)\Delta\tau_1}{\rho c_p}N(\tau,\Delta\tau_1), \qquad (6)$$

where

$$N(\tau,\Delta\tau_1) = \frac{1}{2}[n(\tau + \Delta\tau_1) + n(\tau)];$$

ρc_p = volumetric heat capacity of the material;

$\Delta\tau_1$ = unit time increment for thick-type regions;

$Q(r,z)$ = space-dependent part of the heat generation rate;

$M = (\Delta r)^2/\alpha\Delta\tau_1$ = dimensionless modulus of heat conduction;

$\alpha = k/\rho c_p$ = thermal diffusivity of the material;

k = thermal conductivity of the material;

$n(\tau)$ = time-dependent power function.

If the general finite difference equation is of the form

$$T_{i,j}(\tau + \Delta\tau_1) = B_{i,j}T_{i-1,j}(\tau) + C_{i,j}T_{i,j}(\tau) + D_{i,j}T_{i+1,j}(\tau) + G_{i,j}N(\tau,\Delta\tau_1), \qquad (7)$$

then the coefficients in Eq. (7) are $B_{1,j} = 0$, $C_{1,j} = [1 - (4/M)]$, $D_{1,j} = 4/M$, and $G_{1,j} = Q(r,z)\Delta\tau_1/\rho c_p$. These coefficients are tabulated in the first column of Table I.

3. The Difference Equation for the First Node Point of Annular Regions

In Reference 3, Back shows how a modified energy-balance procedure can be used to derive a difference equation of a slightly different form than (7). The resulting equation is completely stable for any value of the film coefficient h or surface-contact conductance U. Thus, the only requirement for a stable solution of the difference equation will be that the time interval $\Delta\tau_1$ is chosen sufficiently small so that the modulus M is large enough. This feature can represent a saving of computation time for problems where a large film coefficient is the limiting parameter.

Table I

THICK-REGION COEFFICIENTS

Node Point	$i = 1$		$2 \leqslant i \leqslant NI_L - 1$	$i = NI_L$
Coef-ficient \ Region	$L = 1$	$L > 1$	all L	all L
$B_{I,J}$	0	N_1/S	$\left(1 - \frac{\Delta r_L}{2r_i}\right)\Big/M$	w/S
$C_{I,J}$	$1 - D_{I,J}$	$(2M - N_1 - w)/S$	$1 - B_{I,J} - D_{I,J}$	$(2M - N_2 - w)/S$
$D_{I,J}$	$4/M$	w/S	$\left(1 + \frac{\Delta r_L}{2r_i}\right)\Big/M$	N_2/S
$G_{I,J}$	$\frac{q_{o_L}\mu_I\zeta_{L,J}\Delta\tau_1}{(\rho c_p)_{ML,NP}}$	$\frac{q_{o_L}\mu_I\zeta_{L,J}\Delta\tau_1}{(\rho c_p)_{ML,NP}}$	$\frac{q_{o_L}\mu_I\zeta_{L,J}\Delta\tau_1}{(\rho c_p)_{ML,NP}}$	$\frac{q_{o_L}\mu_I\zeta_{L,J}\Delta\tau_1}{(\rho c_p)_{ML,NP}}$
		where $N_1 = \left(\frac{H_{L-1}\Delta r_L}{k_{ML,NP}}\right)\left(\frac{8R_{L-1}}{4R_{L-1} + \Delta r_L}\right)$; $w = 4\left(\frac{2R_{L-1} + \Delta r_L}{4R_{L-1} + \Delta r_L}\right)$; $S = 2M + N + w$		where $N_2 = \left(\frac{H_L \Delta r_L}{k_{ML,NP}}\right)\left(\frac{8R_L}{4R_L - \Delta r_L}\right)$; $w = 4\left(\frac{2R_L - \Delta r_L}{4R_L - \Delta r_L}\right)$; $S = 2M + N + w$

where

$$I \leqslant i \leqslant NI_L \qquad r_i = R_{L-1} + (i-1)\Delta r_L \qquad M = \frac{(\Delta r_L)^2 (\rho c_p)_{ML,NP}}{\Delta\tau_1 k_{ML,NP}}$$

$$I = \sum_{\ell=1}^{L-1} NI_\ell + i \qquad H_{L-1} = \begin{cases} h_{2,L-1,J} \text{ if } K_{L-1} = 5 \\ U_{L-1} \text{ otherwise} \end{cases}$$

$$\Delta r_L = \frac{R_L - R_{L-1}}{NI_L - 1} \qquad H_L = \begin{cases} h_{1,L+1,J} \text{ if } K_{L+1} = 5 \\ U_L \text{ otherwise} \end{cases}$$

An energy balance for the material associated with the outer boundary node point i can be written as follows:

$$\begin{pmatrix}\text{Energy} \\ \text{stored}\end{pmatrix} = \begin{pmatrix}\text{Energy} \\ \text{in}\end{pmatrix} - \begin{pmatrix}\text{Energy} \\ \text{out}\end{pmatrix} + \begin{pmatrix}\text{Energy} \\ \text{generated}\end{pmatrix}.$$

In terms of the temperatures at neighboring node points, this equation becomes

$$\rho c_p V_i \frac{dT_i}{d\tau} = h_i A_i(\overline{T}_{i-1} - \overline{T}_i) - \frac{kA_m}{\Delta r}(\overline{T}_i - \overline{T}_{i+1}) +$$

$$+ Q(r,z)\frac{V_i}{\Delta\tau_i}\int_{\tau}^{\tau+\Delta\tau_1} n(\tau)d\tau, \qquad (8)$$

where

V_i = volume of surface element;

A_i = surface area;

h_i = film coefficient or surface-contact conductance;

A_m = mean heat-conduction area between node points i and $i+1$.

The average node-point temperatures in (8) are approximated by

$$\overline{T}_{i-1} = \frac{1}{2}\left[T_{i-1}(\tau) + T_{i-1}(\tau+\Delta\tau_1)\right] = \frac{1}{2}\left(T_{i-1} + T'_{i-1}\right);$$

$$\overline{T}_{i} = \frac{1}{2}\left[T_{i}(\tau) + T_{i}(\tau+\Delta\tau_1)\right] = \frac{1}{2}\left(T_{i} + T'_{i}\right);$$

$$\overline{T}_{i+1} = \frac{1}{2}\left[T_{i+1}(\tau) + T_{i+1}(\tau+\Delta\tau_1)\right] = \frac{1}{2}\left(T_{i+1} + T'_{i+1}\right).$$

Considering the geometrical layout of these node points, and assuming the element of volume surrounding point i is cut out by radial lines (see Fig. 3) subtending an arc of 1 radian, we derive the following relationships:

$$A_i = (r_i)\Delta Z;$$

$$A_m = \left(r_i + \frac{1}{2}\Delta r\right)\Delta Z;$$

$$V_i = \left(r_i + \frac{\Delta r}{4}\right)\left(\frac{\Delta r \Delta z}{2}\right).$$

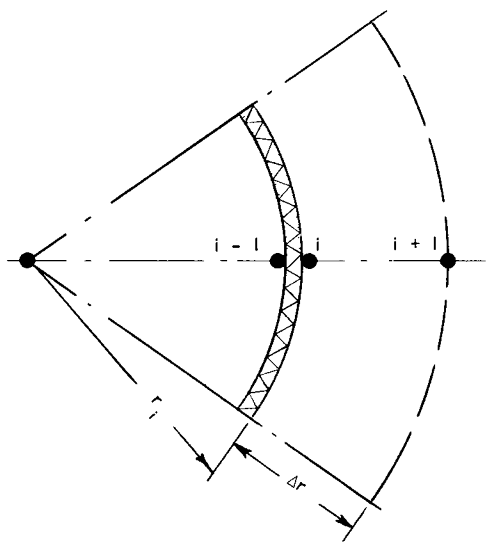

Fig. 3

Layout of Boundary Node Points

The integral in the last term of (8) is approximated by

$$N(\tau, \Delta\tau_1) = \frac{n(\tau) + n(\tau+\Delta\tau_1)}{2} \approx \int_{\tau}^{\tau+\Delta\tau_1} \frac{n}{\Delta\tau_1}\, d\tau.$$

With these substitutions, Eq. (8) now becomes

$$\Delta\tau_1 \frac{dT_i}{d\tau} = 8\left(\frac{h\Delta r}{k}\right)\left(\frac{\alpha\,\Delta\tau_1}{\Delta r^2}\right)\left(\frac{r_i}{4r_i+\Delta r}\right)\left(\frac{T'_{i-1}+T_{i-1}}{2} - \frac{T'_i+T_i}{2}\right)$$

$$+ 4\left(\frac{\alpha\,\Delta\tau_1}{\Delta r^2}\right)\left(\frac{2r_i+\Delta r}{4r_i+\Delta r}\right)\left(\frac{T'_{i+1}+T_{i+1}}{2} - \frac{T'_i+T_i}{2}\right)$$

$$+ \frac{Q(r,z)\Delta\tau_1}{\rho c_p} N(\tau,\Delta\tau_1). \tag{9}$$

If we define the quantities

$$M_1 = \Delta r^2/\alpha\,\Delta\tau_1; \qquad N_1 = \left(\frac{h\Delta r}{k}\right)\left(\frac{8r_i}{4r_i+\Delta r}\right);$$

$$w_1 = 4(2r_i+\Delta r)/(4r_i+\Delta r),$$

and replace the time derivative $dT_i/d\tau$ by the forward difference quotient, then Eq. (9) becomes

$$T_i(\tau+\Delta\tau_1)\left[1+\frac{N_1}{2M_1}+\frac{w_1}{2M_1}\right] = \frac{N_1}{2M_1}(T'_{i-1}+T_{i-1}) + T_i(\tau)\left[1-\frac{N_1}{2M_1}-\frac{w_1}{2M_1}\right]$$

$$+\frac{w_1}{2M_1}(T'_{i+1}+T_{i+1}) + \frac{Q(r,z)\Delta\tau}{\rho c_p} N(\tau,\Delta\tau_1). \tag{10}$$

Finally, if the quantity S is defined by

$$\frac{S}{2M_1} = 1 + \frac{N_1}{2M_1} + \frac{w_1}{2M_1},$$

then Eq. (10) becomes

$$T_i(\tau+\Delta\tau_1) = \frac{N_1}{S}(T'_{i-1}+T_{i-1}) + \frac{2M_1 - N_1 - w_1}{S} T_i(\tau)$$

$$+\frac{w_1}{S}(T'_{i+1}+T_{i+1}) + \frac{2M_1}{S}\frac{Q(r,z)\Delta\tau}{\rho c_p} N(\tau,\Delta\tau_1). \tag{11}$$

A general difference equation for such node points can be written in the form

$$T_i(\tau+\Delta\tau_1) = B_{i,j}[T_{i-1}(\tau+\Delta\tau_1)+T_{i-1}(\tau)] + C_{i,j}T_{i,j}(\tau)$$

$$+D_{i,j}[T_{i+1}(\tau+\Delta\tau_1)+T_{i+1}(\tau)] + G_{i,j}N(\tau,\Delta\tau_1). \tag{12}$$

The coefficients in the second column of Table I are established by comparing Eqs. (11) and (12).

4. The Difference Equation for Interior Points of Any Region

The finite difference equation for a typical interior node point is derived by transforming Eq. (3). The time derivative $\partial T/\partial \tau$ is replaced by the forward difference quotient as follows:

$$\frac{\partial T}{\partial \tau} \rightarrow \frac{T_i(\tau+\Delta\tau_1) - T_i(\tau)}{\Delta \tau_1}, \tag{13}$$

where $\Delta\tau_1$ is the finite time increment. The space derivatives in Eq. (3) are replaced by the following approximations:

$$\frac{\partial^2 T}{\partial r^2} \rightarrow \frac{T_{i+1}(\tau) - 2T_i(\tau) + T_{i-1}(\tau)}{\overline{\Delta r}^2} \tag{14}$$

and

$$\frac{\partial T}{\partial r} \rightarrow \frac{T_{i+1}(\tau) - T_{i-1}(\tau)}{2\Delta r}. \tag{15}$$

Finally, the radius r is replaced by the radius out to the node point, $r \rightarrow r_i$. Substitution of the Eqs. (13), (14), and (15), and simultaneously adding up the heat generation during the finite time increment $\Delta\tau_1$, alters Eq. (3) to

$$\frac{T_i(\tau+\Delta\tau_1) - T_i(\tau)}{\Delta\tau_1} = \alpha \left\{ \frac{T_{i+1}(\tau) - 2T_i(\tau) + T_{i-1}(\tau)}{\overline{\Delta r}^2} + \frac{1}{r_i}\left[\frac{T_{i+1}(\tau) - T_{i-1}(\tau)}{2\Delta r}\right]\right\} + \frac{1}{\rho c_p}\int_{\tau}^{\tau+\Delta\tau_1} q_1(\overline{r},\tau)d\tau/\Delta\tau_1. \tag{16}$$

The heat-generation function is now represented by the product of a space-dependent and a time-dependent function:

$$q_1(\overline{r},\tau) = Q(r,z)n(\tau). \tag{17}$$

The integration in Eq. (16) is approximated by a 2-point trapezoidal rule, and Eq. (16) is simplified to yield

$$T_i(\tau+\Delta\tau) = \left(\frac{\alpha\Delta\tau_1}{\Delta r^2} - \frac{\alpha\Delta\tau_1}{2r_i\Delta r}\right)T_{i-1}(\tau) + \left(1 - \frac{2\alpha\Delta\tau_1}{\Delta r^2}\right)T_i(\tau)$$

$$+\left(\frac{\alpha\Delta\tau_1}{\Delta r^2} + \frac{\alpha\Delta\tau_1}{2r_i\Delta r}\right)T_{i+1}(\tau) + \frac{Q(r,z)\Delta\tau_1}{\rho c_p}N(\tau,\Delta\tau_1). \qquad (18)$$

Following customary practice, as in Reference 4, the modulus M is defined as

$$M = \Delta r^2/\alpha\Delta\tau_1.$$

With this definition, Eq. (18) becomes

$$T_i(\tau+\Delta\tau_1) = \frac{1}{M}\left(1 - \frac{\Delta r}{2r_i}\right)T_{i-1}(\tau) + \left(1 - \frac{2}{M}\right)T_i(\tau)$$

$$+\frac{1}{M}\left(1 + \frac{\Delta r}{2r_i}\right)T_{i+1}(\tau) + \frac{Q(r,z)\Delta\tau_1}{\rho c_p}N(\tau,\Delta\tau_1). \qquad (19)$$

Equation (19) is exactly in the form of Eq. (7), and the coefficients for use with Eq. (7) are given as the third column of Table I.

5. The Finite Difference Equation for the Last Node Point of Any Region

The last node point [i = NI(L)] for any region L will be treated as a boundary point by use of the method of L. H. Back.[3] The details of the derivation of the finite difference equation are exactly like those of Section I.C.3, except for a slight change in the volume of the subelement V_i and the mean heat conduction area A_m.

An equation of the form of Eq. (12) can be derived by the method of Section I.C.3, and the coefficients for use with Eq. (12) are given as the last column of Table I.

6. Summary

The finite difference equations for all node points in thick-type regions are given as Eqs. (7) and (12). If the first node point of the first region is defined to be an interior point, then Eq. (7) is valid for all interior points, and Eq. (12) is valid for all boundary node points.

Finally, it is assumed that the space-dependent heat-generation function can be represented as the product of a normalization factor q_0, a radial-dependent function μ_i, and an axial-dependent function ζ_j, so that

$$Q(r,z) = q_0\mu_i\zeta_j. \qquad (20)$$

D. Finite Difference Equations for Thin Regions

1. Introduction

A thin region will be defined as a stationary material region in which there are a fixed number of node points in a radial row; $NI_L = 2$ for the first region $(L = 1)$ and $NI_L = 3$ for any annular region. This type of region is selected by using the input parameter K = 3 (if heat generation occurs in the material) or K = 4 (if no heat generation occurs). The boundary node points are treated by the Dusinberre method[4] in order to increase the accuracy of the solution as compared with that obtainable with the Back method (Section I.C.3). Furthermore, a distinct time increment $\Delta\tau_2$ is introduced into the finite difference equations for this type of region. Inner iterations (mesh sweeps) are performed over all thin-type regions during the time interval from τ to $\tau + \Delta\tau_1$, where $\Delta\tau_1 = x\Delta\tau_2$, x is an integral power of 2, and $\Delta\tau_1$ is the unit time increment in thick-type regions. The boundary node points and the interior node points are again treated separately when Eq. (3) is expanded into a finite difference form.

2. The Finite Difference Equation for the First Node Point of the First Region

The two node points of the first region $(L = 1)$ are located at the centerline and adjacent to the outer boundary, as illustrated by Fig. 4.

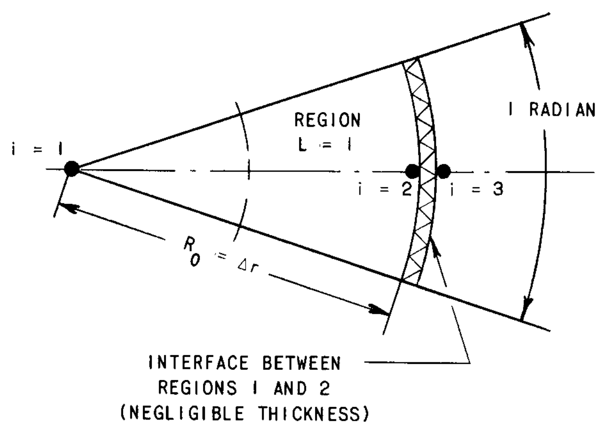

Fig. 4

Node Point Layout, Thin First Region

The first node point $(i = 1)$ is treated exactly as was the first node point of a thick-type region (see Section I.C.2). By means of the geometric relationship $\Delta r = R_0$ and the unit time increment $\Delta\tau_2$, Eq. (6) becomes

$$T_1(\tau + \Delta\tau_2) = \left(1 - \frac{4}{M_2}\right)T_1(\tau) + \frac{4}{M_2}T_2(\tau) + \frac{Q(r,z)\Delta\tau_2}{\rho c_p} N(\tau, \Delta\tau_2). \quad (21)$$

In the general finite difference form, this equation is

$$T_{i,j}(\tau+\Delta\tau_2) = B_{i,j}T_{i-1,j}(\tau) + C_{i,j}T_{i,j}(\tau) + D_{i,j}T_{i+1,j}(\tau) + G_{i,j}N(\tau, \Delta\tau_2). \quad (22)$$

The coefficients given in the first column of Table II are established by comparison of Eqs. (21) and (22).

Table II

THIN-REGION COEFFICIENTS (KL = 3,4)

Node Point	i = 1		i = 2		i = 3
Coefficient \ Region	L = 1	L > 1	L = 1	L > 1	1 < L
$B_{I,J}$	0	N_1/M_2	$4w_2/M_2$	$\left(1-\frac{\Delta r}{2r_i}\right)/M_2$	$4w_3/M_2$
$C_{I,J}$	$1-D_{I,J}$	$1-B_{I,J}-D_{I,J}$	$1-B_{I,J}-D_{I,J}$	$1-B_{I,J}-D_{I,J}$	$1-B_{I,J}-D_{I,J}$
$D_{I,J}$	$\frac{4}{M}$	$4w_1/M_2$	N_2/M_2	$\left(1+\frac{\Delta r}{2r_i}\right)/M_2$	N_2/M_2
$G_{I,J}$	$\frac{q_{o_L}\mu_I\zeta_{L,J}\Delta\tau_2}{(\rho c_p)_{ML,NP}}$	$\frac{q_{o_L}\mu_I\zeta_{L,J}\Delta\tau_2}{(\rho c_p)_{ML,NP}}$	$\frac{q_{o_L}\mu_I\zeta_{L,J}\Delta\tau_2}{(\rho c_p)_{ML,NP}}$	$\frac{q_{o_L}\mu_I\zeta_{L,J}\Delta\tau_2}{(\rho c_p)_{ML,NP}}$	$\frac{q_{o_L}\mu_I\zeta_{L,J}\Delta\tau_2}{(\rho c_p)_{ML,NP}}$
		where $w_1 = \frac{(2R_{L-1}+\Delta r)}{(4R_{L-1}+\Delta r)}$ $N_1 = \left(\frac{H_{L-1}\Delta r}{k}\right)\left(\frac{8R_{L-1}}{4R_{L-1}+\Delta r}\right)$	where $w_2 = \frac{\Delta r}{(4R_L-\Delta r)}$ $N_2 = \left(\frac{H_L\Delta r}{k}\right)\left(\frac{8\Delta r}{4R_L-\Delta r}\right)$	where $r_i = R_{L-1}+\Delta r$	where $w_3 = \frac{(2R_L-\Delta r)}{(4R_L-\Delta r)}$ $N_2 = \left(\frac{H_L\Delta r}{k}\right)\left(\frac{8R_L}{4R_L-\Delta r}\right)$

where

$$I = \sum_{\ell=1}^{L-1} NI_{\ell}+i \qquad H_{L-1} = \begin{cases} h_{2,L-1,J} & \text{if } K_{L-1} = 5 \\ U_L & \text{otherwise} \end{cases} \qquad \Delta r_L = \begin{cases} R_L & \text{if } L = 1 \\ (R_L-R_{L-1})/2 & \text{if } L > 1 \end{cases}$$

$$1 \leqslant i \leqslant 2 \text{ if } L=1 \qquad H_L = \begin{cases} h_{1,L+1,J} & \text{if } K_{L+1} = 5 \\ U_L & \text{otherwise} \end{cases} \qquad M_2 = \frac{(\Delta r_L)^2(\rho c_p)_{ML,NP}}{\Delta\tau_2\, k_{ML,NP}}$$

$$1 \leqslant i \leqslant 3 \text{ if } L<1$$

3. The Finite Difference Equation for the Second Node Point of the First Region

The second node point (i = 2) is treated as a boundary node point with the usual Dusinberre[4] method of solution. The procedure and assumptions of this method of solution will be illustrated here.

(1) Assume that a time interval $\Delta\tau_2$ can be chosen sufficiently small that only the local temperature and the temperature of adjacent referance points need be considered in calculating the change of the local temperature during this time interval. Thus, only $T_1(\tau)$, $T_2(\tau)$, and $T_3(\tau)$ need be considered in calculating $T_2(\tau+\Delta\tau_2)$.

(2) The initial heat transfer rates may be used over the entire interval $\Delta\tau_2$.

(3) The change of heat storage in an element may be calculated from the change of temperature of the reference point located in that element.

Consider the half element (Fig. 4) of width $\ell_r = \Delta r/2$ with node point i = 2 on its surface. A heat balance representing a conservation of energy for this element can be written as

$$\begin{pmatrix}\text{Heat}\\\text{stored}\end{pmatrix} = \begin{pmatrix}\text{Heat}\\\text{conducted}\\\text{in}\end{pmatrix} - \begin{pmatrix}\text{Heat}\\\text{conducted}\\\text{out}\end{pmatrix} + \begin{pmatrix}\text{Heat}\\\text{generated}\end{pmatrix}. \tag{23}$$

By use of the assumptions made above and the temperatures at the appropriate node points, Eq. (23) becomes

$$\rho c_p V_2 \frac{dT_2}{d\tau} = \frac{kA_{12}}{\Delta r}[T_1(\tau) - T_2(\tau)] - \frac{HA_{23}}{1}[T_2(\tau) - T_3(\tau)] + \frac{V}{\Delta\tau_2}\int_{\tau}^{\tau+\Delta\tau_2} Q(r,z)n(\tau)\, d\tau, \tag{24}$$

where

ρc_p = volumetric heat capacity of the material;

k = thermal conductivity;

V_2 = volume of the subelement;

A_{12} = average heat conduction area between node points i = 1 and i = 2;

H = film coefficient (h) or surface contact conductance (U) for this boundary;

A_{23} = surface area of the element.

By considering the geometrical nature of this subelement (see Fig. 4), we find the following relations:

$$A_{12} = \left(\frac{\Delta r}{2}\Delta z\right); \quad A_{23} = \Delta r \Delta z = R_0 \Delta z; \quad V_2 = \frac{\Delta r}{2}\,\Delta z\left[R_0 - \frac{\Delta r}{4}\right].$$

Substitution of these quantities into Eq. (24) gives

$$\frac{dT_2}{d\tau} = \frac{\alpha\left(\frac{\Delta r}{2}\right)[T_1(\tau) - T_2(\tau)]}{\Delta r\left[\frac{\Delta r}{2}\left(R_0 - \frac{\Delta r}{4}\right)\right]} + \frac{H\Delta r[T_3(\tau) - T_2(\tau)]}{\frac{\Delta r}{2}\left(R_0 - \frac{\Delta r}{4}\right)\rho c_p}$$

$$+ \frac{Q(r,z)}{\Delta\tau_2(\rho c_p)}\int_{\tau}^{\tau + \Delta\tau^2} n(\tau)d\tau. \tag{25}$$

Again, the time derivative is replaced by the forward difference quotient and the integral of the last term is approximated by a two-point trapezoidal rule. Equation (25) then becomes

$$T_2(\tau+\Delta\tau_2) = \frac{4}{M_2}\left(\frac{\Delta r}{4R_0 - \Delta r}\right) T_1(\tau) + T_2(\tau)\left[1 - \frac{4}{M_2}\left(\frac{\Delta r}{4R_0 - \Delta r}\right) - \frac{N_2}{M_2}\right]$$

$$+ \frac{N_2}{M_2} T_3(\tau) + \frac{Q(r,z)\Delta\tau_2}{\rho c_p} N(\tau, \Delta\tau_2), \tag{26}$$

where

$M_2 = (\Delta r)^2/\alpha\,\Delta\tau_2$ = dimensionless modulus;

$\alpha = k/\rho c_p$ = thermal diffusivity;

$N_2 = \frac{H\Delta r}{k}\left(\frac{8\Delta r}{4R_0 - \Delta r}\right)$ = modified Nusselt's number.

If we also define $w_2 = \Delta r/(4R_0 - \Delta r)$, Eq. (26) becomes

$$T_2(\tau+\Delta\tau_2) = \frac{4w_2}{M_2} T_1(\tau) + T_2(\tau)\left[1 - \frac{4w_2}{M_2} - \frac{N_2}{M_2}\right] + \frac{N_2}{M_2} T_3(\tau)$$

$$+ \frac{Q(r,z)\Delta\tau_2}{\rho c_p} N(\tau, \Delta\tau_2). \tag{27}$$

Equation (27) is now in the finite difference form of Eq. (22). The coefficients for use in Eq. (22) are given as the third column of Table II.

4. <u>The Finite Difference Equation for the First Node Point of Annular Regions</u>

The three node points of an annular region ($L > 1$) are located at the central radius and adjacent to each boundary, as illustrated by Fig. 5, p. 23.

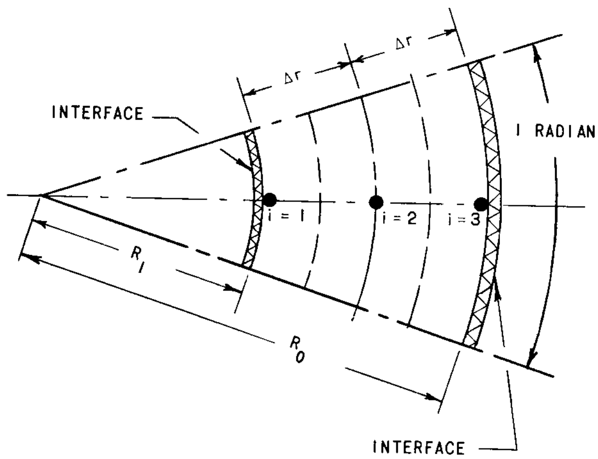

Fig. 5
Node Point Layout, Thin Annular Region

The first node point of this type of region is treated as a boundary node point. Using the procedure outlined in the preceding section, except that the subelement volume is now

$$V_1 = \left[R_1 + \frac{\Delta r}{4}\right] \frac{\Delta r \Delta z}{2},$$

and the average heat conduction area is now

$$A_{12} = \left[R_1 + \frac{\Delta r}{2}\right] \Delta z;$$

the finite difference equation is found to be

$$T_1(\tau+\Delta\tau_2) = \frac{N_1}{M_2} T_{NI \atop (L-1)} + T_1(\tau)\left[1 - \frac{N_1}{M_2} - \frac{4w_1}{M_2}\right] + \frac{4w_1}{M_2} T_2(\tau)$$

$$+ \frac{Q(r,z)\overline{\Delta\tau_2}}{(\rho c_p)} N(\tau, \Delta\tau_2). \tag{28}$$

This result is also in the finite difference form of Eq. (22). The coefficients for use in Eq. (22) are tabulated in the second column of Table II.

5. <u>The Finite Difference Equation for the Central Node Point of Annular Regions</u>

The second node point ($i = 2$) of an annular region ($L > 1$) is treated as an interior point by exactly the procedure of Section I.C.4. If the unit time increment $\Delta\tau_2$ is used, this method yields the finite difference equation

$$T_2(\tau+\Delta\tau_2) = \frac{1}{M_2}\left(1 - \frac{\Delta r}{2r_i}\right) T_1(\tau) + \left(1 - \frac{2}{M_2}\right) T_2(\tau)$$

$$+ \frac{1}{M_2}\left(1 + \frac{\Delta r}{2r_i}\right) T_3(\tau) + \frac{Q(r,z)\Delta\tau_2}{\rho c_p} N(\tau,\Delta\tau_2). \quad (29)$$

This result is again in the finite difference form of Eq. (22), and the coefficients for use in Eq. (22) are tabulated in the fourth column of Table II.

6. The Finite Difference Equation for the Last Node Point of Annular Regions

The third and last node point ($i = 3$) of an annular thin-type region ($L > 1$) is treated as a boundary point with the usual Dusinberre[4] procedure. The method is outlined in Section I.D.3. The results are identical with those of Section I.D.3, except that within this type of region

$$\Delta r = \frac{1}{2}(R_0 - R_1).$$

The coefficients for use in the finite difference Eq. (22) are tabulated as the last column of Table II.

7. Summary

The finite difference equation for all node points in thin-type regions is given as Eq. (22). The coefficients for use with Eq. (22) depend on the location of the node point and are given by Table II.

The space-dependent heat-generation function $Q(r,z)$ is again separated into the product of functions as given by Eq. (20) of Section I.C.6.

E. The Finite Difference Equations for Flowing Coolant Regions

1. Introduction

The temperature of flowing materials is calculated at equally spaced node points along the centerline of the coolant region. A single node point per radial row is taken on the centerline, and a stationary material region must border on each boundary of the coolant region except when the coolant region is outermost.

The rate of increase of the temperature at any node point is equal to the net rate of heat input by convection plus the net heat transferred to the coolant from the adjoining stationary material regions. This fact is expressed by Eq. (5), which is now rewritten as

$$\frac{\partial T}{\partial \tau} = \frac{q_2(r,z,\tau)}{\rho c_p} - v\,\frac{\partial T}{\partial z}, \tag{30}$$

where

$T(z,\tau)$ = coolant temperature;

$v(z,\tau)$ = coolant velocity;

$q_2(r,z,\tau)$ = rate of heat addition to coolant per unit volume;

ρc_p = volumetric heat capacity of coolant.

2. Interior Node Points in a Coolant Channel

For any node point j in a coolant region, the time derivative in Eq. (30) is replaced by the forward difference quotient

$$\frac{\partial T}{\partial \tau} \rightarrow \frac{T_j(\tau + \Delta\tau_1) - T_j(\tau)}{\Delta\tau_1}. \tag{31}$$

For interior points not in a radial row on an end of the configuration, the space derivative is replaced by a central difference formula:

$$\frac{\partial T}{\partial z} = \frac{1}{2\Delta z}\left[T_{j+1}(\tau) - T_{j-1}(\tau)\right]. \tag{32}$$

The instantaneous rate of heat addition to the coolant (on the inner boundary) is

$$q_2 = h_{1,J} A_1 [T_{i-1,j}(\tau) - T_j(\tau)], \tag{33}$$

where

$h_{1,J}$ = film coefficient on the inner boundary of the coolant region;

A_1 = surface area at inner boundary ($A_1 = R_1 \Delta z$);

$T_{i-1,j}(\tau)$ = surface temperature of adjoining region.

A similar equation gives the rate of heat loss through the outer boundary of the coolant region. The volume of coolant, at any instant, in the coolant channel segment is

$$V_j = A_F \Delta Z,$$

where A_F is the coolant channel flow area. By substitutions of these into Eq. (30), we obtain

$$\frac{T_j(\tau+\Delta\tau_1) - T_j(\tau)}{\Delta\tau_1} = \frac{h_{1,j}R_1}{\rho c_p A_F}[T_{i-1,j}(\tau) - T_j(\tau)] + \frac{h_{2,j}R_0}{\rho c_p A_F}[T_{i+1,j}(\tau) - T_j(\tau)]$$

$$- \frac{v}{2\Delta z}[T_{j+1}(\tau) - T_{j-1}(\tau)]. \tag{34}$$

This equation is rearranged to yield

$$T_j(\tau+\Delta\tau_1) = \left(\frac{h_{1,j}R_1\Delta\tau_1}{\rho c_p A_F}\right) T_{i-1,j}(\tau) + \left[1 - \frac{h_{1,j}R_1\Delta\tau_1}{\rho c_p A_F} - \frac{h_{2,j}R_0\Delta\tau_1}{\rho c_p A_F}\right] T_j(\tau)$$

$$+\left(\frac{h_{2,j}R_0\Delta\tau_1}{\rho c_p A_F}\right) T_{i+1,j}(\tau) + \frac{v\Delta\tau_1}{2\Delta z} T_{j-1}(\tau) - \frac{v\Delta\tau_1}{2\Delta z} T_{j+1}(\tau). \tag{35}$$

The finite difference equation for all coolant node points is taken in the general form

$$T_{i,j}(\tau+\Delta\tau_1) = B_{i,j}T_{i-1,j}(\tau) + C_{i,j}T_{i,j}(\tau) + D_{i,j}T_{i+1,j}(\tau)$$

$$+E_{L,j}[T_{i,j-1}(\tau) - T_{i,j+1}(\tau)]. \tag{36}$$

By comparison of Eqs. (35) and (36), the coefficients for the general difference equation are established, and they are tabulated in the two columns of Table III. The first column gives the coefficients for the case of upflow in a coolant channel (flow from node point j = 1 to j = JMAX), and the second column considers the case of downflow (flow from node point j = JMAX to j = 1). This distinction is important only when there is more than one coolant channel with flows in opposite direction.

3. End Node Points in a Coolant Channel

The end node points j = 1 and j = JMAX of a coolant channel are treated in a manner very similar to the interior points except that the space derivative $\frac{\partial T}{\partial z}$ must be replaced by a different formula.

For the first node point, j = 1, the last term of Eq. (34) is replaced by

$$-(v/\Delta z)[T_{i,j+1}(\tau) - T_{i,j}(\tau)].$$

For the last node point, j = JMAX, the last term of Eq. (34) is replaced by

$$-(v/\Delta z)[T_{i,j}(\tau) - T_{i,j-1}(\tau)].$$

These substitutions modify the coefficients $C_{i,j}$ and $E_{L,j}$ for use with Eq. (36), and the changes are reflected in Table III.

Table III

FLOWING COOLANT REGION COEFFICIENTS FOR JMAX ≥ 3

Coefficient	J	$v_0 > 0$	$v_0 < 0$
$B_{I,J}$	1	0.0	$\frac{h_{1,L,J}\Delta\tau_1 R_{L-1}}{A_{F_L}\rho c_{L,J}}$
	$2 \leq J \leq$ JMAX-1	$\frac{h_{1,L,J}\Delta\tau_1 R_{L-1}}{A_{F_L}\rho c_{L,J}}$	$\frac{h_{1,L,J}\Delta\tau_1 R_{L-1}}{A_{F_L}\rho c_{L,J}}$
	JMAX	$\frac{h_{1,L,J}\Delta\tau_1 R_{L-1}}{A_{F_L}\rho c_{L,J}}$	0.0
$C_{I,J}$	1	0.0	$1 - B_{I,J} - D_{I,J} - \lvert E_{L,J}\rvert$
	$2 \leq J \leq$ JMAX-1	$1 - B_{I,J} - D_{I,J}$	$1 - B_{I,J} - D_{I,J}$
	JMAX	$1 - B_{I,J} - D_{I,J} - \lvert E_{L,J}\rvert$	0.0
$D_{I,J}$	1	0.0	$\frac{h_{2,L,J}\Delta\tau_1 R_L}{A_{F_L}\rho c_{L,J}}$
	$2 \leq J \leq$ JMAX-1	$\frac{h_{2,L,J}\Delta\tau_1 R_L}{A_{F_L}\rho c_{L,J}}$	$\frac{h_{2,L,J}\Delta\tau_1 R_L}{A_{F_L}\rho c_{L,J}}$
	JMAX	$\frac{h_{2,L,J}\Delta\tau_1 R_L}{A_{F_L}\rho c_{L,J}}$	0.0
$E_{L,J}$	1	0.0	$v_J(\tau)\Delta\tau_1/\ell_J$
	$2 \leq J \leq$ JMAX-1	$v_J(\tau)\Delta\tau_1/\ell_J$	$v_J(\tau)\Delta\tau_1/\ell_J$
	JMAX	$v_J(\tau)\Delta\tau_1/\ell_J$	0.0
$G_{I,J}$	All J	0.0	0.0

Note:

$$A_{F_L} = \frac{1}{2}\left[R_L^2 - R_{L-1}^2\right] \qquad \ell_J = \begin{cases} 2\Delta z \text{ for } 2 \leq J \leq \text{JMAX} - 1 \\ \Delta z \text{ for } J = 1 \text{ and } J = \text{JMAX} \end{cases}$$

$$\Delta z = \begin{cases} Z \text{ for JMAX} = 1 \\ Z/(\text{JMAX}-1) \text{ for JMAX} \geq 3 \end{cases}$$

For the case of upflow, Eq. (36) is not used for node point $j = 1$, and the term $T_{i,j+1}(\tau)$ is removed from Eq. (36) for node point $j = JMAX$. For the case of downflow, Eq. (36) is not used for node point $j = JMAX$ and the term $T_{i,j-1}(\tau)$ is removed from Eq. (36) for node point $j = 1$.

4. Special Case, Central Coolant Region

In case the first region ($L = 1$) of the configuration is a flowing coolant region, the equations derived above are still valid except that the inner film coefficient $h_{1,j}$ does not exist. Equation (35) can be reduced to the proper form by taking $h_{1,j} = 0$. The coefficients for use with the general Eq. (36) are then given as the first column of Table III for the case of upflow and as the second column for the case of downflow, with those coefficients that contain $h_{1,j}$ being replaced by zero.

5. Special Case, Outermost Coolant Region

In case the outermost region ($L = LMAX$) of the configuration is a flowing coolant region, the equations derived above are again valid except that an exterior boundary condition is applied to Eq. (34). Here it is assumed that the outer boundary of the configuration is perfectly insulated so that no heat is lost across this outer boundary. This boundary condition is satisfied by taking $h_{2,j} = 0$ in Eq. (35). The coefficients for use with the general Eq. (36) are then given as the first column of Table III for the case of upflow and as the second column for the case of downflow, with those coefficients that contain $h_{2,j}$ being replaced by zero.

II. DESCRIPTION OF THE ARGUS PROGRAM

A. Summary and Special Features

The ARGUS program (RE248) considers the specific types of regions in a particular problem and then selects the required difference equations from the set of Eqs. (7), (12), (22), and (36). The appropriate coefficients are chosen by the program from those tabulated in Tables I, II, and III. The coefficients B_{ij}, $C_{ij}, \ldots, G_{ij}$ are calculated from a minimum amount of given input information. Only a few parameters, certain material properties, and regional outer radii are required in the input for the calculations of the coefficients. The remainder of the input for ARGUS includes the time-dependent heat-generation function, the time-dependent coolant-velocity functions, and the initial temperatures.

After certain initial calculations and processing the input data, the program prints the input data, calculates initial values of the film coefficients, and prints them along with the initial temperatures.

Starting from the initial temperatures, which are input under one of three possible options (see Section II.B), the program uses the set of finite difference equations to calculate future temperatures $T_{i,j}(\tau+\Delta\tau_1)$ at all node points (i,j) of the configuration. The sweep over all node points follows a definite sequence which depends on the region-type parameter K(L). The program considers all coolant node points as a first step by means of Eq. (36) or a modification of it for end coolant node points. The program then sweeps over all interior node points of the thick-type regions by means of Eq. (7). As a third step, the program sweeps over all the thin regions (K = 3 and K = 4) by means of Eq. (22), and performs inner iterations on these node points if $\Delta\tau_1 > \Delta\tau_2$. Equations (7), (22), and (36) are all explicit in terms of $T_{i,j}(\tau+\Delta\tau_1)$. Finally, Eq. (12), implicit in terms of $T_{i,j}(\tau+\Delta\tau_1)$, is used for all boundary node points of thick-type regions. This procedure permits the program to determine all the implicit terms of Eq. (12) before they are needed during the calculation sequence. Whenever two thick-type regions are adjacent in the configuration, the program applies Eq. (12) to a pair of adjacent boundary node points, (i,j) and (i+1,j), and solves the two equations simultaneously to eliminate the remaining implicit terms.

1. Choice of Units

The input data can be given in any fully consistent set of units. Note that the coefficients $B_{i,j},\ldots,G_{i,j}$ and quantities such as M, N, W, and S (used in the calculation of the coefficients) are all dimensionless numbers. The responsibility for insuring that a self-consistent set of units is used in all input data lies entirely with the program user.

In this report, the Sample Problems No. 1 and No. 3 use input with units in the system (W, cm, sec, and °C). However, the input for Sample Problem No. 2 has units in the engineering system (Btu, ft, sec, and °F).

2. The Unit Time Increments

To ensure a stable solution of the finite difference equations in the ARGUS code, the following conditions must be met:

(1) $M_1 \geq 4$ for a thick stationary center region;

(2) $M_1 \geq 2$ for a noncentral thick stationary region;

(3) $C_{i,j} \geq 0$ for all thin-type stationary regions;

(4) $C_{i,j} \geq 0$ for all flowing coolant regions.

These criteria are satisfied automatically by ARGUS. If these conditions are not met following any coefficient calculations, the appropriate time interval $\Delta\tau$ is halved and the calculations are repeated. To satisfy conditions (1), (2), and (4), $\Delta\tau_1$ is halved as many times as needed, up to a maximum of four halvings of $\Delta\tau_1$. If $(\Delta\tau_1)_0$ is the input initial time increment, and the conditions (1), (2), and (4) are still not satisfied by using $\Delta\tau_1 = (\Delta\tau_1)_0/16$, then the problem is terminated. The auxiliary time increment $\Delta\tau_2$ must always be less than or equal to $\Delta\tau_1$; therefore, $\Delta\tau_2$ is also reduced whenever it exceeds $\Delta\tau_1$. To satisfy condition (3), $\Delta\tau_2$ is halved as many times as needed while leaving $\Delta\tau_1$ unchanged.

3. Integer Restrictions

The IBM-704 FORTRAN compiler limits integers to ≤ 32767. Therefore certain parameters such as NH, NPR, BETA, and GAMMA, which vary inversely with $\Delta\tau_1$ and are thus doubled when $\Delta\tau_1$ is halved, must be chosen small enough in the input to allow for up to four doublings without exceeding 32767. In other words, these parameters should be ≤ 2047 unless the value of $\Delta\tau_1$ which will satisfy the stability criteria is known in advance.

4. Restart Facilities

Provision has been made for taking periodic restart dumps of the problem data. Each dump is one binary record written on tape 9. If N = number of $\Delta\tau_1$ intervals since the last dump, then the next dump is taken when IMAX·JMAX·N is $\geq 30{,}000$. On the IBM-704, this is approximately every 5 min. The dumps are counted, and the dump number and the value of time (τ) are printed whenever a dump is made.

To restart a problem from a tape dump, the user must simply provide a title card, a problem number card, and a third card with the number of the desired dump (the parameter NDUMP). The rest of the input is omitted.

5. Material Numbers

Materials may be assigned any convenient numbers, different materials having different numbers. New numbers, from 1 to MMAX, will be assigned by the program, preserving the relative ordering within stationary regions first and then within flowing material regions. Material properties must then be specified in this new order in the input.

EXAMPLE:

Region Number (L)	Region Type (K)	Input M (2000 Series)	New M	Order of Input Sets (5000, 6000 Series Cards)	Input M
1	1	13	3	1	2
2	4	27	4	2	5
3	2	5	2	3	9
4	5	12	6	4	13
5	2	5	2	5	27
6	5	9	5	6	12
7	4	2	1		

6. Coolant Velocity Function

The flow is assumed to be turbulent; the coolant velocity is then a function of z and τ, but not of r.

The coolant velocities for a flowing material region (L) are computed for each $\Delta\tau_1$ interval from the following equation:

$$v_{L,j}(\tau) = v_{0_L} \left[\frac{\phi(\tau)+\phi(\tau+\Delta\tau_1)}{2}\right] \frac{\rho_{L,\text{inlet}}(\tau)}{\rho_{L,j}(\tau)},$$

where

v_{0_L} = velocity normalization factor for region L (input);

$\phi(\tau)$ = time-dependent coolant-velocity function (input);

$\rho_{L,\text{inlet}}(\tau)$ = density of material at inlet of region L,

$= \rho_0 + \rho_1 T_{i,\text{inlet}}(\tau) + \rho_2 T^2_{i,\text{inlet}}(\tau)$ (computed);

$\rho_{L,j}(\tau)$ = density of material at row j of region L,

$= \rho_0 + \rho_1 T_{i,j}(\tau) + \rho_2 T^2_{i,j}(\tau)$ (computed).

At a given instant of time (τ), this equation gives a constant mass-flow rate throughout the coolant region L.

7. Film Coefficient Equations

Film coefficients h at the boundaries of flowing regions are calculated by the program from one of the following two sets of equations, depending on IH:

$$IH = 1 \begin{cases} \text{phase 1:} & h = \dfrac{k}{De}[H_1(Re)^{a_1}(Pr)^{b_1} + H_2] \\ \text{phase 2:} & h = \dfrac{k}{De}[H_3(Re)^{a_2}(Pr)^{b_2} + H_4], \\ \text{phase 3:} & h = H_5(\Delta T)^{a_3} + H_6 \end{cases}$$

$$IH = 3 \begin{cases} \text{phase 1:} & h = H_1(\bar{T}_1^4 - \bar{T}_2^4)/(\bar{T}_1 - \bar{T}_2) \\ \text{phase 2:} & h = H_2(\bar{T}_1^4 - \bar{T}_2^4)/(\bar{T}_1 - \bar{T}_2), \\ \text{phase 3:} & h = H_3(\bar{T}_1^4 - \bar{T}_2^4)/(\bar{T}_1 - \bar{T}_2) \end{cases}$$

where

$H_1 \ldots . H_6$, a_1, a_2, a_3, b_1 and b_2 are input;

k = thermal conductivity;

De = equivalent diameter (input);

Re = Reynolds number = $|v| De/\nu$;

v = velocity;

ν = kinematic viscosity;

Pr = Prandtl number = $\nu \rho c_p / k$;

ρc_p = volumetric heat capacity;

$\Delta T = T_1 - T_2$;

T_1 = surface temperature;

T_2 = fluid temperature.

$\overline{T}$ = absolute temperature = T(°C) + 273.2

Note: Temperatures must be in °C if IH = 3.

If some other set of film coefficient equations is desired, one of the above sets can be replaced fairly easily by changing the subprogram HCOMP.

8. Stationary Material Phases

Stationary material phase changes are handled in a manner identical with that described on p. 23 of Reference 1, with the added features of allowing up to 10 phases and allowing cooling through phases. In ARGUS, for increasing temperature, $\Delta T_{\alpha\beta} = (\rho \Delta H)_{\alpha\beta} / (\rho c_p)_{\alpha}$, and for decreasing temperature $\Delta T_{\beta\alpha} = (\rho \Delta H)_{\alpha\beta} / (\rho c_p)_{\beta}$.

9. Flowing Material Phases

Let Ψ_s be the saturation temperature (input) for the coolant material, T_1 the surface temperature of the coolant channel, and T_2 the temperature at the coolant node point. Then the coolant material phase, relative to that channel boundary, is determined as follows:

$$\left.\begin{array}{l} T_1 < \Psi_s \\ T_2 < \Psi_s \end{array}\right\} \text{phase 1 (all liquid);}$$

$$\left.\begin{array}{l} T_1 \geq \Psi_s \\ T_2 < \Psi_s \end{array}\right\} \text{phase 2 (surface boiling);}$$

$$T_2 \geq \Psi_s \} \text{ phase 3 (bulk boiling).}$$

Whenever a calculated value of T_2 exceeds Ψ_s, it is set back equal to Ψ_s. No provision is included in the program for cooling down after bulk boiling is achieved.

B. Description of Input for ARGUS

A detailed description of the input data required by the ARGUS program and the format in which it must be presented is given here.

The lines (or cards) of input are numbered to simplify the description of input. These card numbers may be written in spaces 73-80 if desired, since these columns are not read.

Except for the title card and the problem number, all the input data are supplied by two formats, denoted by I6 or E 12.5 under each parameter in the description of the input.

Parameters with format I6 are integers and must be written without a decimal point. Six spaces (called a field) are allocated to each integer. Blank spaces are interpreted as zero, so the integer must be written at the extreme right of the field.

Parameters with format E 12.5 are decimal numbers. A twelve-space field is allocated for each decimal number. A decimal point is required, but the decimal point and digits may be placed anywhere in the twelve-space field. Alternatively, the number may be written as the product of 10^n and a decimal by writing the decimal, including the decimal point, in any of the first nine spaces, the sign of the exponent in the tenth space, and the exponent n in the eleventh and twelfth space of the field ($-38 < n < 38$).

Card
No.

1100 Title card, with 1 in column 1 and any information in columns 2-72 composed of letters, numbers, and the symbols + - . / ( ) , = *.

1200 Problem number, including a decimal point in column 4, written in columns 1-9. Format F9.5.

1300	Dump no.	IMAX	JMAX	LMAX	MMAX	NPMAX	NH_1	NH_2	NH_3	NPR
	I6	I6	I6	I6	I6	I6	I6	I6	I6	I6

Dump no.: The number of the tape dump to be used to restart the problem if it is a continuation of a previous problem. The dump no. is 0 for a new problem.

Card
No.

IMAX: Number of node points per radial row ($3 \leq IMAX \leq 100$). Note there is one point on each side of every boundary, infinitesimally close to the boundary, except in coolant regions, which have only one point. The center line is denoted by I = 1.

JMAX: Number of radial rows of node points ($JMAX \leq 16$). For $3 \leq JMAX \leq 16$, J = 1 and J = JMAX denote the ends of the configuration. JMAX = 2 is not permitted.

LMAX: Number of regions ($1 \leq LMAX \leq 25$). L = region number, L = 1, 2, 3, ... LMAX. The center region is denoted by L = 1.

MMAX: Number of materials ($1 \leq MMAX \leq 10$). M = material number, M = 1,2, ... MMAX.

NPMAX: Number of temperature ranges for which material properties of stationary materials are specified ($1 \leq NPMAX \leq 10$).

NH_1: Initial number of time intervals between h (heat transfer film coefficient) computations for first (liquid) coolant phase.

NH_2: Initial number of time intervals between h computations for second (surface boiling) coolant phase.

NH_3: Initial number of time intervals between h computations for third (bulk boiling) coolant phase.

NPR: Number of time intervals between print-outs.

1400	Z	τ_f	$\Delta\tau$	g	$\epsilon_d(1)$	$\epsilon_d(2)$
	E 12.5	E 12.5	E 12.5	E 12.5	E 12.5	E 12.5
1500	$\epsilon_d(3)$	$\epsilon_h(1)$	$\epsilon_h(2)$	$\epsilon_h(3)$		
	E 12.5	E 12.5	E 12.5	E 12.5		

Z: Axial length of the configuration.

τ_f: Termination time.

Card
No.

$\Delta\tau$: Initial unit time interval. (Specify a time increment of moderate size and allow the computer to reduce it if necessary.)

g: Acceleration due to gravity.

ϵ_d: Minimum fractional change in h before doubling NH, one value for each coolant phase.

ϵ_h: Maximum fractional change in h before halving NH, one value for each coolant phase.

2011 (region no.) — NI_1 M_1 K_1 R_1 — I6 I6 I6 E 12.5

NI_1: Number of radial node points in region 1.

M_1: Number of material in region 1. (Materials are numbered in the order in which material properties are specified on 5000 and 6000 cards. See Summary and Special Features for details.)

K_1: Parameter to specify type of region:
K = 1 for thick stationary region with heat generation;
K = 2 for thick stationary region without heat generation;
K = 3 for thin stationary region with heat generation;
K = 4 for thin stationary region without heat generation;
K = 5 for flowing coolant.
If K = 1 or K = 2 is specified instead of K = 3 or K = 4 for thin regions, the results will be slightly less accurate, but the computation time will usually be less.

R_1: Outer radius of region 1.

2021 As above for regions 2 through LMAX.

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2(LMAX)1

Card No.	
2500	U(1) U(2) U(3)---- U(n)
	E 12.5 E 12.5 E 12.5 E 12.5

U(n): Surface contact conductance on outer boundary of the n'th stationary region (type 1, 2, 3, or 4). There are as many cards of this number as needed to specify a U for each stationary region (6 values per card). This value is not used to calculate heat transfer from a region bounded by a flowing coolant, but a dummy value, e.g., 1.0, must be specified for such regions also. U = 0 for last region if it contains a stationary material. If a type 3 or 4 region is on either side of an interface, $U < 100{,}000$ Btu/ft^2-hr-°F or $U < 57$ W/°C-cm^2 is recommended to avoid excessive computation time. If a type 1 or 2 region is on either side of an interface, inaccuracies due to round-off errors will occur for $U > 10^6$.

3011 (region no.) $\mu(1)$ $\mu(2)\ldots\mu(NI_1)$

E 12.5 E 12.5 E 12.5

$\mu(r)$: Radially dependent power factors for the first region with heat generation. [Power = $q_0\ \mu(r)\zeta(z)n(\tau)$.] There are as many cards of this number as needed to specify a μ at each radial node point in region 1 (6 values per card).

3012 $\zeta(1)$ $\zeta(2)$ $\zeta(3)\ldots\zeta(JMAX)$ q_0

E 12.5 E 12.5 E 12.5 E 12.5 E 12.5

$\zeta(J)$: Axially dependent power factors for the first region with heat generation.

q_0: Power normalization coefficient for the first region with heat generation. There are as many cards of this number as needed to specify a ζ at each axial node point and a q_0 for the region (6 values per card).

3021, 3022, 3031, 3032, ⋮ — As above for each region with heat generation, in order from the innermost to the outermost region.

NOTE: If there are no type 1 or type 3 regions, omit the 3000 and 7000 series cards.

Card
No.

If all regions are stationary regions, omit 4000 series, 6000 series, and 8000 series cards.

4011 IPT ICS IH

I6 I6 I6

IPT: The number of the coolant velocity function [$\phi(\tau)$ set] to be used for the first flowing coolant region. The velocity functions, specified on 8000 series cards, are numbered consecutively beginning with No. 1.

ICS: Parameter to designate source of coolant. ICS = 0 if coolant is supplied (at constant inlet temperature) from an outside source to this region; ICS = the number of the region from which the coolant is being supplied if the outlet of another region is to be supplied to this region.

IH: Parameter to select a set of equations for calculation of film coefficients at the boundaries of the first flowing coolant region.

IH = 1 for forced convection, and

$$h = \frac{k}{De}[H_1(Re)^{a_1}(Pr)^{b_1} + H_2] \text{ for phase 1;}$$

$$h = \frac{k}{De}[H_3(Re)^{a_2}(Pr)^{b_2} + H_4] \text{ for phase 2;}$$

$$h = H_5(\Delta T)^{a_3} + H_6 \text{ for phase 3;}$$

IH = 3 for radiant heat transfer, and

$$h = H_1(\overline{T}_1^4 - \overline{T}_2^4)/(\overline{T}_1 - \overline{T}_2) \text{ for phase 1;}$$

$$h = H_2(\overline{T}_1^4 - \overline{T}_2^4)/(\overline{T}_1 - \overline{T}_2) \text{ for phase 2;}$$

$$h = H_3(\overline{T}_1^4 - \overline{T}_2^4)/(\overline{T}_1 - \overline{T}_2) \text{ for phase 3;}$$

where

Re = Reynolds No.;

Pr = Prandtl No.;

$\overline{T}_1$ = T_1 (surface temperature) + 273.2;

$\overline{T}_2$ = T_2 (central fluid temperature) + 273.2;

$\Delta T = T_1 - T_2$;

k = thermal conductivity of coolant.
(See Summary and Special Features for details.)

Card No.						
4012	v_0	Ψ_0	Ψ_s	De		
	E 12.5	E 12.5	E 12.5	E 12.5		

v_0: Velocity normalization factor for the first flowing coolant region. (v_0 is negative for flow from J = JMAX to J = 1). See Summary and Special Features for details.

Ψ_0: Inlet coolant temperature for the first flowing coolant region (Ψ_0 = 0.0 if ICS > 0).

Ψ_s: Coolant saturation temperature for the first region. The coolant enters phase 2 when the adjoining surface exceeds Ψ_s. The coolant enters phase 3 when the temperature of its central node point exceeds Ψ_s.

De: Equivalent heat transfer diameter for the first coolant region, for use in film coefficient equations.

4013	a_1	a_2	a_3	b_1	b_2	
	E 12.5	E 12.5	E 12.5	E 12.5	E 12.5	

These are the exponents in the film coefficient equations.

4014	H_1	H_2	H_3	H_4	H_5	H_6
	E 12.5	E 12.5	E 12.5	E 12.5	E 12.5	E 12.5

These are the coefficients in the film coefficient equations.

4021
4022
4023
4024
4031
.
.
.
} As above for each flowing coolant region.

5011 (material no.)	k_1	$k_2 \ldots k_{NPMAX}$
	E 12.5	E 12.5 E 12.5

Thermal conductivity of stationary material number 1, in the successive temperature ranges specified on the 5013 cards. Give NPMAX values, 6 per card.

Card No.	
5012	ρc_1 $\rho c_2 \ldots \rho c_{NPMAX}$ E 12.5 E 12.5 E 12.5 Specific heat times initial density of stationary material 1. Give NPMAX values, 6 per card.
5013	TT_1 $TT_2 \ldots TT_{NPMAX-1}$ E 12.5 E 12.5 E 12.5 Transformation temperatures of stationary material number 1. Give NPMAX-1 values, 6 per card.
5014	$\rho \Delta H_1$ $\rho \Delta H_2 \ldots \rho \Delta H_{NPMAX-1}$ E 12.5 E 12.5 E 12.5 Initial density times heats of transformation for stationary material 1 at the temperatures specified on the 5013 cards. Give NPMAX-1 values, 6 per card. (If NPMAX = 1, omit cards No. 5013 and 5014.) NOTE: For stationary materials ρ denotes the initial density, i.e., since the dimensions are fixed, ρ must also be fixed.
5021 5022 5023 5024 5031 . . .	As above for each stationary material.

6011	k_0 k_1 k_2 E 12.5 E 12.5 E 12.5 Parameters in thermal conductivity equation for the first flowing coolant material: $k = k_0 + k_1 T + k_2 T^2$.
6012	ρc_0 ρc_1 ρc_2 ρc_p E 12.5 E 12.5 E 12.5 E 12.5 Parameters in volumetric heat capacity equation for phases 1 and 2 of the first flowing coolant material: $\rho c = \rho c_0 + \rho c_1 T + \rho c_2 T^2$.

Card No.

ρc_p: Density times specific heat for phase 3 (bulk boiling) of the first flowing coolant material.

6013 ν_0 ν_1 ν_2

E 12.5 E 12.5 E 12.5

Parameters in kinematic viscosity equation for phases 1 and 2 of the first flowing coolant material: $\nu = \nu_0 + \nu_1 T + \nu_2 T^2$.

6014 ρ_0 ρ_1 ρ_2

E 12.5 E 12.5 E 12.5

Parameters in density equation for phases 1 and 2 of the first flowing coolant material: $\rho = \rho_0 + \rho_1 T + \rho_2 T^2$.

6021
6022
6023
6024
6031
.
.
.

} As above for each flowing coolant material.

7001 NN $N\beta$ P

I6 I6 E 12.5

NN: Number of values of $n(\tau)$ to be specified on 7002 cards ($2 \leq NN \leq 500$). If power is to increase exponentially, n(0) is assumed to be 1.0; set NN = 0 and omit 7002, 7003, and 7004 cards. (If there are no type 1 or 3 regions, omit 7001, 7002, 7003, and 7004 cards.)

$N\beta$: Number of values of β to be specified on 7003 cards ($1 \leq N\beta \leq 10$).

P: Period of exponential function if NN = 0. (If NN $\neq$ 0, leave blank.)

Card No.		
7002	$n(\tau)_1$ $n(\tau)_2$ $n(\tau)_3 \ldots n(\tau)_{NN}$ E 12.5 E 12.5 E 12.5 E 12.5	
	$n(\tau)$:	Pointwise values of the time-dependent function governing heat-generation rate. Give NN values of $n(\tau)$, 6 per card, where $n(\tau)_1 \equiv n(0)$.
7003	β_1 β_2 $\beta_3 \ldots \beta_{N\beta}$ E 12.5 E 12.5 E 12.5 E 12.5	
	β_i:	Number of time intervals $(\Delta\tau)$ between specified values of $n(\tau)$ for $\tau_{n_{i-1}} < \tau < \tau_{n_i}$. Give $N\beta$ values, 6 per card.
7004	τ_{n_1} τ_{n_2} $\tau_{n_3} \cdots \tau_{N\beta-1}$ E 12.5 E 12.5 E 12.5 E 12.5	
	τ_{n_i}:	Value of τ at which β_{i+1} replaces β_i. Give $N\beta$ - 1 values, 6 per card. If $N\beta = 1$, omit this card.

Card No.		
8000	NPT I6	Number of time-dependent coolant-velocity functions [$\phi(\tau)$ sets] to be specified on 8000 series cards ($1 \leq NPT \leq 4$).
8101	NPHI $N\gamma$ I6 I6	
	NPHI:	Number of values of the first time-dependent velocity function, $\phi(\tau)$, to be specified on the 8102 cards ($2 \leq NPHI \leq 250$).
	$N\gamma$:	Number of values of γ to be specified for the first $\phi(\tau)$ set ($1 \leq N\gamma \leq 10$).
8102	$\phi(\tau)_1$ $\phi(\tau)_2$ $\phi(\tau)_3 \ldots \phi(\tau)_{NPHI}$ E 12.5 E 12.5 E 12.5 E 12.5	
	$\phi(\tau)_i$	Pointwise values of the first time-dependent coolant-velocity function. See Summary and Special Features for details. Give NPHI values, 6 per card.

Card No.

8103 γ_1 γ_2 $\gamma_3 \ldots \gamma_{N\gamma}$

E 12.5 E 12.5 E 12.5 E 12.5

γ_i: Number of $\Delta\tau$ intervals between the given input values of $\phi(\tau)$ for $\tau_{p_{i-1}} < \tau < \tau_{p_i}$. Give $N\gamma$ values, 6 per card.

8104 τ_{p_1} τ_{p_2} τ_{p_3} $\tau_{p_{N\gamma-1}}$

E 12.5 E 12.5 E 12.5 E 12.5

The values of τ at which γ_{i+1} replaces γ_i. If $N\gamma = 1$ omit this card. Give $N\gamma - 1$ values of τ_p, 6 per card.

8201
8203
8204
8301
.
.
.
8(NPT)04

As above for each time-dependent coolant-velocity function.

9000 ITEMP

I6

Parameter to designate form of initial temperature input: = -1 if the temperature is to be specified at each mesh point; = 0 if the temperature is to be specified for each region; = tape record number if the temperature is to be read from binary tape. In this case, omit all other 9000 series cards.

9001 (If ITEMP = 0)

T_1 $T_2 \ldots T_{LMAX}$

E 12.5 E 12.5 E 12.5

Initial temperature of each region beginning at the center. Give LMAX values, 6 per card.

Card No.	
9001	(If ITEMP = -1) T(1,1) T(1,2). .T(1,JMAX) E 12.5 E 12.5 E 12.5 Initial temperature of each node point on the center line. Give JMAX values, 6 per card.
9002 9003 . . . 9 (IMAX)	As above for each axial column of node points.

704 INPUT DATA
FORM I

COST CODE __________

PROGRAM 1089/RE248 PROBLEM Sample Input ORIGINATOR J. Heestand DATE 7/9/63 PAGE 1 OF 2

1 Title card						1100
Problem #						1200
Dump # / IMAX	JMAX / LMAX	MMAX / NPMAX	NH_1 / NH_2	NH_3 / NPR		1300
Z	τ_f	$\Delta\tau$	g	$\epsilon_d(1)$	$\epsilon_d(2)$	1400
$\epsilon_d(3)$	$\epsilon_h(1)$	$\epsilon_h(2)$	$\epsilon_h(3)$			1500
NI_L / M_L	K_L / R_L					20L1
U(1)	U(2)	. . . . .	U(n)			2500
$\mu(1)$	$\mu(2)$	. . . . .	$\mu(NI_L)$			30L1
$\zeta(1)$	$\zeta(2)$	. . . . .	$\zeta(JMAX)$	q_o		30L2
IPT / ICS	IH					40L1
V_o	ψ_o	ψ_s	De			40L2
a_1	a_2	a_3	b_1	b_2		40L3
H_1	H_2	H_3	H_4	H_5	H_6	40L4
k_1	k_2	. . . . .	k_{NPMAX}			50M1
ρc_1	ρc_2	. . . . .	ρc_{NPMAX}			50M2
TT_1	TT_2	. . . . .	TT_{NPMAX}			50M3
$\rho \Delta H_1$	$\rho \Delta H_2$	. . . . .	$\rho \Delta H_{NPMAX-1}$			50M4
k_o	k_1	k_2				60M1
ρc_o	ρc_1	ρc_2	ρc_p			60M2
ν_o	ν_1	ν_2				60M3

AMD-8 (9-60)

704 INPUT DATA
FORM I

COST CODE ____________

PROGRAM 1089/RE248 PROBLEM Sample Input ORIGINATOR J. Heestand DATE 7/9/63 PAGE 2 OF 2

1–10	11–20	21–30	31–40	41–50	51–60	61–72	73–80
ρ_o	ρ_1	ρ_2					60M4
NN $N\beta$	P						7001
$n(\tau)_1$	$n(\tau)_2$	. . . . .	$n(\tau)_{NN}$				7002
β_1	β_2	. . . . .	$\beta_{N\beta}$				7003
τ_{n_1}	τ_{n_2}	. . . . .	$\tau_{n_{N\beta-1}}$				7004
NRT							8000
NPHI $N\gamma$							8φ01
$\phi(\tau)_1$	$\phi(\tau)_2$	. . . . .	$\phi(\tau)_{NPHI}$				8φ02
γ_1	γ_2	. . . . .	$\gamma_{N\gamma}$				8φ03
τ_{p_1}	τ_{p_2}	. . . . .	$\tau_{p_{N\gamma-1}}$				8φ04
ITEMP							9000
T_1	T_2	. . . . .	T_{LMAX}	if ITEMP = 0			9001
T(I, 1)	T(I, 2)	. . . . .	T(I, JMAX)	if ITEMP = -1			900I

AMD-8 (9-60)

C. Operating Instructions

1089/RE248
704 PROGRAM

GENERAL OPERATING INSTRUCTIONS

Programmer	Date
J. Heestand	3/3/63

	USED	NOT USED
DRUM:		X
UF SWITCH:	X	

READER: 72 x 72 board

PUNCH: not used

PRINTER: not used

SENSE SWITCH SETTINGS: 1, 2, 3, 4, 5 - not used.

6 { up - normal.
down - temperatures and coefficients are output at the end of each $\Delta\tau(1)$ time interval.

TAPES:
Input: 1 - FORTRAN library
7 - input data
9 - additional input (if restart, only)
Scratch: 10 - temperature input (if ITEMP > 0, only)

Output:
- Binary - 9 (periodic restart dumps)
- Printed - 6
- Punched - none

To Be Saved: 9 (if used); 10 (if used)

Rewound by Program Prior to Calculation none After none

Manual EOF Needed 6

TIME BEFORE OUTPUT: ≈ 0

NORMAL RUNNING TIME: Depends on IMAX, JMAX, τ_f, $\Delta\tau(1)$, and $\Delta\tau(2)$. Use $\frac{(\text{IMAX}\cdot\text{JMAX}\cdot\tau_f)}{6{,}000\cdot\Delta\tau(1)}$ minutes as an estimate.

RUNNING PROCEDURE: *(Indicate both regular and restart)*

1. Mount and READY tapes 1, 6, 7.
2. Mount and READY tapes 9, 10 if needed.
3. Set UF switch on.
4. Set SENSE SWITCH 6.
5. READY binary program deck in card reader.
6. CLEAR and LOAD CARDS.
7. Error stops:record console, dump core if requested, remove problem.
8. End of problem (HPR 0,1): save tape 9 for future restarts, if used - No EOF; save tape 10 if used - No EOF.

STOPS (OCTAL):

FORTRAN error stops: see step 7.

Address of SR	Subroutine	Interpretation	Action
111	MAIN CODE	"impossible"	See step 7.
222	PRELIM	"	"
333	ITERAT	"	"
444	POST	"	"
555	INPRNT	"	"
777	TEMPRT	"	"
211	HCOMP	"	"
311	COCOMP	"	"
511	PHASE	"	"
1111	MAINCODE	input error	"
2111	HCOMP	"	"

D. Output Description

1. The problem title, program identification, problem number, and page number are printed at the top of each page of output.

2. If the problem is being restarted, the restart dump number and τ are printed.

3. All problem input is printed with labels.

4. Labelled values of τ, $\Delta\tau(1)$, $\Delta\tau(2)$, the film coefficients H(B,L,J), and the latest node point temperatures TDT(I,J) are printed at specified time intervals [= NPR $\Delta\tau_0(1)$].

5. When the product of IMAX, JMAX, and the number of $\Delta\tau(1)$ intervals since the last dump is greater than or equal to 30000, the problem data are dumped onto tape 9 to facilitate problem interruption and restart. The dump number and τ are printed. This occurs approximately every 5 min on an IBM-704 computer.

6. When a problem is terminated, τ, $\Delta\tau(1)$, $\Delta\tau(2)$, H(B,L,J), TDT(I,J), plus the difference equation coefficients B, C, D, E, and G are printed, followed by a comment indicating the reason for termination.

7. If SENSE SWITCH 6 is down, τ, $\Delta\tau(1)$, $\Delta\tau(2)$, H(B,L,J), TDT(I,J), B, C, D, E, and G are printed at the end of each $\Delta\tau(1)$ time interval.

E. Sample Problems

1. Sample Problem No. 1
(A Comparison with the Exact Analytic Solution)

The object of the first sample problem is to compare the results of an ARGUS calculation with the exact analytic solution for a one-region problem with constant material properties. This is usually referred to as the convergence of the solution by the finite difference method.

The model chosen for problem number 36.90003 is an infinite cylinder, with space- and time-independent heat generation, losing heat by convection to a constant-temperature sink. The input data for these calculations are given in Table IV.

For the ARGUS problem, the central pin of 2.0-cm diameter is represented by a thick-type region (K = 1), and the surrounding medium is represented by an annulus of flowing coolant (K = 5) with an outer diameter of 4.0 cm. The environment is thus simulated with a fictitious flowing material having zero velocity. The central pin is assumed to be infinitely long so that axial heat conduction is negligible and a single radial row of mesh points (JMAX = 1) is sufficient. This choice automatically holds the environment temperature (heat sink) constant.

Table IV

INPUT DATA FOR SAMPLE PROBLEM NO. 1

Heat Generation Q_0	1000.0 W/cm^3
Outer Radius R_{max}	1.00 cm
Thermal Conductivity of Rod, K	0.25 W/cm-°C
Heat Capacity of Rod, RHO*CP	2.00 $W\text{-}sec/cm^3$
Film Coefficient on Boundary, H	25.0 $W/cm^2\text{-}°C$
Final Time τ_f	2.00 sec
Initial Temperature T_0	100.0°C
Environment Temperature T_e	100.0°C

The analytic solution for this problem is given in Reference 5, p. 205, and the temperatures are given by the infinite series

$$T(r,\tau) = T_0 + \frac{Q_0 R^2}{4K}\left[1 - \left(\frac{r}{R}\right)^2 - \frac{2}{Rh}\right] - \frac{2hQ_0}{RK}\sum_{n=1}^{\infty} \frac{\exp(-\kappa\tau\alpha_n^2)J_0(r\alpha_n)}{\alpha_n^2(h^2+\alpha_n^2)J_0(R\alpha_n)}, \qquad (1)$$

where

$T(r,\tau)$ = temperature at radius r and time τ;

T_0 = initial temperature, independent of radius;

Q_0 = rate of heat generation per unit volume;

R = outer radius of cylindrical rod;

K = thermal conductivity of rod material;

h = boundary film coefficient/thermal conductivity;

κ = thermal diffusivity of rod material = $K/\rho c_p$;

and the α_n are the positive eigenvalues of $\alpha J_1(R\alpha) - hJ_0(R\alpha) = 0$.

The solution of this problem (Eq. 1) also requires that the environment temperature T_e be equal to the pin initial temperature T_0 for all time t, and note that the internal heat generation Q_0 must be independent of both radial position and time.

A FORTRAN II code (1528/RE) was written to perform the calculations necessary to obtain the eigenvalues and to evaluate the infinite series involved in the calculation of each temperature.

A single problem was then run on the Argonne IBM-704 with each of the three codes, ARGUS, CYCLOPS (Reference 1), and 1528/RE, for the analytic solution. The results of these calculations are presented in Table V. This table gives the temperatures calculated by each of the three codes for three radial positions in the cylinder at successive values of time. Upon comparing the results from the CYCLOPS (RE 147) calculations, the ARGUS calculations, and the analytical solution, the corresponding temperatures are found to agree within 2° after a temperature rise of over 700°. Note that for this type of problem, the use of the ARGUS code will give a substantial saving of machine computation time compared with the use of the CYCLOPS code.

The film coefficient used in this problem (h = 25.0) is sufficiently large to limit the size of the time increment for a CYCLOPS problem, which in this case arrived at a working value of $\Delta\tau = 0.001$ sec. However, the ARGUS program with the BACK method for treating the convective boundary condition will give a stable solution with a unit time increment which is independent of the size of the film coefficient on the boundary. In this case the ARGUS problem ran successfully with the assumed initial values of $\Delta\tau_1 = 0.004$ sec.

The complete set of input sheets and problem output sheets from the computer are given on the pages following Table V. The ARGUS problem required approximately 2 min of machine time on the Argonne IBM-704 with a monitor system.

Table V

COMPARISON OF RESULTS
SAMPLE PROBLEM NO. 1

ARGUS = RE248 ($\Delta \tau$ = 0.004)

CYCLOPS = RE147 ($\Delta \tau$ = 0.001)*

1528/RE - Analytic Solution

Film Coefficient, h = 25.0

Time (sec)	r = 0 (centerline)	r = 0.6	r = 1.0 cm (outer radius)	Code
0.10	150.00	149.91	105.67	ARGUS
	150.00	149.86	104.51	CYCLOPS
	150.00	149.88	104.46	1528/RE
0.50	348.66	315.87	110.88	ARGUS
	348.53	315.25	109.70	CYCLOPS
	348.61	315.42	109.68	1528/RE
1.00	567.36	452.81	114.19	ARGUS
	566.73	451.89	113.00	CYCLOPS
	567.01	452.10	112.99	1528/RE
1.50	730.73	545.45	116.32	ARGUS
	729.76	544.38	115.12	CYCLOPS
	730.13	544.59	115.12	1528/RE
2.00	846.93	609.92	117.78	ARGUS
	845.79	608.75	116.58	CYCLOPS
	846.15	608.95	116.58	1528/RE

*This time interval was the largest permitted by CYCLOPS to insure a stable solution.

704 INPUT DATA

FORM I

COST CODE 46351-01

PROGRAM ARGUS RE 248 PROBLEM 36.90003 ORIGINATOR Daniel F. Schoeberle DATE 8/15/62 PAGE 1 OF 2

1 ARGUS TEST	PROB. ONE R	EGION OF FUE	L, INFINITE S	INK, H = 25.	0	1100
36.90003						1200
0 22	1 2	2 1	32 32	32 25		1300
1.0	2.0	0.004	980.0	0.005	0.005	1400
0.005	0.02	0.02	0.02			1500
21 1	1 1.	00				2011
1 2	5 2.	00				2021
1.00						2500
1.0	1.0	1.0	1.0	1.0	1.0	3011 A
1.0	1.0	1.0	1.0	1.0	1.0	3011 B
1.0	1.0	1.0	1.0	1.0	1.0	3011 C
1.0	1.0	1.0				3011 D
1.0	1.000+03					3012
1 0	1					4011
0.0	100.0	900.0	1.00			4012
1.0	1.0	1.0	1.0	1.0		4013
0.0	25.0	0.0	25.0	0.0	25.0	4014

AMD-8 (9-60)

704 INPUT DATA
FORM I

COST CODE 46351-01

PROGRAM ARGUS RE 248 PROBLEM 36.90003 ORIGINATOR Daniel F. Schoeberle DATE 8/15/62 PAGE 2 OF 2

1–12	13–24	25–36	37–48	49–60	61–72	73–80
0.25						5011
2.00						5012
1.00	0.0	0.0				6011
1.00	0.0	0.0	9.999999+29			6012
1.00	0.0	0.0				6013
1.00	0.0	0.0				6014
4 1						7001
1.0	1.0	1.0	1.0			7002
500.0						7003
1						8000
4 1						8101
1.0	1.0	1.0	1.0			8102
500.0						8103
0						9000
100.0	100.0					9001

AMD-8 (9-60)

```
ARGUS TEST PROB. ONE REGION OF FUEL,INFINITE SINK, H = 25.0                    1089/RE248  PROB.NO. 36.90003  PAGE   1

INPUT

 GENERAL PROBLEM DATA
  IMAX= 22      JMAX= 1  LMAX= 2          MMAX= 2  NPMAX= 1      NH(1)= 32  NH(2)= 32    NH(3)= 32  NPR= 25
  Z=         1.00000E 00  FINAL TAU= 2.00000E 00  DELTA TAU= 4.00000E-03  G=          9.80000E 02  EPSD(1)=    5.00000E-03
  EPSD(2)=   5.00000E-03  EPSD(3)=   5.00000E-03  EPSH(1)=   2.00000E-02  EPSH(2)=    2.00000E-02  EPSH(3)=    2.00000E-02

  NI(L)= 21   1
  M(L)=   1   2
  K(L)=   1   5

  R(L)
1.00000E 00 2.00000E 00

  U(L)
1.00000E 00 0.


 POWER DISTRIBUTION DATA

  MU(I)  (READ ACROSS)
1.00000E 00 1.00000E 00 1.00000E 00 1.00000E 00 1.00000E 00 1.00000E 00 1.00000E 00 1.00000E 00 1.00000E 00 1.00000E 00
1.00000E 00 1.00000E 00 1.00000E 00 1.00000E 00 1.00000E 00 1.00000E 00 1.00000E 00 1.00000E 00 1.00000E 00 1.00000E 00
1.00000E 00 0.

  ZETA(L,J)  (READ ACROSS)
   L= 1
1.00000E 00

  QO(L)  (READ ACROSS)
1.00000E 03 0.


 FLOWING COOLANT REGION DATA  (READ DOWN)

  L  IPT  ICS  IH          VO          PSIO        PSIS         DE          A1          A2          A3
  2   1    0    1     0.           1.00000E 02 9.00000E 02 1.00000E 00 1.00000E 00 1.00000E 00 1.00000E 00

    B1          B2          H1          H2          H3          H4          H5          H6
1.00000E 00 1.00000E 00 0.          2.50000E 01 0.          2.50000E 01 0.          2.50000E 01


 MATERIAL PROPERTIES

  K  (ONE ROW FOR EACH MATERIAL)
2.50000E-01
1.00000E 00 0.          0.

  RHO*C  (ONE ROW FOR EACH MATERIAL)
2.00000E 00
1.00000E 00 0.          0.          10.00000E 29

  TT OR NU  (ONE ROW FOR EACH MATERIAL)
1.00000E 00 0.          0.
```

```
 ARGUS TEST PROB. ONE REGION OF FUEL,INFINITE SINK, H = 25.0                1089/RE248  PROB.NO. 36.90003  PAGE   2

  RHO*DH OR RHO  (ONE ROW FOR EACH MATERIAL)
1.00000E 00 0.          0.


 N(TAU) DATA

  NN=  4   NBETA= 1  P=-0.

  N(TAU)  (READ ACROSS)
1.00000E 00 1.00000E 00 1.00000E 00 1.00000E 00

  BETA
5.00000E 02


 PHI(TAU) DATA

  NPHI=  4   NGAMMA= 1

  PHI(TAU)  (READ ACROSS)
1.00000E 00 1.00000E 00 1.00000E 00 1.00000E 00

  GAMMA
5.00000E 02
```

```
OUTPUT

TAU=        0.                    DELTA TAU(1)= 4.00000E-03          DELTA TAU(2)= 4.00000E-03

H(B,L,J)
2.50000E 01
0.

TEMPERATURES  (READ I ACROSS, J DOWN)
1.00000E 02 1.00000E 02 1.00000E 02 1.00000E 02 1.00000E 02 1.00000E 02 1.00000E 02 1.00000E 02 1.00000E 02 1.0000E 02
1.00000E 02 1.00000E 02 1.00000E 02 1.00000E 02 1.00000E 02 1.00000E 02 1.00000E 02 1.00000E 02 1.00000E 02 1.0000E 02
1.00000E 02 1.00000E 02


TAU=       10.00000E-02           DELTA TAU(1)= 4.00000E-03          DELTA TAU(2)= 4.00000E-03

H(B,L,J)
2.50000E 01
0.

TEMPERATURES  (READ I ACROSS, J DOWN)
1.50000E 02 1.50000E 02 1.50000E 02 1.50000E 02 1.50000E 02 1.50000E 02 1.50000E 02 1.50000E 02 1.49999E 02 1.5000E 02
1.49992E 02 1.49971E 02 1.49909E 02 1.49739E 02 1.49315E 02 1.48350E 02 1.46329E 02 1.42425E 02 1.35438E 02 1.2380E 02
1.05673E 02 1.00000E 02


TAU=        2.00000E-01           DELTA TAU(1)= 4.00000E-03          DELTA TAU(2)= 4.00000E-03

H(B,L,J)
2.50000E 01
0.

TEMPERATURES  (READ I ACROSS, J DOWN)
1.99999E 02 1.99999E 02 1.99999E 02 1.99997E 02 1.99994E 02 1.99985E 02 1.99967E 02 1.99926E 02 1.99842E 02 1.9967E 02
1.99351E 02 1.98754E 02 1.97695E 02 1.95887E 02 1.92919E 02 1.88225E 02 1.81070E 02 1.70543E 02 1.55577E 02 1.3498E 02
1.07510E 02 1.00000E 02


TAU=        3.00000E-01           DELTA TAU(1)= 4.00000E-03          DELTA TAU(2)= 4.00000E-03

H(B,L,J)
2.50000E 01
0.

TEMPERATURES  (READ I ACROSS, J DOWN)
2.49967E 02 2.49962E 02 2.49945E 02 2.49910E 02 2.49845E 02 2.49731E 02 2.49535E 02 2.49205E 02 2.48661E 02 2.4779E 02
2.46420E 02 2.44325E 02 2.41192E 02 2.36618E 02 2.30096E 02 2.21010E 02 2.08635E 02 1.92152E 02 1.70661E 02 1.4322E 02
1.08859E 02 1.00000E 02


TAU=        4.00000E-01           DELTA TAU(1)= 4.00000E-03          DELTA TAU(2)= 4.00000E-03

H(B,L,J)
```

```
ARGUS TEST PROB. ONE REGION OF FUEL,INFINITE SINK, H = 25.0                    1089/RE248  PROB.NO. 36.90003  PAGE   4
2.50000E 01
0.

TEMPERATURES  (READ I ACROSS, J DOWN)
2.99680E 02 2.99651E 02 2.99560E 02 2.99389E 02 2.99107E 02 2.98664E 02 2.97990E 02 2.96984E 02 2.95508E 02 2.9338E 02
2.90366E 02 2.86163E 02 2.80404E 02 2.72641E 02 2.62353E 02 2.48940E 02 2.31732E 02 2.10004E 02 1.82989E 02 1.4990E 02
1.09952E 02 1.00000E 02


TAU=        5.00000E-01           DELTA TAU(1)= 4.00000E-03           DELTA TAU(2)= 4.00000E-03

H(B,L,J)
2.50000E 01
0.

TEMPERATURES  (READ I ACROSS, J DOWN)
3.48664E 02 3.48584E 02 3.48337E 02 3.47891E 02 3.47196E 02 3.46173E 02 3.44717E 02 3.42686E 02 3.39899E 02 3.3613E 02
3.31102E 02 3.24480E 02 3.15873E 02 3.04829E 02 2.90838E 02 2.73337E 02 2.51716E 02 2.25328E 02 1.93508E 02 1.5558E 02
1.10882E 02 1.00000E 02


TAU=        6.00000E-01           DELTA TAU(1)= 4.00000E-03           DELTA TAU(2)= 4.00000E-03

H(B,L,J)
2.50000E 01
0.

TEMPERATURES  (READ I ACROSS, J DOWN)
3.96373E 02 3.96217E 02 3.95736E 02 3.94891E 02 3.93613E 02 3.91803E 02 3.89330E 02 3.86024E 02 3.81678E 02 3.7604E 02
3.68807E 02 3.59639E 02 3.48139E 02 3.33866E 02 3.16334E 02 2.95019E 02 2.69366E 02 2.38795E 02 2.02717E 02 1.6054E 02
1.11693E 02 1.00000E 02


TAU=        6.99999E-01           DELTA TAU(1)= 4.00000E-03           DELTA TAU(2)= 4.00000E-03

H(B,L,J)
2.50000E 01
0.

TEMPERATURES  (READ I ACROSS, J DOWN)
4.42351E 02 4.42099E 02 4.41328E 02 4.39992E 02 4.38011E 02 4.35272E 02 4.31629E 02 4.26896E 02 4.20850E 02 4.1323E 02
4.03723E 02 3.91991E 02 3.77645E 02 3.60262E 02 3.39385E 02 3.14526E 02 2.85178E 02 2.50818E 02 2.10918E 02 1.6495E 02
1.12414E 02 1.00000E 02


TAU=        7.99999E-01           DELTA TAU(1)= 4.00000E-03           DELTA TAU(2)= 4.00000E-03

H(B,L,J)
2.50000E 01
0.

TEMPERATURES  (READ I ACROSS, J DOWN)
4.86280E 02 4.85920E 02 4.84823E 02 4.82939E 02 4.80183E 02 4.76435E 02 4.71540E 02 4.65305E 02 4.57501E 02 4.4786E 02
4.36090E 02 4.21842E 02 4.04747E 02 3.84404E 02 3.60383E 02 3.32233E 02 2.99488E 02 2.61672E 02 2.18308E 02 1.6892E 02
1.13063E 02 1.00000E 02
```

```
TAU=        8.99999E-01           DELTA TAU(1)= 4.00000E-03           DELTA TAU(2)= 4.00000E-03

H(B,L,J)
2.50000E 01
0.

TEMPERATURES  (READ I ACROSS, J DOWN)
5.27976E 02 5.27501E 02 5.26060E 02 5.23601E 02 5.20037E 02 5.15244E 02 5.09066E 02 5.01310E 02 4.91748E 02 4.8012E 02
4.66127E 02 4.49448E 02 4.29728E 02 4.06585E 02 3.79620E 02 3.48413E 02 3.12535E 02 2.71550E 02 2.25024E 02 1.7253E 02
1.13652E 02 1.00000E 02


TAU=        9.99999E-01           DELTA TAU(1)= 4.00000E-03           DELTA TAU(2)= 4.00000E-03

H(B,L,J)
2.50000E 01
0.

TEMPERATURES  (READ I ACROSS, J DOWN)
5.67357E 02 5.66766E 02 5.64976E 02 5.61935E 02 5.57555E 02 5.51717E 02 5.44263E 02 5.35004E 02 5.23719E 02 5.1015E 02
4.94026E 02 4.75025E 02 4.52814E 02 4.27037E 02 3.97319E 02 3.63271E 02 3.24496E 02 2.80594E 02 2.31167E 02 1.7582E 02
1.14191E 02 1.00000E 02


TAU=        1.10000E 00           DELTA TAU(1)= 4.00000E-03           DELTA TAU(2)= 4.00000E-03

H(B,L,J)
2.50000E 01
0.

TEMPERATURES  (READ I ACROSS, J DOWN)
6.04417E 02 6.03710E 02 6.01575E 02 5.97959E 02 5.92778E 02 5.85914E 02 5.77214E 02 5.66497E 02 5.53548E 02 5.3813E 02
5.19958E 02 4.98753E 02 4.74193E 02 4.45944E 02 4.13654E 02 3.76964E 02 3.35506E 02 2.88910E 02 2.36812E 02 1.7885E 02
1.14686E 02 1.00000E 02


TAU=        1.20000E 00           DELTA TAU(1)= 4.00000E-03           DELTA TAU(2)= 4.00000E-03

H(B,L,J)
2.50000E 01
0.

TEMPERATURES  (READ I ACROSS, J DOWN)
6.39199E 02 6.38380E 02 6.35909E 02 6.31736E 02 6.25778E 02 6.17923E 02 6.08024E 02 5.95907E 02 5.81368E 02 5.6418E 02
5.44076E 02 5.20791E 02 4.94022E 02 4.63456E 02 4.28767E 02 3.89619E 02 3.45672E 02 2.96584E 02 2.42017E 02 1.8164E 02
1.15141E 02 1.00000E 02


TAU=        1.30000E 00           DELTA TAU(1)= 4.00000E-03           DELTA TAU(2)= 4.00000E-03

H(B,L,J)
2.50000E 01
0.

TEMPERATURES  (READ I ACROSS, J DOWN)
```

```
ARGUS TEST PROB. ONE REGION OF FUEL,INFINITE SINK, H = 25.0                  1089/RE248  PROB.NO. 36.90003  PAGE   6
6.71780E 02 6.70853E 02 6.68060E 02 6.63351E 02 6.56650E 02 6.47846E 02 6.36804E 02 6.23354E 02 6.07306E 02 5.8844E 02
5.66517E 02 5.41274E 02 5.12433E 02 4.79702E 02 4.42774E 02 4.01339E 02 3.55080E 02 3.03681E 02 2.46830E 02 1.8422E 02
1.15563E 02 1.00000E 02


TAU=        1.40000E 00            DELTA TAU(1)= 4.00000E-03            DELTA TAU(2)= 4.00000E-03

H(B,L,J)
2.50000E 01
0.

TEMPERATURES  (READ I ACROSS, J DOWN)
7.02254E 02 7.01225E 02 6.98124E 02 6.92906E 02 6.85497E 02 6.75795E 02 6.63667E 02 6.48957E 02 6.31484E 02 6.1104E 02
5.87403E 02 5.60324E 02 5.29543E 02 4.94788E 02 4.55773E 02 4.12209E 02 3.63802E 02 3.10258E 02 2.51289E 02 1.8661E 02
1.15953E 02 1.00000E 02


TAU=        1.50000E 00            DELTA TAU(1)= 4.00000E-03            DELTA TAU(2)= 4.00000E-03

H(B,L,J)
2.50000E 01
0.

TEMPERATURES  (READ I ACROSS, J DOWN)
7.30728E 02 7.29602E 02 7.26210E 02 7.20510E 02 7.12433E 02 7.01880E 02 6.88729E 02 6.72832E 02 6.54018E 02 6.3209E 02
6.06846E 02 5.78048E 02 5.45454E 02 5.08810E 02 4.67849E 02 4.22303E 02 3.71898E 02 3.16361E 02 2.55425E 02 1.8883E 02
1.16315E 02 1.00000E 02


TAU=        1.60000E 00            DELTA TAU(1)= 4.00000E-03            DELTA TAU(2)= 4.00000E-03

H(B,L,J)
2.50000E 01
0.

TEMPERATURES  (READ I ACRUSS, J DOWN)
7.57312E 02 7.56094E 02 7.52428E 02 7.46275E 02 7.37567E 02 7.26215E 02 7.12102E 02 6.95090E 02 6.75017E 02 6.5170E 02
6.24951E 02 5.94544E 02 5.60257E 02 5.21849E 02 4.79076E 02 4.31684E 02 3.79420E 02 3.22030E 02 2.59266E 02 1.9088E 02
1.16651E 02 1.00000E 02


TAU=        1.70000E 00            DELTA TAU(1)= 4.00000E-03            DELTA TAU(2)= 4.00000E-03

H(B,L,J)
2.50000E 01
0.

TEMPERATURES  (READ I ACROSS, J DOWN)
7.82117E 02 7.80813E 02 7.76890E 02 7.70310E 02 7.61011E 02 7.48909E 02 7.33893E 02 7.15835E 02 6.94584E 02 6.6997E 02
6.41810E 02 6.09902E 02 5.74033E 02 5.33982E 02 4.89518E 02 4.40407E 02 3.86413E 02 3.27300E 02 2.62837E 02 1.9280E 02
1.16964E 02 1.00000E 02


TAU=        1.80000E 00            DELTA TAU(1)= 4.00000E-03            DELTA TAU(2)= 4.00000E-03

H(B,L,J)
```

```
ARGUS TEST PROB. ONE REGION OF FUEL,INFINITE SINK, H = 25.0                    1089/RE248  PROB.NO. 36.90003  PAGE   7
2.50000E 01
0.

TEMPERATURES  (READ I ACROSS, J DOWN)
8.05253E 02 8.03868E 02 7.99704E 02 7.92724E 02 7.82871E 02 7.70066E 02 7.54206E 02 7.35169E 02 7.12816E 02 6.8699E 02
6.57512E 02 6.24201E 02 5.86858E 02 5.45273E 02 4.99234E 02 4.48523E 02 3.92918E 02 3.32202E 02 2.66157E 02 1.9458E 02
1.17255E 02 1.00000E 02


TAU=       1.90000E 00           DELTA TAU(1)= 4.00000E-03           DELTA TAU(2)= 4.00000E-03

H(B,L,J)
2.50000E 01
0.

TEMPERATURES  (READ I ACROSS, J DOWN)
8.26825E 02 8.25365E 02 8.20974E 02 8.13620E 02 8.03250E 02 7.89787E 02 7.73136E 02 7.53186E 02 7.29803E 02 7.0284E 02
6.72137E 02 6.37518E 02 5.98798E 02 5.55785E 02 5.08279E 02 4.56076E 02 3.98972E 02 3.36762E 02 2.69247E 02 1.9623E 02
1.17525E 02 1.00000E 02


TAU=       2.00000E 00           DELTA TAU(1)= 4.00000E-03           DELTA TAU(2)= 4.00000E-03

H(B,L,J)
2.50000E 01
0.

TEMPERATURES  (READ I ACROSS, J DOWN)
8.46934E 02 8.45403E 02 8.40802E 02 8.33098E 02 8.22243E 02 8.08166E 02 7.90778E 02 7.69973E 02 7.45629E 02 7.1761E 02
6.85759E 02 6.49920E 02 6.09918E 02 5.65573E 02 5.16699E 02 4.63107E 02 4.04607E 02 3.41007E 02 2.72122E 02 1.9777E 02
1.17776E 02 1.00000E 02

B
 0.          1.00000E-01 1.50000E-01 1.66667E-01 1.75000E-01 1.80000E-01 1.83333E-01 1.85714E-01 1.87500E-01 1.8889E-01
 1.90000E-01 1.90909E-01 1.91667E-01 1.92308E-01 1.92857E-01 1.93333E-01 1.93750E-01 1.94118E-01 1.94444E-01 1.9474E-01
 8.93471E-02 0.
C
 2.00000E-01 6.00000E-01 6.00000E-01 6.00000E-01 6.00000E-01 6.00000E-01 6.00000E-01 6.00000E-01 6.00000E-01 6.0000E-01
 6.00000E-01 6.00000E-01 6.00000E-01 6.00000E-01 6.00000E-01 6.00000E-01 6.00000E-01 6.00000E-01 6.00000E-01 6.0000E-01
-9.50744E-02 0.
D
 8.00000E-01 3.00000E-01 2.50000E-01 2.33333E-01 2.25000E-01 2.20000E-01 2.16667E-01 2.14286E-01 2.12500E-01 2.1111E-01
 2.10000E-01 2.09091E-01 2.08333E-01 2.07692E-01 2.07143E-01 2.06667E-01 2.06250E-01 2.05882E-01 2.05556E-01 2.0526E-01
 4.58190E-01 0.
E(N,J)
 0.
G
 2.00000E 00 2.00000E 00 2.00000E 00 2.00000E 00 2.00000E 00 2.00000E 00 2.00000E 00 2.00000E 00 2.00000E 00 2.0000E 00
 2.00000E 00 2.00000E 00 2.00000E 00 2.00000E 00 2.00000E 00 2.00000E 00 2.00000E 00 2.00000E 00 2.00000E 00 2.0000E 00
 2.00000E 00 0.

 TAU=FINAL TAU.  END OF PROB.NO.  36.90003
```

2. Sample Problem No. 2

The object of the second sample problem (problem No. 26.00010) is to calculate the space- and time-dependent temperatures in an EBR-II core fuel pin heated at an exponentially increasing time rate and cooled by sodium flowing axially past the pin. This sample problem is intended to duplicate the sample problem No. 2 of ANL-6237(1) as nearly as possible.

The ARGUS problem 26.00010 contains a central fuel region of uranium-fissium alloy material, surrounded by a clad region containing a fictitious material which is thermally equivalent to the separate bond and clad materials of an EBR-II pin, and the third region contains sodium flowing axially at v_0 = 25.0 ft/sec. Since the CYCLOPS code of Reference 1 neglects the thermal resistance at the fuel-clad interface, the surface contact conductance U(1) for the ARGUS problem is chosen quite large, U(1) = 1.0×10^6 Btu/(hr)(ft^2)(°F), in order to approximate the condition of zero thermal resistance. The clad region is then represented by a thick-type region K(2) = 2 so that the unit time increment $\Delta\tau_1$ will not be affected by this large value of U.

The material properties of the respective materials are taken identical with those of Reference 1, and the film coefficient parameters are chosen to insure a constant value of h = 2.60 Btu/(sec)(ft^2)(°F) at all node points in the coolant channel. A flat power shape is assumed for the axial direction in the pin (all ζ_j = 1.0), and the radial power distribution (μ_i) is taken from Fig. 3 of Reference 1.

A complete set of input sheets and problem output sheets follows. The ARGUS problem required approximately 2 min of machine time on an IBM-704 with a monitor system.

The results of this problem as shown on the problem output are in good agreement with the problem output on pp. 44 to 47 of Reference 1. The small discrepancies between corresponding temperatures at a given time are due in part to the larger time increment used in the ARGUS problem ($\Delta\tau$ = 0.002 sec instead of $\Delta\tau$ = 0.001 sec), and in part to the temperature drop at the fuel-clad interface which is encountered in the ARGUS problem.

704 INPUT DATA
FORM I

COST CODE 4351-01

PROGRAM ARGUS RE 248 PROBLEM 26.00010 ORIGINATOR Daniel F. Schoeberle DATE 12 July 1962 PAGE 1 OF 2

1–12	13–24	25–36	37–48	49–60	61–72	73–80
1 ARGUS TEST	PROB. NO.2.	THREE REGIO	NS. SEE ANL-6	237, PAGE 40.		1100
26.00010						1200
0 10	9 3	3 4	16 16	16 25		1300
1.185030	0.300	0.002	32.17	0.005	0.005	1400
0.005	0.020	0.020	0.020			1500
6 1	1 0.	00600				2011
3 2	2 0.	00725				2021
1 3	5 0.	03125				2031
277.7778	2.60					2500
0.977	0.978	0.980	0.990	1.008	1.028	3011
1.00	1.00	1.00	1.00	1.00	1.00	3012A
1.00	1.00	1.00	4.000+04			3012B
1 0	1					4011
25.000	700.0	1618.0	1.00			4012
1.00	1.00	1.00	1.00	1.00		4013
0.00	2.60	0.00	2.60	0.00	2.60	4014

AMD-8 (9-60)

704 INPUT DATA
FORM I

COST CODE 46351-01

PROGRAM ARGUS RE 248 PROBLEM 26.00010 ORIGINATOR Daniel F. Schoeberle DATE 12 July 1962 PAGE 2 OF 2

1 2 3 4 5 6 7 8 9	1 (0–9)	2 (0–9)	3 (0–9)	4 (0–9)	5 (0–9)	6 (0–9)	7 (0–9) / 8
3.833-03	6.611-03	7.722-03	8.530-03				5011
40.27	60.50	198.42	40.7				5012
1233.0	1850.0	1976.0					5013
5829.888	0.00	0.00					5014
3.040-03	3.380-03	3.820-03	4.030-03				5021
42.64	45.0	49.87	49.87				5022
208.0	800.0	1600.0					5023
0.00	0.00	0.00					5024
1.00	0.00	0.00					6011
17.07	0.00	0.00	9.999+29				6012
1.00	0.00	0.00					6013
1.00	0.00	0.00					6014
0 0	0.100						7001
1							8000
3 1							8101
1.00	1.00	1.00					8102
500.0							8103
0							9000
700.0	700.0	700.0					9001

AMD-8 (9-60)

```
ARGUS TEST PROB. NO.2. THREE REGIONS.SEE ANL-6237,PAGE 40.                    1089/RE248  PROB.NO. 26.00010  PAGE   1

INPUT

 GENERAL PROBLEM DATA
  IMAX= 10     JMAX= 9  LMAX= 3       MMAX= 3  NPMAX= 4     NH(1)= 16  NH(2)= 16    NH(3)= 16  NPR= 25
  Z=         1.18503E 00  FINAL TAU= 3.00000E-01  DELTA TAU= 2.00000E-03  G=          3.21700E 01  EPSD(1)=    5.00000E-03
  EPSD(2)=  5.00000E-03  EPSD(3)=    5.00000E-03  EPSH(1)=    2.00000E-02  EPSH(2)=    2.00000E-02  EPSH(3)=    2.00000E-02

  NI(L)=  6   3   1
  M(L)=   1   2   3
  K(L)=   1   2   5

  R(L)
6.00000E-03 7.25000E-03 3.12500E-02

  U(L)
2.77778E 02 2.60000E 00 0.


 POWER DISTRIBUTION DATA

  MU(I)  (READ ACROSS)
9.77000E-01 9.78000E-01 9.80000E-01 9.90000E-01 1.00800E 00 1.02800E 00 0.          0.          0.          0.

  ZETA(L,J)  (READ ACROSS)
   L= 1
1.00000E 00 1.00000E 00 1.00000E 00 1.00000E 00 1.00000E 00 1.00000E 00 1.00000E 00 1.00000E 00 1.00000E 00

  QO(L)  (READ ACROSS)
4.00000E 04 0.          0.


 FLOWING COOLANT REGION DATA  (READ DOWN)

  L  IPT  ICS  IH          VO          PSIO        PSIS        DE          A1          A2          A3
  3   1    0    1      2.50000E 01 7.00000E 02 1.61800E 03 1.00000E 00 1.00000E 00 1.00000E 00 1.00000E 00

    B1          B2          H1          H2          H3          H4          H5          H6
1.00000E 00 1.00000E 00 0.          2.60000E 00 0.          2.60000E 00 0.          2.60000E 00


 MATERIAL PROPERTIES

  K  (ONE ROW FOR EACH MATERIAL)
3.83300E-03 6.61100E-03 7.72200E-03 8.53000E-03
3.04000E-03 3.38000E-03 3.82000E-03 4.03000E-03
1.00000E 00 0.          0.

  RHO*C  (ONE ROW FOR EACH MATERIAL)
4.02700E 01 6.05000E 01 1.98420E 02 4.07000E 01
4.26400E 01 4.50000E 01 4.98700E 01 4.98700E 01
1.70700E 01 0.          0.          9.99900E 29
```

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ARGUS TEST PROB. NO.2. THREE REGIONS.SEE ANL-6237,PAGE 40.          1089/RE248   PROB.NO. 26.00010   PAGE   2

  TT OR NU   (ONE ROW FOR EACH MATERIAL)
1.23300E 03 1.85000E 03 1.97600E 03
2.08000E 02 8.00000E 02 1.60000E 03
1.00000E 00 0.          0.

  RHO*DH OR RHO  (ONE ROW FOR EACH MATERIAL)
5.82989E 03 0.          0.
0.          0.          0.
1.00000E 00 0.          0.


 N(TAU) DATA

  NN=  0   NBETA= 0  P=10.00000E-02


 PHI(TAU) DATA

  NPHI=  3   NGAMMA= 1

  PHI(TAU)  (READ ACROSS)
1.00000E 00 1.00000E 00 1.00000E 00

  GAMMA
5.00000E 02
```

```
OUTPUT


TAU=        0.                     DELTA TAU(1)= 2.00000E-03          DELTA TAU(2)= 2.00000E-03

H(B,L,J)
2.60000E 00 2.60000E 00 2.60000E 00 2.60000E 00 2.60000E 00 2.60000E 00 2.60000E 00 2.60000E 00 2.60000E 00
0.          0.          0.          0.          0.          0.          0.          0.          0.

TEMPERATURES  (READ I ACROSS, J DOWN)
7.00000E 02 7.00000E 02 7.00000E 02 7.00000E 02 7.00000E 02 7.00000E 02 7.00000E 02 7.00000E 02 7.00000E 02 7.0000E 02
7.00000E 02 7.00000E 02 7.00000E 02 7.00000E 02 7.00000E 02 7.00000E 02 7.00000E 02 7.00000E 02 7.00000E 02 7.0000E 02
7.00000E 02 7.00000E 02 7.00000E 02 7.00000E 02 7.00000E 02 7.00000E 02 7.00000E 02 7.00000E 02 7.00000E 02 7.0000E 02
7.00000E 02 7.00000E 02 7.00000E 02 7.00000E 02 7.00000E 02 7.00000E 02 7.00000E 02 7.00000E 02 7.00000E 02 7.0000E 02
7.00000E 02 7.00000E 02 7.00000E 02 7.00000E 02 7.00000E 02 7.00000E 02 7.00000E 02 7.00000E 02 7.00000E 02 7.0000E 02
7.00000E 02 7.00000E 02 7.00000E 02 7.00000E 02 7.00000E 02 7.00000E 02 7.00000E 02 7.00000E 02 7.00000E 02 7.0000E 02
7.00000E 02 7.00000E 02 7.00000E 02 7.00000E 02 7.00000E 02 7.00000E 02 7.00000E 02 7.00000E 02 7.00000E 02 7.0000E 02
7.00000E 02 7.00000E 02 7.00000E 02 7.00000E 02 7.00000E 02 7.00000E 02 7.00000E 02 7.00000E 02 7.00000E 02 7.0000E 02
7.00000E 02 7.00000E 02 7.00000E 02 7.00000E 02 7.00000E 02 7.00000E 02 7.00000E 02 7.00000E 02 7.00000E 02 7.0000E 02


TAU=        5.00000E-02            DELTA TAU(1)= 2.00000E-03          DELTA TAU(2)= 2.00000E-03

H(B,L,J)
2.60000E 00 2.60000E 00 2.60000E 00 2.60000E 00 2.60000E 00 2.60000E 00 2.60000E 00 2.60000E 00 2.60000E 00
0.          0.          0.          0.          0.          0.          0.          0.          0.

TEMPERATURES  (READ I ACROSS, J DOWN)
7.61416E 02 7.60894E 02 7.59061E 02 7.54997E 02 7.46902E 02 7.32074E 02 7.29923E 02 7.19573E 02 7.12422E 02 7.0000E 02
7.61417E 02 7.60895E 02 7.59063E 02 7.55002E 02 7.46916E 02 7.32108E 02 7.29957E 02 7.19628E 02 7.12507E 02 7.0016E 02
7.61417E 02 7.60895E 02 7.59064E 02 7.55005E 02 7.46926E 02 7.32132E 02 7.29982E 02 7.19670E 02 7.12576E 02 7.0030E 02
7.61417E 02 7.60896E 02 7.59064E 02 7.55006E 02 7.46930E 02 7.32148E 02 7.29997E 02 7.19699E 02 7.12629E 02 7.0041E 02
7.61417E 02 7.60896E 02 7.59065E 02 7.55007E 02 7.46932E 02 7.32155E 02 7.30005E 02 7.19717E 02 7.12663E 02 7.0049E 02
7.61417E 02 7.60896E 02 7.59065E 02 7.55007E 02 7.46933E 02 7.32159E 02 7.30009E 02 7.19725E 02 7.12681E 02 7.0054E 02
7.61417E 02 7.60896E 02 7.59065E 02 7.55007E 02 7.46933E 02 7.32160E 02 7.30010E 02 7.19728E 02 7.12689E 02 7.0057E 02
7.61417E 02 7.60896E 02 7.59065E 02 7.55007E 02 7.46933E 02 7.32160E 02 7.30010E 02 7.19729E 02 7.12692E 02 7.0057E 02
7.61417E 02 7.60896E 02 7.59065E 02 7.55007E 02 7.46933E 02 7.32160E 02 7.30010E 02 7.19729E 02 7.12692E 02 7.0058E 02


TAU=       10.00000E-02            DELTA TAU(1)= 2.00000E-03          DELTA TAU(2)= 2.00000E-03

H(B,L,J)
2.60000E 00 2.60000E 00 2.60000E 00 2.60000E 00 2.60000E 00 2.60000E 00 2.60000E 00 2.60000E 00 2.60000E 00
0.          0.          0.          0.          0.          0.          0.          0.          0.

TEMPERATURES  (READ I ACROSS, J DOWN)
8.49345E 02 8.47315E 02 8.40832E 02 8.28559E 02 8.07906E 02 7.74756E 02 7.71509E 02 7.48798E 02 7.31673E 02 7.0000E 02
8.49367E 02 8.47340E 02 8.40868E 02 8.28617E 02 8.08001E 02 7.74911E 02 7.71664E 02 7.49004E 02 7.31946E 02 7.0043E 02
8.49383E 02 8.47359E 02 8.40897E 02 8.28664E 02 8.08082E 02 7.75046E 02 7.71801E 02 7.49187E 02 7.32188E 02 7.0081E 02
8.49395E 02 8.47374E 02 8.40919E 02 8.28703E 02 8.08151E 02 7.75165E 02 7.71921E 02 7.49351E 02 7.32410E 02 7.0117E 02
8.49404E 02 8.47384E 02 8.40936E 02 8.28734E 02 8.08207E 02 7.75265E 02 7.72021E 02 7.49491E 02 7.32601E 02 7.0148E 02
8.49410E 02 8.47392E 02 8.40949E 02 8.28759E 02 8.08253E 02 7.75352E 02 7.72108E 02 7.49615E 02 7.32778E 02 7.0179E 02
8.49413E 02 8.47397E 02 8.40958E 02 8.28777E 02 8.08289E 02 7.75418E 02 7.72175E 02 7.49709E 02 7.32908E 02 7.0201E 02
8.49416E 02 8.47399E 02 8.40964E 02 8.28791E 02 8.08320E 02 7.75482E 02 7.72240E 02 7.49804E 02 7.33042E 02 7.0223E 02
```

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ARGUS TEST PROB. NO.2. THREE REGIONS.SEE ANL-6237,PAGE 40.                    1089/RE248  PROB.NO. 26.00010  PAGE   4
8.49416E 02 8.47401E 02 8.40967E 02 8.28798E 02 8.08338E 02 7.75523E 02 7.72281E 02 7.49870E 02 7.33142E 02 7.0242E 02

TAU=        1.50000E-01           DELTA TAU(1)= 2.00000E-03            DELTA TAU(2)= 2.00000E-03

H(B,L,J)
2.60000E 00 2.60000E 00 2.60000E 00 2.60000E 00 2.60000E 00 2.60000E 00 2.60000E 00 2.60000E 00 2.60000E 00
0.          0.          0.          0.          0.          0.          0.          0.          0.

TEMPERATURES  (READ I ACROSS, J DOWN)
9.80615E 02 9.76328E 02 9.62800E 02 9.37729E 02 8.96639E 02 8.32566E 02 8.27032E 02 7.88302E 02 7.57712E 02 7.0000E 02
9.80710E 02 9.76432E 02 9.62929E 02 9.37907E 02 8.96895E 02 8.32941E 02 8.27408E 02 7.88762E 02 7.58277E 02 7.0080E 02
9.80792E 02 9.76521E 02 9.63042E 02 9.38062E 02 8.97118E 02 8.33268E 02 8.27737E 02 7.89169E 02 7.58786E 02 7.0156E 02
9.80864E 02 9.76600E 02 9.63143E 02 9.38205E 02 8.97329E 02 8.33580E 02 8.28050E 02 7.89553E 02 7.59259E 02 7.0224E 02
9.80923E 02 9.76665E 02 9.63227E 02 9.38325E 02 8.97510E 02 8.33855E 02 8.28326E 02 7.89899E 02 7.59689E 02 7.0285E 02
9.80975E 02 9.76723E 02 9.63304E 02 9.38437E 02 8.97678E 02 8.34115E 02 8.28587E 02 7.90232E 02 7.60118E 02 7.0351E 02
9.81015E 02 9.76768E 02 9.63365E 02 9.38527E 02 8.97817E 02 8.34329E 02 8.28802E 02 7.90502E 02 7.60465E 02 7.0405E 02
9.81052E 02 9.76810E 02 9.63422E 02 9.38614E 02 8.97954E 02 8.34542E 02 8.29016E 02 7.90771E 02 7.60802E 02 7.0455E 02
9.81077E 02 9.76838E 02 9.63462E 02 9.38678E 02 8.98060E 02 8.34715E 02 8.29190E 02 7.90995E 02 7.61091E 02 7.0498E 02

TAU=        2.00000E-01           DELTA TAU(1)= 2.00000E-03            DELTA TAU(2)= 2.00000E-03

H(B,L,J)
2.60000E 00 2.60000E 00 2.60000E 00 2.60000E 00 2.60000E 00 2.60000E 00 2.60000E 00 2.60000E 00 2.60000E 00
0.          0.          0.          0.          0.          0.          0.          0.          0.

TEMPERATURES  (READ I ACROSS, J DOWN)
1.18401E 03 1.17602E 03 1.15106E 03 1.10581E 03 1.03370E 03 9.24189E 02 9.14999E 02 8.49604E 02 7.97769E 02 7.0000E 02
1.18425E 03 1.17627E 03 1.15136E 03 1.10620E 03 1.03421E 03 9.24881E 02 9.15693E 02 8.50426E 02 7.98746E 02 7.0133E 02
1.18447E 03 1.17650E 03 1.15163E 03 1.10654E 03 1.03466E 03 9.25501E 02 9.16316E 02 8.51175E 02 7.99660E 02 7.0263E 02
1.18467E 03 1.17672E 03 1.15189E 03 1.10687E 03 1.03510E 03 9.26087E 02 9.16904E 02 8.51872E 02 8.00504E 02 7.0385E 02
1.18484E 03 1.17690E 03 1.15211E 03 1.10715E 03 1.03549E 03 9.26619E 02 9.17438E 02 8.52496E 02 8.01233E 02 7.0481E 02
1.18501E 03 1.17708E 03 1.15233E 03 1.10743E 03 1.03587E 03 9.27153E 02 9.17974E 02 8.53140E 02 8.02001E 02 7.0584E 02
1.18515E 03 1.17723E 03 1.15250E 03 1.10767E 03 1.03619E 03 9.27605E 02 9.18428E 02 8.53694E 02 8.05424E 02 7.0685E 02
1.18528E 03 1.17737E 03 1.15268E 03 1.10790E 03 1.03651E 03 9.28049E 02 9.18874E 02 8.54227E 02 8.06064E 02 7.0777E 02
1.18539E 03 1.17749E 03 1.15282E 03 1.10809E 03 1.03678E 03 9.28434E 02 9.19260E 02 8.54694E 02 8.06623E 02 7.0857E 02

TAU=        2.50000E-01           DELTA TAU(1)= 2.00000E-03            DELTA TAU(2)= 2.00000E-03

H(B,L,J)
2.60000E 00 2.60000E 00 2.60000E 00 2.60000E 00 2.60000E 00 2.60000E 00 2.60000E 00 2.60000E 00 2.60000E 00
0.          0.          0.          0.          0.          0.          0.          0.          0.

TEMPERATURES  (READ I ACROSS, J DOWN)
1.35180E 03 1.34231E 03 1.30985E 03 1.25779E 03 1.21507E 03 1.06834E 03 1.05346E 03 9.54098E 02 8.73364E 02 7.0000E 02
1.35221E 03 1.34268E 03 1.31044E 03 1.25929E 03 1.21599E 03 1.06958E 03 1.05469E 03 9.55565E 02 8.75078E 02 7.0233E 02
1.35255E 03 1.34298E 03 1.31088E 03 1.26038E 03 1.21669E 03 1.07060E 03 1.05572E 03 9.56849E 02 8.76642E 02 7.0455E 02
1.35292E 03 1.34331E 03 1.31140E 03 1.26169E 03 1.21747E 03 1.07167E 03 1.05679E 03 9.58160E 02 8.78256E 02 7.0697E 02
1.35320E 03 1.34356E 03 1.31178E 03 1.26264E 03 1.21807E 03 1.07250E 03 1.05763E 03 9.59179E 02 8.79512E 02 7.0890E 02
1.35348E 03 1.34381E 03 1.31215E 03 1.26355E 03 1.21865E 03 1.07333E 03 1.05846E 03 9.60195E 02 8.80707E 02 7.1052E 02
1.35376E 03 1.34406E 03 1.31255E 03 1.26459E 03 1.21929E 03 1.07419E 03 1.05933E 03 9.61240E 02 8.81942E 02 7.1219E 02
1.35399E 03 1.34426E 03 1.31287E 03 1.26537E 03 1.21978E 03 1.07491E 03 1.06005E 03 9.62142E 02 8.83078E 02 7.1395E 02
1.35419E 03 1.34444E 03 1.31313E 03 1.26605E 03 1.22021E 03 1.07552E 03 1.06067E 03 9.62911E 02 8.84030E 02 7.1539E 02
```

```
ARGUS TEST PROB. NO.2. THREE REGIONS.SEE ANL-6237,PAGE 40.                    1089/RE248  PROB.NO. 26.00010  PAGE   5

TAU=       3.00000E-01          DELTA TAU(1)= 2.00000E-03          DELTA TAU(2)= 2.00000E-03

H(B,L,J)
2.60000E 00 2.60000E 00 2.60000E 00 2.60000E 00 2.60000E 00 2.60000E 00 2.60000E 00 2.60000E 00 2.60000E 00
0.          0.          0.          0.          0.          0.          0.          0.          0.

TEMPERATURES  (READ I ACROSS, J DOWN)
1.68157E 03 1.66615E 03 1.61873E 03 1.53522E 03 1.40708E 03 1.22033E 03 1.19635E 03 1.05631E 03 9.43138E 02 7.0000E 02
1.68254E 03 1.66718E 03 1.61991E 03 1.53663E 03 1.40876E 03 1.22233E 03 1.19836E 03 1.05855E 03 9.45707E 02 7.0348E 02
1.68183E 03 1.66638E 03 1.61894E 03 1.53567E 03 1.40819E 03 1.22256E 03 1.19860E 03 1.05933E 03 9.47054E 02 7.0615E 02
1.68269E 03 1.66729E 03 1.61999E 03 1.53691E 03 1.40970E 03 1.22446E 03 1.20050E 03 1.06152E 03 9.49583E 02 7.0943E 02
1.68338E 03 1.66802E 03 1.62083E 03 1.53793E 03 1.41096E 03 1.22603E 03 1.20208E 03 1.06338E 03 9.51869E 02 7.1296E 02
1.68403E 03 1.66872E 03 1.62166E 03 1.53895E 03 1.41222E 03 1.22756E 03 1.20361E 03 1.06509E 03 9.53816E 02 7.1566E 02
1.68472E 03 1.66944E 03 1.62249E 03 1.53995E 03 1.41345E 03 1.22909E 03 1.20514E 03 1.06678E 03 9.55636E 02 7.1771E 02
1.68528E 03 1.67004E 03 1.62319E 03 1.54082E 03 1.41456E 03 1.23056E 03 1.20661E 03 1.06851E 03 9.57663E 02 7.2041E 02
1.68577E 03 1.67056E 03 1.62381E 03 1.54158E 03 1.41552E 03 1.23181E 03 1.20786E 03 1.07000E 03 9.59464E 02 7.2302E 02

B
 0.          7.58838E-02 1.13826E-01 1.26473E-01 1.32797E-01 9.46867E-03 9.25314E-01 3.73688E-01 2.46805E-01 0.
 0.          7.58838E-02 1.13826E-01 1.26473E-01 1.32797E-01 9.46867E-03 9.25314E-01 3.73688E-01 2.46805E-01 4.7804E-03
 0.          7.58838E-02 1.13826E-01 1.26473E-01 1.32797E-01 9.46867E-03 9.25314E-01 3.73688E-01 2.46805E-01 4.7804E-03
 0.          7.58838E-02 1.13826E-01 1.26473E-01 1.32797E-01 9.46867E-03 9.25314E-01 3.73688E-01 2.46805E-01 4.7804E-03
 0.          7.58838E-02 1.13826E-01 1.26473E-01 1.32797E-01 9.46867E-03 9.25314E-01 3.73688E-01 2.46805E-01 4.7804E-03
 0.          7.58838E-02 1.13826E-01 1.26473E-01 1.32797E-01 9.46867E-03 9.25314E-01 3.73688E-01 2.46805E-01 4.7804E-03
 0.          7.58838E-02 1.13826E-01 1.26473E-01 1.32797E-01 9.46867E-03 9.25314E-01 3.73688E-01 2.46805E-01 4.7804E-03
 0.          7.58838E-02 1.13826E-01 1.26473E-01 1.32797E-01 9.46867E-03 9.25314E-01 3.73688E-01 2.46805E-01 4.7804E-03
 0.          7.58838E-02 1.13826E-01 1.26473E-01 1.32797E-01 9.46867E-03 9.25314E-01 3.73688E-01 2.46805E-01 4.7804E-03
C
 3.92929E-01 6.96465E-01 6.96465E-01 6.96465E-01 6.96465E-01-8.48792E-01-8.93469E-01 2.15625E-01 2.86953E-01 0.
 3.92929E-01 6.96465E-01 6.96465E-01 6.96465E-01 6.96465E-01-8.48792E-01-8.93469E-01 2.15625E-01 2.86953E-01 9.9522E-01
 3.92929E-01 6.96465E-01 6.96465E-01 6.96465E-01 6.96465E-01-8.48792E-01-8.93469E-01 2.15625E-01 2.86953E-01 9.9522E-01
 3.92929E-01 6.96465E-01 6.96465E-01 6.96465E-01 6.96465E-01-8.48792E-01-8.93469E-01 2.15625E-01 2.86953E-01 9.9522E-01
 3.92929E-01 6.96465E-01 6.96465E-01 6.96465E-01 6.96465E-01-8.48792E-01-8.93469E-01 2.15625E-01 2.86953E-01 9.9522E-01
 3.92929E-01 6.96465E-01 6.96465E-01 6.96465E-01 6.96465E-01-8.48792E-01-8.93469E-01 2.15625E-01 2.86953E-01 9.9522E-01
 3.92929E-01 6.96465E-01 6.96465E-01 6.96465E-01 6.96465E-01-8.48792E-01-8.93469E-01 2.15625E-01 2.86953E-01 9.9522E-01
 3.92929E-01 6.96465E-01 6.96465E-01 6.96465E-01 6.96465E-01-8.48792E-01-8.93469E-01 2.15625E-01 2.86953E-01 9.9522E-01
 3.92929E-01 6.96465E-01 6.96465E-01 6.96465E-01 6.96465E-01-8.48792E-01-8.93469E-01 2.15625E-01 2.86953E-01 6.5768E-01
D
 6.07071E-01 2.27652E-01 1.89710E-01 1.77062E-01 1.70739E-01 9.14927E-01 2.14203E-02 4.10687E-01 1.09718E-01 0.
 6.07071E-01 2.27652E-01 1.89710E-01 1.77062E-01 1.70739E-01 9.14927E-01 2.14203E-02 4.10687E-01 1.09718E-01 0.
 6.07071E-01 2.27652E-01 1.89710E-01 1.77062E-01 1.70739E-01 9.14927E-01 2.14203E-02 4.10687E-01 1.09718E-01 0.
 6.07071E-01 2.27652E-01 1.89710E-01 1.77062E-01 1.70739E-01 9.14927E-01 2.14203E-02 4.10687E-01 1.09718E-01 0.
 6.07071E-01 2.27652E-01 1.89710E-01 1.77062E-01 1.70739E-01 9.14927E-01 2.14203E-02 4.10687E-01 1.09718E-01 0.
 6.07071E-01 2.27652E-01 1.89710E-01 1.77062E-01 1.70739E-01 9.14927E-01 2.14203E-02 4.10687E-01 1.09718E-01 0.
 6.07071E-01 2.27652E-01 1.89710E-01 1.77062E-01 1.70739E-01 9.14927E-01 2.14203E-02 4.10687E-01 1.09718E-01 0.
 6.07071E-01 2.27652E-01 1.89710E-01 1.77062E-01 1.70739E-01 9.14927E-01 2.14203E-02 4.10687E-01 1.09718E-01 0.
 6.07071E-01 2.27652E-01 1.89710E-01 1.77062E-01 1.70739E-01 9.14927E-01 2.14203E-02 4.10687E-01 1.09718E-01 0.
E(N,J)
 0.          1.68772E-01 1.68772E-01 1.68772E-01 1.68772E-01 1.68772E-01 1.68772E-01 1.68772E-01 3.37544E-01
G
 1.29190E 00 1.29322E 00 1.29587E 00 1.30909E 00 1.33289E 00 2.04221E 00 0.          0.          0.          0.
 1.29190E 00 1.29322E 00 1.29587E 00 1.30909E 00 1.33289E 00 2.04221E 00 0.          0.          0.          0.
 1.29190E 00 1.29322E 00 1.29587E 00 1.30909E 00 1.33289E 00 2.04221E 00 0.          0.          0.          0.
 1.29190E 00 1.29322E 00 1.29587E 00 1.30909E 00 1.33289E 00 2.04221E 00 0.          0.          0.          0.
```

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ARGUS TEST PROB. NO.2. THREE REGIONS.SEE ANL-6237,PAGE 40.                  1089/RE248  PROB.NO. 26.00010  PAGE   6
1.29190E 00 1.29322E 00 1.29587E 00 1.30909E 00 1.33289E 00 2.04221E 00 0.        0.          0.          0.
1.29190E 00 1.29322E 00 1.29587E 00 1.30909E 00 1.33289E 00 2.04221E 00 0.        0.          0.          0.
1.29190E 00 1.29322E 00 1.29587E 00 1.30909E 00 1.33289E 00 2.04221E 00 0.        0.          0.          0.
1.29190E 00 1.29322E 00 1.29587E 00 1.30909E 00 1.33289E 00 2.04221E 00 0.        0.          0.          0.
1.29190E 00 1.29322E 00 1.29587E 00 1.30909E 00 1.33289E 00 2.04221E 00 0.        0.          0.          0.

TAU=FINAL TAU.  END OF PROB.NO.  26.00010
* * ALL DATA PROCESSED.
```

3. Sample Problem No. 3

The goal of the third sample problem is to demonstrate the stability of the ARGUS method for a multiregion problem with several coolant channels. For this purpose, a model of a proposed experiment in the TREAT meltdown series is selected.

The configuration of problem No. 26.00017 is thus an EBR-II core fuel pin in the small-unit sodium loop of TREAT. The clad fuel pin is surrounded by two concentric stainless steel pipes of different diameters, which form two passages for sodium flow. The coolant annuli are connected at the top of the configuration to give series flow. (See Fig. 6.)

The entire configuration will be mounted in the central test hole in the TREAT core, so that the fuel pin can be subjected to transient nuclear heating. The goal of problem No. 26.00017 is to determine the space- and time-dependent temperatures in the configuration during the course of such an experiment.

In this ARGUS problem, five radial rows of mesh points are used with a total of IMAX = 18 node points in each row - seven in the fuel pin, three each in the clad, the inner pipe, and the outer pipe, and one in each of the coolant regions. The fuel and clad regions are represented by thick-type regions, while the two pipes are represented by thin-type regions: K(4) = 4 and K(6) = 4. These pipes are sufficiently thick so that these regions of the model are not critical in determining the unit time increment for the problem.

The initial value of the unit time increment is taken as $\Delta\tau_1$ = 0.002 sec as based on previous experience with this fuel element and cladding. During the course of the machine calculation, this value is halved by the program in order to maintain a stable solution following a material phase change.

The fuel pin under study is identical with that of Sample Problem No. 2, so the same pin dimensions and material properties are input except that the properties are divided into six temperature phases. The properties of the sodium coolant are taken from Reference 6, and the properties of the stainless steel pipe material are taken from Reference 7.

The time-dependent heat generation function $n(\tau)$ is taken from an experimental power curve for an actual TREAT transient, and pointwise values of the function are read off the power curve at intervals of $\beta\Delta\tau_1$ = 0.1 sec. A flat power shape is assumed for the axial direction in the pin (all ζ_j = 1.0), and the radial power distribution (μ_i) is again taken from Fig. 3 of Reference 1.

The sodium coolant enters the bottom of the configuration, coming from a constant temperature source (Ψ_0 = 260°C), and flows upward. Hence, for the first coolant region (L = 3) the velocity is positive and the parameter ICS = 0. The coolant then flows from region 3 to the top of region 5 and downward through that region. Therefore, for the second coolant region the velocity is input as a negative number, and the parameter ICS is input as ICS = 3. The film coefficient equations are taken from Reference 6.

A complete set of input sheets and problem output sheets follows Fig. 6. The ARGUS problem required approximately 10 min of machine time on an IBM-704 with a monitor system.

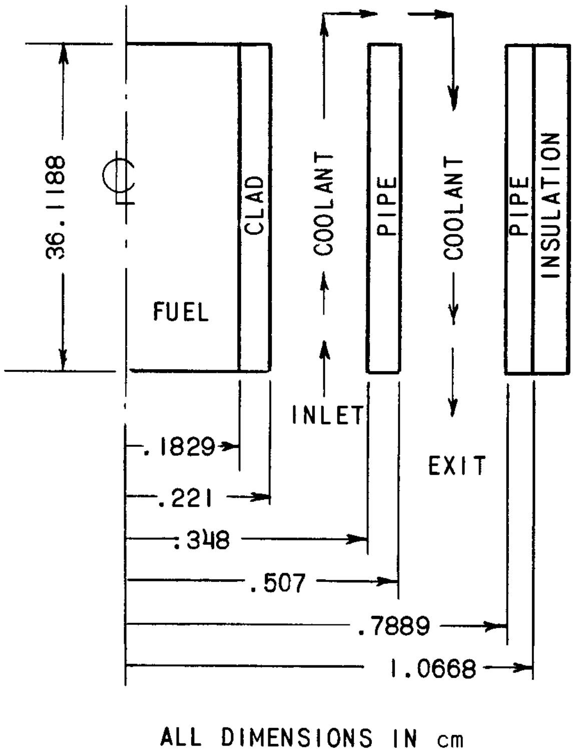

Fig. 6

The Configuration of Sample Problem No. 3

704 INPUT DATA

FORM I

COST CODE 46351-01

PROGRAM ARGUS RE 248 PROBLEM 26.00017 ORIGINATOR Daniel F. Schoeberle DATE 7/31/62 PAGE 1 OF 3

1–12	13–24	25–36	37–48	49–60	61–72	73–80
1 ARGUS TEST	PROB. NO. 3.	EBR-2 PIN IN	SMALL TREAT	LOOP, SERIES	FLOW.	1100
26.00017						1200
0 18	5 6	4 6	32 32	32 100		1300
36.1188	1.20	0.002	980.0	0.01	0.01	1400
0.01	0.05	0.05	0.05			1500
7 1	1 0.	1829				2011
3 2	2 0.	2210				2021
1 4	5 0.	3480				2031
3 3	4 0.	5070				2041
1 4	5 0.	7899				2051
3 3	4 1.	0668				2061
567.859	1.0	1.0	0.0			2500
0.9753	0.9754	0.9772	0.9825	0.9933	1.0097	3011 A
1.0317						3011 B
1.0	1.0	1.0	1.0	1.0	1050.0	3012
1 0	1					4011
457.2	260.0	881.0	0.254			4012
0.80	0.80	0.661	0.80	0.40	0.0	4013
0.0215	6.015	0.028	0.00	2.648	0.0	4014

AMD-8 (9-60)

704 INPUT DATA
FORM I

COST CODE 46351-01

PROGRAM ARGUS RE248 PROBLEM 26.00017 ORIGINATOR Daniel F. Schoeberle DATE 7/31/62 PAGE 2 OF 3

1 3	1					4021
-90.0498	0.0	881.0	0.5658			4022
0.80	0.80	0.661	0.80	0.40	0.0	4023
0.0215	6.015	0.028	0.00	2.648	0.0	4024
0.227	0.276	0.325	0.4117	0.4809	0.5313	5011
2.571	2.883	3.210	3.175	10.402	2.911	5012
390.0	520.0	662.0	1000.0	1080.0		5013
0.0	0.0	221.0	0.0	0.0		5014
0.1894	0.2105	0.2739	0.2510	0.2510	0.2510	5021
2.859	3.018	3.346	3.346	3.346	3.346	5022
98.0	427.0	940.0	1200.0	1300.0		5023
0.0	0.0	0.0	0.0	0.0		5024
0.196	0.222	0.248	0.274	0.300	0.300	5031
4.413	4.733	4.928	5.053	5.077	5.077	5032
450.0	650.0	850.0	1050.0	1250.0		5033
0.0	0.0	0.0	0.0	0.0		5034
0.9212	-0.579-03	1.453-07				6011
1.354	-7.865-04	3.662-07	9.999+29			6012

AMD-8 (9-60)

704 INPUT DATA
FORM I

COST CODE 46351-01

PROGRAM ARGUS RE248 PROBLEM 26.00017 ORIGINATOR Daniel F. Schoeberle DATE 7/31/62 PAGE 3 OF 3

1–10	11–20	21–30	31–40	41–50	51–60	61–70	71–80
5.490-03	-6.825-06	3.375-09					6013
0.9484	-2.107-04	-3.612-08					6014
40 1							7001
7.000-02	2.50 -01	7.00 -01	2.00 +00	7.00 +00	1.80 +01		7002 A
3.60 +01	3.70 +01	2.50 +01	1.50 +01	7.00 +00	3.50 +00		7002 B
2.00 +00	1.30 +00	1.05 +00	9.00 -01	8.40 -01	7.80 -01		7002 C
7.40 -01	7.00 -01	6.80 -01	6.60 -01	6.40 -01	6.20 -01		7002 D
6.00 -01	5.70 -01	5.60 -01	5.40 -01	5.20 -01	5.00 -01		7002 E
4.90 -01	4.80 -01	4.60 -01	4.50 -01	4.40 -01	4.30 -01		7002 F
4.20 -01	4.10 -01	4.00 -01	0.0				7002 G
50.0							7003
1							8000
3 1							8101
1.0	1.0	1.0					8102
1000.0							8103
0							9000
260.0	260.0	260.0	260.0	260.0	260.0		9001

AMD-8 (9-60)

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ARGUS TEST PROB. NO.3.EBR-2 PIN IN SMALL TREAT LOOP,SERIES FLOW.            1089/RE248  PROB.NO. 26.00017  PAGE   1

INPUT

 GENERAL PROBLEM DATA
  IMAX= 18       JMAX= 5  LMAX= 6        MMAX= 4  NPMAX= 6      NH(1)= 32  NH(2)= 32    NH(3)= 32  NPR=100
  Z=         3.61188E 01  FINAL TAU= 1.20000E 00  DELTA TAU= 2.00000E-03  G=           9.80000E 02  EPSD(1)=  10.00000E-03
  EPSD(2)= 10.00000E-03  EPSD(3)=  10.00000E-03  EPSH(1)=    5.00000E-02  EPSH(2)=     5.00000E-02  EPSH(3)=   5.00000E-02

  NI(L)=  7   3   1   3   1   3
  M(L)=   1   2   4   3   4   3
  K(L)=   1   2   5   4   5   4

  R(L)
1.82900E-01 2.21000E-01 3.48000E-01 5.07000E-01 7.89900E-01 1.06680E 00

  U(L)
5.67859E 02 1.00000E 00 0.          1.00000E 00 0.          0.


 POWER DISTRIBUTION DATA

  MU(I)  (READ ACROSS)
9.75300E-01 9.75400E-01 9.77200E-01 9.82500E-01 9.93300E-01 1.00970E 00 1.03170E 00 0.          0.          0.
0.          0.          0.          0.          0.          0.          0.          0.

  ZETA(L,J)  (READ ACROSS)
   L= 1
1.00000E 00 1.00000E 00 1.00000E 00 1.00000E 00 1.00000E 00

  QO(L)  (READ ACROSS)
1.05000E 03 0.          0.          0.          0.          0.


 FLOWING COOLANT REGION DATA  (READ DOWN)

  L  IPT  ICS  IH          VO          PSIO        PSIS         DE          A1          A2          A3
  3   1    0   1      4.57200E 02 2.60000E 02 8.81000E 02 2.54000E-01 8.00000E-01 8.00000E-01 6.61000E-01
  5   1    3   1     -9.00498E 01 0.          8.81000E 02 5.65800E-01 8.00000E-01 8.00000E-01 6.61000E-01

    B1          B2          H1          H2          H3          H4          H5          H6
8.00000E-01 4.00000E-01 2.15000E-02 6.01500E 00 2.80000E-02 0.          2.64800E 00 0.
8.00000E-01 4.00000E-01 2.15000E-02 6.01500E 00 2.80000E-02 0.          2.64800E 00 0.


 MATERIAL PROPERTIES

  K  (ONE ROW FOR EACH MATERIAL)
2.27000E-01 2.76000E-01 3.25000E-01 4.11700E-01 4.80900E-01 5.31300E-01
1.89400E-01 2.10500E-01 2.73900E-01 2.51000E-01 2.51000E-01 2.51000E-01
1.96000E-01 2.22000E-01 2.48000E-01 2.74000E-01 3.00000E-01 3.00000E-01
9.21200E-01-5.79000E-04 1.45300E-07
```

```
  RHO*C  (ONE ROW FOR EACH MATERIAL)
2.57100E 00 2.88300E 00 3.21000E 00 3.17500E 00 1.04020E 01 2.91100E 00
2.85900E 00 3.01800E 00 3.34600E 00 3.34600E 00 3.34600E 00 3.34600E 00
4.41300E 00 4.73300E 00 4.92800E 00 5.05300E 00 5.07700E 00 5.07700E 00
1.35400E 00-7.86500E-04 3.66200E-07 9.99900E 29

  TT OR NU  (ONE ROW FOR EACH MATERIAL)
3.90000E 02 5.20000E 02 6.62000E 02 1.00000E 03 1.08000E 03
9.80000E 01 4.27000E 02 9.40000E 02 1.20000E 03 1.30000E 03
4.50000E 02 6.50000E 02 8.50000E 02 1.05000E 03 1.25000E 03
5.49000E-03-6.82500E-06 3.37500E-09

  RHO*DH OR RHO  (ONE ROW FOR EACH MATERIAL)
0.          0.          2.21000E 02 0.          0.
0.          0.          0.          0.          0.
0.          0.          0.          0.          0.
9.48400E-01-2.10700E-04-3.61200E-08


 N(TAU) DATA

  NN= 40   NBETA= 1  P=-0.

  N(TAU)  (READ ACROSS)
7.00000E-02 2.50000E-01 7.00000E-01 2.00000E 00 7.00000E 00 1.80000E 01 3.60000E 01 3.70000E 01 2.50000E 01 1.50000E 01
7.00000E 00 3.50000E 00 2.00000E 00 1.30000E 00 1.05000E 00 9.00000E-01 8.40000E-01 7.80000E-01 7.40000E-01 7.00000E-01
6.80000E-01 6.60000E-01 6.40000E-01 6.20000E-01 6.00000E-01 5.70000E-01 5.60000E-01 5.40000E-01 5.20000E-01 5.00000E-01
4.90000E-01 4.80000E-01 4.60000E-01 4.50000E-01 4.40000E-01 4.30000E-01 4.20000E-01 4.10000E-01 4.00000E-01 0.

  BETA
5.00000E 01


 PHI(TAU) DATA

  NPHI=  3   NGAMMA= 1

  PHI(TAU)  (READ ACROSS)
1.00000E 00 1.00000E 00 1.00000E 00

  GAMMA
1.00000E 03
```

```
OUTPUT

TAU=        0.                  DELTA TAU(1)= 2.00000E-03          DELTA TAU(2)= 2.00000E-03

H(B,L,J)
2.25927E 01 2.25927E 01 2.25927E 01 2.25927E 01 2.25927E 01
2.25927E 01 2.25927E 01 2.25927E 01 2.25927E 01 2.25927E 01
9.25178E 00 9.25178E 00 9.25178E 00 9.25178E 00 9.25178E 00
9.25178E 00 9.25178E 00 9.25178E 00 9.25178E 00 9.25178E 00

TEMPERATURES  (READ I ACROSS, J DOWN)
2.60000E 02 2.60000E 02 2.60000E 02 2.60000E 02 2.60000E 02 2.60000E 02 2.60000E 02 2.60000E 02 2.60000E 02 2.6000E 02
2.60000E 02 2.60000E 02 2.60000E 02 2.60000E 02 2.60000E 02 2.60000E 02 2.60000E 02 2.60000E 02
2.60000E 02 2.60000E 02 2.60000E 02 2.60000E 02 2.60000E 02 2.60000E 02 2.60000E 02 2.60000E 02 2.60000E 02 2.6000E 02
2.60000E 02 2.60000E 02 2.60000E 02 2.60000E 02 2.60000E 02 2.60000E 02 2.60000E 02 2.60000E 02
2.60000E 02 2.60000E 02 2.60000E 02 2.60000E 02 2.60000E 02 2.60000E 02 2.60000E 02 2.60000E 02 2.60000E 02 2.6000E 02
2.60000E 02 2.60000E 02 2.60000E 02 2.60000E 02 2.60000E 02 2.60000E 02 2.60000E 02 2.60000E 02
2.60000E 02 2.60000E 02 2.60000E 02 2.60000E 02 2.60000E 02 2.60000E 02 2.60000E 02 2.60000E 02 2.60000E 02 2.6000E 02
2.60000E 02 2.60000E 02 2.60000E 02 2.60000E 02 2.60000E 02 2.60000E 02 2.60000E 02 2.60000E 02
2.60000E 02 2.60000E 02 2.60000E 02 2.60000E 02 2.60000E 02 2.60000E 02 2.60000E 02 2.60000E 02 2.60000E 02 2.6000E 02
2.60000E 02 2.60000E 02 2.60000E 02 2.60000E 02 2.60000E 02 2.60000E 02 2.60000E 02 2.60000E 02


TAU=        2.00000E-01         DELTA TAU(1)= 2.00000E-03          DELTA TAU(2)= 2.00000E-03

H(B,L,J)
2.25927E 01 2.25716E 01 2.25636E 01 2.25610E 01 2.25593E 01
2.25927E 01 2.25716E 01 2.25636E 01 2.25610E 01 2.25593E 01
9.25126E 00 9.25111E 00 9.25089E 00 9.24926E 00 9.23705E 00
9.25126E 00 9.25111E 00 9.25089E 00 9.24926E 00 9.23705E 00

TEMPERATURES  (READ I ACROSS, J DOWN)
2.79299E 02 2.79048E 02 2.78277E 02 2.76911E 02 2.74820E 02 2.71804E 02 2.67585E 02 2.67221E 02 2.64006E 02 2.6127E 02
2.60000E 02 2.60000E 02 2.60001E 02 2.60004E 02 2.60006E 02 2.60003E 02 2.60000E 02 2.60000E 02
2.79647E 02 2.79412E 02 2.78689E 02 2.77408E 02 2.75446E 02 2.72615E 02 2.68652E 02 2.68292E 02 2.65305E 02 2.6285E 02
2.61737E 02 2.61463E 02 2.60352E 02 2.60079E 02 2.60036E 02 2.60019E 02 2.60001E 02 2.60000E 02
2.79753E 02 2.79524E 02 2.78819E 02 2.77570E 02 2.75659E 02 2.72900E 02 2.69041E 02 2.68683E 02 2.65790E 02 2.6346E 02
2.62409E 02 2.62020E 02 2.60477E 02 2.60127E 02 2.60081E 02 2.60043E 02 2.60003E 02 2.60000E 02
2.79782E 02 2.79554E 02 2.78855E 02 2.77617E 02 2.75721E 02 2.72988E 02 2.69165E 02 2.68807E 02 2.65948E 02 2.6366E 02
2.62635E 02 2.62208E 02 2.60566E 02 2.60352E 02 2.60406E 02 2.60232E 02 2.60019E 02 2.60003E 02
2.79796E 02 2.79570E 02 2.78873E 02 2.77641E 02 2.75757E 02 2.73039E 02 2.69240E 02 2.68882E 02 2.66046E 02 2.6379E 02
2.62780E 02 2.62367E 02 2.61036E 02 2.62037E 02 2.62780E 02 2.61712E 02 2.60168E 02 2.60028E 02


TAU=        4.00000E-01         DELTA TAU(1)= 2.00000E-03          DELTA TAU(2)= 2.00000E-03

H(B,L,J)
2.25927E 01 2.25716E 01 2.25636E 01 2.25610E 01 2.25593E 01
2.25927E 01 2.25716E 01 2.25636E 01 2.25610E 01 2.25593E 01
9.25126E 00 9.25111E 00 9.25089E 00 9.24926E 00 9.23705E 00
9.25126E 00 9.25111E 00 9.25089E 00 9.24926E 00 9.23705E 00

TEMPERATURES  (READ I ACROSS, J DOWN)
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ARGUS TEST PROB. NO.3.EBR-2 PIN IN SMALL TREAT LOOP,SERIES FLOW.              1089/RE248  PROB.NO. 26.00017  PAGE   4
4.36726E 02 4.34614E 02 4.28078E 02 4.16385E 02 3.98306E 02 3.72387E 02 3.32713E 02 3.29100E 02 2.98307E 02 2.7211E 02
2.60000E 02 2.60003E 02 2.60029E 02 2.60104E 02 2.60147E 02 2.60092E 02 2.60010E 02 2.60001E 02
4.40623E 02 4.38606E 02 4.32369E 02 4.21273E 02 4.04315E 02 3.80176E 02 3.42986E 02 3.39411E 02 3.10742E 02 2.8718E 02
2.76494E 02 2.73919E 02 2.63716E 02 2.61047E 02 2.60620E 02 2.60395E 02 2.60047E 02 2.60010E 02
4.42102E 02 4.40126E 02 4.34028E 02 4.23220E 02 4.06767E 02 3.83383E 02 3.47237E 02 3.43677E 02 3.15903E 02 2.9345E 02
2.83372E 02 2.79723E 02 2.65372E 02 2.61812E 02 2.61334E 02 2.60851E 02 2.60103E 02 2.60023E 02
4.42790E 02 4.40837E 02 4.34807E 02 4.24118E 02 4.07844E 02 3.84714E 02 3.48927E 02 3.45373E 02 3.17925E 02 2.9588E 02
2.86038E 02 2.82050E 02 2.66776E 02 2.64620E 02 2.65095E 02 2.63270E 02 2.60421E 02 2.60102E 02
4.43321E 02 4.41385E 02 4.35409E 02 4.24815E 02 4.08683E 02 3.85755E 02 3.50256E 02 3.46706E 02 3.19518E 02 2.9781E 02
2.88143E 02 2.84328E 02 2.72284E 02 2.81311E 02 2.88143E 02 2.78089E 02 2.62425E 02 2.60635E 02

DUMP NUMBER   1  TAU =    5.82999E-01


TAU=        5.99999E-01            DELTA TAU(1)=10.00000E-04            DELTA TAU(2)=10.00000E-04

H(B,L,J)
2.25927E 01 2.20171E 01 2.17698E 01 2.16714E 01 2.15919E 01
2.25927E 01 2.20171E 01 2.17698E 01 2.16714E 01 2.15919E 01
9.23362E 00 9.22530E 00 9.21282E 00 9.15057E 00 8.80875E 00
9.23362E 00 9.22530E 00 9.21282E 00 9.15057E 00 8.80875E 00

TEMPERATURES  (READ I ACROSS, J DOWN)
1.02186E 03 1.01394E 03 9.93460E 02 9.33890E 02 8.43445E 02 7.22174E 02 5.65786E 02 5.56070E 02 4.25178E 02 3.1232E 02
2.60000E 02 2.60034E 02 2.60338E 02 2.61073E 02 2.61454E 02 2.60968E 02 2.60134E 02 2.60035E 02
1.03799E 03 1.03153E 03 1.01078E 03 9.74420E 02 8.96596E 02 7.84100E 02 6.35357E 02 6.25821E 02 5.01158E 02 3.9465E 02
3.44631E 02 3.34391E 02 2.85411E 02 2.68463E 02 2.65566E 02 2.63770E 02 2.60543E 02 2.60149E 02
1.04554E 03 1.03931E 03 1.02040E 03 9.92000E 02 9.20572E 02 8.12398E 02 6.62000E 02 6.56776E 02 5.45255E 02 4.5058E 02
3.93122E 02 3.74289E 02 2.98712E 02 2.75093E 02 2.71654E 02 2.67905E 02 2.61152E 02 2.60319E 02
1.04786E 03 1.04218E 03 1.02512E 03 9.99683E 02 9.29459E 02 8.18882E 02 6.78842E 02 6.63977E 02 5.59405E 02 4.7176E 02
4.17722E 02 3.96543E 02 3.11040E 02 2.96572E 02 2.98859E 02 2.86730E 02 2.64121E 02 2.61193E 02
1.05079E 03 1.04545E 03 1.02946E 03 1.00297E 03 9.37733E 02 8.36021E 02 7.07834E 02 6.99411E 02 5.81017E 02 4.9147E 02
4.37922E 02 4.18199E 02 3.52583E 02 4.01954E 02 4.37922E 02 3.82263E 02 2.80289E 02 2.66260E 02


TAU=        7.99998E-01            DELTA TAU(1)=10.00000E-04            DELTA TAU(2)=10.00000E-04

H(B,L,J)
2.25927E 01 2.05427E 01 1.94876E 01 1.89908E 01 1.85453E 01
2.25927E 01 2.05427E 01 1.94876E 01 1.89908E 01 1.85453E 01
9.15862E 00 9.10488E 00 9.02051E 00 8.69463E 00 7.44085E 00
9.15862E 00 9.10488E 00 9.02051E 00 8.69463E 00 7.44085E 00

TEMPERATURES  (READ I ACROSS, J DOWN)
1.17194E 03 1.15891E 03 1.11993E 03 1.05524E 03 9.45544E 02 8.00154E 02 6.19815E 02 6.11660E 02 4.62288E 02 3.2460E 02
2.60000E 02 2.60217E 02 2.62115E 02 2.65817E 02 2.67493E 02 2.65392E 02 2.60949E 02 2.60307E 02
1.33681E 03 1.32381E 03 1.28488E 03 1.22032E 03 1.13049E 03 1.01583E 03 8.63202E 02 8.54779E 02 6.97683E 02 5.5365E 02
4.57035E 02 4.43062E 02 3.43101E 02 2.94571E 02 2.85752E 02 2.78801E 02 2.63451E 02 2.61158E 02
1.42680E 03 1.41440E 03 1.37724E 03 1.31546E 03 1.22922E 03 1.11863E 03 9.83817E 02 9.75804E 02 8.21754E 02 6.8174E 02
5.83230E 02 5.53690E 02 3.94482E 02 3.24834E 02 3.13541E 02 2.99372E 02 2.67307E 02 2.62456E 02
1.49294E 03 1.48108E 03 1.44554E 03 1.38652E 03 1.30423E 03 1.19888E 03 1.07069E 03 1.06548E 03 9.05890E 02 7.6270E 02
6.59912E 02 6.23861E 02 4.49761E 02 4.06528E 02 4.08579E 02 3.71899E 02 2.82688E 02 2.68074E 02
1.56253E 03 1.55171E 03 1.51928E 03 1.46533E 03 1.38988E 03 1.29287E 03 1.17417E 03 1.16541E 03 9.98890E 02 8.5188E 02
7.44612E 02 7.10760E 02 6.03003E 02 6.82313E 02 7.44612E 02 6.26532E 02 3.48389E 02 2.94973E 02

DUMP NUMBER   2  TAU =    9.16997E-01
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ARGUS TEST PROB. NO.3.EBR-2 PIN IN SMALL TREAT LOOP,SERIES FLOW.                1089/RE248  PROB.NO. 26.00017  PAGE   5

TAU=        9.99997E-01            DELTA TAU(1)=10.00000E-04            DELTA TAU(2)=10.00000E-04

H(B,L,J)
2.25927E 01 2.06269E 01 1.90768E 01 1.81281E 01 1.66176E 01
2.25927E 01 2.06269E 01 1.90768E 01 1.81281E 01 1.66675E 01
9.02956E 00 8.83599E 00 8.54745E 00 7.84278E 00 6.56880E 00
9.02956E 00 8.83599E 00 8.54745E 00 7.84278E 00 6.56880E 00

TEMPERATURES  (READ I ACROSS, J DOWN)
7.45527E 02 7.36807E 02 7.10705E 02 6.67509E 02 6.08054E 02 5.26791E 02 4.29805E 02 4.25981E 02 3.56284E 02 2.9069E 02
2.60000E 02 2.60774E 02 2.67397E 02 2.77608E 02 2.81568E 02 2.76781E 02 2.63843E 02 2.61527E 02
1.01760E 03 1.00166E 03 9.52965E 02 8.96206E 02 8.27606E 02 7.48361E 02 6.62000E 02 6.55112E 02 5.54771E 02 4.6232E 02
4.00145E 02 3.98493E 02 3.61894E 02 3.26743E 02 3.20237E 02 3.08345E 02 2.72251E 02 2.65173E 02
1.08234E 03 1.07863E 03 1.06135E 03 1.01957E 03 9.50049E 02 8.70298E 02 7.79070E 02 7.75552E 02 6.85326E 02 5.9879E 02
5.35160E 02 5.26715E 02 4.47350E 02 3.90024E 02 3.80203E 02 3.56422E 02 2.84970E 02 2.70705E 02
1.13680E 03 1.13106E 03 1.11390E 03 1.08540E 03 1.04570E 03 9.68667E 02 8.78281E 02 8.74762E 02 7.83970E 02 6.9611E 02
6.27940E 02 6.21379E 02 5.55339E 02 5.25063E 02 5.22930E 02 4.74069E 02 3.24108E 02 2.89937E 02
1.24936E 03 1.24321E 03 1.22488E 03 1.19469E 03 1.15317E 03 1.10098E 03 1.03893E 03 1.03642E 03 9.45549E 02 8.5813E 02
7.84310E 02 7.89358E 02 7.86062E 02 7.91572E 02 7.84310E 02 7.16477E 02 4.41166E 02 3.58840E 02


TAU=        1.19999E 00            DELTA TAU(1)=10.00000E-04            DELTA TAU(2)=10.00000E-04

H(B,L,J)
2.25927E 01 2.20552E 01 2.04580E 01 1.93386E 01 1.78226E 01
2.25927E 01 2.20552E 01 2.04580E 01 1.93386E 01 1.78226E 01
8.96615E 00 8.70919E 00 8.30783E 00 7.68247E 00 7.10928E 00
8.96615E 00 8.70919E 00 8.30783E 00 7.68247E 00 7.10928E 00

TEMPERATURES  (READ I ACROSS, J DOWN)
4.71161E 02 4.66896E 02 4.54239E 02 4.33641E 02 4.05815E 02 3.71689E 02 3.30566E 02 3.29567E 02 3.00437E 02 2.7295E 02
2.60000E 02 2.61680E 02 2.75822E 02 2.93384E 02 2.99275E 02 2.92573E 02 2.69765E 02 2.64761E 02
5.58508E 02 5.53418E 02 5.38425E 02 5.14477E 02 4.81351E 02 4.40078E 02 3.91998E 02 3.90810E 02 3.49467E 02 3.0962E 02
2.90183E 02 2.96180E 02 3.32247E 02 3.43581E 02 3.47421E 02 3.35068E 02 2.86123E 02 2.73920E 02
6.81246E 02 6.78766E 02 6.71843E 02 6.62000E 02 6.15050E 02 5.66689E 02 5.10895E 02 5.09549E 02 4.69555E 02 4.2827E 02
3.99245E 02 4.07544E 02 4.31867E 02 4.27176E 02 4.27697E 02 4.04002E 02 3.11544E 02 2.87947E 02
7.67729E 02 7.63564E 02 7.51033E 02 7.30003E 02 7.00262E 02 6.62000E 02 6.14609E 02 6.13236E 02 5.72410E 02 5.2984E 02
4.97967E 02 5.10480E 02 5.46869E 02 5.49122E 02 5.48285E 02 5.13496E 02 3.69229E 02 3.25821E 02
9.65314E 02 9.58687E 02 9.39736F 02 9.10857E 02 8.74135E 02 8.30913E 02 7.82052E 02 7.80484E 02 7.31829E 02 6.8318E 02
6.44061E 02 6.62285E 02 7.11151E 02 6.77058E 02 6.44061E 02 6.34682E 02 4.94374E 02 4.28101E 02

B
 0.          5.15121E-02 7.72682E-02 8.58536E-02 9.01462E-02 8.55148E-02 1.05051E-02 8.89400E-01 1.83130E-01 1.1825E-01
 0.          1.21836E-01 6.37388E-03 1.34811E-02 2.14787E-02 2.81180E-02 2.14428E-03 4.47871E-03
 0.          5.44783E-02 8.17174E-02 8.58536E-02 9.01462E-02 9.27218E-02 1.25679E-02 8.89400E-01 1.83130E-01 1.1896E-01
1.17264E-01 1.18938E-01 6.37388E-03 1.34811E-02 2.13475E-02 2.73121E-02 2.14428E-03 4.47871E-03
 0.          6.97722E-02 1.04658E-01 1.16287E-01 9.53370E-02 9.80609E-02 1.25679E-02 8.75803E-01 2.14928E-01 1.4245E-01
1.15524E-01 1.10324E-01 6.37388E-03 1.34811E-02 2.10953E-02 2.60535E-02 2.14428E-03 4.47871E-03
 0.          6.97722E-02 1.04658E-01 1.16287E-01 1.22101E-01 1.25590E-01 1.45562E-02 8.75803E-01 2.14928E-01 1.4412E-01
1.13736E-01 9.72366E-02 6.73128E-03 1.42371E-02 2.05615E-02 2.24634E-02 2.14428E-03 4.47871E-03
 0.          6.97722E-02 1.04658E-01 1.16287E-01 1.22101E-01 1.25590E-01 1.83959E-02 8.75803E-01 2.14928E-01 1.4644E-01
1.10282E-01 8.60681E-02 7.22208E-03 1.52752E-02 0.          2.07874E-02 2.26451E-03 4.47871E-03
C
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ARGUS TEST PROB. NO.3.EBR-2 PIN IN SMALL TREAT LOOP,SERIES FLOW.            1089/RE248  PROB.NO. 26.00017  PAGE   6
 5.87903E-01 7.93951E-01 7.93951E-01 7.93951E-01 7.93951E-01 8.09967E-01-7.68827E-01-8.15216E-01 6.15609E-01 2.5819E-01
 0.          8.63350E-01 9.85945E-01 9.33320E-01 9.36039E-01 9.67053E-01 9.95366E-01 9.95521E-01
 5.64174E-01 7.82087E-01 7.82087E-01 7.93951E-01 7.93951E-01 7.93951E-01-7.44930E-01-8.15216E-01 6.15609E-01 2.6580E-01
 6.98084E-01 8.66249E-01 9.85945E-01 9.34845E-01 9.45393E-01 9.67859E-01 9.95366E-01 9.95521E-01
 4.41823E-01 7.20911E-01 7.20911E-01 7.20911E-01 7.82087E-01 7.82087E-01-7.44930E-01-7.98265E-01 5.48865E-01 2.9147E-01
 7.02565E-01 8.74862E-01 9.85945E-01 9.37226E-01 9.46039E-01 9.69118E-01 9.95366E-01 9.95521E-01
 4.41823E-01 7.20911E-01 7.20911E-01 7.20911E-01 7.20911E-01 7.20911E-01-7.20663E-01-7.98265E-01 5.48865E-01 3.0661E-01
 7.07167E-01 8.87119E-01 9.85157E-01 9.43262E-01 9.47404E-01 9.72437E-01 9.95366E-01 9.95521E-01
 4.41823E-01 7.20911E-01 7.20911E-01 7.20911E-01 7.20911E-01 7.20911E-01-7.24359E-01-7.98265E-01 5.48865E-01 3.2770E-01
 6.59497E-01 8.97147E-01 9.84075E-01 9.46952E-01 0.          9.74113E-01 9.95106E-01 9.95521E-01
D
 4.12097E-01 1.54536E-01 1.28780E-01 1.20195E-01 1.15902E-01 1.04518E-01 8.73909E-01 1.82080E-02 2.01260E-01 2.5266E-01
 0.          1.48139E-02 7.68070E-03 5.31989E-02 3.34636E-02 4.82865E-03 2.48983E-03 0.
 4.35826E-01 1.63435E-01 1.36196E-01 1.20195E-01 1.15902E-01 1.13327E-01 8.59897E-01 1.82080E-02 2.01260E-01 2.4814E-01
 1.84651E-01 1.48139E-02 7.68070E-03 5.16743E-02 3.32591E-02 4.82865E-03 2.48983E-03 0.
 5.58177E-01 2.09317E-01 1.74430E-01 1.62802E-01 1.22576E-01 1.19852E-01 8.59897E-01 2.33298E-02 2.36206E-01 2.1182E-01
 1.81911E-01 1.48139E-02 7.68070E-03 4.92929E-02 3.28662E-02 4.82865E-03 2.48983E-03 0.
 5.58177E-01 2.09317E-01 1.74430E-01 1.62802E-01 1.56987E-01 1.53499E-01 8.45775E-01 2.33298E-02 2.36206E-01 2.0257E-01
 1.79096E-01 1.56446E-02 8.11139E-03 4.25005E-02 3.20346E-02 5.09941E-03 2.48983E-03 0.
 5.58177E-01 2.09317E-01 1.74430E-01 1.62802E-01 1.56987E-01 1.53499E-01 8.43784E-01 2.33298E-02 2.36206E-01 1.8971E-01
 1.73656E-01 1.67853E-02 8.70282E-03 3.77733E-02 0.          5.09941E-03 2.62945E-03 0.
E(N,J)
 0.          2.55157E-02 2.62794E-02 2.70352E-02 5.65652E-02
-9.01851E-03-4.56760E-03-4.67037E-03-4.83888E-03 0.
G
 3.55208E-01 3.55245E-01 3.55900E-01 3.57830E-01 3.61764E-01 4.12363E-01 4.21348E-01 0.          0.          0.
 0.          0.          0.          0.          0.          0.          0.          0.
 3.19023E-01 3.19056E-01 3.19645E-01 3.57830E-01 3.61764E-01 3.67737E-01 3.75749E-01 0.          0.          0.
 0.          0.          0.          0.          0.          0.          0.          0.
 3.22540E-01 3.22573E-01 3.23168E-01 3.24921E-01 3.24911E-01 3.30276E-01 3.75749E-01 0.          0.          0.
 0.          0.          0.          0.          0.          0.          0.          0.
 3.22540E-01 3.22573E-01 3.23168E-01 3.24921E-01 3.28493E-01 3.33917E-01 3.37472E-01 0.          0.          0.
 0.          0.          0.          0.          0.          0.          0.          0.
 3.22540E-01 3.22573E-01 3.23168E-01 3.24921E-01 3.28493E-01 3.33917E-01 3.41192E-01 0.          0.          0.
 0.          0.          0.          0.          0.          0.          0.          0.

 TAU=FINAL TAU.  END OF PROB.NO.  26.00017
* * ALL DATA PROCESSED.

EXECUTION TERMINATED BY LOAD DRUM, VIA OPERATOR OR PROGRAM.
```

APPENDIX

FORTRAN Program Listing

```
C     MAIN PROGRAM   1089/RE248   J HEESTAND   9/62
C
C     PURPOSE--(1) READ AND STORE PROGRAM INPUT DATA.
C              (2) TEST FOR TAKING AUTOMATIC PERIODIC RESTART DUMPS.
C              (3) LINK REMAINING CALCULATIONS VIA SUBROUTINES.
C     SUBROUTINES USED--LINER, INPRNT, PRELIM, ITERAT, POST, (RTN),
C              (LEV), (STH), (CSH), (FIL), (BDC), (DBC), (IOH)O, (IOH)I.
C
      DIMENSION AF(25),AMU(100),ANU(10,9),A1(10),A2(10),A3(10),
     1          B(100,16),BETA(10),B1(10),B2(10),
     2          C(100,16),CAY(10,10),CURPHI(4),
     3          D(100,16),DE(10),DENTAU(2),DIAN(10),DPHI(4),
     4          DR(25),DT(2),DTT(10,10),DTT1(10,9),
     5          E(10,16),EE(25),ENTAU(500),EPSD(3),EPSH(3),
     6          F(25),G(100,16),GAMMA(4,10),
     7          H(2,10,16),H1(10),H2(10),H3(10),H4(10),H5(10),H6(10),
     8          ICS(10),IH(10),IP(100,16),IPF(2,10,16),IPT(10),
     9          ITYPE(100),K(25),M(25),MM(25)
      DIMENSION NF(25),NFI(4),NG(4),NGAM(4),NGAMMA(4),NH(3),NI(25),
     1          NNH(3),NPHI(4),PHI(4,250),PSIS(10),PSIO(10),
     2          QMUZ(100,16),Q0(25),
     3          R(25),RHO(10,9),RHOC(10,10),RHODH(10,9),ROC(10,16),
     4          ROW(10),R2(100),SL2(3),SL3(3),
     5          T(100,16),TAUN(9),TAUP(4,9),TDT(100,16),TEMP(25),
     6          TITLE(12),TPRIME(100,16),TT(10,9),U(25),V(10),V0(10),
     7          WIDAN(10),W1(25),W2(25),Y(1      ),ZETA(25,16)
      EQUIVALENCE (Y,TDT),(ANU,TT),(RHO,RHODH)
      COMMON AF,AK,AMU,ANEW,ANU,A1,A2,A3,B,BETA,B1,B2,
     1       C,CAY,CURPHI,CURREN,D,DE,DEK,DENTAU,DIAN,
     2       DPHI,DR,DT,DTT,DTT1,DZ,DZ2,E,EE,EM,EN,ENTAU,
     3       EPSD,EPSH,F,G,GAMMA,GEE,GR,H,HPRIME,H1,H2,H3,H4,H5,H6,
     4       I,ICNTRL,ICS,IH,IJ,IJSUM,ILINE,IMAX,INIT,IP,IPAGE,
     5       IPF,IPT,ITEMP,ITYP,ITYPE,IX,J,JLINE,JMAX,JMX,J1,
     6       K,L,LA,LB,LINE,LLINE,LMAX,L1,L2,M,MINML,ML,MM,MMAX,
     7       N,NABCDM,NABCDR,NACR,NB,NBET,NBETA,NDTH,NDUMP,
     8       NENTAU,NF,NFI,NFR,NG,NGAM,NGAMMA,NH,NI,NIL,NN,
     9       NNEXT,NNH,NP,NPHI,NPMAX,NPMX,NPR,NPRC,NPT,N1,N2,N3,N4
      COMMON P,PHI,PR,PROB,PSIS,PSIO,QMUZ,Q0,R,RE,RHO,RHOC,
     1       RO,ROC,ROW,R2,SL2,SL3,S1,S2,S3,T,TAU,TAUF,TAUN,
     2       TAUP,TDT,TEMP,TITLE,TPRIME,T1PR,T2PR,T3PR,
     3       U,V,V0,WIDAN,W1,W2,X,X0,X1,X2,X3,Z,ZETA
    1 FORMAT (12A6)
    2 FORMAT (6E12.5)
    3 FORMAT (12I6)
    4 FORMAT (3I6,E12.5)
    5 FORMAT (2I6,E12.5)
    6 FORMAT (F9.5)
    7 FORMAT (13H0DUMP NUMBER I3,7H  TAU =1PE14.5)
    8 FORMAT (54H0 DELTA TAU HAS BEEN HALVED 4 TIMES.  END OF PROB.NO. F
     19.5)
   10 DO 15 I=1,21000
   15 Y(I)=0.0
   20 SENSE LIGHT 0
C
C     READ AND STORE GENERAL PROBLEM AND REGION DATA
C
   25 READ INPUT TAPE 7,1,(TITLE(I),I=1,12)
   30 READ INPUT TAPE 7,6,PROB
   35 READ INPUT TAPE 7,3,NDUMP,IMAX,JMAX,LMAX,MMAX,NPMAX,NH(1),NH(2),
     1                    NH(3),NPR
   40 IF (NDUMP) 1111,90,45
   45 N=NDUMP-1
```

```
   50 IF (N) 111,65,55
   55 DO 60 I=1,N
   60 READ TAPE 9
   65 READ TAPE 9,(Y(I),I=1,21000)
   70 CALL LINER
   75 WRITE OUTPUT TAPE 6,7,NDUMP,TAU
   80 LINE=LINE+2
   85 GO TO 845
   90 READ INPUT TAPE 7,2,Z,TAUF,DT(1),GEE,EPSD(1),EPSD(2),EPSD(3),
     1                         EPSH(1),EPSH(2),EPSH(3)
   95 NABCDR=0
  100 DO 135 L=1,LMAX
  105 READ INPUT TAPE 7,4,NI(L),M(L),K(L),R(L)
  110 IF (K(L)-5) 115,130,1111
  115 NABCDR=NABCDR+1
  120 MM(L)=M(L)
  125 GO TO 135
  130 MM(L)=0
  135 CONTINUE
  140 NFR=LMAX-NABCDR
  145 NABCDM=0
  150 DO 190 L=1,LMAX
  155 IF (MM(L)) 111,190,160
  160 NABCDM=NABCDM+1
  161 IF (L-LMAX) 165,190,111
  165 L1=L+1
  170 DO 185 L2=L1,LMAX
  175 IF (MM(L2)-M(L)) 185,180,185
  180 MM(L2)=0
  185 CONTINUE
  190 CONTINUE
  195 DO 200 L=1,LMAX
  200 MM(L)=0
C
C     READ NON-COOLANT REGION DATA
C
  205 IF (NABCDR) 111,245,210
  210 READ INPUT TAPE 7,2,(TEMP(N),N=1,NABCDR)
  215 N=0
  220 DO 240 L=1,LMAX
  225 IF (K(L)-5) 230,240,111
  230 N=N+1
  235 U(L)=TEMP(N)
  240 CONTINUE
C
C     READ AND STORE POWER DISTRIBUTION DATA
C
  245 NACR=0
  250 N=1
  255 NIL=NI(1)
  260 DO 295 L=1,LMAX
  265 IF (K(L)-3) 270,275,290
  270 IF (K(L)-1) 1111,275,290
  275 READ INPUT TAPE 7,2,(AMU(I),I=N,NIL)
  280 READ INPUT TAPE 7,2,(ZETA(L,J),J=1,JMAX),QO(L)
  285 NACR=NACR+1
  290 N=1+NIL
  295 NIL=NIL+NI(L+1)
C
C     READ AND STORE COOLANT REGION DATA
C
  300 IF (NFR) 1111,325,305
```

```
  305 DO 321 N=1,NFR
  310 READ INPUT TAPE 7,3,IPT(N),ICS(N),IH(N)
  315 READ INPUT TAPE 7,2,V0(N),PSI0(N),PSIS(N),DE(N)
  320 READ INPUT TAPE 7,2,A1(N),A2(N),A3(N),B1(N),B2(N)
  321 READ INPUT TAPE 7,2,H1(N),H2(N),H3(N),H4(N),H5(N),H6(N)
C
C     READ AND STORE MATERIAL PROPERTY DATA
C
  325 IF (NABCDM) 111,420,330
  330 DO 415 N=1,NABCDM
  335 MINML=32767
  340 DO 360 L=1,LMAX
  345 IF (MM(L)) 111,350,360
  350 IF (K(L)-5) 355,360,111
  355 MINML=XMINOF(MINML,M(L))
  360 CONTINUE
  365 DO 380 L=1,LMAX
  370 IF (M(L)-MINML) 380,375,380
  375 MM(L)=N
  380 CONTINUE
  385 NPMX=NPMAX-1
  390 READ INPUT TAPE 7,2,(CAY(N,NP),NP=1,NPMAX)
  395 READ INPUT TAPE 7,2,(RHOC(N,NP),NP=1,NPMAX)
  400 IF (NPMX) 1111,415,405
  405 READ INPUT TAPE 7,2,(TT(N,NP),NP=1,NPMX)
  410 READ INPUT TAPE 7,2,(RHODH(N,NP),NP=1,NPMX)
  415 CONTINUE
  420 IF (NFR) 111,525,425
  425 NNEXT=NABCDM+1
  430 DO 505 N=NNEXT,MMAX
  435 MINML=32767
  440 DO 460 L=1,LMAX
  445 IF (MM(L)) 111,450,460
  450 IF (K(L)-5) 111,455,111
  455 MINML=XMINOF(MINML,M(L))
  460 CONTINUE
  465 DO 480 L=1,LMAX
  470 IF (M(L)-MINML) 480,475,480
  475 MM(L)=N
  480 CONTINUE
  485 READ INPUT TAPE 7,2,(CAY(N,NP),NP=1,3)
  490 READ INPUT TAPE 7,2,(RHOC(N,NP),NP=1,4)
  495 READ INPUT TAPE 7,2,(ANU(N,NP),NP=1,3)
  500 READ INPUT TAPE 7,2,(RHO(N,NP),NP=1,3)
  505 CONTINUE
  510 DO 520 L=1,LMAX
  515 M(L)=MM(L)
  520 MM(L)=0
C
C     READ N(TAU) AND PHI(TAU) DATA
C
  525 IF (NACR) 111,565,530
  530 READ INPUT TAPE 7,5,NN,NBETA,P
  535 IF (NN) 1111,565,540
  540 READ INPUT TAPE 7,2,(ENTAU(N),N=1,NN)
  545 READ INPUT TAPE 7,2,(BETA(N),N=1,NBETA)
  550 N1=NBETA-1
  555 IF (N1) 1111,565,560
  560 READ INPUT TAPE 7,2,(TAUN(N),N=1,N1)
  565 IF (NFR) 111,625,570
  570 READ INPUT TAPE 7,3,NPT
  575 DO 620 N=1,NPT
```

```
  580 READ INPUT TAPE 7,3,NPHI(N),NGAMMA(N)
  585 N1=NPHI(N)
  590 READ INPUT TAPE 7,2,(PHI(N,N2),N2=1,N1)
  595 N1=NGAMMA(N)
  600 READ INPUT TAPE 7,2,(GAMMA(N,N2),N2=1,N1)
  605 N1=N1-1
  610 IF (N1) 1111,620,615
  615 READ INPUT TAPE 7,2,(TAUP(N,N2),N2=1,N1)
  620 CONTINUE
C
C     READ AND STORE INITIAL TEMPERATURE DATA
C
  625 J1=JMAX+1
  630 N=0
  635 DO 655 L=1,LMAX
  640 IF (K(L)-5) 655,645,111
  645 N=N+1
  650 NF(L)=N
  655 CONTINUE
  660 READ INPUT TAPE 7,3,ITEMP
  665 IF (ITEMP) 755,700,670
  670 I=ITEMP-1
  675 IF (I) 111,690,680
  680 DO 685 N1=1,I
  685 READ TAPE 10
  690 READ TAPE 10,(Y(I),I=1,1600)
  695 GO TO 765
  700 READ INPUT TAPE 7,2,(TEMP(L),L=1,LMAX)
  705 N=1
  710 NIL=NI(1)
  715 DO 745 L=1,LMAX
  720 DO 730 J=1,JMAX
  725 DO 730 I=N,NIL
  730 TDT(I,J)=TEMP(L)
  735 N=1+NIL
  740 NIL=NIL+NI(L+1)
  745 CONTINUE
  750 GO TO 765
  755 DO 760 I=1,IMAX
  760 READ INPUT TAPE 7,2,(TDT(I,J),J=1,JMAX)
  765 LLINE=(LMAX+9)/10
  770 JLINE=(JMAX+9)/10
  775 ILINE=(IMAX+9)/10
  780 IJ=IMAX*JMAX
  785 IJSUM=-IJ
  790 CALL INPRNT
  791 MINML=6
  795 CALL PRELIM
  796 IF (MINML-7) 800,797,111
  797 SENSE LIGHT 4
  798 CALL TEMPRT
  799 WRITE OUTPUT TAPE 6,8,PROB
      GO TO 10
C
C     TEST FOR TAKING AUTOMATIC PERIODIC RESTART DUMP.
C
  800 IJSUM=IJSUM+IJ
  805 IF (IJSUM-30000) 845,810,810
  810 IJSUM=0
  815 NDUMP=NDUMP+1
  820 WRITE TAPE 9,(Y(I),I=1,21000)
  825 IF (LINE-57) 835,830,830
```

```
 830 CALL LINER
 835 WRITE OUTPUT TAPE 6,7,NDUMP,TAU
 840 LINE=LINE+2
 845 CALL ITERAT
 850 CALL POST
 855 MINML=MINML
 860 GO TO (800,10),MINML
 111 PAUSE 111
 865 GO TO 10
1111 PAUSE 1111
 870 GO TO 10
 875 END (0,1,0,1,0)
```

```
C     SUBROUTINE PRELIM   1089/RE248   J HEESTAND   9/62
C
C     PURPOSE--TO PERFORM ALL NECESSARY PRELIMINARY CALCULATIONS
C              AND INITIALIZATIONS BEFORE STARTING THE ITERATIVE
C              PORTION OF THE PROBLEM.
C     SUBROUTINES USED--HCOMP, COCOMP, LINER, TEMPRT, EXP, (RTN),
C              (LEV), (STH), (FIL), (BDC), (DBC), (IOH)I, (IOH)O.
C
      SUBROUTINE PRELIM
C
      DIMENSION AF(25),AMU(100),ANU(10,9),A1(10),A2(10),A3(10),
     1          B(100,16),BETA(10),B1(10),B2(10),
     2          C(100,16),CAY(10,10),CURPHI(4),
     3          D(100,16),DE(10),DENTAU(2),DIAN(10),DPHI(4),
     4          DR(25),DT(2),DTT(10,10),DTT1(10,9),
     5          E(10,16),EE(25),ENTAU(500),EPSD(3),EPSH(3),
     6          F(25),G(100,16),GAMMA(4,10),
     7          H(2,10,16),H1(10),H2(10),H3(10),H4(10),H5(10),H6(10),
     8          ICS(10),IH(10),IP(100,16),IPF(2,10,16),IPT(10),
     9          ITYPE(100),K(25),M(25),MM(25)
      DIMENSION NF(25),NFI(4),NG(4),NGAM(4),NGAMMA(4),NH(3),NI(25),
     1          NNH(3),NPHI(4),PHI(4,250),PSIS(10),PSIO(10),
     2          QMUZ(100,16),Q0(25),
     3          R(25),RHO(10,9),RHOC(10,10),RHODH(10,9),ROC(10,16),
     4          ROW(10),R2(100),SL2(3),SL3(3),
     5          T(100,16),TAUN(9),TAUP(4,9),TDT(100,16),TEMP(25),
     6          TITLE(12),TPRIME(100,16),TT(10,9),U(25),V(10),V0(10),
     7          WIDAN(10),W1(25),W2(25),Y(1      ),ZETA(25,16)
      EQUIVALENCE (Y,TDT),(ANU,TT),(RHO,RHODH)
      COMMON AF,AK,AMU,ANEW,ANU,A1,A2,A3,B,BETA,B1,B2,
     1       C,CAY,CURPHI,CURREN,D,DE,DEK,DENTAU,DIAN,
     2       DPHI,DR,DT,DTT,DTT1,DZ,DZ2,E,EE,EM,EN,ENTAU,
     3       EPSD,EPSH,F,G,GAMMA,GEE,GR,H,HPRIME,H1,H2,H3,H4,H5,H6,
     4       I,ICNTRL,ICS,IH,IJ,IJSUM,ILINE,IMAX,INIT,IP,IPAGE,
     5       IPF,IPT,ITEMP,ITYP,ITYPE,IX,J,JLINE,JMAX,JMX,J1,
     6       K,L,LA,LB,LINE,LLINE,LMAX,L1,L2,M,MINML,ML,MM,MMAX,
     7       N,NABCDM,NABCDR,NACR,NB,NBET,NBETA,NDTH,NDUMP,
     8       NENTAU,NF,NFI,NFR,NG,NGAM,NGAMMA,NH,NI,NIL,NN,
     9       NNEXT,NNH,NP,NPHI,NPMAX,NPMX,NPR,NPRC,NPT,N1,N2,N3,N4
      COMMON P,PHI,PR,PROB,PSIS,PSIO,QMUZ,Q0,R,RE,RHO,RHOC,
     1       RO,ROC,ROW,R2,SL2,SL3,S1,S2,S3,T,TAU,TAUF,TAUN,
     2       TAUP,TDT,TEMP,TITLE,TPRIME,T1PR,T2PR,T3PR,
     3       U,V,V0,WIDAN,W1,W2,X,X0,X1,X2,X3,Z,ZETA
    4 FORMAT(7HOOUTPUT)
C
C     ASSIGN ITYPE(I)
C
```

```
    5 N2=1
   10 NIL=NI(1)
   15 DO 265 L=1,LMAX
   20 DO 255 N=N2,NIL
   25 IF (K(L)-4) 30,75,35
   30 IF (K(L)-2) 175,185,85
   35 IF (L-LMAX) 40,65,222
   40 IF (L-1) 222,45,55
   45 ITYPE(N)=1
   50 GO TO 255
   55 ITYPE(N)=2
   60 GO TO 255
   65 ITYPE(N)=3
   70 GO TO 255
   75 N1=0
   80 GO TO 90
   85 N1=16
   90 IF (N-NIL) 95,100,222
   95 IF (N-N2) 222,150,140
  100 IF (L-LMAX) 105,110,222
  105 IF (L-1) 222,120,130
  110 ITYPE(N)=9+N1
  115 GO TO 255
  120 ITYPE(N)=7+N1
  125 GO TO 255
  130 ITYPE(N)=8+N1
  135 GO TO 255
  140 ITYPE(N)=6+N1
  145 GO TO 255
  150 IF (L-1) 222,155,165
  155 ITYPE(N)=4+N1
  160 GO TO 255
  165 ITYPE(N)=5+N1
  170 GO TO 255
  175 N1=5
  180 GO TO 190
  185 N1=0
  190 IF (N-NIL) 195,235,222
  195 IF (N-N2) 222,210,200
  200 ITYPE(N)=12+N1
  205 GO TO 255
  210 IF (L-1) 222,215,225
  215 ITYPE(N)=10+N1
  220 GO TO 255
  225 ITYPE(N)=11+N1
  230 GO TO 255
  235 IF (L-LMAX) 240,250,222
  240 ITYPE(N)=13+N1
  245 GO TO 255
  250 ITYPE(N)=14+N1
  255 CONTINUE
  260 N2=NIL+1
  265 NIL=NIL+NI(L+1)
C
C     PRELIMINARY CALCULATIONS
C
  270 DT(2)=DT(1)
  275 JMX=JMAX-1
  280 IF (JMX) 222,285,295
  285 DZ=Z
  290 GO TO 310
  295 S1=JMX
```

```
300 DZ=Z/S1
305 DZ2=2.0*DZ
310 N=0
315 DO 500 L=1,LMAX
320 IF (K(L)-2) 435,435,325
325 IF (K(L)-5) 330,385,222
330 IF (L-1) 222,335,355
335 DR(L)=R(L)
340 W1(L)=0.0
345 EE(L)=0.0
350 GO TO 370
355 DR(L)=(R(L)-R(L-1))*.5
360 W1(L)=(2.*R(L-1)+DR(L))/(4.*R(L-1)+DR(L))
365 EE(L)=8.*R(L-1)/(4.*R(L-1)+DR(L))
370 W2(L)=(2.*R(L)-DR(L))/(4.*R(L)-DR(L))
375 F(L)=8.*R(L)/(4.*R(L)-DR(L))
380 GO TO 500
385 N=N+1
395 IF (L-1) 222,415,400
400 DR(L)=R(L)-R(L-1)
405 DIAN(N)=R(L)+R(L-1)
410 GO TO 425
415 DR(L)=R(L)
420 DIAN(N)=R(L)
425 WIDAN(N)=DR(L)**3
430 GO TO 500
435 S1=NI(L)-1
440 IF (L-1) 222,445,475
445 DR(L)=R(L)/S1
450 W1(L)=0.0
455 W2(L)=(2.*R(L)-DR(L))/(4.*R(L)-DR(L))*4.
460 EE(L)=0.0
465 F(L)=8.*R(L)/(4.*R(L)-DR(L))
470 GO TO 500
475 DR(L)=(R(L)-R(L-1))/S1
480 W1(L)=(2.*R(L-1)+DR(L))/(4.*R(L-1)+DR(L))*4.
485 W2(L)=(2.*R(L)-DR(L))/(4.*R(L)-DR(L))*4.
490 EE(L)=8.*R(L-1)/(4.*R(L-1)+DR(L))
495 F(L)=8.*R(L)/(4.*R(L)-DR(L))
500 CONTINUE
505 N=1
510 NIL=NI(1)
515 DO 570 L=1,LMAX
520 S1=-1.0
525 IF (K(L)-4) 530,530,565
530 DO 560 I=N,NIL
535 S1=S1+1.0
540 IF (L-1) 222,545,555
545 R2(I)=2.0*DR(L)*S1
550 GO TO 560
555 R2(I)=(R(L-1)+S1*DR(L))*2.0
560 CONTINUE
565 N=1+NIL
570 NIL=NIL+NI(L+1)
575 DO 605 ML=1,NABCDM
580 DTT(ML,1)=RHODH(ML,1)/RHOC(ML,1)
585 IF (NPMAX-1) 222,605,590
590 DO 600 NP=2,NPMAX
595 DTT(ML,NP)=RHODH(ML,NP)/RHOC(ML,NP)
600 DTT1(ML,NP)=RHODH(ML,NP-1)/RHOC(ML,NP)
605 CONTINUE
C
```

```
C     COMPUTE INITIAL PHASES
C
  615 N=1
  620 NIL=NI(1)
  625 DO 815 L=1,LMAX
  630 ML=M(L)
  635 IF (K(L)-5) 640,705,222
  640 DO 695 I=N,NIL
  645 DO 695 J=1,JMAX
  646 QMUZ(I,J)=QO(L)*AMU(I)*ZETA(L,J)
  650 IF (NPMX) 222,655,665
  655 NP=1
  660 GO TO 690
  665 DO 680 NP=1,NPMX
  670 NP=NP
  675 IF (TDT(I,J)-TT(ML,NP)) 690,690,680
  680 CONTINUE
  685 NP=NPMAX
  690 IP(I,J)=NP
  695 CONTINUE
  700 GO TO 810
  705 N2=NF(L)
  710 IF (L-1) 222,715,725
  715 AF(L)=.5*R(L)*R(L)
  720 GO TO 730
  725 AF(L)=.5*(R(L)+R(L-1))*(R(L)-R(L-1))
  730 I=N
  735 DO 805 J=1,JMAX
  736 QMUZ(I,J)=0.0
  740 IF (TDT(I,J)-PSIS(N2)) 765,745,745
  745 IPF(1,N2,J)=3
  750 IPF(2,N2,J)=3
  755 SENSE LIGHT 2
  760 GO TO 805
  765 IF (TDT(I-1,J)-PSIS(N2)) 780,770,770
  770 IPF(1,N2,J)=2
  775 GO TO 785
  780 IPF(1,N2,J)=1
  785 IF (TDT(I+1,J)-PSIS(N2)) 800,790,790
  790 IPF(2,N2,J)=2
  795 GO TO 805
  800 IPF(2,N2,J)=1
  805 CONTINUE
  810 N=1+NIL
  815 NIL=NIL+NI(L+1)
  820 IF (K(1)-5) 835,825,222
  825 DO 830 J=1,JMAX
  830 IPF(1,1,J)=0
  835 IF (K(LMAX)-5) 850,840,222
  840 DO 845 J=1,JMAX
  845 IPF(2,NFR,J)=0
  850 IF (NFR) 222,1025,855
  855 DO 910 N=1,NFR
  860 IF (ICS(N)) 222,865,890
  865 IF (VO(N)) 870,880,880
  870 MM(N)=2
  875 GO TO 910
  880 MM(N)=1
  885 GO TO 910
  890 IF (VO(N)) 895,905,905
  895 MM(N)=4
  900 GO TO 910
```

```
  905 MM(N)=3
  910 CONTINUE
  915 DO 925 I=1,NPT
  920 DPHI(I)=(PHI(I,2)-PHI(I,1))/GAMMA(I,1)
  925 CURPHI(I)=PHI(I,1)+DPHI(I)/2.0
  930 NNH(1)=1
  935 NNH(2)=1
  940 NNH(3)=1
  945 DO 960 I=1,NPT
  950 NFI(I)=1
  955 NGAM(I)=1
  960 NG(I)=1
  965 I=1
  970 NIL=NI(1)
  975 DO 1020 L=1,LMAX
  980 IF (K(L)-5) 1015,985,222
  985 N=NF(L)
  990 ML=M(L)
  995 IF (VO(N)) 1000,1010,1010
 1000 ROW(N)=RHO(ML,1)+TDT(I,JMAX)*(RHO(ML,2)+TDT(I,JMAX)*RHO(ML,3))
 1005 GO TO 1015
 1010 ROW(N)=RHO(ML,1)+TDT(I,1)*(RHO(ML,2)+TDT(I,1)*RHO(ML,3))
 1015 I=1+NIL
 1020 NIL=NIL+NI(L+1)
 1025 IF (NACR) 222,1075,1030
 1030 IF (NN) 222,1035,1045
 1035 CURREN=(1.0+EXPF(DT(1)/P))/2.0
 1040 GO TO 1060
 1045 DENTAU(1)=(ENTAU(2)-ENTAU(1))/BETA(1)
 1050 DENTAU(2)=DENTAU(1)
 1055 CURREN=ENTAU(1)+DENTAU(1)*.5
 1060 NB=1
 1065 NBET=1
 1070 NENTAU=1
 1075 INIT=1
 1146 NDTH=0
C
C      CALCULATE INITIAL H(B,N,J)
C
 1080 L2=1
 1085 CALL HCOMP
C
C      CALCULATE INITIAL COEFFICIENTS
C
 1090 LA=1
 1095 LB=1
 1100 CALL COCOMP
 1105 CALL LINER
 1110 WRITE OUTPUT TAPE 6,4
 1115 LINE=LINE+3
 1120 TAU=0.0
 1125 CALL TEMPRT
 1130 DO 1140 I=1,IMAX
 1135 DO 1140 J=1,JMAX
 1140 T(I,J)=TDT(I,J)
 1145 NPRC=1
 1150 GO TO 1155
  222 PAUSE 222
 1155 RETURN
 1160 END (0,1,0,1,0)
```

```
C     SUBROUTINE ITERAT   1089/RE248   J HEESTAND   8/62
C
C     PURPOSE--EVALUATE NEW TEMPERATURES AT EACH POINT USING
C             TEMPERATURE DIFFERENCE EQUATIONS.
C     SUBROUTINES USED--EXP
C     CALLED BY--MAIN PROGRAM
C
      SUBROUTINE ITERAT
C
      DIMENSION AF(25),AMU(100),ANU(10,9),A1(10),A2(10),A3(10),
     1          B(100,16),BETA(10),B1(10),B2(10),
     2          C(100,16),CAY(10,10),CURPHI(4),
     3          D(100,16),DE(10),DENTAU(2),DIAN(10),DPHI(4),
     4          DR(25),DT(2),DTT(10,10),DTT1(10,9),
     5          E(10,16),EE(25),ENTAU(500),EPSD(3),EPSH(3),
     6          F(25),G(100,16),GAMMA(4,10),
     7          H(2,10,16),H1(10),H2(10),H3(10),H4(10),H5(10),H6(10),
     8          ICS(10),IH(10),IP(100,16),IPF(2,10,16),IPT(10),
     9          ITYPE(100),K(25),M(25),MM(25)
      DIMENSION NF(25),NFI(4),NG(4),NGAM(4),NGAMMA(4),NH(3),NI(25),
     1          NNH(3),NPHI(4),PHI(4,250),PSIS(10),PSIO(10),
     2          QMUZ(100,16),QO(25),
     3          R(25),RHO(10,9),RHOC(10,10),RHODH(10,9),ROC(10,16),
     4          ROW(10),R2(100),SL2(3),SL3(3),
     5          T(100,16),TAUN(9),TAUP(4,9),TDT(100,16),TEMP(25),
     6          TITLE(12),TPRIME(100,16),TT(10,9),U(25),V(10),VO(10),
     7          WIDAN(10),W1(25),W2(25),Y(1      ),ZETA(25,16),ZOTS(32)
      EQUIVALENCE (Y,TDT),(ANU,TT),(RHO,RHODH)
      COMMON AF,AK,AMU,ANEW,ANU,A1,A2,A3,B,BETA,B1,B2,
     1       C,CAY,CURPHI,CURREN,D,DE,DEK,DENTAU,DIAN,
     2       DPHI,DR,DT,DTT,DTT1,DZ,DZ2,E,EE,EM,EN,ENTAU,
     3       EPSD,EPSH,F,G,GAMMA,GEE,GR,H,HPRIME,H1,H2,H3,H4,H5,H6,
     4       I,ICNTRL,ICS,IH,IJ,IJSUM,ILINE,IMAX,INIT,IP,IPAGE,
     5       IPF,IPT,ITEMP,ITYP,ITYPE,IX,J,JLINE,JMAX,JMX,J1,
     6       K,L,LA,LB,LINE,LLINE,LMAX,L1,L2,M,MINML,ML,MM,MMAX,
     7       N,NABCDM,NABCDR,NACR,NB,NBET,NBETA,NDTH,NDUMP,
     8       NENTAU,NF,NFI,NFR,NG,NGAM,NGAMMA,NH,NI,NIL,NN,
     9       NNEXT,NNH,NP,NPHI,NPMAX,NPMX,NPR,NPRC,NPT,N1,N2,N3,N4
      COMMON P,PHI,PR,PROB,PSIS,PSIO,QMUZ,QO,R,RE,RHO,RHOC,
     1       RO,ROC,ROW,R2,SL2,SL3,S1,S2,S3,T,TAU,TAUF,TAUN,
     2       TAUP,TDT,TEMP,TITLE,TPRIME,T1PR,T2PR,T3PR,
     3       U,V,VO,WIDAN,W1,W2,X,XO,X1,X2,X3,Z,ZETA
    5 DO 15 J=1,JMAX
   10 DO 15 I=1,IMAX
   15 T(I,J)=SWAPF(T(I,J),TDT(I,J))
   20 ICNTRL=1
   25 TAU=TAU+DT(1)
   30 IF (NFR) 333,325,35
   35 IF (JMX) 333,325,40
C
C     COMPUTE COOLANT TEMPERATURES.
C
   40 L1=1
   45 I=1
   50 NIL=NI(1)
   55 DO 80 L=1,LMAX
   60 IF (K(L)-5) 75,65,333
   65 N=NF(L)
   70 IF (MM(N)-2) 185,205,75
   75 I=NIL+1
   80 NIL=NI(L+1)+NIL
```

```
  85 L1=2
  90 N3=0
  95 I=1
 100 NIL=NI(1)
 105 DO 160 L=1,LMAX
 110 IF (K(L)-5) 155,115,333
 115 N=NF(L)
 120 IF (MM(N+10)) 333,125,155
 125 N4=ICS(N)
 130 N4=NF(N4)
 135 IF (MM(N4+10)) 333,140,150
 140 N3=1
 145 GO TO 155
 150 IF (MM(N)-3) 333,185,205
 155 I=NIL+1
 160 NIL=NI(L+1)+NIL
 165 IF (N3) 333,170,90
 170 DO 175 N=1,NFR
 175 MM(N+10)=0
 180 GO TO 270
 185 N1=JMAX
 190 TDT(I,1)=PSIO(N)
 195 TDT(I,N1)=B(I,N1)*T(I-1,N1)+C(I,N1)*T(I,N1)+D(I,N1)*T(I+1,N1)+
    1          E(N,N1)*T(I,N1-1)
 200 GO TO 220
 205 N1=1
 210 TDT(I,JMAX)=PSIO(N)
 215 TDT(I,1)=B(I,1)*T(I-1,1)+C(I,1)*T(I,1)+D(I,1)*T(I+1,1)-
    1          E(N,1)*T(I,2)
 220 DO 225 J=2,JMX
 225 TDT (I,J)=B(I,J)*T(I-1,J)+C(I,J)*T(I,J)+D(I,J)*T(I+1,J)+
    1          E(N,J)*(T(I,J-1)-T(I,J+1))
 226 IF (NFR-1) 333,270,230
 230 MM(N+10)=1
 235 DO 260 N2=1,NFR
 240 N4=ICS(N2)
 241 IF (N4) 245,260,245
 245 N4=NF(N4)
 250 IF (N4-N) 260,255,260
 255 PSIO(N2)=TDT(I,N1)
 260 CONTINUE
 265 GO TO (75,155),L1
C
C     SET TEMPERATURE OF BOILING COOLANT POINTS TO PSIS(N).
C
 270 I=1
 275 NIL=NI(1)
 280 DO 320 L=1,LMAX
 285 IF (5-K(L)) 333,290,315
 290 N=NF(L)
 295 DO 310 J=1,JMAX
 300 IF (PSIS(N)-TDT(I,J))305,310,310
 305 TDT(I,J)=PSIS(N)
 310 CONTINUE
 315 I=NIL+1
 320 NIL=NIL+NI(L+1)
C
C     COMPUTE TEMPERATURE OF INTERIOR POINTS OF THICK REGIONS.
C
 325 N1=1
 330 NIL=NI(1)
 335 DO 375 L=1,LMAX
```

```
  340 IF (K(L)-2) 345,345,370
  345 IF (L-1) 333,346,348
  346 N2=1
  347 GO TO 350
  348 N2=N1+1
  350 N3=NIL-1
  355 DO 365 I=N2,N3
  360 DO 365 J=1,JMAX
  365 TDT(I,J)=B(I,J)*T(I-1,J)+C(I,J)*T(I,J)+D(I,J)*T(I+1,J)+
     1          G(I,J)*CURREN
  370 N1=NIL+1
  375 NIL=NIL+NI(L+1)
C
C     COMPUTE THIN REGION TEMPERATURES.
C
  380 X2=0.0
  381 N1=1
  385 NIL=NI(1)
  390 L=1
  395 J1=0
  396 IF (K(L)-3) 810,404,400
  400 IF (K(L)-4) 333,405,810
  404 J1=1
  405 IF (INIT-1) 333,410,430
C
C     NO INNER ITERATIONS.
C
  410 DO 420 J=1,JMAX
  415 DO 420 I=N1,NIL
  420 TDT(I,J)=B(I,J)*T(I-1,J)+C(I,J)*T(I,J)+D(I,J)*T(I+1,J)+
     1          G(I,J)*CURREN
  425 GO TO 810
C
C     INNER ITERATIONS.
C     DETERMINE TYPE OF REGION TO LEFT AND RIGHT OF THIN REGION(S)
C     AND NUMBER OF HORIZONTAL POINTS IN THIN REGION(S).
C
  430 IF (L-1) 333,435,450
  435 L1=1
  440 IX=2
  445 GO TO 475
  450 IF (K(L-1)-5) 465,455,333
  455 L1=2
  460 GO TO 470
  465 L1=3
  470 IX=3
  475 IF (L-LMAX) 476,520,333
  476 N2=L+1
  480 DO 505 L2=N2,LMAX
  485 L2=L2
  490 IF (K(L2)-3) 530,499,495
  495 IF (K(L2)-4) 333,500,530
  499 J1=1
  500 IX=IX+3
  505 L=L+1
  510 L2=LMAX
  520 L2=1
  525 GO TO 550
  530 IF (K(L2)-5) 545,535,333
  535 L2=2
  540 GO TO 550
  545 L2=3
```

```
  550 N2=N1+IX-1
C
C      SAVE OLD BOUNDARY TEMPERATURES.
C
  555 DO 560 J=1,JMAX
  560 ZOTS(J)=T(N1,J)
  565 DO 570 J=1,JMAX
  570 ZOTS(J+16)=T(N2,J)
  575 S3=INIT
  580 IF (J1) 333,610,585
  585 IF (NN) 333,590,605
  590 X1=TAU-DT(1)
  595 X2=(EXPF(X1/P)+EXPF((X1+DT(2))/P))*.5
  600 GO TO 610
  605 X2=CURREN-DENTAU(1)+DENTAU(2)
  610 DO 780 IX=1,INIT
  615 X0=IX-1
  620 DO 730 J=1,JMAX
  625 GO TO (630,640,655),L1
  630 T1PR=0.0
  635 GO TO 660
  640 S1=(TDT(N1-1,J)-T(N1-1,J))/S3
  645 T1PR=T(N1-1,J)+X0*S1
  650 GO TO 660
  655 T1PR=T(N1-1,J)
  660 GO TO (665,675,690),L2
  665 T2PR=0.0
  670 GO TO 695
  675 S2=(TDT(N2+1,J)-T(N2+1,J))/S3
  680 T2PR=T(N2+1,J)+X0*S2
  685 GO TO 695
  690 T2PR=T(N2+1,J)
  695 TDT(N1,J)=B(N1,J)*T1PR+C(N1,J)*T(N1,J)+D(N1,J)*T(N1+1,J)+
     1          G(N1,J)*X2
  700 TDT(N2,J)=B(N2,J)*T(N2-1,J)+C(N2,J)*T(N2,J)+D(N2,J)*T2PR+
     1          G(N2,J)*X2
  705 IF (N2-N1-1) 333,730,710
  710 N3=N1+1
  715 N4=N2-1
  720 DO 725 I=N3,N4
  725 TDT(I,J)=B(I,J)*T(I-1,J)+C(I,J)*T(I,J)+D(I,J)*T(I+1,J)+G(I,J)*X2
  730 CONTINUE
  735 DO 745 J=1,JMAX
  740 DO 745 I=N1,N2
  745 T(I,J)=TDT(I,J)
  750 IF (J1) 333,780,755
  755 IF (NN) 333,760,775
  760 X1=X1+DT(2)
  765 X2=(EXPF(X1/P)+EXPF((X1+DT(2))/P))*.5
  770 GO TO 780
  775 X2=X2+DENTAU(2)
  780 CONTINUE
C
C      RESTORE OLD BOUNDARY TEMPERATURES.
C
  785 DO 790 J=1,JMAX
  790 T(N1,J)=ZOTS(J)
  795 DO 800 J=1,JMAX
  800 T(N2,J)=ZOTS(J+16)
  805 NIL=N2
  810 IF (L-LMAX) 815,835,333
  815 L=L+1
```

```
  820 N1=NIL+1
  825 NIL=NIL+NI(L)
  830 GO TO 395
C
C     COMPUTE THICK REGION BOUNDARY TEMPERATURES.
C
  835 N1=1
  840 NIL=NI(1)
  845 DO 955 L=1,LMAX
  850 IF (K(L)-2) 855,855,950
  855 IF (L-1) 333,880,860
  860 N2=K(L-1)
  865 GO TO (880,880,870,870,870),N2
C
C     THICK LEFT BOUNDARY NEXT TO THIN OR COOLANT REGION.
C
  870 DO 875 J=1,JMAX
  875 TDT(N1,J)=B(N1,J)*(TDT(N1-1,J)+T(N1-1,J))+C(N1,J)*T(N1,J)+
     1            D(N1,J)*(TDT(N1+1,J)+T(N1+1,J))+G(N1,1)*CURREN
  880 IF (L-LMAX) 885,940,333
  885 N2=K(L+1)
  890 GO TO (895,895,940,940,940),N2
C
C     INTERFACE OF TWO ADJACENT THICK REGIONS.
C
  895 DO 930 J=1,JMAX
  900 X0=B(NIL,J)*(TDT(NIL-1,J)+T(NIL-1,J))+C(NIL,J)*T(NIL,J)+
     1   D(NIL,J)*T(NIL+1,J)
  905 X1=D(NIL,J)
  910 X2=B(NIL+1,J)*T(NIL,J)+C(NIL+1,J)*T(NIL+1,J)+
     1   D(NIL+1,J)*(TDT(NIL+2,J)+T(NIL+2,J))
  915 X3=B(NIL+1,J)
  920 S3=1.0-X1*X3
  925 TDT(NIL,J)=(X0+X1*X2)/S3+G(NIL,J)*CURREN
  930 TDT(NIL+1,J)=(X2+X3*X0)/S3+G(NIL+1,J)*CURREN
  935 GO TO 950
C
C     THICK RIGHT BOUNDARY NEXT TO THIN OR COOLANT REGION.
C
  940 DO 945 J=1,JMAX
  945 TDT(NIL,J)=B(NIL,J)*(TDT(NIL-1,J)+T(NIL-1,J))+C(NIL,J)*T(NIL,J)+
     1            D(NIL,J)*(TDT(NIL+1,J)+T(NIL+1,J))+G(NIL,J)*CURREN
  950 N1=NIL+1
  955 NIL=NIL+NI(L+1)
  960 GO TO 965
  333 PAUSE 333
  965 RETURN
  970 END (0,1,0,1,0)


C     SUBROUTINE POST   1089/RE248   J HEESTAND   9/62
C
C     PURPOSE--(1) TESTS FOR PROBLEM TERMINATION AND ROUTINE PRINTOUTS.
C              (2) MAINTAINS PROGRAM COUNTERS, N(TAU), AND PHI(TAU).
C              (3) CALLS SUBROUTINES PHASE, HCOMP, AND COCOMP TO
C                  PREPARE FOR NEXT ITERATION.
C              (4) COMPUTES NEW ROW(N) AND E(N,J).
C     SUBROUTINES USED--EXP, PHASE, HCOMP, COCOMP, TEMPRT,
C              (LEV), (IOH)O, (STH), (FIL).
C     CALLED BY--MAIN PROGRAM.
C
```

```
      SUBROUTINE POST
C
      DIMENSION AF(25),AMU(100),ANU(10,9),A1(10),A2(10),A3(10),
     1          B(100,16),BETA(10),B1(10),B2(10),
     2          C(100,16),CAY(10,10),CURPHI(4),
     3          D(100,16),DE(10),DENTAU(2),DIAN(10),DPHI(4),
     4          DR(25),DT(2),DTT(10,10),DTT1(10,9),
     5          E(10,16),EE(25),ENTAU(500),EPSD(3),EPSH(3),
     6          F(25),G(100,16),GAMMA(4,10),
     7          H(2,10,16),H1(10),H2(10),H3(10),H4(10),H5(10),H6(10),
     8          ICS(10),IH(10),IP(100,16),IPF(2,10,16),IPT(10),
     9          ITYPE(100),K(25),M(25),MM(25)
      DIMENSION NF(25),NFI(4),NG(4),NGAM(4),NGAMMA(4),NH(3),NI(25),
     1          NNH(3),NPHI(4),PHI(4,250),PSIS(10),PSIO(10),
     2          QMUZ(100,16),Q0(25),
     3          R(25),RHO(10,9),RHOC(10,10),RHODH(10,9),ROC(10,16),
     4          ROW(10),R2(100),SL2(3),SL3(3),
     5          T(100,16),TAUN(9),TAUP(4,9),TDT(100,16),TEMP(25),
     6          TITLE(12),TPRIME(100,16),TT(10,9),U(25),V(10),VO(10),
     7          WIDAN(10),W1(25),W2(25),Y(1      ),ZETA(25,16)
      EQUIVALENCE (Y,TDT),(ANU,TT),(RHO,RHODH)
      COMMON AF,AK,AMU,ANEW,ANU,A1,A2,A3,B,BETA,B1,B2,
     1       C,CAY,CURPHI,CURREN,D,DE,DEK,DENTAU,DIAN,
     2       DPHI,DR,DT,DTT,DTT1,DZ,DZ2,E,EE,EM,EN,ENTAU,
     3       EPSD,EPSH,F,G,GAMMA,GEE,GR,H,HPRIME,H1,H2,H3,H4,H5,H6,
     4       I,ICNTRL,ICS,IH,IJ,IJSUM,ILINE,IMAX,INIT,IP,IPAGE,
     5       IPF,IPT,ITEMP,ITYP,ITYPE,IX,J,JLINE,JMAX,JMX,J1,
     6       K,L,LA,LB,LINE,LLINE,LMAX,L1,L2,M,MINML,ML,MM,MMAX,
     7       N,NABCDM,NABCDR,NACR,NB,NBET,NBETA,NDTH,NDUMP,
     8       NENTAU,NF,NFI,NFR,NG,NGAM,NGAMMA,NH,NI,NIL,NN,
     9       NNEXT,NNH,NP,NPHI,NPMAX,NPMX,NPR,NPRC,NPT,N1,N2,N3,N4
      COMMON P,PHI,PR,PROB,PSIS,PSIO,QMUZ,Q0,R,RE,RHO,RHOC,
     1       RO,ROC,ROW,R2,SL2,SL3,S1,S2,S3,T,TAU,TAUF,TAUN,
     2       TAUP,TDT,TEMP,TITLE,TPRIME,T1PR,T2PR,T3PR,
     3       U,V,VO,WIDAN,W1,W2,X,X0,X1,X2,X3,Z,ZETA
    1 FORMAT (34H0 TAU=FINAL TAU.  END OF PROB.NO. F9.5)
    2 FORMAT (35H0 N(TAU) USED UP.  END OF PROB.NO. F9.5)
    3 FORMAT (6H0 PHI(I1,32H,TAU) USED UP.  END OF PROB.NO. F9.5)
    4 FORMAT (54H0 DELTA TAU HAS BEEN HALVED 4 TIMES.  END OF PROB.NO. F
     19.5)
C
C     MAINTAIN N(TAU).
C
    5 NBET=NBET
   10 IF (TAU+.5*DT(1)-TAUF) 25,25,15
   15 MINML=1
   20 GO TO 285
   25 IF (NACR) 444,130,30
   30 IF (NN) 444,125,35
   35 IF (NBET-NBETA) 40,45,45
   40 IF (TAU+.5*DT(1)-TAUN(NBET)) 45,70,70
   45 N=BETA(NBET)
   50 IF (NB-N) 55,75,75
   55 NB=NB+1
   60 CURREN=CURREN+DENTAU(1)
   65 GO TO 130
   70 NBET=NBET+1
   75 NENTAU=NENTAU+1
   80 IF (NENTAU-NN) 95,85,85
   85 MINML=2
   90 GO TO 285
   95 NB=1
```

```
  100 DENTAU(1)=(ENTAU(NENTAU+1)-ENTAU(NENTAU))/BETA(NBET)
  105 X=INIT
  110 DENTAU(2)=DENTAU(1)/X
  115 CURREN=ENTAU(NENTAU)+DENTAU(1)*.5
  120 GO TO 130
  125 CURREN=(EXPF(TAU/P)+EXPF((TAU+DT(1))/P))*.5
  130 IF (NFR) 444,240,135
C
C     MAINTAIN PHI(TAU).
C
  135 DO 235 N=1,NPT
  140 N1=NGAM(N)
  145 N2=NFI(N)
  150 N3=GAMMA(N,N1)
  155 IF (NGAM(N)-NGAMMA(N)) 160,165,165
  160 IF (TAU+.5*DT(1)-TAUP(N,N1)) 165,185,185
  165 IF (NG(N)-N3) 170,195,195
  170 NG(N)=NG(N)+1
  175 CURPHI(N)=CURPHI(N)+DPHI(N)
  180 GO TO 235
  185 NGAM(N)=NGAM(N)+1
  190 N1=N1+1
  195 NFI(N)=NFI(N)+1
  200 N2=N2+1
  205 IF (NFI(N)-NPHI(N)) 220,210,210
  210 MINML=3
  215 GO TO 285
  220 NG(N)=1
  225 DPHI(N)=(PHI(N,N2+1)-PHI(N,N2))/GAMMA(N,N1)
  230 CURPHI(N)=PHI(N,N2)+DPHI(N)*.5
  235 CONTINUE
C
C     TEST FOR PRINTING.
C
  240 IF (NPRC-NPR) 245,265,444
  245 NPRC=NPRC+1
  250 IF (SENSE SWITCH 6) 255,280
  255 MINML=4
  260 GO TO 285
  265 NPRC=1
  270 MINML=5
  275 GO TO 285
  280 MINML=6
C
C     TEST PHASE
C
  285 CALL PHASE
  290 IF (NFR) 444,297,410
C
C     COMPUTE NEW ROW(N) AND E(N,J).
C
                  295
  410 IF (JMX) 444,515,415
  415 I=1
  420 NIL=NI(1)
  425 DO 510 L=1,LMAX
  430 IF (K(L)-5) 505,435,444
  435 N=NF(L)
  440 ML=M(L)
  445 IF (VO(N)) 450,465,465
  450 N2=JMAX
  455 N1=1
  460 GO TO 475
```

```
  465 N2=1
  470 N1=JMAX
  475 ROW(N)=RHO(ML,1)+TDT(I,N2)*(RHO(ML,2)+TDT(I,N2)*RHO(ML,3))
  480 S2=RHO(ML,1)+TDT(I,N1)*(RHO(ML,2)+TDT(I,N1)*RHO(ML,3))
  481 C(I,N1)=C(I,N1)+ABSF(E(N,N1))
  485 E(N,N1)=ROW(N)/S2*V(N)/DZ*DT(1)
  486 C(I,N1)=C(I,N1)-ABSF(E(N,N1))
  487 IF (C(I,N1)) 488,490,490
  488 LA=1
  489 LB=1
  491 GO TO 305
  490 DO 500 J=2,JMX
  495 S2=RHO(ML,1)+TDT(I,J)*(RHO(ML,2)+TDT(I,J)*RHO(ML,3))
  500 E(N,J)=ROW(N)/S2*V(N)/DZ2*DT(1)
  505 I=1+NIL
  510 NIL=NI(L+1)+NIL
C
C     COMPUTE NEW H(B,N,J).
C
  295 L2=0
  296 CALL HCOMP
  297 IF (SENSE LIGHT 1) 300,310
  300 LA=2
  301 LB=2
C
C     COMPUTE NEW COEFFICIENTS.
C
  305 CALL COCOMP
  310 IF (NFR) 444,515,315
  315 DO 405 IX=1,3
  320 IF (NNH(IX)-NH(IX)) 325,335,444
  325 NNH(IX)=NNH(IX)+1
  330 GO TO 405
C
C     ADJUST NH ON BASIS OF RESULTS OF HCOMP.
C
  335 DO 355 N=1,NFR
  340 DO 355 J=1,JMAX
  345 DO 355 N1=1,2
  350 IF (IPF(N1,N,J)-IX) 355,365,355
  355 CONTINUE
  360 GO TO 400
  365 IF (SL2(IX)-EPSD(IX)) 370,385,385
  370 IF (NH(IX)-16383) 375,375,400
  375 NH(IX)=NH(IX)+NH(IX)
  380 GO TO 400
  385 IF (SL2(IX)-EPSH(IX)) 400,390,390
  390 IF (NH(IX)-1)444,400,395
  395 NH(IX)=NH(IX)/2
  400 NNH(IX)=1
  401 SL2(IX)=0.0
  405 CONTINUE
  515 MINML=MINML
  520 GO TO (525,545,565,585,600,620,630),MINML
  525 SENSE LIGHT 4
  530 CALL TEMPRT
  535 WRITE OUTPUT TAPE 6,1,PROB
  540 GO TO 610
  545 SENSE LIGHT 4
  550 CALL TEMPRT
  555 WRITE OUTPUT TAPE 6,2,PROB
  560 GO TO 610
```

```
565 SENSE LIGHT 4
570 CALL TEMPRT
575 WRITE OUTPUT TAPE 6,3,PROB
580 GO TO 610
585 SENSE LIGHT 4
590 CALL TEMPRT
595 GO TO 620
600 CALL TEMPRT
605 GO TO 620
610 MINML=2
615 GO TO 625
620 MINML=1
625 RETURN
630 SENSE LIGHT 4
635 CALL TEMPRT
640 WRITE OUTPUT TAPE 6,4,PROB
645 GO TO 610
444 PAUSE 444
650 GO TO 610
655 END (0,1,0,1,0)
```

```
C     SUBROUTINE LINER   1089/RE248   J HEESTAND   8/62
C
C     PURPOSE--(1) INCREASE OUTPUT PAGE NUMBER.
C              (2) RESTORE PAPER.
C              (3) WRITE OUT CASE ID, PROGRAM ID, AND PAGE NUMBER.
C              (4) RESET LINE COUNTER TO 1.
C     SUBROUTINES USED--(LEV), (IOH)O, (STH), (FIL).
C     CALLED BY--MAIN PROGRAM, INPRNT, TEMPRT.
C
      SUBROUTINE LINER
C
      DIMENSION AF(25),AMU(100),ANU(10,9),A1(10),A2(10),A3(10),
     1          B(100,16),BETA(10),B1(10),B2(10),
     2          C(100,16),CAY(10,10),CURPHI(4),
     3          D(100,16),DE(10),DENTAU(2),DIAN(10),DPHI(4),
     4          DR(25),DT(2),DTT(10,10),DTT1(10,9),
     5          E(10,16),EE(25),ENTAU(500),EPSD(3),EPSH(3),
     6          F(25),G(100,16),GAMMA(4,10),
     7          H(2,10,16),H1(10),H2(10),H3(10),H4(10),H5(10),H6(10),
     8          ICS(10),IH(10),IP(100,16),IPF(2,10,16),IPT(10),
     9          ITYPE(100),K(25),M(25),MM(25)
      DIMENSION NF(25),NFI(4),NG(4),NGAM(4),NGAMMA(4),NH(3),NI(25),
     1          NNH(3),NPHI(4),PHI(4,250),PSIS(10),PSIO(10),
     2          QMUZ(100,16),QO(25),
     3          R(25),RHO(10,9),RHOC(10,10),RHODH(10,9),ROC(10,16),
     4          ROW(10),R2(100),SL2(3),SL3(3),
     5          T(100,16),TAUN(9),TAUP(4,9),TDT(100,16),TEMP(25),
     6          TITLE(12),TPRIME(100,16),TT(10,9),U(25),V(10),VO(10),
     7          WIDAN(10),W1(25),W2(25),Y(1      ),ZETA(25,16)
      EQUIVALENCE (Y,TDT),(ANU,TT),(RHO,RHODH)
      COMMON AF,AK,AMU,ANEW,ANU,A1,A2,A3,B,BETA,B1,B2,
     1       C,CAY,CURPHI,CURREN,D,DE,DEK,DENTAU,DIAN,
     2       DPHI,DR,DT,DTT,DTT1,DZ,DZ2,E,EE,EM,EN,ENTAU,
     3       EPSD,EPSH,F,G,GAMMA,GEE,GR,H,HPRIME,H1,H2,H3,H4,H5,H6,
     4       I,ICNTRL,ICS,IH,IJ,IJSUM,ILINE,IMAX,INIT,IP,IPAGE,
     5       IPF,IPT,ITEMP,ITYP,ITYPE,IX,J,JLINE,JMAX,JMX,J1,
     6       K,L,LA,LB,LINE,LLINE,LMAX,L1,L2,M,MINML,ML,MM,MMAX,
     7       N,NABCDM,NABCDR,NACR,NB,NBET,NBETA,NDTH,NDUMP,
     8       NENTAU,NF,NFI,NFR,NG,NGAM,NGAMMA,NH,NI,NIL,NN,
```

```
   9        NNEXT,NNH,NP,NPHI,NPMAX,NPMX,NPR,NPRC,NPT,N1,N2,N3,N4
    COMMON P,PHI,PR,PROB,PSIS,PSIO,QMUZ,QO,R,RE,RHO,RHOC,
   1        RO,ROC,ROW,R2,SL2,SL3,S1,S2,S3,T,TAU,TAUF,TAUN,
   2        TAUP,TDT,TEMP,TITLE,TPRIME,T1PR,T2PR,T3PR,
   3        U,V,VO,WIDAN,W1,W2,X,XO,X1,X2,X3,Z,ZETA
  5 FORMAT (12A6,9X,20H1089/RE248  PROB.NO.F9.5,7H  PAGE I3)
 10 IPAGE=IPAGE+1
 15 WRITE OUTPUT TAPE  6,5,(TITLE(I),I=1,12),PROB,IPAGE
 20 LINE=1
 25 RETURN
 30 END (0,1,0,1,0)



C     SUBROUTINE INPRNT   1089/RE248   J HEESTAND   8/62
C
C     PURPOSE--WRITE OUT CASE INPUT.
C     SUBROUTINES USED--LINER, (LEV), (IOH)O, (STH), (FIL).
C     CALLED BY--MAIN PROGRAM.
C
      SUBROUTINE INPRNT
C
      DIMENSION AF(25),AMU(100),ANU(10,9),A1(10),A2(10),A3(10),
     1          B(100,16),BETA(10),B1(10),B2(10),
     2          C(100,16),CAY(10,10),CURPHI(4),
     3          D(100,16),DE(10),DENTAU(2),DIAN(10),DPHI(4),
     4          DR(25),DT(2),DTT(10,10),DTT1(10,9),
     5          E(10,16),EE(25),ENTAU(500),EPSD(3),EPSH(3),
     6          F(25),G(100,16),GAMMA(4,10),
     7          H(2,10,16),H1(10),H2(10),H3(10),H4(10),H5(10),H6(10),
     8          ICS(10),IH(10),IP(100,16),IPF(2,10,16),IPT(10),
     9          ITYPE(100),K(25),M(25),MM(25)
      DIMENSION NF(25),NFI(4),NG(4),NGAM(4),NGAMMA(4),NH(3),NI(25),
     1          NNH(3),NPHI(4),PHI(4,250),PSIS(10),PSIO(10),
     2          QMUZ(100,16),QO(25),
     3          R(25),RHO(10,9),RHOC(10,10),RHODH(10,9),ROC(10,16),
     4          ROW(10),R2(100),SL2(3),SL3(3),
     5          T(100,16),TAUN(9),TAUP(4,9),TDT(100,16),TEMP(25),
     6          TITLE(12),TPRIME(100,16),TT(10,9),U(25),V(10),VO(10),
     7          WIDAN(10),W1(25),W2(25),Y(1      ),ZETA(25,16)
      EQUIVALENCE (Y,TDT),(ANU,TT),(RHO,RHODH)
      COMMON AF,AK,AMU,ANEW,ANU,A1,A2,A3,B,BETA,B1,B2,
     1       C,CAY,CURPHI,CURREN,D,DE,DEK,DENTAU,DIAN,
     2       DPHI,DR,DT,DTT,DTT1,DZ,DZ2,E,EE,EM,EN,ENTAU,
     3       EPSD,EPSH,F,G,GAMMA,GEE,GR,H,HPRIME,H1,H2,H3,H4,H5,H6,
     4       I,ICNTRL,ICS,IH,IJ,IJSUM,ILINE,IMAX,INIT,IP,IPAGE,
     5       IPF,IPT,ITEMP,ITYP,ITYPE,IX,J,JLINE,JMAX,JMX,J1,
     6       K,L,LA,LB,LINE,LLINE,LMAX,L1,L2,M,MINML,ML,MM,MMAX,
     7       N,NABCDM,NABCDR,NACR,NB,NBET,NBETA,NDTH,NDUMP,
     8       NENTAU,NF,NFI,NFR,NG,NGAM,NGAMMA,NH,NI,NIL,NN,
     9       NNEXT,NNH,NP,NPHI,NPMAX,NPMX,NPR,NPRC,NPT,N1,N2,N3,N4
      COMMON P,PHI,PR,PROB,PSIS,PSIO,QMUZ,QO,R,RE,RHO,RHOC,
     1       RO,ROC,ROW,R2,SL2,SL3,S1,S2,S3,T,TAU,TAUF,TAUN,
     2       TAUP,TDT,TEMP,TITLE,TPRIME,T1PR,T2PR,T3PR,
     3       U,V,VO,WIDAN,W1,W2,X,XO,X1,X2,X3,Z,ZETA
    1 FORMAT (/6HOINPUT/22HO GENERAL PROBLEM DATA/8H   IMAX=I3,6X,5HJMAX
     1=I2,7H  LMAX=I2,8X,5HMMAX=I2,8H  NPMAX=I2,5X,6HNH(1)=I3,8H  NH(2)=
     2I3,4X,6HNH(3)=I3,6H  NPR=I3/3X,2HZ=1PE19.5,12H  FINAL TAU=E12.5,12
     3H  DELTA TAU=E12.5,4H  G=E20.5,10H  EPSD(1)=E14.5/3X,8HEPSD(2)=E13
     4.5,10H  EPSD(3)=E14.5,10H  EPSH(1)=E14.5,10H  EPSH(2)=E14.5,10H  E
     5PSH(3)=E14.5)
    2 FORMAT (9HO  NI(L)=I3,19I4)
```

```
    3 FORMAT (8H    M(L)=20I4)
    4 FORMAT (8H    K(L)=20I4)
    5 FORMAT (7HO  R(L)/(1P10E12.5))
    6 FORMAT (7HO  U(L)/(1P10E12.5))
    7 FORMAT (/25HO POWER DISTRIBUTION DATA/23HO  MU(I)  (READ ACROSS)/(
     11P10E12.5))
    8 FORMAT (27HO  ZETA(L,J)  (READ ACROSS))
    9 FORMAT (4X,2HL=I2/(1P10E12.5))
   10 FORMAT (23HO  QO(L)  (READ ACROSS)/(1P10E12.5))
   11 FORMAT (/42HO FLOWING COOLANT REGION DATA  (READ DOWN)/18HO  L  IP
     1T  ICS  IH11X,2HV09X,4HPSI08X,4HPSIS9X,2HDE10X,2HA110X,2HA210X,2HA
     23)
   12 FORMAT (2I4,I6,I4,1PE18.5,6E12.5)
   13 FORMAT (/5X,2HB110X,2HB210X,        2HH110X,2HH210X,2HH310X,2HH410
     1X,2HH510X,2HH6)
   14 FORMAT (1P10E12.5)
   15 FORMAT (/21HO MATERIAL PROPERTIES/33HO  K  (ONE ROW FOR EACH MATER
     1IAL))
   16 FORMAT (37HO  RHO*C  (ONE ROW FOR EACH MATERIAL))
   17 FORMAT (40HO  TT OR NU  (ONE ROW FOR EACH MATERIAL))
   18 FORMAT (45HO  RHO*DH OR RHO  (ONE ROW FOR EACH MATERIAL))
   19 FORMAT (/13HO N(TAU) DATA/6HO  NN=I3,9H   NBETA=I2,4H  P=1PE12.5)
   20 FORMAT (24HO  N(TAU)  (READ ACROSS))
   21 FORMAT (7HO  BETA/1P10E12.5)
   22 FORMAT (12HO  TAU(BETA)/1P10E12.5)
   23 FORMAT (/15HO PHI(TAU) DATA)
   24 FORMAT (8HO  NPHI=I3,10H   NGAMMA=I2/26HO  PHI(TAU)  (READ ACROSS)
     1)
   25 FORMAT (8HO  GAMMA/1P10E12.5)
   26 FORMAT (13HO  TAU(GAMMA)/1P10E12.5)
   30 CALL LINER
C
C     WRITE OUT GENERAL PROBLEM AND REGION DATA
C
   35 WRITE OUTPUT TAPE  6,1,IMAX,JMAX,LMAX,MMAX,NPMAX,NH(1),NH(2),
     1NH(3),NPR,Z,TAUF,DT(1),GEE,EPSD(1),EPSD(2),EPSD(3),EPSH(1),EPSH(2)
     2,EPSH(3)
   40 WRITE OUTPUT TAPE  6,2,(NI(L),L=1,LMAX)
   45 WRITE OUTPUT TAPE  6,3,(M(L),L=1,LMAX)
   50 WRITE OUTPUT TAPE  6,4,(K(L),L=1,LMAX)
   56 WRITE OUTPUT TAPE  6,5,(R(L),L=1,LMAX)
   60 WRITE OUTPUT TAPE  6,6,(U(L),L=1,LMAX)
   65 LINE=16+LLINE+LLINE
   70 IF (NACR) 555,150,75
C
C     WRITE OUT POWER DISTRIBUTION FUNCTIONS, MU(I), ZETA(J), QO(L)
C
   75 WRITE OUTPUT TAPE  6,7,(AMU(I),I=1,IMAX)
   80 LINE=LINE+7+ILINE
   85 WRITE OUTPUT TAPE  6,8
   90 DO 125 L=1,LMAX
   95 IF (K(L)-3) 100,105,125
  100 IF (K(L)-1)  555,105,125
  105 IF (57-LINE-JLINE) 110,110,115
  110 CALL LINER
  115 WRITE OUTPUT TAPE  6,9,L,(ZETA(L,J),J=1,JMAX)
  120 LINE=LINE+1+JLINE
  125 CONTINUE
  130 IF (56-LINE-LLINE) 135,135,140
  135 CALL LINER
  140 WRITE OUTPUT TAPE 6,10,(QO(L),L=1,LMAX)
  145 LINE=LINE+2+LLINE
```

```
  150 IF (NFR) 555,265,155
C
C     WRITE OUT FLOWING COOLANT REGION DATA
C
  155 IF (53-LINE) 160,160,165
  160 CALL LINER
  165 WRITE OUTPUT TAPE  6,11
  170 LINE=LINE+5
  175 N=0
  180 DO 215 L=1,LMAX
  185 IF (5-K(L)) 555,190,215
  190 N=N+1
  195 IF (58-LINE) 200,200,205
  200 CALL LINER
  205 WRITE OUTPUT TAPE  6,12,L,IPT(N),ICS(N),IH(N),V0(N),PSIO(N),
     1PSIS(N),DE(N),A1(N),A2(N),A3(N)
  210 LINE=LINE+1
  215 CONTINUE
  220 IF (57-LINE) 225,225,230
  225 CALL LINER
  230 WRITE OUTPUT TAPE  6,13
  235 LINE=LINE+2
  240 DO 260 N=1,NFR
  245 IF (58-LINE) 250,250,255
  250 CALL LINER
  255 WRITE OUTPUT TAPE  6,14,B1(N),B2(N),      H1(N),H2(N),H3(N),H4(N),
     1H5(N),H6(N)
  260 LINE=LINE+1
C
C     WRITE OUT MATERIAL PROPERTY DATA
C
  265 IF (53-LINE-MMAX) 270,270,275
  270 CALL LINER
  275 WRITE OUTPUT TAPE  6,15
  280 DO 285 N=1,NABCDM
  285 WRITE OUTPUT TAPE  6,14,(CAY(N,NP),NP=1,NPMAX)
  290 IF (NFR) 555,305,295
  295 DO 300 N=NNEXT,MMAX
  300 WRITE OUTPUT TAPE  6,14,(CAY(N,NP),NP=1,3)
  305 LINE=LINE+5+MMAX
  310 IF (56-LINE-MMAX) 315,315,320
  315 CALL LINER
  320 WRITE OUTPUT TAPE  6,16
  325 DO 330 N=1,NABCDM
  330 WRITE OUTPUT TAPE  6,14,(RHOC(N,NP),NP=1,NPMAX)
  335 IF (NFR) 555,350,340
  340 DO 345 N=NNEXT,MMAX
  345 WRITE OUTPUT TAPE  6,14,(RHOC(N,NP),NP=1,4)
  350 LINE=LINE+2+MMAX
  355 IF (56-LINE-MMAX) 360,360,365
  360 CALL LINER
  365 WRITE OUTPUT TAPE  6,17
  370 IF (NPMX) 555,385,375
  375 DO 380 N=1,NABCDM
  380 WRITE OUTPUT TAPE  6,14,(TT(N,NP),NP=1,NPMX)
  385 IF (NFR) 555,400,390
  390 DO 395 N=NNEXT,MMAX
  395 WRITE OUTPUT TAPE  6,14,(ANU(N,NP),NP=1,3)
  400 LINE=LINE+2+MMAX
  405 IF (56-LINE-MMAX) 410,410,415
  410 CALL LINER
  415 WRITE OUTPUT TAPE  6,18
```

```
  420 IF (NPMX) 555,435,425
  425 DO 430 N=1,NABCDM
  430 WRITE OUTPUT TAPE  6,14,(RHODH(N,NP),NP=1,NPMX)
  435 IF (NFR) 555,450,440
  440 DO 445 N=NNEXT,MMAX
  445 WRITE OUTPUT TAPE  6,14,(RHO(N,NP),NP=1,3)
  450 LINE=LINE+2+MMAX
  455 IF (NACR) 555,595,460
C
C     WRITE OUT HEAT GENERATION FUNCTION, N(TAU)
C
  460 IF (54-LINE) 465,465,470
  465 CALL LINER
  470 WRITE OUTPUT TAPE  6,19,NN,NBETA,P
  475 LINE=LINE+5
  480 IF (NN)555,595,485
  485 IF (57-LINE) 490,490,495
  490 CALL LINER
  495 WRITE OUTPUT TAPE  6,20
  500 LINE=LINE+2
  505 DO 540 N=1,NN,10
  510 IF (58-LINE) 515,515,520
  515 CALL LINER
  520 N1=N+9
  525 IF (NN-N1) 530,535,535
  530 N1=NN
  535 WRITE OUTPUT TAPE  6,14,(ENTAU(N2),N2=N,N1)
  540 LINE=LINE+1
  545 IF (56-LINE) 550,550,556
  550 CALL LINER
  556 WRITE OUTPUT TAPE  6,21,(BETA(N),N=1,NBETA)
  560 LINE=LINE+3
  565 N1=NBETA-1
  570 IF (N1) 555,595,575
  575 IF (56-LINE) 580,580,585
  580 CALL LINER
  585 WRITE OUTPUT TAPE  6,22,(TAUN(N),N=1,N1)
  590 LINE=LINE+3
  595 IF (NFR) 555,755,600
C
C     WRITE OUT VELOCITY FUNCTION, PHI(TAU)
C
  600 IF (56-LINE) 605,605,610
  605 CALL LINER
  610 WRITE OUTPUT TAPE  6,23
  615 LINE=LINE+3
  620 DO 745 N=1,NPT
  625 IF (55-LINE) 630,630,635
  630 CALL LINER
  635 WRITE OUTPUT TAPE  6,24,NPHI(N),NGAMMA(N)
  640 LINE=LINE+4
  645 N1=NPHI(N)
  650 DO 685 N2=1,N1,10
  655 IF (58-LINE) 660,660,665
  660 CALL LINER
  665 N3=N2+9
  670 IF (N1-N3) 675,680,680
  675 N3=N1
  680 WRITE OUTPUT TAPE  6,14,(PHI(N,N4),N4=N2,N3)
  685 LINE=LINE+1
  690 N1=NGAMMA(N)
  695 IF (56-LINE) 700,700,705
```

```
700 CALL LINER
705 WRITE OUTPUT TAPE  6,25,(GAMMA(N,N2),N2=1,N1)
710 LINE=LINE+3
715 N1=N1-1
720 IF (N1) 555,745,725
725 IF (56-LINE) 730,730,735
730 CALL LINER
735 WRITE OUTPUT TAPE  6,26,(TAUP(N,N2),N2=1,N1)
740 LINE=LINE+3
745 CONTINUE
750 GO TO 755
555 PAUSE 555
755 RETURN
760 END (0,1,0,1,0)
```

```
C      SUBROUTINE TEMPRT   1089/RE248   J HEESTAND   8/62
C
C      PURPOSE--(1) WRITE OUT TAU, DELTA TAU(1), DELTA TAU(2), FILM
C                   COEFFICIENTS H(B,L,J), AND CURRENT TEMPERATURES
C                   TDT(I,J).
C               (2) WRITE OUT COEFFICIENTS OF TEMPERATURE DIFFERENCE
C                   EQUATIONS IF SENSE LIGHT 4 IS ON.
C      SUBROUTINES USED--LINER, (LEV), (IOH)O, (STH), (FIL).
C      CALLED BY--PRELIM, POST.
C
       SUBROUTINE TEMPRT
C
       DIMENSION AF(25),AMU(100),ANU(10,9),A1(10),A2(10),A3(10),
      1          B(100,16),BETA(10),B1(10),B2(10),
      2          C(100,16),CAY(10,10),CURPHI(4),
      3          D(100,16),DE(10),DENTAU(2),DIAN(10),DPHI(4),
      4          DR(25),DT(2),DTT(10,10),DTT1(10,9),
      5          E(10,16),EE(25),ENTAU(500),EPSD(3),EPSH(3),
      6          F(25),G(100,16),GAMMA(4,10),
      7          H(2,10,16),H1(10),H2(10),H3(10),H4(10),H5(10),H6(10),
      8          ICS(10),IH(10),IP(100,16),IPF(2,10,16),IPT(10),
      9          ITYPE(100),K(25),M(25),MM(25)
       DIMENSION NF(25),NFI(4),NG(4),NGAM(4),NGAMMA(4),NH(3),NI(25),
      1          NNH(3),NPHI(4),PHI(4,250),PSIS(10),PSIO(10),
      2          QMUZ(100,16),Q0(25),
      3          R(25),RHO(10,9),RHOC(10,10),RHODH(10,9),ROC(10,16),
      4          ROW(10),R2(100),SL2(3),SL3(3),
      5          T(100,16),TAUN(9),TAUP(4,9),TDT(100,16),TEMP(25),
      6          TITLE(12),TPRIME(100,16),TT(10,9),U(25),V(10),VO(10),
      7          WIDAN(10),W1(25),W2(25),Y(1       ),ZETA(25,16)
       EQUIVALENCE (Y,TDT),(ANU,TT),(RHO,RHODH)
       COMMON AF,AK,AMU,ANEW,ANU,A1,A2,A3,B,BETA,B1,B2,
      1       C,CAY,CURPHI,CURREN,D,DE,DEK,DENTAU,DIAN,
      2       DPHI,DR,DT,DTT,DTT1,DZ,DZ2,E,EE,EM,EN,ENTAU,
      3       EPSD,EPSH,F,G,GAMMA,GEE,GR,H,HPRIME,H1,H2,H3,H4,H5,H6,
      4       I,ICNTRL,ICS,IH,IJ,IJSUM,ILINE,IMAX,INIT,IP,IPAGE,
      5       IPF,IPT,ITEMP,ITYP,ITYPE,IX,J,JLINE,JMAX,JMX,J1,
      6       K,L,LA,LB,LINE,LLINE,LMAX,L1,L2,M,MINML,ML,MM,MMAX,
      7       N,NABCDM,NABCDR,NACR,NB,NBET,NBETA,NDTH,NDUMP,
      8       NENTAU,NF,NFI,NFR,NG,NGAM,NGAMMA,NH,NI,NIL,NN,
      9       NNEXT,NNH,NP,NPHI,NPMAX,NPMX,NPR,NPRC,NPT,N1,N2,N3,N4
       COMMON P,PHI,PR,PROB,PSIS,PSIO,QMUZ,Q0,R,RE,RHO,RHOC,
      1       RO,ROC,ROW,R2,SL2,SL3,S1,S2,S3,T,TAU,TAUF,TAUN,
      2       TAUP,TDT,TEMP,TITLE,TPRIME,T1PR,T2PR,T3PR,
      3       U,V,VO,WIDAN,W1,W2,X,XO,X1,X2,X3,Z,ZETA
```

```
    1 FORMAT (/6H0 TAU=1PE18.5,11X,13HDELTA TAU(1)=E12.5,11X,13HDELTA TA
     1U(2)=E12.5)
    2 FORMAT (10H0 H(B,L,J))
    3 FORMAT (1PE13.5,8E12.5,E11.4)
    4 FORMAT (39H0 TEMPERATURES  (READ I ACROSS, J DOWN))
    5 FORMAT (2H0B)
    6 FORMAT (2H C)
    7 FORMAT (2H D)
    8 FORMAT (7H E(N,J))
    9 FORMAT (2H G)
C
C     WRITE OUT TAU, DT(1), DT(2)
C
   15 IF (56-LINE) 20,20,25
   20 CALL LINER
   25 WRITE OUTPUT TAPE  6,1,TAU,DT(1),DT(2)
   30 LINE=LINE+3
   35 IF (NFR) 777,90,40
C
C     WRITE OUT H(B,L,J)
C
   40 IF (57-LINE) 45,45,50
   45 CALL LINER
   50 WRITE OUTPUT TAPE  6,2
   55 LINE=LINE+2
   60 DO 85 L=1,NFR
   65 DO 85 N=1,2
   70 IF (58-LINE-JLINE) 75,75,80
   75 CALL LINER
   80 WRITE OUTPUT TAPE  6,3,(H(N,L,J),J=1,JMAX)
   85 LINE=LINE+JLINE
C
C     WRITE OUT TDT(I,J)
C
   90 IF (57-LINE) 95,95,100
   95 CALL LINER
  100 WRITE OUTPUT TAPE  6,4
  105 LINE=LINE+2
  110 DO 130 J=1,JMAX
  115 IF (58-LINE-ILINE) 120,120,125
  120 CALL LINER
  125 WRITE OUTPUT TAPE  6,3,(TDT(I,J),I=1,IMAX)
  130 LINE=LINE+ILINE
  135 IF (SENSE LIGHT  4) 140,495
C
C     WRITE OUT COEFFICIENTS
C
  140 IF (57-LINE) 145,145,150
  145 CALL LINER
  150 WRITE OUTPUT TAPE  6,5
  155 LINE=LINE+2
  160 DO 180 J=1,JMAX
  165 IF (58-LINE-ILINE) 170,170,175
  170 CALL LINER
  175 WRITE OUTPUT TAPE  6,3,(B(I,J),I=1,IMAX)
  180 LINE=LINE+ILINE
  185 IF (58-LINE) 190,190,195
  190 CALL LINER
  195 WRITE OUTPUT TAPE  6,6
  200 LINE=LINE+1
  205 DO 225 J=1,JMAX
  210 IF (58-LINE-ILINE) 215,215,220
```

```
215 CALL LINER
220 WRITE OUTPUT TAPE  6,3,(C(I,J),I=1,IMAX)
225 LINE=LINE+ILINE
230 IF (58-LINE) 235,235,240
235 CALL LINER
240 WRITE OUTPUT TAPE  6,7
245 LINE=LINE+1
250 DO 270 J=1,JMAX
255 IF (58-LINE-ILINE) 260,260,265
260 CALL LINER
265 WRITE OUTPUT TAPE  6,3,(D(I,J),I=1,IMAX)
270 LINE=LINE+ILINE
395 IF (NFR) 777,445,400
400 IF (58-LINE) 405,405,410
405 CALL LINER
410 WRITE OUTPUT TAPE  6, 8
415 LINE=LINE+1
420 DO 440 N=1,NFR
425 IF (58-LINE-JLINE) 430,430,435
430 CALL LINER
435 WRITE OUTPUT TAPE  6,3,(E(N,J),J=1,JMAX)
440 LINE=LINE+JLINE
445 IF (58-LINE) 450,450,455
450 CALL LINER
455 WRITE OUTPUT TAPE  6, 9
460 LINE=LINE+1
465 DO 485 J=1,JMAX
470 IF (58-LINE-ILINE) 475,475,480
475 CALL LINER
480 WRITE OUTPUT TAPE  6,3,(G(I,J),I=1,IMAX)
485 LINE=LINE+ILINE
490 GO TO 495
777 PAUSE 777
495 RETURN
500 END (0,1,0,1,0)
```

```
C      SUBROUTINE HCOMP   1089/RE248   J HEESTAND   8/62
C
C      PURPOSE--(1) COMPUTE V(N) FOR EVERY COOLANT REGION, EVERY ENTRY
C                   (EVERY TIME ITERATION PLUS EVERY CHANGE IN DT(1)).
C               (2) COMPUTE ROC(N,J) FOR EVERY H(B,N,J) COMPUTED.
C               (3) COMPUTE FILM COEFFICIENT H(B,N,J)--
C                   (A) L2=1, ALL H(B,N,J) ARE COMPUTED.
C                   (B) L2=0, H(B,N,J) IS COMPUTED IF MATERIAL PHASE OF
C                       POINT B,N,J HAS CHANGED, OR IF THE COUNTER ON NH
C                       (THE NUMBER OF ITERATIONS BETWEEN AUTOMATIC
C                       RECOMPUTATION OF H) = NH.
C               (4) TEST PERCENT CHANGE IN H FOR POSSIBLE HALVING
C                   OR DOUBLING OF NH (IF L2=0).
C      SUBROUTINES USED--ABSF, XABSF, EXP(3.
C      CALLED BY--PRELIM, COCOMP, POST.
C
       SUBROUTINE HCOMP
C
       DIMENSION AF(25),AMU(100),ANU(10,9),A1(10),A2(10),A3(10),
      1          B(100,16),BETA(10),B1(10),B2(10),
      2          C(100,16),CAY(10,10),CURPHI(4),
      3          D(100,16),DE(10),DENTAU(2),DIAN(10),DPHI(4),
      4          DR(25),DT(2),DTT(10,10),DTT1(10,9),
      5          E(10,16),EE(25),ENTAU(500),EPSD(3),EPSH(3),
```

```
    6           F(25),G(100,16),GAMMA(4,10),
    7           H(2,10,16),H1(10),H2(10),H3(10),H4(10),H5(10),H6(10),
    8           ICS(10),IH(10),IP(100,16),IPF(2,10,16),IPT(10),
    9           ITYPE(100),K(25),M(25),MM(25)
     DIMENSION NF(25),NFI(4),NG(4),NGAM(4),NGAMMA(4),NH(3),NI(25),
    1           NNH(3),NPHI(4),PHI(4,250),PSIS(10),PSIO(10),
    2           QMUZ(100,16),Q0(25),
    3           R(25),RHO(10,9),RHOC(10,10),RHODH(10,9),ROC(10,16),
    4           ROW(10),R2(100),SL2(3),SL3(3),
    5           T(100,16),TAUN(9),TAUP(4,9),TDT(100,16),TEMP(25),
    6           TITLE(12),TPRIME(100,16),TT(10,9),U(25),V(10),VO(10),
    7           WIDAN(10),W1(25),W2(25),Y(1      ),ZETA(25,16)
     EQUIVALENCE (Y,TDT),(ANU,TT),(RHO,RHODH)
     COMMON AF,AK,AMU,ANEW,ANU,A1,A2,A3,B,BETA,B1,B2,
    1       C,CAY,CURPHI,CURREN,D,DE,DEK,DENTAU,DIAN,
    2       DPHI,DR,DT,DTT,DTT1,DZ,DZ2,E,EE,EM,EN,ENTAU,
    3       EPSD,EPSH,F,G,GAMMA,GEE,GR,H,HPRIME,H1,H2,H3,H4,H5,H6,
    4       I,ICNTRL,ICS,IH,IJ,IJSUM,ILINE,IMAX,INIT,IP,IPAGE,
    5       IPF,IPT,ITEMP,ITYP,ITYPE,IX,J,JLINE,JMAX,JMX,J1,
    6       K,L,LA,LB,LINE,LLINE,LMAX,L1,L2,M,MINML,ML,MM,MMAX,
    7       N,NABCDM,NABCDR,NACR,NB,NBET,NBETA,NDTH,NDUMP,
    8       NENTAU,NF,NFI,NFR,NG,NGAM,NGAMMA,NH,NI,NIL,NN,
    9       NNEXT,NNH,NP,NPHI,NPMAX,NPMX,NPR,NPRC,NPT,N1,N2,N3,N4
     COMMON P,PHI,PR,PROB,PSIS,PSIO,QMUZ,Q0,R,RE,RHO,RHOC,
    1       RO,ROC,ROW,R2,SL2,SL3,S1,S2,S3,T,TAU,TAUF,TAUN,
    2       TAUP,TDT,TEMP,TITLE,TPRIME,T1PR,T2PR,T3PR,
    3       U,V,VO,WIDAN,W1,W2,X,X0,X1,X2,X3,Z,ZETA
   5 I=1
  10 NIL=NI(1)
  15 DO 250 L=1,LMAX
  20 IF (5-K(L)) 211,25,245
  25 IF (LMAX-L) 211,65,30
  30 IF (L-1) 211,35,50
  35 N2=2
  40 N3=2
  45 GO TO 75
  50 N2=1
  55 N3=2
  60 GO TO 75
  65 N2=1
  70 N3=1
  75 N=NF(L)
  80 ML=M(L)
  85 L1=IPT(N)
C
C     COMPUTE V(N)
C
  90 V(N)=VO(N)*CURPHI(L1)
  95 IF (L2) 211,135,100
C
C     LOOP TO COMPUTE ALL VALUES OF H
C
 100 DO 125 N1=N2,N3
 105 L1=N1-1
 110 DO 125 J=1,JMAX
 115 IX=XABSF(IPF(N1,N,J))
 120 GO TO 255
 125 CONTINUE
 126 SENSE LIGHT 1
 130 GO TO 245
C
C     LOOP TO COMPUTE H IF IPF(B,N,J) IS NEGATIVE, OR NNH=NH
```

```
C
  135 DO 240 N1=N2,N3
  140 L1=N1-1
  145 DO 240 J=1,JMAX
  150 IX=XABSF(IPF(N1,N,J))
  155 IF (NH(IX)-NNH(IX)) 211,160,170
  160 ICNTRL=1
  165 GO TO 255
  170 ICNTRL=0
  175 IF (IPF(N1,N,J)) 255,211,240
  180 IF (ICNTRL) 211,210,185
C
C     TEST CHANGE IN H FOR POSSIBLE CHANGE IN NH
C
  185 S1=ABSF((H(N1,N,J)-HPRIME)/HPRIME)
  190 SL2(IX)=MAX1F(SL2(IX),S1)
C
C     SET IP(I,J) NEGATIVE FOR POINTS INVOLVING NEW H VALUES
C
  210 IF (L1) 211,215,225
  215 IP(I-1,J)=-XABSF(IP(I-1,J))
  220 GO TO 230
  225 IP(I+1,J)=-XABSF(IP(I+1,J))
  230 IPF(N1,N,J)=-IX
  235 SENSE LIGHT 1
  240 CONTINUE
  245 I=1+NIL
  250 NIL=NIL+NI(L+1)
  251 GO TO 620
  255 IF (2-IX) 260,270,270
C
C     COMPUTE ROC(N,J)
C
  260 ROC(N,J)=RHOC(ML,4)
  265 GO TO 275
  270 ROC(N,J)=RHOC(ML,1)+TDT(I,J)*(RHOC(ML,2)+TDT(I,J)*RHOC(ML,3))
  275 HPRIME=H(N1,N,J)
  280 IF (2-IH(N))295,285,300
  285 IX=IX+3
  290 GO TO 300
  295 IX=IX+6
  300 GO TO (305,340,375,400,465,490,515,550,585),IX
C
C     COMPUTE H BY SERIES I EQUATIONS
C
  305 AK=CAY(ML,1)+TDT(I,J)*(CAY(ML,2)+TDT(I,J)*CAY(ML,3))
  310 ANEW=ANU(ML,1)+TDT(I,J)*(ANU(ML,2)+TDT(I,J)*ANU(ML,3))
  315 DEK=AK/DE(N)
  320 PR=ANEW/AK*ROC(N,J)
  321 RO=RHO(ML,1)+TDT(I,J)*(RHO(ML,2)+TDT(I,J)*RHO(ML,3))
  325 RE=ABSF(V(N)*ROW(N)/RO)/ANEW*DE(N)
  330 H(N1,N,J)=DEK*(H1(N)*RE**A1(N)*PR**B1(N)+H2(N))
  335 GO TO 615
  340 AK=CAY(ML,1)+TDT(I,J)*(CAY(ML,2)+TDT(I,J)*CAY(ML,3))
  345 ANEW=ANU(ML,1)+TDT(I,J)*(ANU(ML,2)+TDT(I,J)*ANU(ML,3))
  350 DEK=AK/DE(N)
  355 PR=ANEW/AK*ROC(N,J)
  356 RO=RHO(ML,1)+TDT(I,J)*(RHO(ML,2)+TDT(I,J)*RHO(ML,3))
  360 RE=ABSF(V(N)*ROW(N)/RO)/ANEW*DE(N)
  365 H(N1,N,J)=DEK*(H3(N)*RE**A2(N)*PR**B2(N)+H4(N))
  370 GO TO 615
  375 IF (L1) 211,380,390
```

* Correction

*280-300: 280 IF (2-IH(N)) 295, 285, 281
281 IX = IX
GO TO 300
295 IX = IX+6
300 GO TO (305, 340, 375, 400, 465, 490, 515, 550, 585), IX

CORRECTION # NOVEMBER 30, 1965

ERRATA NO. 2

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  380 H(N1,N,J)=H5(N)*(TDT(I-1,J)-TDT(I,J))**A3(N)+H6(N)
  385 GO TO 615
  390 H(N1,N,J)=H5(N)*(TDT(I+1,J)-TDT(I,J))**A3(N)+H6(N)
  395 GO TO 615
C
C     COMPUTE H BY SERIES II EQUATIONS
C
  400 AK=CAY(ML,1)+TDT(I,J)*(CAY(ML,2)+TDT(I,J)*CAY(ML,3))
  405 ANEW=ANU(ML,1)+TDT(I,J)*(ANU(ML,2)+TDT(I,J)*ANU(ML,3))
  410 RO=RHO(ML,1)+TDT(I,J)*(RHO(ML,2)+TDT(I,J)*RHO(ML,3))
  415 S1=RHO(ML,1)+T(I,J)*(RHO(ML,2)+T(I,J)*RHO(ML,3))
  420 PR=ANEW/AK*ROC(N,J)
  425 S2=(S1/RO-1.0)/(TDT(I,J)-T(I,J))
      S2= [RHO(ML,2)+2.0*RHO(ML,3)*TDT(I,J)]/RO
  430 IF (L1) 211,435,445
  435 S1=TDT(I-1,J)-TDT(I,J)
  440 GO TO 450
  445 S1=TDT(I+1,J)-TDT(I,J)
  450 GR=GEE*S2*S1/ANEW*WIDAN(N)/ANEW
  455 H(N1,N,J)=AK/DIAN(N)*(H1(N)*GR**A1(N)*PR**B1(N)+H2(N))
  460 GO TO 615
  465 IF (L1) 211,470,480
  470 H(N1,N,J)=H3(N)*(TDT(I-1,J)-TDT(I,J))**A2(N)+H4(N)
  475 GO TO 615
  480 H(N1,N,J)=H3(N)*(TDT(I+1,J)-TDT(I,J))**A2(N)+H4(N)
  485 GO TO 615
  490 IF (L1) 211,495,505
  495 H(N1,N,J)=H5(N)*(TDT(I-1,J)-TDT(I,J))**A3(N)+H6(N)
  500 GO TO 615
  505 H(N1,N,J)=H5(N)*(TDT(I+1,J)-TDT(I,J))**A3(N)+H6(N)
  510 GO TO 615
C
C     COMPUTE H BY SERIES III EQUATIONS
C
  515 IF (L1) 211,530,520
  520 S1=TDT(I+1,J)+273.2
  525 GO TO 535
  530 S1=TDT(I-1,J)+273.2
  535 S2=TDT(I,J)+273.2
  540 H(N1,N,J)=H1(N)*(S1+S2)*(S1*S1+S2*S2)
  545 GO TO 615
  550 IF (L1) 211,565,555
  555 S1=TDT(I+1,J)+273.2
  560 GO TO 570
  565 S1=TDT(I-1,J)+273.2
  570 S2=TDT(I,J)+273.2
  575 H(N1,N,J)=H2(N)*(S1+S2)*(S1*S1+S2*S2)
  580 GO TO 615
  585 IF (L1) 211,600,590
  590 S1=TDT(I+1,J)+273.2
  595 GO TO 605
  600 S1=TDT(I-1,J)+273.2
  605 S2=TDT(I,J)+273.2
  610 H(N1,N,J)=H3(N)*(S1+S2)*(S1*S1+S2*S2)
  615 IF (L2) 211,180,125
  620 IF DIVIDE CHECK 2111,630
 2111 PAUSE 2111
  625 GO TO 630
  211 PAUSE 211
  630 RETURN
  635 END (0,1,0,1,0)
```

```
C     SUBROUTINE COCOMP   1089/RE248   J HEESTAND   9/62
C
C     PURPOSE--(1) COMPUTE ALL COEFFICIENTS NEEDED FOR
C                  TEMPERATURE DIFFERENCE EQUATIONS.
C                  (A) LA=0, NO THICK NOR COOLANT REGION
C                           COEFFICIENTS NEED BE COMPUTED.
C                  (B) LA=1, COMPUTE ALL THICK AND COOLANT
C                           REGION COEFFICIENTS.
C                  (C) LA=2, COMPUTE THICK AND COOLANT REGION
C                           COEFFICIENTS ONLY FOR POINTS WITH
C                           NEGATIVE IP(I,J) OR IPF(B,N,J).
C                  (D) LB=0, NO THIN REGION COEFFICIENTS NEED
C                    BE COMPUTED.
C                  (E) LB=1, COMPUTE ALL THIN REGION COEFFICIENTS.
C                  (F) LB=2, COMPUTE THIN REGION COEFFICIENTS ONLY
C                           FOR POINTS WITH NEGATIVE IP(I,J).
C              (2) TEST FOR NEGATIVE COEFFICIENTS, REDUCE
C                  TIME INTERVAL WHEN APPROPRIATE, AND REPEAT
C                  APPROPRIATE COEFFICIENT CALCULATIONS.
C     SUBROUTINES USED--HCOMP,EXP
C     CALLED BY--PRELIM(WITH LA=LB=1),POST(WITH LA=LB=2)
C
      SUBROUTINE COCOMP
C
      DIMENSION AF(25),AMU(100),ANU(10,9),A1(10),A2(10),A3(10),
     1          B(100,16),BETA(10),B1(10),B2(10),
     2          C(100,16),CAY(10,10),CURPHI(4),
     3          D(100,16),DE(10),DENTAU(2),DIAN(10),DPHI(4),
     4          DR(25),DT(2),DTT(10,10),DTT1(10,9),
     5          E(10,16),EE(25),ENTAU(500),EPSD(3),EPSH(3),
     6          F(25),G(100,16),GAMMA(4,10),
     7          H(2,10,16),H1(10),H2(10),H3(10),H4(10),H5(10),H6(10),
     8          ICS(10),IH(10),IP(100,16),IPF(2,10,16),IPT(10),
     9          ITYPE(100),K(25),M(25),MM(25)
      DIMENSION NF(25),NFI(4),NG(4),NGAM(4),NGAMMA(4),NH(3),NI(25),
     1          NNH(3),NPHI(4),PHI(4,250),PSIS(10),PSIO(10),
     2          QMUZ(100,16),Q0(25),
     3          R(25),RHO(10,9),RHOC(10,10),RHODH(10,9),ROC(10,16),
     4          ROW(10),R2(100),SL2(3),SL3(3),
     5          T(100,16),TAUN(9),TAUP(4,9),TDT(100,16),TEMP(25),
     6          TITLE(12),TPRIME(100,16),TT(10,9),U(25),V(10),VO(10),
     7          WIDAN(10),W1(25),W2(25),Y(1      ),ZETA(25,16)
      EQUIVALENCE (Y,TDT),(ANU,TT),(RHO,RHODH)
      COMMON AF,AK,AMU,ANEW,ANU,A1,A2,A3,B,BETA,B1,B2,
     1       C,CAY,CURPHI,CURREN,D,DE,DEK,DENTAU,DIAN,
     2       DPHI,DR,DT,DTT,DTT1,DZ,DZ2,E,EE,EM,EN,ENTAU,
     3       EPSD,EPSH,F,G,GAMMA,GEE,GR,H,HPRIME,H1,H2,H3,H4,H5,H6,
     4       I,ICNTRL,ICS,IH,IJ,IJSUM,ILINE,IMAX,INIT,IP,IPAGE,
     5       IPF,IPT,ITEMP,ITYP,ITYPE,IX,J,JLINE,JMAX,JMX,J1,
     6       K,L,LA,LB,LINE,LLINE,LMAX,L1,L2,M,MINML,ML,MM,MMAX,
     7       N,NABCDM,NABCDR,NACR,NB,NBET,NBETA,NDTH,NDUMP,
     8       NENTAU,NF,NFI,NFR,NG,NGAM,NGAMMA,NH,NI,NIL,NN,
     9       NNEXT,NNH,NP,NPHI,NPMAX,NPMX,NPR,NPRC,NPT,N1,N2,N3,N4
      COMMON P,PHI,PR,PROB,PSIS,PSIO,QMUZ,Q0,R,RE,RHO,RHOC,
     1       RO,ROC,ROW,R2,SL2,SL3,S1,S2,S3,T,TAU,TAUF,TAUN,
     2       TAUP,TDT,TEMP,TITLE,TPRIME,T1PR,T2PR,T3PR,
     3       U,V,VO,WIDAN,W1,W2,X,XO,X1,X2,X3,Z,ZETA
C
C     LOOP TO COMPUTE APPROPRIATE THICK AND COOLANT REGION COEFFICIENTS.
C
    5 IF (LA-1) 135,10,10
```

```
   10 N1=1
   15 NIL=NI(1)
   20 DO 130 L=1,LMAX
   25 IF (5-K(L)) 311,30,40
   30 N=NF(L)
   35 GO TO 45
   40 IF (2-K(L)) 125,45,45
   45 ML=M(L)
   50 DO 120 I=N1,NIL
   55 ITYP=ITYPE(I)
   60 DO 120 J=1,JMAX
   65 IF (5-K(L)) 311,70,100
   70 IF (LA-1) 311,85,75
   75 IF (IPF(1,N,J)) 85,80,80
   80 IF (IPF(2,N,J)) 85,120,120
   85 IPF(1,N,J)=XABSF(IPF(1,N,J))
   90 IPF(2,N,J)=XABSF(IPF(2,N,J))
   95 GO TO 115
  100 IF (LA-1) 311,110,105
  105 IF (IP(I,J)) 110,120,120
  110 IP(I,J)=XABSF(IP(I,J))
  111 NP=IP(I,J)
  112 IF (ITYP-15) 115,113,113
  113 G(I,J)=QMUZ(I,J)*DT(1)/RHOC(ML,NP)
  115 GO TO (220,235,255,311,311,311,311,311,311,570,595,660,705,735,
     1        570,595,660,705,735,311,311,311,311,311,311),ITYP
  120 CONTINUE
  125 N1=NIL+1
  130 NIL=NIL+NI(L+1)
  135 IF (LB-1) 215,140,140
C
C     LOOP TO COMPUTE APPROPRIATE THIN REGION COEFFICIENTS.
C
  140 N1=1
  145 NIL=NI(1)
  150 DO 210 L=1,LMAX
  155 IF (4-K(L)) 205,165,160
  160 IF (3-K(L)) 311,165,205
  165 ML=M(L)
  166 DO 200 I=N1,NIL
  170 ITYP=ITYPE(I)
  175 DO 200 J=1,JMAX
  180 IF (LB-1) 311,190,185
  185 IF (IP(I,J)) 190,200,200
  190 IP(I,J)=XABSF(IP(I,J))
  191 NP=IP(I,J)
  192 IF (ITYP-20) 195,193,193
  193 G(I,J)=QMUZ(I,J)*DT(2)/RHOC(ML,NP)
  195 GO TO (311,311,311,355,380,430,465,510,560,311,311,311,311,311,
     1        311,311,311,311,311,355,380,430,465,510,560),ITYP
  200 CONTINUE
  205 N1=NIL+1
  210 NIL=NIL+NI(L+1)
  215 RETURN
C
C     ITYP=1--CENTER COOLANT REGION.
C
  220 D(I,J)=H(2,1,J)/ROC(1,J)*R(1)/AF(1)*DT(1)
  225 C(I,J)=1.0-D(I,J)
  230 IF (C(I,J)) 786,270,270
C
C     ITYP=2--INTERIOR COOLANT REGION.
```

```
C
  235 B(I,J)=H(1,N,J)/ROC(N,J)*R(L-1)/AF(L)*DT(1)
  240 D(I,J)=H(2,N,J)/ROC(N,J)*R(L)/AF(L)*DT(1)
  245 C(I,J)=1.0-B(I,J)-D(I,J)
  250 IF (C(I,J)) 786,270,270
C
C     ITYP=3--OUTSIDE COOLANT REGION.
C
  255 B(I,J)=H(1,N,J)/ROC(N,J)*R(L-1)/AF(L)*DT(1)
  260 C(I,J)=1.0-B(I,J)
  265 IF (C(I,J)) 786,270,270
  270 IF (JMX) 311,285,275
  275 IF (J-1) 311,280,330
  280 IF (VO(N)) 310,285,285
  285 B(I,J)=0.0
  290 C(I,J)=0.0
  295 D(I,J)=0.0
  300 E(N,J)=0.0
  305 GO TO 120
  310 S2=RHO(ML,1)+TDT(I,J)*(RHO(ML,2)+TDT(I,J)*RHO(ML,3))
  315 E(N,J)=ROW(N)/S2*V(N)/DZ*DT(1)
  320 C(I,J)=C(I,J)-ABSF(E(N,J))
  325 IF (C(I,J)) 786,120,120
  330 IF (J-JMAX) 340,335,311
  335 IF (VO(N)) 285,310,310
  340 S2=RHO(ML,1)+TDT(I,J)*(RHO(ML,2)+TDT(I,J)*RHO(ML,3))
  345 E(N,J)=ROW(N)/S2*V(N)/DZ2*DT(1)
  350 GO TO 120
C
C     ITYP=4,20--CENTER THIN REGION, I=1.
C
  355 EM=DR(1)/DT(2)*DR(1)/CAY(ML,NP)*RHOC(ML,NP)
  360 IF (EM-4.0) 960,365,365
  365 D(I,J)=4.0/EM
  370 C(I,J)=1.0-D(I,J)
  375 GO TO 200
C
C     ITYP=5,21--INTERIOR OR OUTSIDE THIN REGION, LEFT BOUNDARY.
C
  380 IF (5-K(L-1)) 311,395,385
  385 X=U(L-1)
  390 GO TO 405
  395 N=NF(L-1)
  400 X=H(2,N,J)
  405 EM=DR(L)/DT(2)*DR(L)/CAY(ML,NP)*RHOC(ML,NP)
  406 EN=X*DR(L)/CAY(ML,NP)*EE(L)
  410 B(I,J)=EN/EM
  415 D(I,J)=4.0*W1(L)/EM
  420 C(I,J)=1.0-B(I,J)-D(I,J)
  425 IF (C(I,J)) 960,200,200
C
C     ITYP=6,22--INTERIOR OR OUTSIDE THIN REGION, MID-POINT.
C
  430 EM=DR(L)/DT(2)*DR(L)/CAY(ML,NP)*RHOC(ML,NP)
  435 S1=DR(L)/R2(I)
  440 B(I,J)=(1.0-S1)/EM
  445 D(I,J)=(1.0+S1)/EM
  450 C(I,J)=1.0-B(I,J)-D(I,J)
  460 IF (C(I,J)) 960,200,200
C
C     ITYP=7,23--CENTER THIN REGION, RIGHT BOUNDARY.
C
```

```
  465 IF (5-K(2)) 311,480,470
  470 X=U(1)
  475 GO TO 490
  480 N=NF(2)
  485 X=H(1,N,J)
  490 EM=DR(1)/DT(2)*DR(1)/CAY(ML,NP)*RHOC(ML,NP)
  491 EN=X*DR(L)/CAY(ML,NP)*F(L)
  495 B(I,J)=4.0/EM*W2(L)
  500 D(I,J)=EN/EM
  501 C(I,J)=1.0-B(I,J)-D(I,J)
  505 IF (C(I,J)) 960,200,200
C
C     ITYP=8,24--INTERIOR THIN REGION, RIGHT BOUNDARY.
C
  510 IF (5-K(L+1)) 311,525,515
  515 X=U(L)
  520 GO TO 535
  525 N=NF(L+1)
  530 X=H(1,N,J)
  535 EM=DR(L)/DT(2)*DR(L)/CAY(ML,NP)*RHOC(ML,NP)
  536 EN=X*DR(L)/CAY(ML,NP)*F(L)
  540 B(I,J)=4.0*W2(L)/EM
  545 D(I,J)=EN/EM
  550 C(I,J)=1.0-B(I,J)-D(I,J)
  555 IF (C(I,J)) 960,200,200
C
C     ITYP=9,25--OUTSIDE THIN REGION, RIGHT BOUNDARY.
C
  560 X=0.0
  565 GO TO 535
C
C     ITYP=10,15--CENTER THICK REGION, I=1.
C
  570 EM=DR(1)/DT(1)*DR(1)/CAY(ML,NP)*RHOC(ML,NP)
  575 IF (EM-4.0) 786,580,580
  580 D(I,J)=4.0/EM
  585 C(I,J)=1.0-D(I,J)
  590 GO TO 120
C
C     ITYP=11,16--INTERIOR OR OUTSIDE THICK REGION, LEFT BOUNDARY.
C
  595 IF (5-K(L-1)) 311,610,600
  600 X=U(L-1)
  605 GO TO 620
  610 N=NF(L-1)
  615 X=H(2,N,J)
  620 EM=DR(L)/DT(1)*DR(L)/CAY(ML,NP)*RHOC(ML,NP)*2.0
  625 IF (EM-4.0) 786,630,630
  630 EN=X*DR(L)/CAY(ML,NP)*EE(L)
  635 S1=EM+EN+W1(L)
  640 B(I,J)=EN/S1
  645 C(I,J)=(EM-EN-W1(L))/S1
  650 D(I,J)=W1(L)/S1         <-- G(I,J) = G(I,J)*EM/S1
  655 GO TO 120
C
C     ITYP=12,17--ALL THICK REGIONS, INTERIOR POINTS.
C
  660 EM=DR(L)/DT(1)*DR(L)/CAY(ML,NP)*RHOC(ML,NP)
  665 IF (L-1) 311,670,675
  670 IF (EM-4.0) 786,680,680
  675 IF (EM-2.0) 786,680,680
  680 S2=DR(L)/R2(I)
```

```
  685 B(I,J)=(1.0-S2)/EM
  690 D(I,J)=(1.0+S2)/EM
  695 C(I,J)=1.0-B(I,J)-D(I,J)
  700 GO TO 120
C
C     ITYP=13,18--CENTER OR INTERIOR THICK REGION, RIGHT BOUNDARY.
C
  705 IF (5-K(L+1)) 311,720,710
  710 X=U(L)
  715 GO TO 740
  720 N=NF(L+1)
  725 X=H(1,N,J)
  730 GO TO 740
C
C     ITYP=14,19--OUTSIDE THICK REGION, RIGHT BOUNDARY.
C
  735 X=0.0
  740 EM=DR(L)/DT(1)*DR(L)/CAY(ML,NP)*RHOC(ML,NP)*2.0
  745 IF (L-1) 311,750,755
  750 IF (EM-8.0) 786,760,760
  755 IF (EM-4.0) 786,760,760
  760 EN=X*DR(L)/CAY(ML,NP)*F(L)
  765 S2=EM+EN+W2(L)
  770 B(I,J)=W2(L)/S2
  775 C(I,J)=(EM-EN-W2(L))/S2
  780 D(I,J)=EN/S2
  785 GO TO 120 <—— G(I,J)=G(I,J)*EM/S2
C
C     REDUCE DT(1), RECOMPUTE TIME DEPENDENT VARIABLES, REPEAT
C     APPROPRIATE COEFFICIENT CALCULATIONS.
C
  786 NDTH=NDTH+1
  787 IF (NDTH-5) 790,985,985
  790 DT(1)=DT(1)*0.5
  795 NPR=NPR*2
  800 NPRC=NPRC*2-1
  805 IF (NFR) 311,870,810
  810 DO 840 N1=1,NPT
  815 N3=NGAMMA(N1)
  820 DO 825 N2=1,N3
  825 GAMMA(N1,N2)=GAMMA(N1,N2)*2.0
  830 DPHI(N1)=DPHI(N1)*0.5
  835 CURPHI(N1)=CURPHI(N1)-DPHI(N1)*0.5
  840 NG(N1)=NG(N1)*2-1
  845 DO 855 N1=1,3
  850 NNH(N1)=NNH(N1)*2-1
  855 NH(N1)=NH(N1)*2
  860 L2=1
  865 CALL HCOMP
  870 IF (NACR) 311,915,875
  875 IF (NN) 311,910,880
  880 DO 885 N1=1,NBETA
  885 BETA(N1)=BETA(N1)*2.0
  890 DENTAU(1)=DENTAU(1)*0.5
  895 CURREN=CURREN-DENTAU(1)*0.5
  900 NB=NB*2-1
  905 GO TO 915
  910 CURREN=(EXPF(TAU/P)+EXPF((TAU+DT(1))/P))*0.5
  915 IF (INIT-1) 311,920,945
  920 DT(2)=DT(1)
  925 DENTAU(2)=DENTAU(1)
  930 LA=1
```

```
  935 LB=1
  940 GO TO 5
  945 INIT=INIT/2
  955 GO TO 930
C
C     REDUCE DT(2), RECOMPUTE TIME DEPENDENT VARIABLES, REPEAT
C     APPROPRIATE COEFFICIENT CALCULATIONS.
C
  960 DT(2)=DT(2)*0.5
  965 DENTAU(2)=DENTAU(2)*0.5
  970 INIT=INIT*2
  975 LB=1
  980 GO TO 135
  985 MINML=7
  990 GO TO 215
  311 PAUSE 311
  995 GO TO 215
 1000 END (0,1,0,1,0)


C     SUBROUTINE PHASE   1089/RE248   J HEESTAND   8/62
C
C     PURPOSE--(1) CHECKS MATERIAL PHASE OF EACH POINT IN MESH.
C              (2) IF PHASE HAS CHANGED, CORRECT ONE IS COMPUTED
C                  AND SET MINUS AS A SIGNAL TO HCOMP AND COCOMP.
C              (3) ONCE A COOLANT POINT REACHES PHASE 3, IT IS HELD AT
C                  THE SATURATION TEMPERATURE, AND SENSE LIGHT 2 IS
C                  TURNED ON (AND KEPT ON).
C     SUBROUTINES USED--ABSF.
C     CALLED BY--POST.
C
      SUBROUTINE PHASE
C
      DIMENSION AF(25),AMU(100),ANU(10,9),A1(10),A2(10),A3(10),
     1          B(100,16),BETA(10),B1(10),B2(10),
     2          C(100,16),CAY(10,10),CURPHI(4),
     3          D(100,16),DE(10),DENTAU(2),DIAN(10),DPHI(4),
     4          DR(25),DT(2),DTT(10,10),DTT1(10,9),
     5          E(10,16),EE(25),ENTAU(500),EPSD(3),EPSH(3),
     6          F(25),G(100,16),GAMMA(4,10),
     7          H(2,10,16),H1(10),H2(10),H3(10),H4(10),H5(10),H6(10),
     8          ICS(10),IH(10),IP(100,16),IPF(2,10,16),IPT(10),
     9          ITYPE(100),K(25),M(25),MM(25)
      DIMENSION NF(25),NFI(4),NG(4),NGAM(4),NGAMMA(4),NH(3),NI(25),
     1          NNH(3),NPHI(4),PHI(4,250),PSIS(10),PSIO(10),
     2          QMUZ(100,16),QO(25),
     3          R(25),RHO(10,9),RHOC(10,10),RHODH(10,9),ROC(10,16),
     4          ROW(10),R2(100),SL2(3),SL3(3),
     5          T(100,16),TAUN(9),TAUP(4,9),TDT(100,16),TEMP(25),
     6          TITLE(12),TPRIME(100,16),TT(10,9),U(25),V(10),VO(10),
     7          WIDAN(10),W1(25),W2(25),Y(1      ),ZETA(25,16)
      EQUIVALENCE (Y,TDT),(ANU,TT),(RHO,RHODH)
      COMMON AF,AK,AMU,ANEW,ANU,A1,A2,A3,B,BETA,B1,B2,
     1      C,CAY,CURPHI,CURREN,D,DE,DEK,DENTAU,DIAN,
     2      DPHI,DR,DT,DTT,DTT1,DZ,DZ2,E,EE,EM,EN,ENTAU,
     3      EPSD,EPSH,F,G,GAMMA,GEE,GR,H,HPRIME,H1,H2,H3,H4,H5,H6,
     4      I,ICNTRL,ICS,IH,IJ,IJSUM,ILINE,IMAX,INIT,IP,IPAGE,
     5      IPF,IPT,ITEMP,ITYP,ITYPE,IX,J,JLINE,JMAX,JMX,J1,
     6      K,L,LA,LB,LINE,LLINE,LMAX,L1,L2,M,MINML,ML,MM,MMAX,
     7      N,NABCDM,NABCDR,NACR,NB,NBET,NBETA,NDTH,NDUMP,
     8      NENTAU,NF,NFI,NFR,NG,NGAM,NGAMMA,NH,NI,NIL,NN,
```

```
     9        NNEXT,NNH,NP,NPHI,NPMAX,NPMX,NPR,NPRC,NPT,N1,N2,N3,N4
      COMMON  P,PHI,PR,PROB,PSIS,PSIO,QMUZ,QO,R,RE,RHO,RHOC,
     1        RO,ROC,ROW,R2,SL2,SL3,S1,S2,S3,T,TAU,TAUF,TAUN,
     2        TAUP,TDT,TEMP,TITLE,TPRIME,T1PR,T2PR,T3PR,
     3        U,V,VO,WIDAN,W1,W2,X,X0,X1,X2,X3,Z,ZETA
    5 N1=1
   10 NIL=NI(1)
   15 DO 415 L=1,LMAX
   20 IF (5-K(L)) 511,25,210
C
C     LOOP FOR COOLANT PHASE TESTS
C
   25 I=N1
   30 N=NF(L)
   35 IF (LMAX-L) 511,75,40
   40 IF (L-1) 511,45,60
   45 N3=2
   50 N4=2
   55 GO TO 85
   60 N3=1
   65 N4=2
   70 GO TO 85
   75 N3=1
   80 N4=1
   85 DO 200 N2=N3,N4
   86 L1=N2-1
   90 DO 195 J=1,JMAX
   95 IF (3-IPF(N2,N,J)) 511,115,100
  100 IF (PSIS(N)-TDT(I,J)) 105,105,125
  105 IPF(N2,N,J)=-3
  110 SENSE LIGHT 2
  115 TDT(I,J)=PSIS(N)
  120 GO TO 195
  125 IF (L1) 511,130,165
  130 IF (PSIS(N)-TDT(I-1,J)) 150,150,135
  135 IF (IPF(1,N,J)-1) 511,195,140
  140 IPF(1,N,J)=-1
  145 GO TO 195
  150 IF (2-IPF(1,N,J)) 511,195,155
  155 IPF(1,N,J)=-2
  160 GO TO 195
  165 IF (PSIS(N)-TDT(I+1,J)) 185,185,170
  170 IF (IPF(2,N,J)-1) 511,195,175
  175 IPF(2,N,J)=-1
  180 GO TO 195
  185 IF (2-IPF(2,N,J)) 511,195,190
  190 IPF(2,N,J)=-2
  195 CONTINUE
  200 CONTINUE
  205 GO TO 410
C
C     LOOP FOR NON-COOLANT PHASE TESTS
C
  210 IF (NPMAX-1) 511,410,215
  215 ML=M(L)
  220 DO 405 I=N1,NIL
  225 DO 405 J=1,JMAX
  230 NP=IP(I,J)
  235 IF (NPMAX-NP) 511,250,240
  240 IF (TT(ML,NP)-TDT(I,J)) 330,245,245
  245 IF (NP-1) 511,255,250
  250 IF (TDT(I,J)-TT(ML,NP-1)) 265,255,255
```

```
255 TPRIME(I,J)=0.0
260 GO TO 395
265 IF (TPRIME(I,J)) 275,275,270
270 TPRIME(I,J)=0.0
275 S1=TDT(I,J)+TPRIME(I,J)
280 S2=S1-TT(ML,NP-1)
285 IF (DTT1(ML,NP)-ABSF(S2)) 305,305,290
290 TPRIME(I,J)=S2
295 TDT(I,J)=TT(ML,NP-1)
300 GO TO 395
305 TDT(I,J)=S1+DTT1(ML,NP)
310 TPRIME(I,J)=0.0
315 NP=NP-1
320 SENSE LIGHT 3
325 GO TO 245
330 IF (TPRIME(I,J)) 335,340,340
335 TPRIME(I,J)=0.0
340 S1=TDT(I,J)+TPRIME(I,J)
345 S2=S1-TT(ML,NP)
350 IF (DTT(ML,NP)-ABSF(S2)) 370,370,355
355 TPRIME(I,J)=S2
360 TDT(I,J)=TT(ML,NP)
365 GO TO 395
370 TDT(I,J)=S1-DTT(ML,NP)
375 TPRIME(I,J)=0.0
380 NP=NP+1
385 SENSE LIGHT 3
390 GO TO 235
395 IF (SENSE LIGHT 3) 400,405
400 IP(I,J)=-NP
401 SENSE LIGHT 1
405 CONTINUE
410 N1=1+NIL
415 NIL=NIL+NI(L+1)
420 RETURN
511 PAUSE 511
425 GO TO 420
430 END (0,1,0,1,0)
```

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