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HEATING and HEATING 2

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A Program Description of a Generalized Heat Transfer Code for Solution of Transient and/or Steady-State Problems in One, Two, or Three Dimensional Cartesian or Cylindrical Coordinate Systems

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HEATING and HEATING 2

A Program Description of a Generalized Heat
Transfer Code for Solution of Transient and/
or Steady-State Problems in One, Two, or
Three Dimensional Cartesian or Cylindrical
Coordinate Systems

by

R. D. Brunell

Mathematics and Computer Applications

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ABSTRACT

HEATING and HEATING 2 are generalized heat transfer codes capable of solving transient and/or steady-state problems in one, two or three dimensional Cartesian or cylindrical coordinate systems.

The simplified input of HEATING makes it a very useful code for those problems having geometrical configurations which can be described by parallel and perpendicular lines or planes, or concentric circles. These figures can be broken up into a maximum of 100 one-material regions with position and time dependent volumetric heat generation rates. Up to 40 materials with constant properties can be described, and the initial temperatures of these regions are position dependent. The boundaries of these regions can be contact, insulated, time dependent temperature controlled or forced convection with a time dependent sink temperature.

HEATING 2 differs from HEATING in that it can also have a radiation boundary with a time dependent sink temperature and a maximum of 750 nodes as opposed to the maximum of 1000 nodes of HEATING.

ACKNOWLEDGEMENTS

The original analysis, for the numerical methods used in this code, was done by T. B. Fowler and E. R. Volk at Oak Ridge National Laboratory, and originally appeared in the G.H.T. code⁴. The geometry section was added at ASTRA, Inc., by R. R. Liguori and J. W. Stephenson, and appeared as the original HEATING code⁵.

The revisions made here at Atomics International were those necessary to make the program compatible with the North American Aviation, Inc., computer system, and the addition of a radiation boundary condition and of CRT output capability. This document brings together the information contained in ORNL-2734 and ASTRA 417.50 in order to make a self-contained document easily obtainable by the users here at Atomics International, and to indicate the changes brought about by the revisions.

I would like to thank P. M. Gresho for his help in setting up the test cases and in checking out the radiation boundary condition. I would also like to thank A. F. Lillie for his help in the addition of the CRT output.

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I. IDENTIFICATION

HEATING and HEATING 2 are generalized heat transfer codes for simple geometries. They are written in FORTRAN II for use on an IBM 7094 with the NAA FIB III monitor system. The deck numbers for HEATING and HEATING 2 are 3W464 and 3W798 respectively and are on file with Department 792 at Atomics International.

II. INTRODUCTION

The problems considered here consist essentially of solving certain partial differential equations; in all cases the temperature distribution is the desired unknown. For the purpose of illustration, the equations are written in terms of Cartesian coordinates.

For steady-state conditions the conduction equation considered is

$$k \frac{\partial^2 T}{\partial x^2} + k \frac{\partial^2 T}{\partial y^2} + k \frac{\partial^2 T}{\partial z^2} + q(x, y, z) = 0 \quad (1)$$

where T is temperature, k is the thermal conductivity, and q is the volume-heat-generation rate which can be a function of position. At the boundary, specified by subscript b , T is given by either

$$T_b = T_k \quad (2)$$

or

$$-k \left(\frac{\partial T}{\partial x} \right)_b = h [T_b - T_k] \quad (3)$$

where T_k is a constant sink temperature, and h is an effective heat transfer coefficient.

For unsteady-state conditions, the mathematical system is

$$k \frac{\partial^2 T}{\partial x^2} + k \frac{\partial^2 T}{\partial y^2} + k \frac{\partial^2 T}{\partial z^2} + q(x, y, z, \tau) = c \frac{\partial T}{\partial \tau} \quad (4)$$

where τ represents time, c is the volume heat capacity, q is a function of position and time. At the boundary, T satisfies either

$$T_b = F(\tau) \quad (5)$$

or

$$-k\left(\frac{\partial T}{\partial x}\right)_b = h[T_b - F(\tau)] \quad (6)$$

where F is a function of time. As formulated, the time variation of F at a specified position must be linear in a given time interval; up to 20 such time intervals can be considered.

Derivation of the steady-state and transient equations is done by performing a heat balance about a nodal point which is connected (thermally) to M other nodal points. The resulting equations may also be derived from the appropriate partial-differential equation of heat conduction by writing the latter in difference form. By choosing the mesh size (associated with nodal points) small enough, the numerical results give a practical solution to the appropriate differential equation. The major problem in the numerical calculation is the iteration method used in obtaining the final temperature distribution. The numerical procedure is such that points on the boundary are treated in essentially the same manner as points interior to the boundary, taking into consideration the known information, for example, the appropriate value for the effective conductance.

III. NUMERICAL METHOD

A. Steady-State Equation

Consider a specified nodal point, J , which is thermally connected with M adjacent nodal points. Under steady-state conditions the rate at which energy is conducted away from point J must equal the rate of energy generation at that point. Thus, if T_i is the temperature at nodal point i , T_J must satisfy the equation

$$\sum_{i=1}^M J K_i (T_i - T_J) + Q_J = 0, \quad (7)$$

where $J K_i$ is the thermal conductance between points J and i , Q_J is the rate of energy generation at point J , T_J is the temperature at point J

and T_i is the temperature at points i adjacent to J . The value of T_J which satisfies equation (7) can be obtained only after a number of iterations; it is assumed that the $(n+1)$ th iteration on T_J termed T_J^{n+1} , satisfies equation (7), but that the n th iteration gives

$$\sum_{i=1}^M J K_i (T_i - T_J^n) + Q_J = \epsilon, \quad (8)$$

where ϵ is a residual term. It follows that

$$\epsilon = \sum_{i=1}^M J K_i (T_J^{n+1} - T_J^n). \quad (9)$$

Combining equations (8) and (9) gives

$$(T_J^{n+1} - T_J^n) \sum_{i=1}^M J K_i = \sum_{i=1}^M J K_i (T_i - T_J^n) + Q_J. \quad (10)$$

If the values of T_i are taken at iteration n this would be the "Richardson method", but in these codes we use the "Liebmann method" and take $T_i = T_i^n$ for values of $i > J$, and $T_i = T_i^{n+1}$ for values of $i < J$ to increase the convergence rate.

By use of equation (10) the temperature unbalance is brought to zero for each nodal point as it is calculated; however, to increase convergence it is desirable to "overrelax" the unbalance. This can be done by multiplying the right side of equation (10) by a constant, termed β . Thus equation (10) becomes

$$(T_J^{n+1} - T_J^n) \sum_M J K_M = \beta \left[\sum J K_M (T_M - T_J^n) + Q_J \right] \quad (11)$$

upon rearranging, this becomes

$$T_J^{m+1} = T_J^m(1-\beta) + \frac{\beta \left(\sum_j K_M T_M + Q_J \right)}{\sum_j K_M} \quad (12)$$

Equation 12 is commonly called the "extrapolated Liebmann" equation.

The value of β must be in the range $1 \leq \beta < 2$.

The value of β which will produce the optimum convergence rate for all points is difficult to obtain analytically for simple geometries and is practically impossible to obtain for complex geometries. However, by combining analytical and empirical results, a method of computing β was developed which has been satisfactory for a wide variety of test cases.

Consider a rectangular array of points (l, k) , with p equal divisions in the l direction and q equal divisions in the k direction; let the boundary conditions be $T = C_1$ at $l = 0, p$ and $T = C_2$ at $k = 0, q$; Frankel has shown that

$$K_{\text{Lieb}}^* \cong \left[1 - \frac{\pi^2(p^{-2} + q^{-2})}{4} \right]^2, \quad (13)$$

where

$$K_{\text{Lieb}}^* = \frac{\epsilon^{m+1}}{\epsilon^m}, \quad (14)$$

and where

$$\epsilon^m = (T^m - T_{\text{final}}), \quad (15)$$

$$\epsilon^{m+1} = (T^{m+1} - T_{\text{final}}). \quad (16)$$

For the extrapolated Liebmann method, it has been shown¹ that

$$K_{ex\ Lieb.}^* \cong 1 - \sqrt{2} \pi (p^{-2} + q^{-2})^{1/2}, \quad (17)$$

or

$$K_{ex\ Lieb.}^* = 4\alpha - 1, \quad (18)$$

where $4\alpha \equiv \beta$. Assuming that $K_{Lieb.}^*$ can be determined and that the geometry factor $(p^{-2} + q^{-2})$ is unknown, an equation for β can be obtained in terms of $K_{Lieb.}^*$, namely,

$$\beta = 2 - \sqrt{8} (1 - \sqrt{K_{Lieb.}^*})^{1/2}. \quad (19)$$

The problem is now one of determining the value of $K_{Lieb.}^*$.

By plotting the results of many test cases, it was found that the nodal point with the slowest convergence rate satisfied equations of the form

$$T^{n+1} - T^n = A e^{-m(n+1)}, \quad (20)$$

$$T^{n+2} - T^{n+1} = A e^{-m(n+2)}, \quad (21)$$

where A and m are parameters. Eliminating the constant A from these two equations gives

$$e^{-m} = \frac{T^{n+2} - T^{n+1}}{T^{n+1} - T^n}. \quad (22)$$

Also, if equations (20) and (21) are valid, T_{final} can be obtained from

$$T_{final} = T^n + \int_{x=n}^{\infty} A e^{-mx} dx, \quad (23)$$

$$T_{final} = T^{n+1} + \int_{x=n+1}^{\infty} A e^{-mx} dx. \quad (24)$$

Integration gives

$$T_{final} = T^n + \frac{A e^{-m(n)}}{m}, \quad (25)$$

$$T_{final} = T^{n+1} + \frac{A e^{-m(n+1)}}{m}. \quad (26)$$

It also follows that

$$T_{final} = T^{n+2} + \frac{A e^{-m(n+2)}}{m}. \quad (27)$$

Eliminating A from the above equations gives

$$e^{-m} = \frac{T^{n+1} - T_{final}}{T^n - T_{final}}, \quad (28)$$

$$e^{-m} = \frac{T^{n+2} - T_{final}}{T^{n+1} - T_{final}}. \quad (29)$$

Combining equations (14), (15), (16), (22) and (28) gives

$$K_{Lieb}^* = \frac{T^{n+2} - T^{n+1}}{T^{n+1} - T^n}. \quad (30)$$

Also, from a number of test cases it has been found that if $\sqrt{8}$ in equation (19) is replaced by 2, a better value of β is obtained. Therefore the equation used in these codes for calculating β is

$$\beta = 2 - 2 \left[1 - \left(\frac{T^{n+2} - T^{n+1}}{T^{n+1} - T^n} \right)^{1/2} \right]^{1/2}. \quad (31)$$

The value of β calculated from equation (31) will be smaller than the optimum value unless n becomes very large. It is recommended that $n+2$ be equal to (35) before β is calculated. A small value of β will not seriously slow down the convergence, and in most cases the convergence will exceed that for the optimum value if the Aitken δ^2 process² is used for extrapolating the temperatures. This extrapolation process can be obtained by combining equations (28) and (29), which gives

$$T_{final} = \frac{(T^n)(T^{n+2}) - (T^{n+1})^2}{T^{n+2} + T^n - 2T^{n+1}} \quad (32)$$

Adding and subtracting T^{n+2} from the right side of equation (32) gives

$$T_{final} = T^{n+2} + \frac{(T^{n+2} - T^{n+1})^2}{(T^{n+1} - T^n) - (T^{n+2} - T^{n+1})} \quad (33)$$

Due to boundary conditions, geometry factors, β , and initial conditions, the temperatures at certain nodal points for some problems will not converge in accordance with equations (20) and (21), but will converge in an "oscillating" fashion. To prevent these particular nodal points from extrapolating, the program is written so that equation (33) cannot be applied unless the following conditions are satisfied:

$$|(T^{n+1} - T^n)| > |(T^{n+2} - T^{n+1})|, \quad (34)$$

$$(T^{n+2} - T^{n+1})(T^{n+1} - T^n) > 0. \quad (35)$$

B. Transient Equation

Consider a specified nodal point, J , which is thermally connected with M adjacent nodal points. Under transient conditions the rate at which energy is conducted away from point J must equal the rate of energy generation plus the rate change of energy storage associated with that point. With the same nomenclature as in equation (7), the non-steady-state equation is

$$\sum_{i=1}^M J K_i [T_i(\tau) - T_J(\tau)] + q_J(\tau) = C_J \frac{\Delta T_J}{\Delta \tau}, \quad (36)$$

where C_J is the thermal capacitance associated with point J , $q_J(\tau)$ is the rate of heat generation at J as a function of time, and ΔT_J is the change in temperature of point J in the time interval $\Delta \tau$.

It is assumed that the time variation of q_J is linear with time in a specified time interval (the number of specified time intervals can be as great as 20). Thus $q_J(\tau)$ is considered to be of the form

$$q_J(\tau) = Q_J + \Delta Q_J(\tau), \quad (37)$$

Combining equations (36) and (37) gives

$$T_J(\tau + \Delta \tau) = T_J(\tau) + \frac{\Delta \tau}{C_J} \left\{ \sum_{i=1}^M J K_m [T_i(\tau) - T_J(\tau)] + Q_J + \Delta Q_J(\tau) \right\} \quad (38)$$

The calculation of T_J as a function of time as specified by equation (38) is straightforward so long as the $\Delta \tau$ associated with each iteration is kept sufficiently small. Thus $\Delta \tau$ should be based on a stability criteria such that the numerical result utilizing equation (38) does not diverge from the correct solution. The criterion for $\Delta \tau$ derived in reference 3 is used in these codes; this is written as

$$\Delta \tau \leq \left(\frac{C_J}{\sum_{i=1}^M J K_i} \right), \quad (39)$$

where the right side refers to that nodal point which gives the smallest value for $\Delta \tau$.

C. Radiation Boundary

In HEATING 2 the following boundary condition was added for the steady-state equation

$$-K \left(\frac{\partial T}{\partial x} \right)_b = \sigma \epsilon [T_b^4 - T_\infty^4] \quad (40)$$

where T_K is a constant sink temperature. In order to linearize this expression, so that it may be incorporated into the numerical technique used by the code, we factor the right side of the equation and obtain

$$-K \left(\frac{\partial T}{\partial x} \right)_b = \sigma F [(T_b - T_K)(T_b + T_K)(T_b^2 + T_K^2)]. \quad (41)$$

We now assume that in the last two terms on the right that $T_b = T_K$ and we get

$$-K \left(\frac{\partial T}{\partial x} \right)_b = \sigma F 4 T_b^3 (T_b - T_K). \quad (42)$$

From this we get that the heat transfer on a radiative path from any node is

$$4 \sigma F A T_b^3 (T_b - T_K), \quad (43)$$

where σ is the Stephen-Boltzman constant, F is the form factor and A is the radiating area.

IV. CODE RESTRICTIONS AND FEATURES

There are several inherent limitations in these codes. One of these is the maximum number of nodes that can be used. HEATING can calculate up to 1000 nodes, and HEATING 2 is capable of a maximum of 750 nodes. These nodes are set up by the total lattice structure determined by the gross lattice and fine mesh lines. The maximum number of gross lattice lines that can be read in on either code in any one dimension is 40. The maximum total number of lattice lines that can exist in any one dimension is 100.

When using cylindrical geometry special problems exist. The center line temperatures can not be calculated because of indexing problems. So the code will always see an insulated cylinder at the center of the problem with a radius to the first node in R . This problem can be minimized by disregarding the center line and placing the first gross lattice line in R very close to the center. Another problem in the cylindrical coordinate system is that if the θ dimension runs all the way from 0 to 2π the nodes at 0 and 2π will not be connected. In other words the code will see a small slab of insulation running the length of the problem

between the center and outer radius at 0 and 2π . This too is necessary because of the difficulty in communicating to the computer how to determine the paths between these nodes.

A nodal temperature is given where ever two lattice lines cross, and the conduction between nodes takes place along the lattice lines. The bounds of a node exist half way between the intersection of the two lines determining the node and the intersection of lattice lines determining all nodes to which it is thermally connected (see figure 1).

Figure 1

Figure 1 shows a simple case where all nodes to which N is thermally connected are equal distances from node N . The volume which node N occupies is indicated by the cross sectional areas in the above drawing. The temperature calculated at a node is a weighted average depending on the distances and materials that exist between it and it's neighboring nodes.

V. PROGRAM USAGE

A. General

1. Regions

The particular problem configuration is first divided into regions, depending on the shape, material structure, indentations, cutouts and other deviations from the general geometry. In some cases, zoning into regions must be done in order to describe a specific boundary condition. There are three basic rules governing region division:

(a) Boundary lines or planes must be parallel to the coordinate axes (two points, four lines, or six planes are required to enclose a region in 1, 2, or 3 dimensional geometry, respectively).

(b) A region may contain only one material (however, many regions may contain the same material).

(c) The boundary number must apply along the full length of its associated side.

Consider, for example, a case consisting of a simple rectangle in $x - y$ geometry, half of which contains one material, and the other half a second material, as depicted in Figure 2.

Figure 2

This elementary case would require two regions (as indicated) -- one for each different material. If the upper right corner of the rectangle is omitted as in Figure 3, three regions are required as shown.

Figure 3

The division of the right half of the rectangle into two regions accounts for the indented or cutout upper right corner. Note that regions 2 and 3 of Figure 3 contain the same material.

Now consider the case of Figure 3 introducing boundary conditions as in Figure 4. The left boundary of the leftmost rectangle now contains two different boundary types. Thus, in accordance with the second basic rule, region zoning is performed to account for the different boundary conditions, and an additional region is required.

Figure 4

2. Gross Lattice Arrangement

The second requirement for describing the overall configuration is to indicate the dimensions. The dimensions of each region in each direction are specified. Also, the number of mesh points, lines, or planes in each region in each direction must be specified. This is accomplished by describing an overall gross lattice and indicating the number of mesh spaces desired between each pair of gross lattice lines. Gross lattice lines may be placed within a region if unequal mesh spacing in that region is required, but all region boundaries must coincide with gross lattice lines.

3. Time and Position Dependent Input Data

The initial temperature pattern may be specified as a function of position. Boundary temperature may be time dependent. Heat generation rates may be time and position dependent.

The position dependence of a function is given by the product of up to three position functions. Thus, the initial temperature,

$$T_0(x, y, z) = F_x(x) \cdot F_y(y) \cdot F_z(z)$$

or

$$T_0(r, \theta, z) = F_x(r) \cdot F_y(\theta) \cdot F_z(z)$$

where

$$F_m(v) = c_{m,1} + c_{m,2}v + c_{m,3}v^2 + c_{m,4}\cos(c_{m,5}v) + c_{m,6}\exp(c_{m,7}v)$$

Also, the heat generation rate;

$$Q_g(x, y, z, t) = F_x(x) \cdot F_y(y) \cdot F_z(z) \cdot G_m(t)$$

or

$$Q_g(r, \theta, z, t) = F_x(r) \cdot F_y(\theta) \cdot F_z(z) \cdot G_m(t)$$

where $G_m(t)$ is given by a set of points which are assumed connected by straight lines. The program interpolates in the interval containing t to find $G_m(t)$. If $t < t_1$, where t_1 is the first point given, the value of $G(t_1)$ is used; if $t > t_2$ where t_2 is the largest entry, $G(t_2)$ is used.

The boundary temperatures are given by

$$T_e(t) = T_e \cdot G_e(t)$$

The coefficients of the position dependent functions, the points describing the time dependent functions, and the T_e values are given in the input data.

Thus, an overall "blue print" of the problem layout, along with the number of mesh points and mesh spacing, form the input to the program. The following sections describe in detail how this information is to be presented. Physically, these numbers are to be punched on cards; hence, the card arrangement is also indicated in the detailed description.

B. Input Data

1. Job Description (Card #1)

The job description is contained on a single card and may include any comment (alphabetic, numeric, or spaces) up to 72 characters in length. The card itself cannot be omitted although it may be left blank.

2. Input Parameters (Cards #2 through #5)

Type Geometry

The HEATING program offers nine possible geometries which are members of either cylindrical polar or rectangular coordinate systems. These are listed below:

Cylindrical

- 1 R- θ -Z
- 2 R- θ
- 3 R-Z
- 4 R
- 5 Z

Rectangular

- 6 x-y-Z
- 7 x-y
- 8 x-Z
- 9 x

One, two, or three dimensional systems are allowed in either cylindrical

polar or rectangular coordinates by entering the appropriate number (1 - 9, as indicated) as the first word of card #2.

Total Number of Regions

The total number of regions of the entire configuration is entered as the second word. Regions are to be numbered consecutively beginning with number one. A maximum of 100 regions is acceptable.

Total Number of Materials

The third entry of this card contains the total number of different materials. Different materials are to be numbered consecutively beginning with number one. A maximum of 40 materials is allowed.

Total Number of Initial Temperature Functions

Each initial temperature function number has position dependent function numbers associated with it. This entry (the fourth on card #2) is the total number of different initial temperature functions, up to a maximum of 25 (numbered consecutively, beginning with one).

Total Number of Position Dependent Functions

Each position dependent function has a number; these should be numbered consecutively beginning with one, up to a maximum of 15. The fifth entry (card #2) is the total number of different position dependent functions.

Total Number of Heat Generation Functions

Heat generation functions are numbered consecutively (a maximum of 15). The total number of different heat generation functions is the sixth entry of card #2.

Total Number of Time Dependent Functions

The total number of time dependent functions is the seventh word of this card (#2). The different time functions are numbered consecutively, beginning with one up to a maximum of 15.

Gross Lattice Size

The first three words of this card (#3) contain the total number of gross lattice lines in (1) x or R direction, (2) Y or θ direction, (3) Z direction. If any dimension is omitted, a zero is inserted in the appropriate entry for the total number of gross lattice lines.

Total Number of Boundary Types

The fourth entry of card #3 is the total number of numbered

boundaries. Each boundary is numbered beginning with number one and numbered consecutively up to a maximum of 40.

Type of Problem

The first word of card #4 is the type of problem. It may be steady-state only, transient only, or combinations of steady-state and transient calculations. The number to be entered is in accordance with the following list:

1	S-S only	-1	trans. only
2	S-S, trans.	-2	trans., S-S
3	S-S, trans., S-S	-3	trans., S-S, trans.
4	S-S, trans., S-S, trans.	-4	trans., S-S, trans., S-S
:	:	:	:
n	S-S, trans., S-S, trans., S-S, etc.	-n	trans., S-S, trans., S-S trans., etc.

If, for example, a 3 is entered, the program will first perform a steady-state calculation at time zero; next the transient calculation; then a steady-state calculation using the final transient temperatures and at the final transient time. Any number of combinations is allowable; however, machine running time should be considered. (Note, careful consideration must be given to formation of time dependent and heat generation functions when a problem type which uses more than one transient and one steady-state pass.)

Maximum Number of Steady-State Iterations Allowed

If the maximum number of steady-state iterations is reached, and the convergence criterion is not satisfied, the program will write "END STEADY-STATE CALCULATIONS, CONVERGENCE NOT SATISFIED" on the output tape and will terminate the calculation and call for the next problem. This entry is the second of card #4.

Number of Iterations Before Calculating β

The third word of card #4 specifies the steady-state iteration number after which β is to be calculated. It has been found that 35 is a reasonable value for this number. If β is not to be calculated, this number should be greater than the maximum number of steady-state iterations allowed, and the value of β to be used must be entered on card #5.

Extrapolation Cycle

A value of 50 is recommended for this number. When the number of steady-state iterations reaches this value, the program will attempt to extrapolate (accelerate) the temperatures. The method of extrapolation is the Aitken δ^2 process, which will be attempted every n-th iteration, where n is the number specified. This is the fourth entry of this card (#4).

Number of Transient Iterations per Output Cycle

This is the fifth word of card #4. It specifies the number of transient iterations to be performed between output printing. For example, if a value of 5 is entered, the results of every fifth transient iteration will be printed as output. For steady-state only calculations, this entry may be left blank.

Convergence Criterion

This number affects the steady-state type of calculation only and may be left blank for a transient only problem. The steady-state calculation will continue until the convergence criterion is met. It has been found that for a vlaue of 10^{-5} , the maximum error for several test cases was less than 1%. This is the first entry of card #5.

Beta

The value of β must not exceed the limits $1.0 \leq \beta < 2.0$. If β is to be calculated, a value of 1.0 is entered here, and the number of iterations before calculating β must be specified. If β is not to be calculated by the program, the value to be used is entered here, and the number of iterations before calculating β must be greater than the maximum number of iterations allowed.

Time Increment

The time increment (Δt) is the time step taken between successive iterations in a transient calculation. The time increment must satisfy certain convergence requirements. The HEATING Program calculates the convergence criterion, and if the specified Δt is too large (but not more than a factor of 10 too large), the program calculates an acceptable value for Δt and writes, CONVERGENCE CRITERION NOT SATISFIED BY INPUT DELTA T -- DELTA T IS NOW = and indicates the value of Δt used subsequently. If the input Δt is too large by more than a factor of 10, the program writes CASE DELETED, DELTA T MUST NOT EXCEED _____ (indicates allowable value) and goes on to the next problem.

The units of Δt must be compatible with those of the heat generation function, etc. In the case of a steady-state only problem, this entry may be left blank. This is the third word of card #5.

Total Time per Transient Calculation

The total time that each transient calculation is to be run is specified as the fourth word of card #5. If, for example, a trans., S-S, trans. problem is run, the first transient calculation will begin at time zero and continue for t is specified time. The steady-state calculation will then be performed at this time. The second transient calculation will begin with the final time of the first transient calculation and again proceed for this specified total time. (The final time of the second transient calculation will be twice the total time specified.)

The total time and the time increment must be in the same units. Any units may be used in the HEATING Program; however, compatibility of units must be observed.

In the case of a steady-state only problem, this entry may be left blank, since it effects the transient calculation only.

Stepan-Boltzman Constant

This value is input only on deck 3W798 and the units must be consistent with the rest of the input parameters. The only restriction being that the units must be in an absolute system.

3. Region Data

Region data cards contain mixtures of fixed point integers and floating point numbers, and, therefore, the type of number required is indicated in each section. There are two cards associated with each region, and the pairs of region cards are arranged consecutively beginning with the pair for Region 1 and continuing up to the total number of regions. The total number of cards is equal to twice the total number of regions.

Card #1 (R)

Region Number

Regions are to be numbered consecutively beginning with number one up to a maximum of 100 regions. The region numbering system does not require that a region occupy any particular zone in the overall configuration. In the example of Figure 1 the left most region could be numbered Region 2, and the right-most region, Region 1. This entry is the first on card #1 (R) and must be a fixed point integer.

Material in Region

The second word of card #1 (R) indicates by a fixed point integer what material occupies the region named in the first word of this card. Materials are numbered consecutively beginning with number one up to a maximum of 40 materials.

Region Dimensions

Regions dimensions are entered as floating point numbers and are arranged in the following order:

- (1) left (x) or inner radial (R) boundary
- (2) right (x) or outer radial (R) boundary
- (3) lower (y) or left (θ) boundary
- (4) upper (y) or right (θ) boundary
- (5) rear (Z) boundary
- (6) front (Z) boundary

Although it is usually more convenient to place the overall configuration at the origin in X-Y-Z geometry, it is not necessary to do so; however, all dimensions are entered as their distance from the origin. In R- θ -Z geometry, R = 0.0 must be located at the origin with R increasing radially; Z is not necessarily begin at the origin, but must extend upward; or so that the observer looks at the circular face; θ lines or planes increase clockwise in order to be compatible with the X-Y-Z system.

Mesh points are numbered by the program to agree with these conventions. Points are numbered from left to right along an X (or R) coordinate up to the outermost boundary of the configuration; then continue at the innermost boundary in the succeeding Y (or θ) plane up to the limit of the Y (or θ) boundary; then finally proceed to the following Z plane.

Card #2 (R)

Initial Temperature of Region

The initial temperature function number of the region specified by the first word of card #1 (R) is entered as a fixed point number.

Heat Generation Function Number

The heat generation rate per unit volume must be given for each region if heat generation is present. The heat generation rate per unit volume may be a function of time. A maximum of 15 different heat

generation functions are allowable and are numbered consecutively beginning with number one. The second word (fixed point integer) of card #2 (R) indicates the heat generation function associated with the region given on the first card of this pair.

Boundary Number

Each different kind of boundary is given a number. These boundaries are numbered consecutively, beginning with number one up to a maximum of 40. Insulated and contact type boundaries are given a number of zero and are not numbered otherwise. The next six entries of this card (#2(R)) are the boundary numbers (see boundary data) appearing on the six boundaries of the region designated by the first word of the first card of this pair. These numbers are fixed point integers and are entered in the following order:

<u>Order</u>	<u>X-Y-Z Geometry</u>	<u>R-θ-Z Geometry</u>
1st	left (X) boundary	inner (R) boundary
2nd	right (X) boundary	outer (R) boundary
3rd	lower (Y) boundary	left (θ) boundary
4th	upper (Y) boundary	right (θ) boundary
5th	back (Z) boundary	back (Z) boundary
6th	front (Z) boundary	front (Z) boundary

For the degenerate cases (i.e., one- or two-dimensional) where there is no boundary in some direction, a zero is entered. Viz., for X-Y geometry (no Z dimension), the fifth and sixth words of this group would be entered as zeros.

4. Material Data

One card of material data is required for each different material. Materials are numbered consecutively (each different material has a number) beginning with number one up to a maximum of 40 materials. Every material data card contains four numbers: material number, material density (ρ), specific heat (C_p) of the material, and the thermal conductivity (K) of the material, in that order. The first word (material number) is entered as a fixed point integer. The next three words (ρ , C_p , K) are floating point numbers.

5. Heat Generation Function Data

Each different heat generation function is numbered, beginning with number one, consecutively up to a maximum of 15 heat generation

functions. The heat generation function data cards indicate the function number, the time dependent function number, the X or R position dependent function number, the Y or θ position dependent function number, and the Z position dependent function number, arranged in that order, respectively. Thus, there are five fixed point integer entries on each heat generation function data card, and there are as many cards as there are different heat generation functions.

6. Initial Temperature Function Data

Each different initial temperature function is given a number. Beginning with number one, the initial temperature functions are numbered consecutively up to a maximum of 25. The initial temperature function data cards consist of the initial temperature function number and the associated X or R, Y or θ , and Z position dependent function numbers. In the event of a degenerate geometry (one- or two-dimensional) problem, a zero is entered for the omitted dimension's position dependent function number. All of the words on these cards are fixed point integers, the number of cards corresponding with the number of initial temperature functions.

7. General Position Dependent Functions

The general position dependent function is of the form:

$$f(p) = A_1 + A_2 p + A_3 p^2 + A_4 \cos A_5 p + A_6 \exp(A_7 p)$$

where p is a position dependent variable (X, Y, Z or R, θ , Z). To obtain the function desired, one merely inserts the appropriate values for the coefficients A_i in the above equation. Zeros are entered for the coefficients of those terms of the general function that are not to be included. For example, if $f(x) = 100.0 \cdot \cos 5.0X$, the entries would be $A_1 = 0.0$, $A_2 = 0.0$, $A_3 = 0.0$, $A_4 = 100.0$, $A_5 = 5.0$, $A_6 = 0.0$, $A_7 = 0.0$

Each different position dependent function is numbered consecutively, beginning with number one up to a maximum of 15 functions. The first entry is the position dependent function number (fixed point integer). The next seven words are the coefficients A_i , which are entered as floating point numbers, including zeros (0.0).

8. Time Dependent Function Data

Each time dependent function is numbered consecutively beginning with one up to a maximum of 15 functions. The time dependent function is assumed to be a set of linearly connected points. The function is described by specifying the value of the function at a particular time. These numbers are entered in pairs; viz., $t, f(t_1)$; $t_2 f(t_2)$; etc. A maximum of 20 points is allowed, and linear interpolation is performed by the program between points.

The first word on the first card (fixed point integer) is the time function number. The number of points (fixed point integer) is the second entry. The next six words of the first card are the first three points of the time function. If there are more than three points in the function, they are entered (as pairs) on subsequent cards. Figure 5 is an example of an acceptable time dependent function. The input for this example is:

Card 1	1	9	0.0	25.0	1.0	30.0	2.0	30.0
Card 2	2.5	35.0	3.5	35.0	4.0	30.0	4.5	30.0
Card 3	5.5	20.0	5.501	10.0

Figure 5

9. Boundary Data

Excluding insulated or contact type boundaries, which are numbered zero, each different boundary is numbered consecutively up to a maximum of 40. Each boundary data card, depending on which deck is used, will include the following information: the number of the boundary, the boundary type (see next paragraph), the boundary temperature(s), the radiation form factor and/or the film coefficient and the boundary time function number(s).

There are two possible entries for the boundary type. For a radiation and/or convective boundary an integer 1 is entered as the second word in the boundary card. An integer 2 is entered in this position if a controlled temperature boundary is desired.

10. Gross Lattice and Fine Mesh Lines

For each direction the data necessary to set up the lattice is entered on two types of cards. One indicating the gross lattice lines and the second specifying the number of mesh spaces between each gross lattice line. For illustration consider the input for the lattice in the X direction for a cartesian coordinate system. First starting with the lowest value on the X axis put the value of each gross lattice line in ascending order using as many cards as necessary to list all of them. Then, starting on a new card list the mesh spaces to be used between each of the gross lattice lines again using as many cards as necessary. The second set of cards should contain one less entry than the first set. Repeat this process until all the dimensions of the particular geometry needed to describe the configuration of the problem are set up. In the case of a degenerate geometry do not use blank cards for the unused dimension, just disregard it.

11. Data for CRT Output

The CRT output generated by the code will display temperature as a function of distance along any chosen axis. At the present time the code does not have the ability to plot in time. For a transient solution only the final values may be plotted. The necessity of the above arrangement is created, as most limitations in this code are created, by the size of the core used by the computer. All values to be plotted on any one frame must be taken from a single two dimensional plane. For a one or two dimensional geometry this is of no concern, however, in a three

dimensional case this plane must be specified. Each CRT plot is specified separately, and each plot is completely independent of any other plot. So that any combination of plots may be requested.

The first entry on card #1 (C) must be an integer 1, 2, 3, or 4. In the case of a one or two dimensional problem this entry must be an integer 4, and for a one dimensional problem this is the only entry required. All others may be disregarded. In the case of a two dimensional problem the second entry in card #1 (C) can be disregarded, but further entries are necessary. An integer 1, 2, or 3 in this position is only to be used in the case of a three dimensional problem, and the integers are associated with the "natural order" of the coordinate axes X, Y, Z or R, θ , Z. Consider a three dimensional problem in a X, Y, Z coordinate system. If an integer 1 is entered in the first field of card #1 (C), the code would expect to find the points to be plotted lying in a YZ plane which would cut the X axis at a X mesh point to be specified in the second field of card #1(C). In a R, θ , Z problem, if an integer 3 is entered in this position, the code would expect to find the points to be plotted lying in a R θ plane. The integer to be entered will be the one associated with the missing dimension.

As already stated above, the second entry in card #1 (C) will be the number of the mesh point at which the two dimensional plane will cut the indicated axis.

It is now left to determine for which of the two dimensions certain mesh lines will be specified to be plotted for the entire range of the remaining dimension. This will be accomplished by the third entry in card #1 (C). This entry must be an integer 1 or 2, and again these integers are associated with the normal convention of order for the two dimensions. The number entered here will be that one which is associated with the dimension which will not appear as the abscissa of the graph. Consider a problem in a YZ plane. If an integer 1 is entered in this field, the code will plot certain Y mesh lines, to be specified later, for the range of Z.

The fourth entry of card #1 (C) must be an integer equal to the number of mesh lines to be plotted on the graph. This number cannot exceed 20. The remaining entries, on card #1 (C) and for as many cards as necessary, will be the integers associated with the mesh lines to be plotted, as they are designed by the code.

C. Data Deck Set-Up

	Program Name	Parameter	Format
CARD #1		Job Description	12A6
CARD #2		Limits for Read Statements	
Entry #1	NGEOM	Type Geometry	I9
#2	NOREGT	Total Number of Regions	I9
#3	MATLT	Total Number of Materials	I9
#4	NINTFN	Total Number of Initial Temperature Functions	I9
#5	NPDFN	Total Number of Position Dependent Functions	I9
#6	NGENFN	Total Number of Heat Generation Functions	I9
#7	NTDFN	Total Number of Time Dependent Functions	I9
#8	IOUT	Number of CRT Plots Desired	I9
CARD #3		Limits for Read Statements	
Entry #1	IGT	Total Number of Gross Lattices Lines (X or R)	I9
#2	JGT	Total Number of Gross Lattices Lines (Y or θ)	I9
#3	KGT	Total Number of Gross Lattices Lines (Z)	I9
#4	NBDTPT	Total Number of Numbered Boundaries	I9
CARD #4		Control Parameters	
Entry #1	NTYPE	Type Problem	I9
* #2	NOITX	Maximum Number of Steady-State Iterations	I9
* #3	NEXI	Number of Iterations Before Calculating β	I9
* #4	NEX	Number of Iterations Before Extrapolation Cycle	I9
* #5	NDTA	Number of Transient Iterations per Print Cycle	I9

*Card or Entry may be omitted

	Program Name	Parameter	Format
CARD #5		Control Parameters	
* Entry #1	EPI	Convergence Criterion	E9.5
* #2	BETA	Value of Beta	E9.5
* #3	DELTAT	Time Increment	E9.5
* #4	TIME	Total Time per Transient Calculation	E9.5
+ #5	SIGMA	Stephan-Boltzman Constant	E9.5
CARD #(1)R		Region Data	
Entry #1	NOREG	Region Number	I9
#2	MATL(NOREG)	Material in Region	I9
#3	RRIN(")	Left (X) or Inner (R) Region Dimen.	E9.5
#4	RROT(")	Right (X) or Outer (R) Region Dimen.	E9.5
#5	THLT(")	Lower (Y) or Left (Θ) Region Dimen.	E9.5
#6	THRT(")	Upper (Y) or Right (Θ) Region Dimen.	E9.5
#7	ZZBM(")	Rear (Z) Region Dimension	E9.5
#8	ZZFR(")	Front (Z) Region Dimension	E9.5
CARD #(2)R		Region Data	
Entry #1	INTEM(NOREG)	Initial Temperature Function Number of Region	I9
#2	NGEN(")	Heat Generation Function No. of Region	I9
#3	NBDIN(")	Left (X) or Inner (R) Boundary No.	I9
#4	NBOUT(")	Right (X) or Outer (R) Boundary No.	I9
#5	NBDLT(")	Lower (Y) or Left (Θ) Boundary No.	I9
#6	NBDRT(")	Upper (Y) or Right (Θ) Boundary No.	I9
#7	NBDDBA(")	Back (Z) Boundary Number	I9
#8	NBDFR(")	Front (Z) Boundary Number	I9
CARD #1(M)		Material Data	
Entry #1	MAT	Material Number	I9
#2	RHO(MAT)	Density of Material	E9.5
#3	CSUBP(MAT)	Heat Capacity of Material	E9.5
#4	COND(MAT)	Conductivity of Material	E9.5

*Card or Entry may be omitted

+For use on deck number 3W798 only

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	Program Name	Parameter	Format
*CARD #1(G)		Heat Generation Function Data	
Entry #1	NGN	Heat Generation Function Number	I9
#2	NGNTM(NGN)	Time Dependent Function Number	I9
#3	NGNR(")	Position Dependent Function Number (X or R)	I9
#4	NGNTH(")	Position Dependent Function Number (Y or Θ)	I9
#5	NGNZ(")	Position Dependent Function No. (Z)	I9
CARD #1(I)		Initial Temperature Function Data	
Entry #1	INTM	Initial Temperature Function Number	I9
#2	ITMR(INTM)	Position Dependent Function Number (X or R)	I9
#3	ITMTH(")	Position Dependent Function Number (Y or Θ)	I9
#4	ITMZ(")	Position Dependent Function No. (Z)	I9
CARD #1(P)		Position Dependent Function Data	
Entry #1	NFN	Position Dependent Function Number	I9
* #2	POSFN(NFN,1)	Function Coefficient A1	E9.5
* #3	POSFN(NFN,2)	Function Coefficient A2	E9.5
* #4	POSFN(NFN,3)	Function Coefficient A3	E9.5
* #5	POSFN(NFN,4)	Function Coefficient A4	E9.5
* #6	POSFN(NFN,5)	Function Coefficient A5	E9.5
* #7	POSFN(NFN,6)	Function Coefficient A6	E9.5
* #8	POSFN(NFN,7)	Function Coefficient A7	E9.5
*CARD #1(T)		Time Dependent Function Data	
Entry #1	NTM	Time Dependent Function Number	I9
#2	NTIMFD(NTM)	Number of Function Points	I9
#3	TIMFN(NTM,1)	Value of t_1	E9.5
#4	TIMFN(NTM,2)	Value of $F(t_1)$	E9.5
#5	TIMFN(NTM,3)	Value of t_2	E9.5
#6	TIMFN(NTM,4)	Value of $F(t_2)$	E9.5
* #7	TIMFN(NTM,5)	Value of t_3	E9.5
* #8	TIMFN(NTM,6)	Value of $F(t_3)$	E9.5

* Card or word can be omitted.

	Program Name	Parameter	Format
*CARD #2(T)		Time Dependent Function Data (Can use up to 5 cards)	
Entry #1	TIMFN(NTM,7)	Value of t_4	E9.5
#2	TIMFN(NTM,8)	Value of $F(t_4)$	E9.5
* #3	TIMFN(NTM,9)	Value of t_5	E9.5
* #4	TIMFN(NTM,10)	Value of $F(t_5)$	E9.5
* #5	TIMFN(NTM,11)	Value of t_6	E9.5
* #6	TIMFN(NTM,12)	Value of $F(t_6)$	E9.5
* #7	TIMFN(NTM,13)	Value of t_7	E9.5
* #8	TIMFN(NTM,14)	Value of $F(t_7)$	E9.5
CARD #1(B)		Boundary Data (For Deck #3 V464 Only)	
Entry #1	NBDTP	Number of Boundary	I9
#2	NBYTYP(NBDTP)	Boundary Type Number	I9
#3	BYTEMP(")	Boundary Temperature	E9.5
#4	BYH(")	Boundary Film Coefficient	E9.5
#5	NBYTFN(")	Boundary Time Function Number	I9
CARD #1(B)		Boundary Data (For Deck #3 W798 Only)	
Entry #1	NBDTP	Number of Boundary	I9
#2	NBYTYP(NBDTP)	Boundary Type Number	I9
#3	NBYTFN(")	Convection Boundary Time Function No.	I9
#4	NRTFN(")	Radiation Boundary Time Function No.	I9
#5	BYTEMP(")	Convection Boundary Temperature	E9.5
#6	RTEMP(")	Radiation Boundary Temperature	E9.5
#7	BYH(")	Film Coefficient	E9.5
#8	EF (")	Form Factor	E9.5
*CARD #1(L1)		Gross Lattice (X or R)	
Entries		List All Gross Lattice Lines in (X or R) starting with Smallest	E9.5
*CARD #2(L1)		Mesh Spacing (X or R)	
Entries		List Desired Mesh Spaces Between Above Gross Lattice	I9
*CARD #1(L2)		Gross Lattice (Y or t)	
Entries		Same as Card #1(L1) except in Y or t	E9.5

* Card or Entry May Be Omitted.

	Program Name	Parameter	Format
*CARD #2(L2) Entries		Mesh Spacing (Y or Θ) Same as Card #2(L1) except in Y or Θ	I9
*CARD #1(L3) Entries		Gross Lattice (Z) Same as card #1(L1) except in Z	E9.5
*CARD #2(L3) Entries		Mesh Spacing (Z) Same as Card #2(L1) except in Z	I9
*CARD #1(C) Entry #1	KGE $\emptyset$ M	CRT Setup FLAG to determine geometry for use on Graph	I9
* #2	KGP	Mesh line at which plane will cut third axis	I9
* #3	KNGE $\emptyset$ M	FLAG to determine abscissa of graph	I9
* #4	N $\emptyset\emptyset$ G	Total number of mesh lines to be plotted	I9
* #5	NX(1)	First mesh line to be plotted	I9
* #6	NX(2)	Second mesh line to be plotted	I9
* #7	NX(3)	Third mesh line to be plotted	I9
* #8	NX(4)	Fourth mesh line to be plotted	I9
*CARD #2(C)		To be used only if more than 4 mesh lines are to be plotted	
Entry #1	NX(5)	Fifth mesh line to be plotted	I9
* #2	NX(6)	Sixth mesh line to be plotted	I9
* #3	NX(7)	Seventh mesh line to be plotted	I9
* #4	NX(8)	Eighth mesh line to be plotted	I9
* #5	NX(9)	Ninth mesh line to be plotted	I9
* #6	NX(10)	Tenth mesh line to be plotted	I9
* #7	NX(11)	Eleventh mesh line to be plotted	I9
* #8	NX(12)	Twelfth mesh line to be plotted	I9

*Card or Entry May Be Omitted

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VI SAMPLE PROBLEM

One of the many test cases run on the HEATING Program was the sample problem given by Fowler and Volk for the GHT code. Since this problem is of high instructive value, due to its simplicity and consideration of several variables, it is also presented as a sample problem in this report. The problem configuration is shown in Figure 6. It is identical with the GHT problem except the configuration is inverted in order to have coincidence of point numbers. The problem consists of two materials in x-y geometry. The heat generation rate is time dependent and position independent (equal to $200 \text{ BTU}\cdot\text{hr}^{-1}\cdot\text{in}^{-3}$). The material properties are:

Material 1

$$k = 1.0 \text{ BTU}\cdot\text{hr}^{-1}\cdot\text{in}^{-1}(\text{°F})^{-1}$$

$$\rho = 1.0 \text{ lbs.}/\text{in}^3$$

$$C_P = 0.05 \text{ BTU lb}^{-1}(\text{°F})^{-1}$$

Material 2

$$k = 2.0 \text{ BTU}\cdot\text{hr}^{-1}\cdot\text{in}^{-1}(\text{°F})^{-1}$$

$$\rho = 1.0 \text{ lbs}/\text{in}^3$$

$$C_P = 0.05 \text{ BTU}\cdot\text{lb}^{-1}(\text{°F})^{-1}$$

The time function for the heat generation rate is given by Figure 7. Time dependence for three boundaries are required. Their time functions are given by Figure 8.

The overall configuration was divided into six regions as indicated in Figure 5. One initial temperature function, two position dependent functions (both constant), one heat generation function, and four time dependent functions were required.

The problem was steady-state-transient (type 2) and included three numbered boundaries. There were four, six, and zero gross lattice lines in the x,y, and z directions, respectively. Since all of the input data is summarized in the program output, it will not be reiterated here.

There are two sample problems reproduced below. Both use the same configuration as it is shown on the following pages. The first was run on HEATING, deck number 3W464, and the second on HEATING 2, deck number 3W798. Only the boundary conditions differ in order to show how they are to be used with each code.

Sample Problem For the HEATING Program

Figure 6

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Time Dependent Function Used with Heat Generation Rate

Figure 7

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Time Dependent Functions Used with Numbered Boundaries

Figure 8

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FORTRAN WORK SHEET

DECK NO. _____ PROGRAMMER _____ DATE _____ PAGE 1 OF 2 JOB NO. _____

FOR PROGRAM NO. _____ TITLE _____ BY DEPT. _____ GROUP _____

														IDENTIFICATION	
1	10	20	30	40	50	60	70	73	80						
SAMPLE PROBLEM FOR HEATING 1 DECK NO. 3W464														1C	
7	6	2	1	2	1	4	2		2.0						
5	5	0	3						3.0						
2	1.00	5.0	3.5	1.00					4.0						
.00001	1.0	0.002	0.502						5.0						
1	1	1.0	1.5	0.0	4.0	6.0	0.0		6.0						
1	1	0	0	0	0	0	0		7.0						
2	2	1.5	2.0	0.0	1.5	6.0	0.0		8.0						
1	1	0	1	0	0	0	0		9.0						
3	1	1.5	4.0	2.5	4.0	0.0	0.0		1.00						
1	1	0	0	0	0	0	0		1.10						
4	2	3.0	4.0	2.0	2.5	0.0	0.0		1.20						
1	1	0	0	0	3	0	0		1.30						
5	2	1.5	3.0	2.0	2.5	0.0	0.0		1.40						
1	1	0	0	0	0	0	0		1.50						
6	2	1.5	2.0	1.5	2.0	6.0	0.0		1.60						
1	1	0	2	0	0	0	0		1.70						
1	1.0	0.05	1.0						1.80						
2	1.0	0.05	2.0						1.90						
1	4	2	0	0					2.00						
1	1	0	0						2.10						
1	1.00.0								2.20						
2	2.00.0								2.30						
1	6	0.0	1.0	0.2	2.0	6.3	2.0		2.40						
0.4	3.0	0.5	3.0	0.502	1.0				2.50						

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FOR PROGRAM NO. _____ TITLE _____ BY DEPT. _____ GROUP _____

[illegible]

FORTRAN WORK SHEET

DECK NO. _____ PROGRAMMER _____ DATE _____ PAGE 1 OF 2 JOB NO. -34-
FOR PROGRAM NO. _____ TITLE _____ BY DEPT. _____ GROUP _____

								IDENTIFICATION
1	10	20	30	40	50	60	70	73
S.A.M.P.L.E. P.R.O.B.L.E.M. F.O.R. H.E.A.T.I.N.G. 2. DECK N ^o . 30798.								10
7	6	2	1	2	1	4	2	20
5	5	0	3					30
2	250	50	35	100				40
.0.0.0.0.1.	1.0	0.0.0.2	0.502	0.119E-10				50
1	1	1.0	1.5	0.0	4.0	0.0	0.0	60
1	1	0	0	0	0	0	0	70
2	2	1.5	2.0	0.0	1.5	0.0	0.0	80
1	1	0	1	0	0	0	0	90
3	1	1.5	4.0	2.5	4.0	0.0	0.0	100
1	1	0	0	0	0	0	0	110
4	2	3.0	4.0	2.0	2.5	0.0	0.0	120
1	1	0	0	0	3	0	0	130
5	2	1.5	3.0	2.0	2.5	0.0	0.0	140
1	1	0	0	0	0	0	0	150
6	2	1.5	2.0	1.5	2.0	0.0	0.0	160
1	1	0	2	0	0	0	0	170
1	1.0	.0.5	1.0					180
2	1.0	.05	2.0					190
1	4	2	0	0				200
1	1	0	0					210
1	500.							220
2	200.							230
1	6	0.0	1.0	0.2	2.0	0.3	2.0	240
0.4	3.0	0.5	3.0	0.502	1.0			250

C. Output of Sample Problems

All of the input data is recapitulated in the output, appearing before the temperature profiles. The format is best illustrated by example, and the reader is referred to the sample problem.

For the steady-state calculation, the program writes RESULTS FROM STEADY-STATE CALCULATION; indicates the time at which the steady-state was performed, and the number of steady-state calculations completed. The point temperatures are then listed sequentially along with the point numbers. Since point numbers are calculated by the program and are not program input, the point coordinates, i, j, k (corresponding to the x, y, z or R, θ , Z directions, respectively), are also listed. The point coordinates are readily correlated with the fine lattice data to establish the point location.

For the transient calculation, the program writes RESULTS FROM TRANSIENT CALCULATION; indicates the time at which the temperature profile is written and the number of transient iterations completed. The temperature profile is then listed in the same manner as for the steady-state. Each transient output cycle also lists the temperatures at numbered boundaries.

C. Output from sample problems - 1. For convection only problem

A.I. HEATING 1 DECK NUMBER 3W464

INPUT RETURN

JOB DESCRIPTION-- SAMPLE PROBLEM FOR HEATING 1 DECK NO. 3W464

GEOMETRY TYPE NO. 7

NUMBER OF REGIONS 6

NUMBER OF MATERIALS 2

NUMBER OF INITIAL TEMPERATURE FUNCTIONS 1

NUMBER OF GENERAL POSITION DEPENDENT FUNCTIONS 2

NUMBER OF HEAT GENERATION FUNCTIONS 1

NUMBER OF TIME DEPENDENT FUNCTIONS 4

NUMBER OF CRT PLOTS DESIRED 2

NUMBER OF POINTS IN GROSS X OR R LATTICE 5

NUMBER OF POINTS IN GROSS Y OR THETA LATTICE 5

NUMBER OF POINTS IN GROSS Z LATTICE 0

NUMBER OF DIFFERENT KINDS OF BOUNDARIES 3

PROBLEM TYPE NUMBER 2

MAXIMUM NUMBER OF STEADY-STATE ITERATIONS 100

NUMBER OF S-S ITERATIONS BEFORE CALC BETA 50

NUMBER OF S-S ITERATIONS BEFORE EXTRAPOLATION 35

NUMBER OF DELTATS PER MONITOR PRINT 100

CONVERGENCE CRITERION 0.00001000

INITIAL BETA 1.00000000

TIME INCREMENT (DELTAT) 0.00200000

REGION DATA

1	1	1.0000	1.5000	0.	4.0000	-0.	-0.	-0.
1	1	0	0	0	0	-0	-0	-0
2	2	1.5000	2.0000	0.	1.5000	-0.	-0.	-0.
1	1	0	1	0	0	-0	-0	-0
3	1	1.5000	4.0000	2.5000	4.0000	-0.	-0.	-0.
1	1	0	0	0	0	-0	-0	-0
4	2	3.0000	4.0000	2.0000	2.5000	-0.	-0.	-0.
1	1	0	0	3	0	-0	-0	-0
5	2	1.5000	3.0000	2.0000	2.5000	-0.	-0.	-0.
1	1	0	0	0	0	-0	-0	-0
6	2	1.5000	2.0000	1.5000	2.0000	-0.	-0.	-0.
1	1	0	2	0	0	-0	-0	-0

MATERIAL DESCRIPTION DATA

MATERIAL	RHO	C SUB P	K
1	0.09999999E 01	0.49999999E-01	0.09999999E 01
2	0.09999999E 01	0.49999999E-01	0.20000000E 01

HEAT GENERATION FUNCTION DATA

1	4	2	0	0
---	---	---	---	---

INITIAL TEMPERATURE FUNCTION DATA

1	1	0	0
---	---	---	---

GENERAL POSITION DEPENDENT FUNCTION COEFFICIENTS

1	0.09999999E 03	-0.	-0.	-0.	-0.
	-0.	-0.			
2	0.20000000E 03	-0.	-0.	-0.	-0.
	-0.	-0.			

TIME DEPENDENT FUNCTION DATA

1	6	0.	1.0000000	0.2000000	2.0000000	0.3000000	2.0000000
0.4000000	3.0000000	0.5000000	3.0000000	0.5020000	1.0000000		
2	4	0.	1.5000000	0.2000000	3.0000000	0.5000000	3.0000000
0.5020000	1.0000000						
3	6	0.	2.0000000	0.2000000	4.0000000	0.3000000	4.0000000
0.4000000	3.0000000	0.5000000	3.0000000	0.0502000	1.0000000		
4	4	0.	1.0000000	0.2000000	1.5000000	0.5000000	1.1250000
0.5020000	0.						

BOUNDARY DATA

1	1	0.12500000E 03	0.49999999E 01	1
2	1	0.09999999E 03	0.49999999E 01	2
3	1	0.15000000E 03	0.49999999E 01	3

GROSS LATTICES AND NUMBERS OF INCREMENTS

R OR X

1.000000	1.500000	2.000000	3.000000	4.000000
----------	----------	----------	----------	----------

1	1	2	2
---	---	---	---

THETA OR Y

0.	1.500000	2.000000	2.500000	4.000000
----	----------	----------	----------	----------

2	1	1	2
---	---	---	---

FINE LATTICE, X OR R, Y OR THETA, Z

1	1.000000	2	1.500000	3	2.000000	4	2.500000
5	3.000000	6	3.500000	7	4.000000		
1	0.	2	0.750000	3	1.500000	4	2.000000
5	2.500000	6	3.250000	7	4.000000		

CONVERGENCE CRITERION NOT SATISFIED BY INPUT DELTA T -- DELTA T IS NOW = 0.66666666E-03

CONVERGENCE ACCELERATION APPLIED AT ITERATION NUMBER 35

RESULTS FROM STEADY STATE CALCULATION

TIME= 0.

ITERATIONS COMPLETED = 44

LATTICE POINT TEMPERATURES

POINT NUMBER	I	INDICIES J	K	POINT TEMPERATURE
1	1	1	1	271.2904625
2	2	1	1	236.7594433
3	3	1	1	182.2862167
4	1	2	1	292.7288399
5	2	2	1	255.0680656
6	3	2	1	192.7131310
7	1	3	1	371.1300011
8	2	3	1	328.9458275
9	3	3	1	247.1782227
10	1	4	1	466.3496323
11	2	4	1	437.6529999
12	3	4	1	398.3750305
13	4	4	1	490.5542183
14	5	4	1	449.2434196
15	6	4	1	406.7700195

RESULTS FROM STEADY STATE CALCULATION

TIME= 0.

ITERATIONS COMPLETED = 44

LATTICE POINT TEMPERATURES

POINT NUMBER	I	INDICIES J	K	POINT TEMPERATURE
16	7	4	1	399.3453598
17	1	5	1	568.9551849
18	2	5	1	546.2626877
19	3	5	1	525.0890732
20	4	5	1	544.7993240
21	5	5	1	530.6027679
22	6	5	1	510.2093964
23	7	5	1	503.6033516
24	1	6	1	714.2000122
25	2	6	1	709.9121857
26	3	6	1	704.1601715
27	4	6	1	702.7921829
28	5	6	1	697.2013016
29	6	6	1	690.5900116
30	7	6	1	687.9473114

RESULTS FROM STEADY STATE CALCULATION

TIME= 0.

ITERATIONS COMPLETED = 44

LATTICE POINT TEMPERATURES

POINT NUMBER	I	INDICIES J	K	POINT TEMPERATURE
31	1	7	1	766.2301559
32	2	7	1	764.3532257
33	3	7	1	760.8679428
34	4	7	1	757.7902222
35	5	7	1	753.6011124
36	6	7	1	749.5470123
37	7	7	1	747.9009399

RESULTS FROM STEADY STATE CALCULATION

TIME= 0.

ITERATIONS COMPLETED = 44

TEMPERATURES ON NUMBERED BOUNDARIES

BOUNDARY NUMBER	TEMPERATURE
1	125.0000000
2	150.0000000
3	300.0000000

NODAL HEAT GENERATION RATE AND NET HEAT FLOW FROM CONVECTION BOUNDARY NODES

NODE	BOUNDARY	HEAT GENERATION	CONVECTION HEAT FLOW
1		0.18750000E 02	
2		0.37500000E 02	
3	1		-0.10741165E 03
3		0.18750000E 02	
4		0.37500000E 02	
5		0.75000000E 02	
6	1		-0.25392424E 03
6		0.37500000E 02	
7		0.31250000E 02	
8		0.62500000E 02	
9	1		-0.22908416E 03
9	2		-0.12147278E 03
9		0.31250000E 02	
10		0.25000000E 02	
11		0.50000000E 02	
12	2		-0.31046879E 03
12		0.37500000E 02	
13		0.25000000E 02	
14	3		-0.18655427E 03
14		0.25000000E 02	
15	3		-0.26692504E 03
15		0.25000000E 02	
16	3		-0.12418170E 03
16		0.12500000E 02	
17		0.31250000E 02	
18		0.62500000E 02	
19		0.62500000E 02	
20		0.62500000E 02	
21		0.62500000E 02	
22		0.62500000E 02	
23		0.31250000E 02	
24		0.37500000E 02	
25		0.75000000E 02	
26		0.75000000E 02	
27		0.75000000E 02	
28		0.75000000E 02	
29		0.75000000E 02	
30		0.37500000E 02	
31		0.18750000E 02	

32
33
34
35
36
37

0.37500000E 02
0.37500000E 02
0.37500000E 02
0.37500000E 02
0.37500000E 02
0.18750000E 02

TOTAL

0.16000000E 04

-0.16000226E 04

RESULTS FROM TRANSIENT CALCULATION

TIME= 0.200000

ITERATIONS COMPLETED = 300

LATTICE POINT TEMPERATURES

POINT NUMBER	I	INDICIES J	K	POINT TEMPERATURE
1	1	1	1	433.5084724
2	2	1	1	390.6316490
3	3	1	1	322.3524170
4	1	2	1	459.3407440
5	2	2	1	413.0282059
6	3	2	1	335.3969727
7	1	3	1	553.6964340
8	2	3	1	503.9378891
9	3	3	1	406.1853027
10	1	4	1	666.1102219
11	2	4	1	635.1184158
12	3	4	1	594.9888229
13	4	4	1	729.1194229
14	5	4	1	721.4904633
15	6	4	1	693.9541016

RESULTS FROM TRANSIENT CALCULATION

TIME= 0.200000

ITERATIONS COMPLETED = 300

LATTICE POINT TEMPERATURES

POINT NUMBER	I	INDICIES J	K	POINT TEMPERATURE
16	7	4	1	689.5315018
17	1	5	1	783.2339859
18	2	5	1	760.5296478
19	3	5	1	744.5514297
20	4	5	1	786.2535324
21	5	5	1	793.7925491
22	6	5	1	786.2045670
23	7	5	1	783.3842545
24	1	6	1	941.6234131
25	2	6	1	938.8481445
26	3	6	1	938.3368301
27	4	6	1	946.5123901
28	5	6	1	950.9375076
29	6	6	1	951.3157043
30	7	6	1	951.0957642

RESULTS FROM TRANSIENT CALCULATION

TIME= 0.200000

ITERATIONS COMPLETED = 300

LATTICE POINT TEMPERATURES

POINT NUMBER	I	INDICIES J	K	POINT TEMPERATURE
31	1	7	1	997.1194000
32	2	7	1	996.7086029
33	3	7	1	997.6322556
34	4	7	1	1001.3642960
35	5	7	1	1004.2945404
36	6	7	1	1005.4251785
37	7	7	1	1005.6460495

RESULTS FROM TRANSIENT CALCULATION

TIME= 0.200000

ITERATIONS COMPLETED = 300

TEMPERATURES ON NUMBERED BOUNDARIES

BOUNDARY NUMBER	TEMPERATURE
1	249.5831490
2	299.4997787
3	598.9995575

RESULTS FROM TRANSIENT CALCULATION

TIME= 0.399999

ITERATIONS COMPLETED = 600

LATTICE POINT TEMPERATURES

POINT NUMBER	I	INDICIES J	K	POINT TEMPERATURE
1	1	1	1	524.1820831
2	2	1	1	488.2221184
3	3	1	1	432.6021729
4	1	2	1	547.1772766
5	2	2	1	506.8139915
6	3	2	1	442.0487404
7	1	3	1	632.8316650
8	2	3	1	581.4410629
9	3	3	1	481.3562317
10	1	4	1	746.5209503
11	2	4	1	707.7173157
12	3	4	1	648.7326736
13	4	4	1	756.8713837
14	5	4	1	680.7355423
15	6	4	1	612.5058899

RESULTS FROM TRANSIENT CALCULATION

TIME= 0.399999

ITERATIONS COMPLETED = 600

LATTICE POINT TEMPERATURES

POINT NUMBER	I	INDICIES J	K	POINT TEMPERATURE
16	7	4	1	600.5653152
17	1	5	1	876.5113678
18	2	5	1	845.6332245
19	3	5	1	813.5842361
20	4	5	1	831.5890045
21	5	5	1	802.0662994
22	6	5	1	767.8600998
23	7	5	1	757.0555267
24	1	6	1	1067.4712982
25	2	6	1	1061.5902405
26	3	6	1	1053.1361542
27	4	6	1	1049.6862946
28	5	6	1	1040.1444550
29	6	6	1	1029.7907867
30	7	6	1	1025.7566223

RESULTS FROM TRANSIENT CALCULATION

TIME= 0.399999

ITERATIONS COMPLETED = 600

LATTICE POINT TEMPERATURES

POINT NUMBER	I	INDICIES J	K	POINT TEMPERATURE
31	1	7	1	1136.6631317
32	2	7	1	1134.2326050
33	3	7	1	1129.6758575
34	4	7	1	1125.5026245
35	5	7	1	1119.6714783
36	6	7	1	1114.0423889
37	7	7	1	1111.7696838

RESULTS FROM TRANSIENT CALCULATION

TIME= 0.399999

ITERATIONS COMPLETED = 600

TEMPERATURES ON NUMBERED BOUNDARIES

BOUNDARY NUMBER	TEMPERATURE
1	374.1651192
2	300.0000000
3	451.0018463

RESULTS FROM TRANSIENT CALCULATION

TIME= 0.502665

ITERATIONS COMPLETED = 754

LATTICE POINT TEMPERATURES

POINT NUMBER	I	INDICIES J	K	POINT TEMPERATURE
1	1	1	1	520.7829819
2	2	1	1	467.5070381
3	3	1	1	310.2014809
4	1	2	1	539.9041977
5	2	2	1	483.0640297
6	3	2	1	318.6034927
7	1	3	1	613.1933060
8	2	3	1	548.9244995
9	3	3	1	365.6122169
10	1	4	1	715.0017166
11	2	4	1	671.5232239
12	3	4	1	579.1807404
13	4	4	1	694.8785553
14	5	4	1	550.3816528
15	6	4	1	434.1378708

RESULTS FROM TRANSIENT CALCULATION

TIME= 0.502665

ITERATIONS COMPLETED = 754

LATTICE POINT TEMPERATURES

POINT NUMBER	I	INDICIES J	K	POINT TEMPERATURE
16	7	4	1	415.9227409
17	1	5	1	833.1894150
18	2	5	1	802.4146423
19	3	5	1	765.5306320
20	4	5	1	779.0977478
21	5	5	1	736.4330292
22	6	5	1	692.8216629
23	7	5	1	680.7954941
24	1	6	1	1008.7701797
25	2	6	1	1001.8537750
26	3	6	1	990.1297607
27	4	6	1	981.8260651
28	5	6	1	967.8886795
29	6	6	1	954.7105103
30	7	6	1	949.7573090

RESULTS FROM TRANSIENT CALCULATION

TIME= 0.502665

ITERATIONS COMPLETED = 754

LATTICE POINT TEMPERATURES

POINT NUMBER	I	INDICES J	K	POINT TEMPERATURE
31	1	7	1	1072.7260437
32	2	7	1	1069.0938873
33	3	7	1	1061.1381531
34	4	7	1	1052.2161102
35	5	7	1	1041.8540497
36	6	7	1	1033.0856934
37	7	7	1	1029.6966858

RESULTS FROM TRANSIENT CALCULATION

TIME= 0.502665

ITERATIONS COMPLETED = 754

TEMPERATURES ON NUMBERED BOUNDARIES

BOUNDARY NUMBER	TEMPERATURE
1	125.0000000
2	100.0000000
3	150.0000000

THE FOLLOWING SHOWS THE SETUP OF THE CRT FOR THE ABOVE CASE

GRAPH NUMBER 1 THIS PLOT IS IN THE XY PLANE
THE FOLLOWING X MESH LINES ARE PLOTTED FOR ALL Y

1 2 5 7

GRAPH NUMBER 2 THIS PLOT IS IN THE XY PLANE
THE FOLLOWING Y MESH LINES ARE PLOTTED FOR ALL X

3 4 5 6

SAMPLE PROBLEM FOR HEATING 1 DECK NO. 3W464

SAMPLE PROBLEM FOR HEATING 1 DECK NO. 3W464

C. Output from sample problems - 2. For radiation problem

A.I. HEATING 2 DECK NUMBER 3W798

INPUT RETURN

JOB DESCRIPTION-- SAMPLE PROBLEM FOR A.I. HEATING 2

GEOMETRY TYPE NO. 7

NUMBER OF REGIONS 6

NUMBER OF MATERIALS 2

NUMBER OF INITIAL TEMPERATURE FUNCTIONS 1

NUMBER OF GENERAL POSITION DEPENDENT FUNCTIONS 2

NUMBER OF HEAT GENERATION FUNCTIONS 1

NUMBER OF TIME DEPENDENT FUNCTIONS 4

TYPE OF OUTPUT DESIRED 0

NUMBER OF POINTS IN GROSS X OR R LATTICE 4

NUMBER OF POINTS IN GROSS Y OR THETA LATTICE 6

NUMBER OF POINTS IN GROSS Z LATTICE 0

NUMBER OF DIFFERENT KINDS OF BOUNDARIES 3

PROBLEM TYPE NUMBER 2

MAXIMUM NUMBER OF STEADY-STATE ITERATIONS 250

NUMBER OF S-S ITERATIONS BEFORE CALC BETA 50

NUMBER OF S-S ITERATIONS BEFORE EXTRAPOLATION 35

NUMBER OF DELTATS PER MONITOR PRINT 100

CONVERGENCE CRITERION 0.00001000

INITIAL BETA 1.00000000

TIME INCREMENT (DELTAT) 0.00200000

TOTAL TIME 0.40000000

STEPHAN-BOLTZMAN CONSTANT 0.11900000E-10

REGION DATA

1	1	1.0000	1.5000	0.	4.0000	0.	0.
1	1	0	0	0	0	0	0
2	2	1.5000	2.0000	0.	1.5000	0.	0.
1	1	0	1	0	0	0	0
3	1	1.5000	4.0000	2.5000	4.0000	0.	0.
1	1	0	0	0	0	0	0
4	2	3.0000	4.0000	2.0000	2.5000	0.	0.
1	1	0	0	3	0	0	0
5	2	1.5000	3.0000	2.0000	2.5000	0.	0.
1	1	0	0	0	0	0	0
6	2	1.5000	2.0000	1.5000	2.0000	0.	0.
1	1	0	2	0	0	0	0

MATERIAL DESCRIPTION DATA

MATERIAL	RHO	C SUB P	K
1	0.09999999E 01	0.49999999E-01	0.09999999E 01
2	0.09999999E 01	0.49999999E-01	0.20000000E 01

HEAT GENERATION FUNCTION DATA

1	4	2	0	0
---	---	---	---	---

INITIAL TEMPERATURE FUNCTION DATA

1	1	0	0
---	---	---	---

GENERAL POSITION DEPENDENT FUNCTION COEFFICIENTS

1	0.50000000E 03	0.	0.	0.	0.
	0.	0.			
2	0.20000000E 03	0.	0.	0.	0.
	0.	0.			

TIME DEPENDENT FUNCTION DATA

1	6	0.	1.0000000	0.2000000	2.0000000	0.3000000	2.0000000
0.4000000	3.0000000	0.5000000	3.0000000	0.5020000	1.0000000		
2	4	0.	1.5000000	0.2000000	3.0000000	0.5000000	3.0000000
0.5020000	1.0000000						
3	6	0.	2.0000000	0.2000000	4.0000000	0.3000000	4.0000000
0.4000000	3.0000000	0.5000000	3.0000000	0.5020000	1.0000000		
4	4	0.	1.0000000	0.2000000	1.5000000	0.5000000	1.1250000
0.5020000	0.						

BOUNDARY DATA

1	1	0.50000000E 03	0.09999999E 01	1
		0.60000000E 03	0.49999999E 01	3
2	1	0.60000000E 03	0.09999999E 01	2
		0.50000000E 03	0.49999999E 01	2
3	1	0.50000000E 03	0.09999999E 01	1
		0.	0.	0

GROSS LATTICES AND NUMBERS OF INCREMENTS

R OR X

1.000000	1.500000	2.000000	4.000000
1	1	2	

THETA OR Y

0.	1.500000	2.000000	2.500000	3.000000	4.000000
2	1	1	1	1	

FINE LATTICE, X OR R, Y OR THETA, Z

1	1.000000	2	1.500000	3	2.000000	4	3.000000
5	4.000000						
1	0.	2	0.750000	3	1.500000	4	2.000000
5	2.500000	6	3.000000	7	4.000000		

CONVERGENCE CRITERION NOT SATISFIED BY INPUT DELTA T -- DELTA T IS NOW = 0.99999999E-03

CONVERGENCE ACCELERATION APPLIED AT ITERATION NUMBER 35

RESULTS FROM STEADY STATE CALCULATION

TIME= 0.

ITERATIONS COMPLETED = 63

LATTICE POINT TEMPERATURES

POINT NUMBER	I	INDICIES J	K	POINT TEMPERATURE
1	1	1	1	1073.6775208
2	2	1	1	1032.0624695
3	3	1	1	961.8013153
4	1	2	1	1111.0465240
5	2	2	1	1068.7409210
6	3	2	1	994.5941925
7	1	3	1	1226.2814178
8	2	3	1	1189.3974915
9	3	3	1	1120.6024933
10	1	4	1	1332.8044586
11	2	4	1	1312.0854187
12	3	4	1	1296.9183350
13	4	4	1	1248.6375580
14	5	4	1	1150.9309692
15	1	5	1	1430.7532196

RESULTS FROM STEADY STATE CALCULATION

TIME= 0.

ITERATIONS COMPLETED = 63

LATTICE POINT TEMPERATURES

POINT NUMBER	INDICIES			POINT TEMPERATURE
	I	J	K	
16	2	5	1	1407.8476715
17	3	5	1	1382.4939575
18	4	5	1	1335.8936615
19	5	5	1	1276.7366028
20	1	6	1	1524.5075684
21	2	6	1	1516.6168671
22	3	6	1	1501.5950317
23	4	6	1	1465.1174316
24	5	6	1	1433.9818115
25	1	7	1	1609.3460388
26	2	7	1	1605.5549927
27	3	7	1	1596.2354736
28	4	7	1	1569.5596924
29	5	7	1	1551.7702637

RESULTS FROM STEADY STATE CALCULATION

AI-64-MEMO-177

-73-

TIME= 0.

ITERATIONS COMPLETED = 63

TEMPERATURES ON NUMBERED BOUNDARIES

BOUNDARY NUMBER	CONVECTION SINK	RADIATION SINK
1	500.0000000	1200.0000000
2	900.0000000	750.0000000
3	500.0000000	0.

AI-64-MEMO-177
-73-

NET HEAT FLOW FROM RADIATION AND CONVECTION BOUNDARY NODES

NODE	BOUNDARY	CONVECTION	RADIATION	TOTAL
3	1	-0.17317549E 03	0.27173515E 02	-0.14600197E 03
6	1	-0.37094564E 03	0.48866538E 02	-0.32207910E 03
9	1	-0.23272593E 03	0.11082441E 02	-0.22164349E 03
9	2	-0.55150623E 02	-0.18749961E 02	-0.73900585E 02
12	2	-0.99229583E 02	-0.37376533E 02	-0.13660611E 03
13	3	-0.37431878E 03	-0.	-0.37431878E 03
14	3	-0.32546549E 03	-0.	-0.32546549E 03
TOTALS		-0.16310115E 04	0.30995999E 02	-0.16000155E 04

NODE	HEAT GENERATION RATE
1	0.18750000E 02
2	0.37500000E 02
3	0.18750000E 02
4	0.37500000E 02
5	0.75000000E 02
6	0.37500000E 02
7	0.31250000E 02
8	0.62500000E 02
9	0.31250000E 02
10	0.25000000E 02
11	0.50000000E 02
12	0.50000000E 02
13	0.50000000E 02
14	0.25000000E 02
15	0.25000000E 02
16	0.50000000E 02
17	0.75000000E 02
18	0.09999999E 03
19	0.50000000E 02
20	0.37500000E 02
21	0.75000000E 02
22	0.11250000E 03
23	0.15000000E 03
24	0.75000000E 02
25	0.25000000E 02
26	0.50000000E 02
27	0.75000000E 02
28	0.09999999E 03
29	0.50000000E 02

TOTAL 0.16000000E 04

RESULTS FROM TRANSIENT CALCULATION

TIME= 0.200000

ITERATIONS COMPLETED = 200

LATTICE POINT TEMPERATURES

POINT NUMBER	INDICIES			POINT TEMPERATURE
	I	J	K	
1	1	1	1	1941.8027344
2	2	1	1	1951.4577179
3	3	1	1	1969.8213043
4	1	2	1	1934.0014343
5	2	2	1	1941.7489777
6	3	2	1	1959.9421692
7	1	3	1	1910.3240967
8	2	3	1	1904.5691223
9	3	3	1	1895.0723572
10	1	4	1	1904.2079926
11	2	4	1	1888.0446625
12	3	4	1	1850.2309723
13	4	4	1	1679.4341583
14	5	4	1	1569.1550751
15	1	5	1	1917.6595154

RESULTS FROM TRANSIENT CALCULATION

TIME= 0.200000

ITERATIONS COMPLETED = 200

LATTICE POINT TEMPERATURES

POINT NUMBER	I	INDICIES J	K	POINT TEMPERATURE
16	2	5	1	1901.7946930
17	3	5	1	1869.4880219
18	4	5	1	1749.1981049
19	5	5	1	1675.3338013
20	1	6	1	1944.0709839
21	2	6	1	1935.7556000
22	3	6	1	1914.2923279
23	4	6	1	1841.6061249
24	5	6	1	1799.5511780
25	1	7	1	1977.2415161
26	2	7	1	1972.2107544
27	3	7	1	1958.4419098
28	4	7	1	1913.4911652
29	5	7	1	1888.7673340

RESULTS FROM TRANSIENT CALCULATION

TIME= 0.200000

ITERATIONS COMPLETED = 200

TEMPERATURES ON NUMBERED BOUNDARIES

BOUNDARY NUMBER	CONVECTION SINK	RADIATION SINK
1	997.4995346	2393.9988708
2	1795.4991608	1496.2492981
3	997.4995346	0.

RESULTS FROM TRANSIENT CALCULATION

TIME= 0.399999

ITERATIONS COMPLETED = 400

LATTICE POINT TEMPERATURES

POINT NUMBER	INDICIES			POINT TEMPERATURE
	I	J	K	
1	1	1	1	1982.6400604
2	2	1	1	1931.7010651
3	3	1	1	1851.8491211
4	1	2	1	2004.3747253
5	2	2	1	1951.9886017
6	3	2	1	1866.9108734
7	1	3	1	2082.1723022
8	2	3	1	2030.1222992
9	3	3	1	1933.7008820
10	1	4	1	2174.4319458
11	2	4	1	2140.3484497
12	3	4	1	2099.5948792
13	4	4	1	2101.1327209
14	5	4	1	2023.3153534
15	1	5	1	2269.6080322

RESULTS FROM TRANSIENT CALCULATION

TIME= 0.399999

ITERATIONS COMPLETED = 400

LATTICE POINT TEMPERATURES

POINT NUMBER	I	INDICIES J	K	POINT TEMPERATURE
16	2	5	1	2239.7148438
17	3	5	1	2203.7033997
18	4	5	1	2176.6079407
19	5	5	1	2127.2854919
20	1	6	1	2364.2345886
21	2	6	1	2353.4649963
22	3	6	1	2332.9901733
23	4	6	1	2294.4812317
24	5	6	1	2263.4927063
25	1	7	1	2448.5027466
26	2	7	1	2442.8674622
27	3	7	1	2429.1180420
28	4	7	1	2392.4380493
29	5	7	1	2370.4377747

RESULTS FROM TRANSIENT CALCULATION

TIME= 0.399999

ITERATIONS COMPLETED = 400

TEMPERATURES ON NUMBERED BOUNDARIES

BOUNDARY NUMBER	CONVECTION SINK	RADIATION SINK
1	1494.9973602	1806.0031281
2	1800.0000000	1500.0000000
3	1494.9973602	0.

RESULTS FROM TRANSIENT CALCULATION

TIME= 0.400999

ITERATIONS COMPLETED = 401

LATTICE POINT TEMPERATURES

POINT NUMBER	INDICIES			POINT TEMPERATURE
	I	J	K	
1	1	1	1	1979.4518890
2	2	1	1	1928.6494141
3	3	1	1	1849.2092285
4	1	2	1	2001.6164398
5	2	2	1	1949.3359680
6	3	2	1	1864.5891113
7	1	3	1	2080.6973572
8	2	3	1	2028.7692261
9	3	3	1	1932.5948181
10	1	4	1	2173.9961548
11	2	4	1	2140.1585388
12	3	4	1	2100.0048218
13	4	4	1	2104.7956238
14	5	4	1	2028.1739807
15	1	5	1	2269.9538269

RESULTS FROM TRANSIENT CALCULATION

TIME= 0.400999

ITERATIONS COMPLETED = 401

LATTICE POINT TEMPERATURES

POINT NUMBER	I	INDICIES J	K	POINT TEMPERATURE
16	2	5	1	2240.2070313
17	3	5	1	2204.6683960
18	4	5	1	2179.9792175
19	5	5	1	2131.7239075
20	1	6	1	2365.1847534
21	2	6	1	2354.5426941
22	3	6	1	2334.4524536
23	4	6	1	2297.4289856
24	5	6	1	2267.1427002
25	1	7	1	2449.9505310
26	2	7	1	2444.4096680
27	3	7	1	2430.9312439
28	4	7	1	2395.1829224
29	5	7	1	2373.6370850

RESULTS FROM TRANSIENT CALCULATION

TIME= 0.400999

ITERATIONS COMPLETED = 401

TEMPERATURES ON NUMBERED BOUNDARIES

BOUNDARY NUMBER	CONVECTION SINK	RADIATION SINK
1	1500.0000000	1800.0000000
2	1800.0000000	1500.0000000
3	1500.0000000	0.

VII

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