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TRIN: COMPUTER PROGRAM TO CALCULATE TEMPERATURE DISTRIBUTIONS IN CIRCULAR AND RECTANGUALR SECTIONS EXPOSED TO THERMAL RADIATION FROM NUCLEAR WEAPON EXPLOSIONS

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TRIN: COMPUTER PROGRAM TO CALCULATE TEMPERATURE DISTRIBUTIONS IN CIRCULAR AND RECTANGULAR SECTIONS EXPOSED TO THERMAL RADIATION FROM NUCLEAR WEAPON EXPLOSIONS

This study is part of a continuing effort to determine the susceptibility of critical shipboard topside systems to thermal radiation and thermal radiation-airblast interaction effects from nuclear weapon detonations, and to develop techniques to protect against these effects. This report presents a computer program developed to calculate temperature distributions in two or three dimensions, for materials of rectangular and circular cross sections exposed to transient thermal radiation heating.

This work is sponsored by the Naval Ship Systems Command under subproject SF 26-553-001, Task Number 11292.

ROBERT WILLIAMSON II
Captain, USN
Commander

W. W. Scanlon

W. W. SCANLON
By direction

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INTRODUCTION

A computer program (TRIN) has been developed to calculate two and three dimensional distributions of temperature in a structural element exposed to the thermal radiation pulse from a nuclear weapon explosion. The element may be circular or rectangular in cross section, for example, a round bar, rectangular bar, hollow circular tube or boxbeam. It may be stationary during irradiation, or rotate at an arbitrary rate about an axis normal to its cross section.

A characteristic of a nuclear weapon explosion in the atmosphere is a pulse of intense thermal radiation which can deliver appreciable energy to a distant target. The irradiance history of this pulse, normalized about its peak, is given in Table 1 and illustrated in Figure 1 (reference (1)). The time to maximum irradiance (t_m) increases with weapon yield, and is of the order of 0.1 second for a 10 kiloton yield weapon, and one second for a 1000 kiloton (one megaton) yield weapon. A short time (order of seconds) after the thermal pulse peaks, the airblast pressure pulse caused by the explosion arrives at the target. Eighty percent or more of the total thermal radiation energy released is incident on the target prior to the time of blast arrival for most situations of interest in ship system vulnerability studies.

Military targets exposed to the thermal pulse can undergo temperature rises sufficient to thermally stress them, and to cause significant strength loss as well. These effects alone can cause unacceptable damage to a shipboard system such as a radar antenna, and can also enhance the effects of the oncoming airblast pressure pulse. Calculation of temperature distribution histories in structural elements is therefore central to determining susceptibility of essential military systems to nuclear weapon thermal radiation and thermal radiation-airblast interaction effects. Specialized numerical analyses have been developed for this purpose under Naval Ship Systems Command support. Examples are reported in References (2) - (6). These analyses are restricted to calculation of temperature distributions which vary, at most, in two spatial dimensions. Reference (2), for example, presents a mathematical analysis and computer program to calculate temperature distributions in two dimensions (radial and circumferential) for a circular cylinder exposed to the nuclear weapon thermal radiation pulse. When such a cylinder is incorporated in a topside structure such as a radar antenna, its ends are joined to another element which can function as a heat source or sink, and the temperature distribution may then vary along the cylinder (longitudinally) as well as radially and circumferentially. In this case, the two-dimensional analysis is valid only at cylinder locations which are sufficiently distant* from the ends of the cylinder (i.e., the sources or sinks). In general three spatial dimensions are required to completely describe the temperature distribution, which in turn determines the thermal stress. The temperature calculation programs developed to date are adequate for identifying problem areas and potential "weak links" in a structure. A capability for calculating temperature distributions in three dimensions is required to examine the interaction of one structural element with another, and to evaluate the importance of heat sources and sinks in real structures.

There are a number of general three-dimensional heat transfer programs that could be used for calculating the desired temperature distributions. One such program which is in wide use and has been well-documented is the TRUMP code (reference (7)). The principal difficulty in using TRUMP or similar codes is that a considerable amount of input data must be prepared. To simplify the data preparation, computer programs have been developed to generate input for TRUMP for specific types of problems (references (8)-(11)). These programs not only reduce the time and expense of key-punching, but also reduce the possibility of an undetected key punching error. None of these previous efforts, however, is directly useful for the problems of interest here. It was therefore decided to develop a computer program to generate the input data required for TRUMP to calculate thermal radiation induced temperature distributions in structural elements of circular and rectangular cross section. This program, with TRUMP appended as a subroutine, is called TRIN. Some capabilities of TRIN are as follows:

1. One end of the element is insulated. The other end may be insulated, have a prescribed temperature history, or undergo convective heat exchange with a time-dependent heat sink.

2. The element is of circular or rectangular cross section, and maybe solid or hollow.

3. External surfaces may lose heat by convection or radiation and internal surfaces may lose heat by convection.

4. The element may be stationary, or rotate at an arbitrary rate about the axis normal to its cross section.

5. The irradiance history of the heating pulse is assumed to be that given in Effects of Nuclear Weapons (reference (1)).

* The concept "sufficiently distant" connotes more than the physical distance of the location from the source or sink. The thermophysical properties and the time at which the temperature is required must also be considered.

SYMBOLS

α	absorptance
c	specific heat at constant pressure
Fe	radiative exchange factor (product of radiative view factor and surface emissivity)
h_b	heat transfer coefficient for convective cooling at the base plane
h_e	heat transfer coefficient for the convective cooling of external surfaces
h_i	heat transfer coefficient for the convective cooling of internal surfaces
H	irradiance
H'	irradiance modified to account for the relative position of the source (see equations (7) and (14))
Hm	maximum irradiance
K	thermal conductivity
Lx	length of the box beams
Ly	width of the box beams
Lz	height of the box beams or cylinders
n_e	heat transfer exponent for the convective cooling of external surfaces
h_i	heat transfer exponent for the convective cooling of internal surfaces
r	radial coordinate
Ri	inner radius of the cylinders
Ro	outer radius of the cylinders
t	time
tm	time at which maximum irradiance of nuclear weapon thermal pulse occurs.
T	temperature
T_b	temperature of the heat sink located at the base of the cylinder or box beam structural element.
Te	external ambient temperature
Ti	internal ambient temperature (temperature of the medium enclosed by the cylinder or box beam)
To	initial temperature
V	symbol used to represent either the X or Y direction
x	Cartesian coordinate measured along a leg of a box beam
y	Cartesian coordinate measured along a leg of a box beam and perpendicular to the x rectangular coordinate
z	Cartesian coordinate perpendicular to both the x and y rectangular coordinate and measured from the base of the cylindrical or box beam structural elements.
ω	angular rotation speed
ρ	density
θ	angular coordinate, measured from the most forward point on a cylinder with respect to the initial irradiance for a nuclear weapon detonation

θ_1 the angle between the initial irradiance from a nuclear weapon detonation and the box beam face initially exposed (face 1)

θ_2 the angle between the axis of symmetry of the cylinder or box beam and the incident irradiance (taken as the angle of inclination of the cylinder or box beam in this report)

σ the Stefan-Boltzmann constant

MATHEMATICAL DESCRIPTION OF THE CIRCULAR CYLINDER AND BOX BEAM HEATING PROBLEMS

In this section, the describing equations and boundary conditions will be given for the circular cylindrical and box beam structural elements. The boundary conditions for these structures are radiation heating by a nuclear weapon thermal radiation pulse and cooling by convection and radiation. Since the cylinder or box beam may be hollow, convection cooling is also allowed to occur on the inner surfaces. Furthermore, the structural elements are free to rotate about an axis normal to their cross section or have a heat sink at their base. Also, inclination of these elements with respect to the vertical will be approximated by allowing the incoming radiation to strike their surfaces at an arbitrary angle. These problems are three-dimensional in that temperatures may vary with length, width and height or with radius, circumference and altitude. Temperature variations in the length-width or radius-circumference planes are primarily due to the non-uniformity of the thermal radiation arriving at the surface of the structures. These temperature gradients are complicated by rotation of the structures. Temperature variations in the height or altitude direction are due to the presence of a heat sink at their base. Since the geometries of the cylinder and the box beam are radically different, their describing equations and boundary conditions are discussed separately below.

<u>Cylinder Heating Problem</u>

The partial differential equation for three-dimensional heat conduction in a circular cylinder is:

$$\rho c \frac{\partial T}{\partial t} = \frac{1}{r} \frac{\partial}{\partial r}\left(K \frac{\partial T}{\partial r}\right) + \frac{1}{r^2} \frac{\partial}{\partial \theta}\left(K \frac{\partial T}{\partial \theta}\right) + \frac{\partial}{\partial z}\left(K \frac{\partial T}{\partial z}\right) \qquad (1)$$

It is assumed that initially the cylinder is at a uniform temperature, i.e.,

$$\text{at } t = 0 \qquad T = To \qquad (2)$$

The boundary conditions discussed above are expressed by the following equations.

$$\text{at } r = Ri \qquad -K \frac{\partial T}{\partial r} = h_i (T_i - T)^{n_i} \qquad (3)$$

$$\text{a } r = Ro \qquad K \frac{\partial T}{\partial r} = AH' \sin \theta 2 - he(T-Te)^{ne} - \sigma Fe(T^4 - Te^4) \qquad (4)$$

$$\text{at } z = Lz \qquad K \frac{\partial T}{\partial z} = 0 \qquad (5)$$

$$\text{at } z = 0 \qquad -K \frac{\partial T}{\partial z} = h_b (T_b - T) \qquad (6)$$

The first boundary condition, (equation (3)), states that convective cooling is allowed on the inner surface as described by a constant heat transfer coefficient, h_i, and a constant convective exponent, n_i. The second condition, (equation (4)), states that thermal radiation heating given by the irradiance, H', is absorbed and that both convective and radiative cooling are allowed. The radiative exchange factor, Fe, and the absorptance, A, are assumed to be constant in equation (4). The irradiance is given in terms of the normalized thermal irradiance history of a nuclear weapon air burst in the lower atmosphere (see Figure 1 and Table 1). As the cylinder rotates, the weapon thermal irradiance will fall on different areas of the cylinder. Expressed mathematically, the irradiance is:

$$H' = \begin{cases} H \cos(\theta+\omega t) & \cos(\theta+\omega t) > 0 \\ 0 & \cos(\theta+\omega t) < 0 \end{cases} \tag{7}$$

where the angular rotation speed, ω, is a constant and H is the nuclear weapon thermal irradiance history. The third boundary condition, equation (5), states that the upper surface of the circular cylinder is thermally insulated while the fourth, equation (6), states that convective cooling or heating is allowed at the cylinder base. In equation (6), the external temperature, T_b, can be given as a function of time. The fourth boundary condition represents two alternate conditions in addition to convective cooling. That is, by specifying that h is zero, the bottom of the cylinder is insulated against heat transfer. Also, by specifying that h is large, there will be little thermal resistance between the cylinder and the heat sink and T_b will be the actual temperature of the cylindrical base.

Box Beam Heating Problem

The partial differential equation for three-dimensional heat conduction in a rectangular parallelpiped (box beam) is:

$$\rho c \frac{\partial T}{\partial t} = \frac{\partial}{\partial x}\left(K \frac{\partial T}{\partial x}\right) + \frac{\partial}{\partial y}\left(K \frac{\partial T}{\partial y}\right) + \frac{\partial}{\partial z}\left(K \frac{\partial T}{\partial z}\right) \tag{8}$$

It is assumed that initially the box beam is at a uniform temperature, i.e.,

$$\text{at } t = 0 \qquad T = To \tag{9}$$

The boundary conditions described previously will be given in equation form below. To avoid the writing of repetitious equations for each of the ten boundary surface planes of the box beam, the boundary equations are expressed in a condensed form.

Inner Surface Planes $$K \frac{\partial T}{\partial V} = h_i (T_i - T)^{n_i} \qquad (10)$$

Outer Surface Planes $$-K \frac{\partial T}{\partial V} = AH' \sin \theta 2 - h_e (T - Te)^{n_e}$$

$$- \sigma Fe (T^4 - Te^4) \qquad (11)$$

Top Plane (x=Lz) $$K \frac{\partial T}{\partial z} = 0 \qquad (12)$$

Bottom Plane (z=0) $$-K \frac{\partial T}{\partial z} = h_b (T_b - T) \qquad (13)$$

Where V represents the x or y direction depending on the surface plane under consideration.

The first boundary condition, equation (10), states that convective cooling is allowed on inner surfaces as described by a constant heat transfer coefficient, h_i, and a constant convective exponent, n_i. The second condition, equation (11), states that the thermal radiation heating given by the irradiance, H', is absorbed and that both convective and radiative cooling are allowed. The radiative exchange factor, Fe, and the absorptance, A, are assumed to be constant. The irradiance is given in terms of the normalized thermal irradiance history of a nuclear weapon air burst in the lower atmosphere (see Figure 1 and Table 1). As the box beam rotates, the irradiance will fall on different surface planes. For the purpose of illustration, these will be referred to as face 1, 2, 3, and 4 where face 1 is initially exposed to the irradiance and successive faces are perpendicular to the first in a counter-clockwise direction. The irradiance can now be given mathematically as:

$$H' = \begin{cases} H \cos (\theta + \theta 1 + \omega t + B) & \cos(\theta + \theta 1 + \omega t + B) > 0 \\ 0 & \cos(\theta + \theta 1 + \omega t + B) < 0 \end{cases} \qquad (14)$$

Where

$$B = \begin{array}{ll} 0 & \text{Face 1} \\ \pi/2 & \text{Face 2} \\ \pi & \text{Face 3} \\ 3\pi/2 & \text{Face 4} \end{array} \qquad (15)$$

Here, the rotation speed, ω, is a constant and H is the nuclear weapon thermal irradiance history. The third and fourth boundary conditions, equations (11) and (12), are identical to the top and bottom plane conditions on the cylinders. That is, the top is insulated and the base is either insulated, undergoes a prescribed temperature history, or is heated or cooled by convection.

THE TRUMP PROGRAM

The computer program TRUMP (reference (7)) is a versatile code that numerically solves problems of flow in various kinds of potential fields including, but not limited to, heat flow in temperature fields. In considering thermal problems, it solves the general three-dimensional equation of heat conduction with mass flow, internal heat generation, and chemical reactions. Steady state or transient heating problems are solved in structures having either simple configurations or arbitrary complex shapes. Initial temperatures may vary with spatial position. Boundary temperatures and heat transfer rates which vary with time and position may be specified. Also several different materials may be considered and the thermophysical properties of each of these may vary with temperature or time. The NOL version of TRUMP does not allow chemical reactions, mass flows or all of the options given in reference (7). The following discussion of TRUMP will pertain only to the NOL version.

TRUMP is a numerical program which uses the method of finite differences to compute temperatures at a number of discrete points in successive time steps. That is, the structure must be initially divided into a number of volume elements or nodes, each containing a nodal point located arbitrarily within (but usually at the center). These nodes may be of different sizes and shapes but should be constructed such that the entire volume of the structure is covered. Nodes may be internal to the structure, or on its surface. External or "boundary" nodes may be used to specify prescribed boundary conditions. The nodes must be numbered and input as data to the TRUMP program. Also input are the required thermal connections between nodes. Each thermal connection between two internal nodes is described by giving two nodal point numbers, two connecting lengths between adjacent nodes, and two interfacial length factors which are used to compute the interfacial area between adjacent nodes. The thermal connections involving surface and boundary nodes are handled similarly except that there are no connecting lengths. A finite difference equation is derived for each of these nodes by writing the partial differential equation of heat conduction and its boundary conditions in finite difference form. The TRUMP program solves these equations successively in time. That is, the solution at a given time forms the initial conditions for the equations at the next time step. The systems of finite difference equations may be solved by either implicit or explicit methods, or by a combination of both. Explicit methods are usually more efficient for large problems but have the disadvantage that the difference equations become unstable if the time step is too large. The TRUMP program may be ended by reaching a maximum temperature, a maximum time (either computer or real), a maximum number of time steps or by reaching a steady state.

Since TRUMP is a large program with capability to consider many kinds of thermal problems, a large amount of input information is required to run the program. This input is organized into data blocks. Each data block represents a few or many key-punched computer cards depending on the complexity of the problem being solved. The following is a table of the data blocks required for the NOL version of TRUMP

Block*	Description
1	Program controls and limits
2	Material properties
4	Node dimensions and numbering system
5	Internal thermal connections
6	External thermal connections
7	External temperatures (boundary nodes)
8	Internal heat generation rates
9	Initial temperatures and initial heat generation rates
11	Graphical output controls
12	Nodes with properties dependent on remote temperatures

If a data block(s) does not pertain to a given problem, it may be omitted from the data. The above table shows that most of the input data of TRUMP is concerned with setting up a nodal system and specifying all possible thermal connections between nodes. This procedure is difficult for complex problems and experience in the set-up of problems is necessary to avoid errors. This report describes a computer program, TRIN, which generates the data blocks 1 through 7 for two particular complex problems, namely, the three-dimensional rotating circular cylinder and the three-dimensional rotating rectangular parallelepiped, both of which are exposed to the thermal radiation pulse of a nuclear explosion. Some options of TRUMP are not necessary and will be omitted, leaving only a relatively small amount of input data required by TRIN.

USE OF THE COMPUTER PROGRAM TRIN

The computer program, TRIN, prepares the input data for the TRUMP program for either the circular cylinder or box beam problems previously described. The cylinder and box beam have significantly different geometries but their boundary heating and cooling conditions are identical. Hence, a common input will be used by TRIN for either problem, with some variables having different meanings for each problem. The purpose of TRIN is to greatly reduce and simplify the input data required to run TRUMP. That is, with TRIN it is possible to run TRUMP without acquiring a knowledge of the use and set-up of nodal systems in solving heat transfer problems. However, it is necessary to know how the nodal system is generated by TRIN because the temperatures computed by TRUMP are printed for the nodal points. The location and the numbering

* Block 3 and 10, describing chemical reactions and mass flow, are omitted in the NOL version of TRUMP.

system of nodal points generated by TRIN is discussed in the next section of this report A.listing of the TRIN program is given in Appendix A.

The input for TRIN consists of ten basic cards from which TRIN calculates all of the input data for TRUMP for either the cylinder or box beam problems. Also, a reduced input of seven cards will be given as the input envisioned for the majority of problems. That is, the last three cards of the input deck are optional and are used to specify additional controls on TRUMP to allow convection or radiation cooling or to allow a change in phase of the material. A listing of the input variables which appear on each of the ten input cards, and their required format, is given in the following table.

Card	Variables	Format
1	NAMEE	7A10
2	IINPUT, IPRINT, IGEOM, LTABC, LTABK, LTABHS, DELTI, TIMAX, TONE	6I6,3E12.4
3	NELTH, NELZ, NELY, NELX, THICK, Z, Y, X	4I6,4E12.4
4	TM, HM, THETA1, OMEGA, THETA2, ABSORB, DENS, HB	8E10.4
5*	CAPT (I), TVARC(I), I=1, LTABC	8E10.4
6*	CONT(I), TVARK(I), I=1, LTABK	8E10.4
7**	TEMPB(I), TIMEB(I), I=1, LTABHS	8E10.4
Optional Cards		
8	ILIST, KSPEC, MCYC, ITEMP, DELTO, SMALL, TVARY	4I6,3E12.4
9	HI, ANI, TINT, HE, ANE, TEXT, FE, SIGM	8E10.4
10	LOCTOP, LOCBTM, LOCOF, LOCIF, LOCCIR, TMELT, HMELT	5I6,2E12.4

The units of these variables are arbitrary as long as a consistent set of units is used throughout. The only variation to this rule is in accounting for radiation cooling. Here, the variable ITEM (card 8) is used to indicate if absolute (Rankine or Kelvin) or relative (Fahrenheit or Centigrade) temperature scales are used and the Stefan-Boltzmann constant (SIGM, Card 9) must be input with units corresponding to the consistent set used throughout. The meaning and use of each of these variables will be given in a

* Card 5 or Card 6 may be 1, 2 or 3 cards depending on the number of CAPT/TVARC or CONT/TVARC values input (up to ten pairs of values allowed)

** Card 7 may be from 1-5 cards depending on the number of TEMPB/TIMEB values input (up to 20 pairs of values allowed).

discussion of each input card in turn. Also, the difference in meaning for a cylinder or box beam problem will be pointed out as they occur.

CARD 1 NAMEE

This card permits an identifying name or numbers to be given to the problem. This name is printed on each page of printed output generated by the TRUMP program.

CARD 2 IINPUT, IPRINT, IGEOM, LTABC, LTABK, DELTI, TIMAX, TONE

This card specifies program controls and limits in a manner similar to the block 1 control cards of TRUMP. The definition of the variables are as follows.

IINPUT indicates reduced (7 Card) input (IINPUT = 1) or full (10 Card) input (IINPUT = 0)

IPRINT is the number of time steps between a printout of the temperatures at each nodal point (except that the first, second and final time steps are always printed)

IGEOM is used to indicate if a box beam or a cylinder problem is to be solved. The choices of IGEOM are

$$\text{IGEOM} = \begin{cases} 0 & \text{box beam geometry} \\ 1 & \text{circular cylinder geometry} \end{cases}$$

LTABC, LTABK and LTABHS are the number of entries in the material specific heat table (Card 5), the material thermal conductivity table (Card 6) and the table which specifies the temperature history of the heat sink (or source) at the structural element base (Card 7).

DELTI is the time increment used by TRUMP in numerically computing temperatures. Care must be exercised in choosing this value since it effects both the accuracy and the efficiency of the TRUMP computations. It is recommended that DELTI be 0.01 seconds or less for typical problems involving heating from a nuclear weapon thermal pulse.

TIMAX is the total real time for which temperature calculations are desired.

TONE is the constant initial temperature of the structural element

CARD 3 NELTH, NELZ, NELY, NELX, THICK, Z, Y, X

This card specifies the geometry of the structural element. The geometrical variables and the coordinate system used for each problem are shown in Figure 2 as an aid in the following definitions

NELTH is the number of elements in the "thickness" directions, i.e., the radial direction of a cylinder or through either leg of a box beam in an X-Y plane (see Figure 2).

NELZ is the number of elements in the Z direction

NELY*** is the number of elements in the circumferential (θ) direction for a cylinder or in the y direction for a box beam. For a box beam, the x and y directions represent a plane perpendicular to the box beam axis of rotation. The x direction represents the leg that is initially exposed to the nuclear weapon's thermal radiation and the y direction is perpendicular to this leg (see Figure 2)

NELX*** is the number of elements in the x direction for a box beam. This variable need not be specified for cylinder problems.

THICK is the total thickness of the box beam or cylinder, i.e., the length dimension in the radial direction of a cylinder or the thickness of the x and y legs of a box beam.

Z is the length of the cylinder or box beam, measured in the z direction.

Y is the outer radius of a cylinder or the length of the y direction box beam legs.

X is the length of the x direction box beam legs. This variable need not be specified for the cylinder.

CARD 4 TM, HM, THETA1, OMEGA, THETA2, ABSORB, DENS, HB

This card specifies the characteristics of the nuclear weapon thermal pulse, the orientation, absorptance, material density, and rotation speed of the structural element and the convective coefficient for the heat sink at the base of the structural element. The definitions of the variables are as follows.

TM is the time to maximum irradiance of the nuclear weapon thermal radiation pulse

*** The number of corner elements are not included in NELY or NELX for box beam problems (see Figure 2).

HM is the maximum irradiance of the nuclear weapon thermal radiation pulse

THETA1 is the initial angle between the incident thermal radiation and the first exposed face of a box beam (see equation (14) and Figure 2). This quantity need not be specified for cylinder problems.

OMEGA is the rotational speed in the counter clockwise direction in radians per unit time.

THETA2 is the angle of inclination of the cylinder or box beam with respect to the vertical (see Figure 2).

ABSORB is the absorptance of the surface of the cylinder or box beam for thermal radiation.

DENS is the material density of the box beam or cylinder.

HB is the convective coefficient between the base plane of the cylinder or box beam and an external heat sink or source (see equation (6)).

CARD 5 CAPT(I), TVARC(I) I = 1, LTABC

CARD 6 CONT(I), TVARK (I), I = 1, LTABK

These cards specify the specific heat and the thermal conductivity as a function of temperature. The specific heat and thermal conductivity tables are input by specifying a property value and its corresponding temperature. Four of these pairs of numbers are placed on each input card and three cards are required to specify the maximum allowed number (10) of property value pairs. The definitions of the variables are as follows.

CAPT is the material specific heat
TVARC* is the temperature at which the specific heat is specified
CONT is the material thermal conductivity
TVARK* is the temperature at which the thermal conductivity is specified.

CARD 7 TEMPB(I) TIMEB(I) I = 1, LTABHS

This card specifies the temperature history of the heat sink at the base of the cylinder or box beam. As noted previously this heat sink can be used to represent three different kinds of boundary conditions. These are: (1) the convective coefficient, HB, on Card 4 is zero, hence the base is insulated against heat flow, (2) the convective coefficient, HB, is very large hence the

* These temperatures need not be specified if only one value of CAPT and CONT is given

temperatures given on Card 7 represent the actual temperature imposed on the base of the structure, (3) the convective coefficient, HB, is used to exchange heat with the heat sink or source by convection. Note that these variables are input in pairs (four pairs to a card) and that five cards are required to specify the maximum allowed number (20) of heat sink temperatures. The definition of the variables are as follows.

TEMPB is the temperature of the heat sink or source.

TIMEB is the time at which the above temperature exists.

CARD 8 ILIST, KSPEC, MCYC, ITEMP, DELTO, SMALL, TVARY

This card is the first of three optional cards which are used to specify convective or radiative cooling from exposed surfaces, melting of material, or to place additional controls on the TRUMP calculation or on the printout of data. Card 8 and part of card 10 are for controlling the TRUMP calculations. All of the variables given on these optional cards are required by TRUMP, and standard or "default" values are supplied by the TRIN program when the optional cards are not used. The standard values represent the best choices for most situations. The TRUMP controls given on Cards 8 and 10 should only be used by personnel familiar with nodal systems and numerical computer programs. Card 8 allows control over the way numerical calculations are made and printed. The definition of the variables on Card 8 are as follows.

ILIST is used to print out or punch onto cards the data generated by TRIN. Specifically, these are the data blocks required to run the TRUMP program (see table in the previous section entitled, "The TRUMP Program"). The choices for ILIST are:

ILIST =
- 0 data generated by TRIN is not printed or punched (the default value)
- 1 data generated by TRIN is printed only
- 2 data generated by TRIN is punched only
- 3 data generated by TRIN is both printed and punched

KSPEC is used to control the mode of solution for the finite difference equations in TRUMP, i.e., these equations may be solved in implicit mode, explicit mode, or both. If both implicit and explicit solutions are allowed, the program will switch from an explicit method to an implicit one for nodes where the solution becomes unstable for the program time step specified. The choices for KSPEC are:

KSPEC = { -1 only explicit nodal equations are allowed; 0 both implicit and explicit nodal equations are allowed; 1 only implicit nodal equations are allowed (The default value); 2 only implicit nodal equations using backward differences are allowed; 3 only implicit nodal equations using central differences are allowed }

KSPEC =	
-1	only explicit nodal equations are allowed
0	both implicit and explicit nodal equations are allowed
1	only implicit nodal equations are allowed (The default value)
2	only implicit nodal equations using backward differences are allowed
3	only implicit nodal equations using central differences are allowed

MCYC is the maximum number of time steps allowed. The actual number of time steps is given by the ratio of TIMAX and DELTI if optional cards 8, 9 and 10 are not used. This variable is important in controlling the number of calculations when the time step is allowed to vary ($KSPEC \leq 0$). If MCYC is set equal to zero or unspecified, a default value of 30,000 is assumed for MCYC.

ITEMP is used to indicate the temperature scale used in problems where radiation from the external surfaces is accounted for. The possible choices for ITEMP are:

ITEMP =	
1	temperature scale in degrees Centigrade
2	temperature scale in degrees Kelvin
3	temperature scale in degrees Fahrenheit
4	temperature scale in degrees Rankine

Note no default option for ITEMP is required. That is, if radiative losses are not considered the temperature scale agrees with the temperature units of the input variables and the value of the initial temperature, TONE.

DELTO is the maximum allowable time step. DELTO must be specified if $KSPEC > 0$. Default option, if DELTO is specified to be zero, DELTO is set equal to 10^{12}. When the optional cards are not used, DELTO is set equal to DELTI.

SMALL is the minimum allowable time step. If small is specified to be zero, SMALL is set equal to 10^{-12}. If the optional cards are not used SMALL is set equal to DELTI.

TVARY is the maximum allowable temperature change in each time step. If this limiting temperature change is approached at any node, the program will lower the value of the time step, DELTI, between the limits of DELTO and SMALL. Default option: if TVARY is zero or unspecified, TVARY is set equal to 5.0.

CARD 9 HI, ANI, TINT, HE, ANE, TEXT, FE, SIGM

This card is used to allow convection or radiation cooling or heating of external surfaces or convective cooling or heating of internal surfaces. If Card 9 is not present, the default option sets of all these variables equal to zero. The definitions of the variables are as follows:

HI, ANI and TINT are the convective heat transfer coefficient, the convective exponent and the ambient temperature for convective cooling or heating of internal surfaces, i.e., the inner surface planes of box beams or the cylindrical surface defined by r = Ri (see equations (3) and (10)).

HE, ANE and TEXT are the convective heat transfer coefficient, the convective exponent and the ambient temperature for convective cooling or heating of external surfaces, i.e., the outer surface planes of box beams or the cylindrical surface defined by r = Ro (see equations (4) and (11)).

FE is the emissivity of the surface (see equations (4) and (11)).

SIGM is the Stefan-Boltzmann constant. As previously stated, this quantity must be expressed in units which are consistent with the other units throughout the problem and with the temperature scale (ITEMP)

CARD 10 LOCTOP, LOCBTM, LOCOF, LOCIF, LOCCIR, TMELT, HMELT

This card is used to control the location of the nodal point in the boundary nodes and also to allow for a change of phase in the material. The nodal points are usually located at the center of the nodes, however, the accuracy of the numerical calculations may be improved by moving the nodal points. For example, accuracy is improved by placing nodal points at the surface when the heat transfer rate depends on the surface temperature. The definition of the variables appearing on this card are:

LOCTOP locates the nodal point in nodes of the uppermost plane, i.e., the plane adjacent to the upper insulated boundary (z = Lz for the cylinder or the box beam). The choice for the LOCTOP are:

LOCTOP =
- 0 nodal points are at the geometrical center of the node (The default value)
- 1 nodal points are at the structure-insulated boundary interface.

LOCBTM locates the nodal point in nodes at the bottom-most layer, i.e., the plane adjacent to the heat sink (z = 0). The choices for LOCBTM are:

LOCBTM =
- 0 nodal points are at the geometrical center of the node
- 1 nodal points are at the structure-heat sink interface (The default value)

LOCOF locates the nodal point in nodes of the outer external surface layer (r = Ro for the cylinder and the outer surface planes of box beams). LOCOF is not used in box beam problems unless the box beam is only one element thick (NELTH = 1). The choices for LOCOF are:

LOCOF =
- -1 nodal points are at the backfaces of the external surface nodes
- 0 nodal points are at the geometrical center of the external surface nodes (The default value)
- 1 nodal points are at the surface of the external surface nodes

LOCIF locates the nodal point in nodes on the internal surface of a cylinder (r = Ri). LOCIF is not used in box beam problems or in cylinder problems where the cylinder is only one element thick (NELTH = 1). The choices for LOCIF are:

LOCIF =
- 0 nodal points are at the geometrical center of the internal surface nodes (the default value)
- 1 nodal points are at the surface of the internal surface nodes.

LOCCIR locates the nodal point in the circumferential direction for all nodes in a cylinder problem. LOCCIR is not used in box beam problems. The nodal point will be positioned on the left boundary of the node (when viewed from the top) unless it is moved by choosing an appropriate value for LOCCIR. The choices for LOCCIR are:

LOCCIR =
- 1 nodal points are on the left boundary (the default value)
- 0 nodal points are in the geometrical center (in the circumferential direction)
- -1 nodal points are on the right boundary

TMELT is the temperature at which a phase change occurs

HMELT is the latent heat of fusion at TMELT.

The default option sets both TMELT and HMELT equal to zero if card 10 is not present.

NODAL NUMBERING SYSTEM

The TRUMP program requires that the structural element being analyzed be initially divided into a number of volume elements called nodes, each containing a nodal point. Because the temperatures computed by TRUMP are printed for each nodal point, it is necessary to know where these nodal points are located on the structural element. In TRUMP, these nodes are identified by assigning each node a unique number. Although any node may be assigned any number from -9,999 to 99,999, except 0, it is convenient to use a nodal numbering convention that enables the user to readily identify the location of each node. In this section, the nodal numbering system generated by TRIN for TRUMP will be illustrated by giving examples of both cylindrical and rectangular geometries.

Cylindrical Structural Elements

Consider a hollow cylinder in which both the top and the bottom are insulated and hence the heat transfer is two-dimensional. Figure 3 illustrates the numbering convention for a two-dimensional cylinder in which the cylinder is divided into six elements in the circumferential direction and three elements in the radial direction. Note that there may be a maximum of 100 elements in the circumferential direction and that each adjacent element in the radial direction is incremented by 100. Also, a maximum of ten elements are allowed in the radial direction.

Figure 4 illustrates the numbering convention for a three-dimensional cylinder problem. The example of Figure 4 is the same as the example of Figure 3 except that the height dimension of the cylinder is divided into three sections. The numbering system for the top section of both cylinders is identical. The middle section is numbered similarly to the top section except that each corresponding node is incremented by 1000, i.e., node 1001 is directly underneath node 1, node 1002 is directly underneath node 2, etc.. The bottom section is numbered similarly to the middle section except that each corresponding node number is incremented by 1000, i.e., node 2001 is directly underneath node 1001, node 2002 is directly underneath node 1002, etc.. A maximum of 98 sections in the height direction are allowed by the nodal numbering system. However, it is unlikely that 98 sections would ever be used in any problem because there are limitations on the total number of nodes. These limits are discussed later in this section.

For stationary cylinders there is symmetry about the line $\theta = 0$ and $\theta = \pi$ (see Figure 5) so that only 1/2 of the cylinder need be considered. The TRIN program will automatically take advantage of this symmetry whenever the rotation speed, ω, is zero. Figure 5 illustrates the numbering convention for a stationary two-dimensional cylinder using the symmetry feature of TRIN. The numbering system for a stationary three-dimensional cylinder is analogous to Figures 3 and 4.

Rectangular Structural Elements

Consider a hollow rectangular parallelepiped (box beam) in which the top and bottom are insulated and hence the heat transfer is two-dimensional. Figure 6 illustrates the numbering convention for a two-dimensional box beam in which the x-direction legs are divided into eight elements (excluding the corners) and the y-direction legs are divided into six elements (also excluding the corners). The thickness direction is divided into two elements hence there are four additional elements at each corner. Each leg can be divided into a maximum of 25 elements minus the number of thickness elements which appear at the corners. Thus, if the thickness is divided into two elements each leg could be divided into a maximum of 23 elements.

Figure 7 illustrates the numbering convention for three-dimensional box beams. The example of Figure 7 is the same as the example of Figure 6 except that the length of the box beam is divided into three sections. The numbering convention for the top section is identical to the two-dimensional example of Figure 3. The middle section is numbered similarly to the top section except that each corresponding node is incremented by 1000, i.e., node 1001 is directly underneath node 1, node 1002 is directly underneath node 2, etc.. The bottom section is numbered similarly to the middle section except that each corresponding node number is incremented by 1000, i.e., node 2001 is directly underneath node 1001, node 2002 is directly underneath node 1002 etc.. As in the cylinder, a maximum of 98 sections in the height direction are allowed.

Zero Volume and Boundary Nodes

The TRUMP program requires that the surface nodal points be connected to any external sources of heating such as convection and radiation through external thermal connections (specified in Block 6 of TRUMP input data). One set of boundary nodes are required for each external temperature that characterizes an external source. Hence, a boundary node must be present whose temperature as a function of time be connected to each surface node through an external thermal connection. The concept of "zero-volume" nodes has been developed to reduce the number of required external thermal connections. These are connected to the boundary nodes with negligible thermal resistance, i.e., with large heat transfer coefficients and small nodal volumes, so that the temperature history of a boundary node and its associated "zero-volume" node are practically the same. Each surface node is connected to a "zero-volume" node through an internal thermal connection and the "zero-volume" node is subsequently connected to the boundary node through an external thermal connection. The number of external thermal connections is greatly reduced because there are many fewer "zero-volume" nodes than surface nodes. The number of internal thermal connections has been increased by the use of "zero-volume" nodes, however the TRUMP program handles internal connections much more efficiently than external connections.

The numbering system used by TRIN-TRUMP for the "zero-volume" and surface nodes are as follows. Node numbers 98001 - 99000 are reserved for "zero-volume" nodes and node numbers 99001 - 99999 for boundary nodes. Node number 98001 and 99001 are used for the temperature, T_b, of the heat sink or source at the base of the cylinder or box beam structure (see equations (6) and (13)). These are input to the TRUMP program by TRIN data Card 7 (see previous section, "Use of the Computer Program TRIN"). Node numbers 98002 and 99002 are used for the external ambient temperature, Te, for outer surface convection or radiation (see equations (4) and (11)). Node number 98003 and 99003 are used for the internal ambient temperature, Ti, for inner surface convection (see equations (3) and (10)). The internal and external ambient temperatures are input to TRUMP by TRIN data Card 9. Since Card 9 is optional, these temperatures will not be present when the reduced input (7 cards) is used. The remaining "zero-volume" and boundary nodes are used to describe the nuclear weapon thermal radiation pulse and input it into the TRUMP program. This is accomplished by creating two fictitious convective heating rates whose net effect is equal to the weapons thermal pulse, i.e.,

$$q = 1(H' - T_c) - 1(0 - T_c) \tag{16}$$

In equation (16), the first term represents convective heating with a convective coefficient of 1.0 and an external temperature equal to the thermal irradiance, H', of the nuclear weapon. The second term represents convective cooling with a convective coefficient of -1.0 and an external temperature equal to zero. The normalized nuclear weapon thermal radiation pulse (see Figure 1 and Table 1) is part of the permanent data stored in TRIN. The specific pulse for a given problem is input by specifying the thermal pulse characteristics of the weapon (tm, Hm) on Card 4. Node number 98004 and 99004 are used for the external temperature, which is zero in equation (16). Nodes number 98005 and 99005 and successively numbered nodes are used for the external temperature which is equal to the thermal irradiance. The actual nodal numbering system is different for cylindrical and box beam structures. For a box beam, there are four pertinent thermal irradiances corresponding to four external surfaces. Node numbers 98005 and 99005 are used for the thermal irradiance history of face 1 (the face initially exposed to the radiant heating). Successive faces are found by traveling in a counterclockwise direction when observing from the top. Node numbers 98006 and 99006 are used for face 2, 98007 and 99007 for face 3 and 98008 and 99008 for face 4. For a cylinder, there is a discrete thermal irradiance for each element in the circumferential direction (there are NELY of these elements, see figure 2). Node numbers 98005 and 99005 are used for the most forward circumferential element (the element first exposed to the radiant heating). Succeeding "zero-volume" and boundary nodes will be incremented by one for successive circumferential surface nodes in a counterclockwise direction viewed from the top.

Limits on Number of Nodes in TRUMP

The nodal numbering system has been devised to allow up to ten elements in the thickness direction (NELTH), 98 elements in the height direction (NELZ) and 100 elements in the circumferential direction (NELY*). These limits are not absolute as the TRIN program can be easily modified to increase the number in any direction. For example, the number could be doubled by the introduction of negative numbers and the general numbering system would still be retained. However, the total number of nodes available in a particular problem is limited by the TRUMP program and the size of the computer on which it is run. At NOL, there are presently two versions of the TRUMP program for the CDC 6400 computer. The "small TRUMP", which runs as a "shared" computer program, is limited to about 250 nodal points. The "large TRUMP" is limited to about 750 nodal points. These limits are not absolute because the number of internal and external thermal connections also limit the number of nodal points and these depend upon the manner (i.e., direction) in which the points are specified. Hence it is recommended that the number of nodal points be limited to 200 and 600 for the TRUMP programs in use at NOL.

VERIFICATION OF AND COMMENTS ON THE TRIN PROGRAM

The TRIN-TRUMP program discussed herein has been verified by comparing its calculated temperatures with temperatures generated by other sources for the same problems. Two existing numerical programs will be used for making comparisons. These are; (1) the program which calculates the temperature distribution history in the radial and circumferential directions for circular cylinders (reference (3)) and (2) the program which calculates the temperature distribution history in thermally-thin box beams (reference (6)). Both of these programs will be used to compare temperatures resulting from exposure to the thermal radiation pulse of a nuclear weapon. However, TRIN can consider the problem of a circular cylinder being cooled by convection to an external medium and having a heat sink at its base held at a temperature lower than its initial temperature. This problem has an analytical solution which is available on the charts of Reference (12). Temperature distribution histories from the two existing programs and the charts of Reference (12) have been compared to temperature distribution histories generated by TRIN for the same problem. These comparisons are given in Appendix A along with a statement of the problems solved and instructions on the set-up of TRIN for the problem. The results of Appendix A show that the TRIN program is in excellent agreement with the compared sources, hence it is concluded that TRIN is correct for calculating the temperature distribution history in either box beam or cylindrical structural elements. Appendix A also

* For a box beam, the number of elements in the circumferential direction is 2(NELY + NELX + 2 · NELTH)

presents an additional example on the set-up and results of the TRIN program for a box beam and for a cylinder problem.

The TRIN program has been written to conveniently use the more complicated TRUMP program for cylindrical and box beam structural elements. In doing this, it takes advantage of some, but not all, of the many options and features of TRUMP. For example, TRUMP allows heat to be generated at internal nodes, different materials in the structural elements and graphical output of the computations. None of these are allowed by TRIN but they could be added through suitable modifications. Also, TRUMP allows either implicit or explicit numerical solutions. It was found that implicit solutions are more easily obtained by TRUMP for problems involving thermal radiation heating from a nuclear weapon detonation. This occurs because TRUMP adjusts the time step in explicit solutions to limit changes in the thermal irradiance over a time step to an average of one percent of the total thermal irradiance. However, implicit solutions generally require more computer time, especially for problems requiring a large number of nodes. If program efficiency is important, it would be possible to modify TRUMP and remove the limitation on time step changes due to changes in the thermal irradiance. In spite of its limitations, it is concluded that the TRIN program is a practical and correct method of obtaining the temperature distribution history in three-dimensional circular cylindrical or box beam structural elements.

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TABLE 1. NORMALIZED THERMAL IRRADIANCE HISTORY FOR A NUCLEAR WEAPON EXPLOSION

NORMALIZED TIME (t/tm)	NORMALIZED IRRADIANCE (H/Hm)	NORMALIZED TIME (t/tm)	NORMALIZED IRRADIANCE (H/Hm)
0.0	0.0	2.4	0.320
0.1	0.026	2.5	0.300
0.2	0.105	2.6	0.284
0.3	0.201	2.7	0.270
0.4	0.357	2.8	0.256
0.5	0.540	3.0	0.230
0.6	0.717	3.4	0.190
0.7	0.840	3.8	0.159
0.8	0.926	4.2	0.133
0.9	0.988	4.6	0.114
0.95	0.997	5.0	0.100
1.0	1.000	5.5	0.085
1.05	0.997	6.0	0.074
1:1	0.988	6.5	0.065
1.2	0.946	7.0	0.058
1.3	0.880	7.5	0.051
1.4	0.790	8.0	0.047
1.5	0.670	9.0	0.040
1.6	0.590	10.0	0.036
1.7	0.530	15.0	0.0175
1.8	0.483	20.0	0.011
1.9	0.445	30.0	0.0057
2.0	0.415	40.0	0.0036
2.1	0.384	50.0	0.0025
2.2	0.360	90.0	0.001
2.3	0.340		

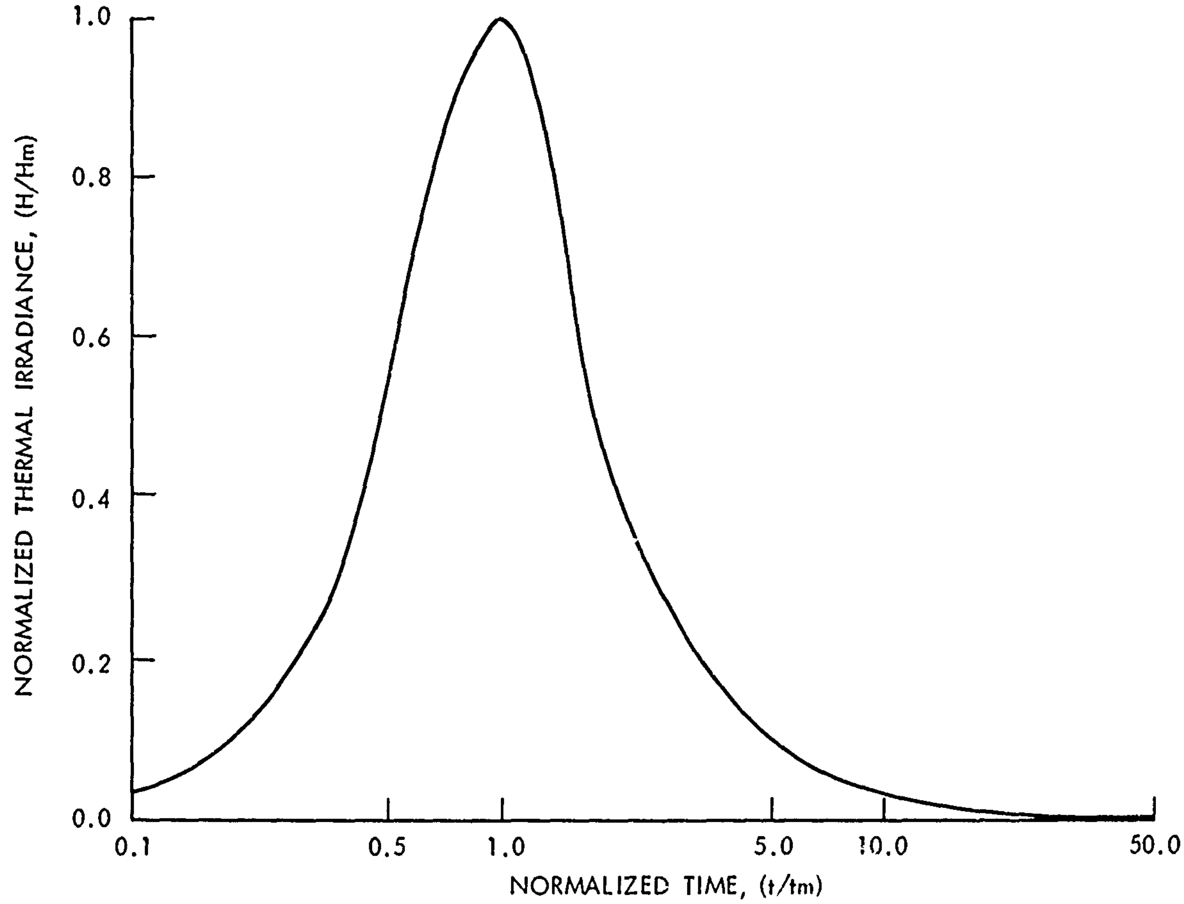

FIG. 1 NORMALIZED NUCLEAR WEAPON THERMAL RADIATION PULSE

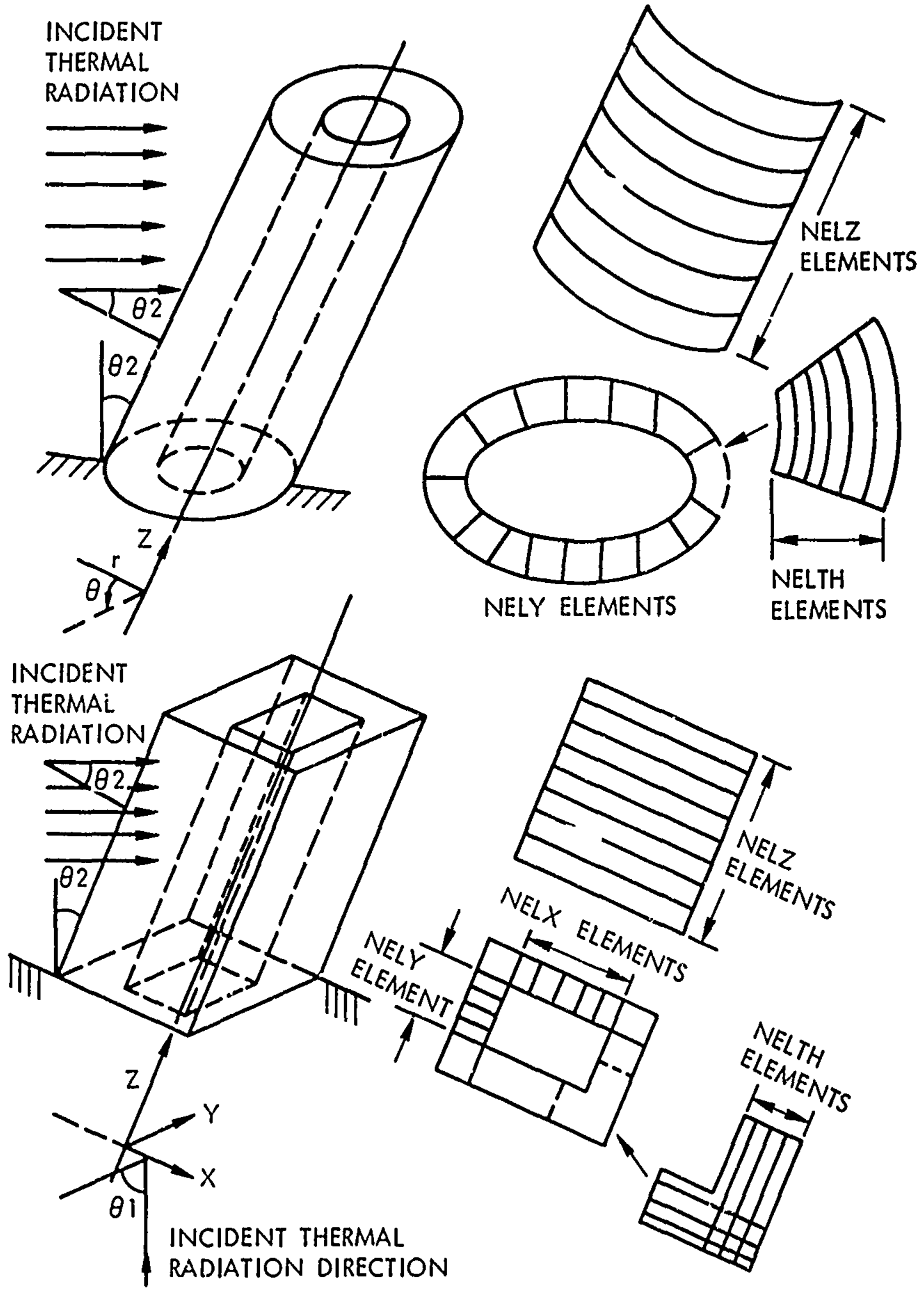

FIG. 2 THE DIVISION OF A CYLINDER OR A BOX BEAM INTO ITS ELEMENTS

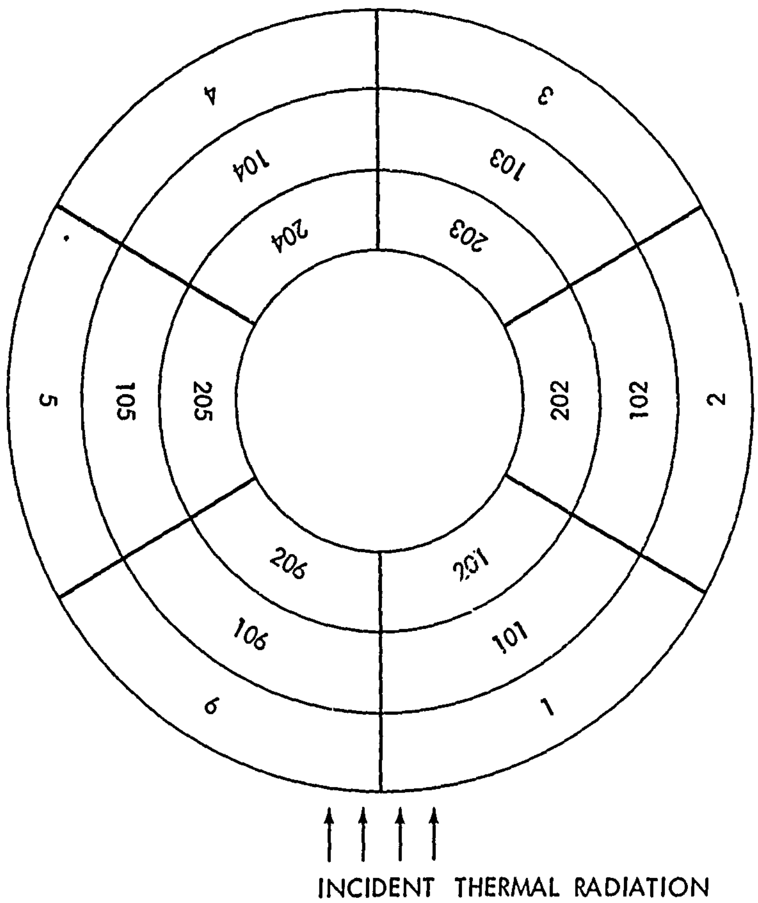

FIG. 3 - NUMBERING CONVENTION FOR TWO-DIMENSIONAL CYLINDRICAL PROBLEMS

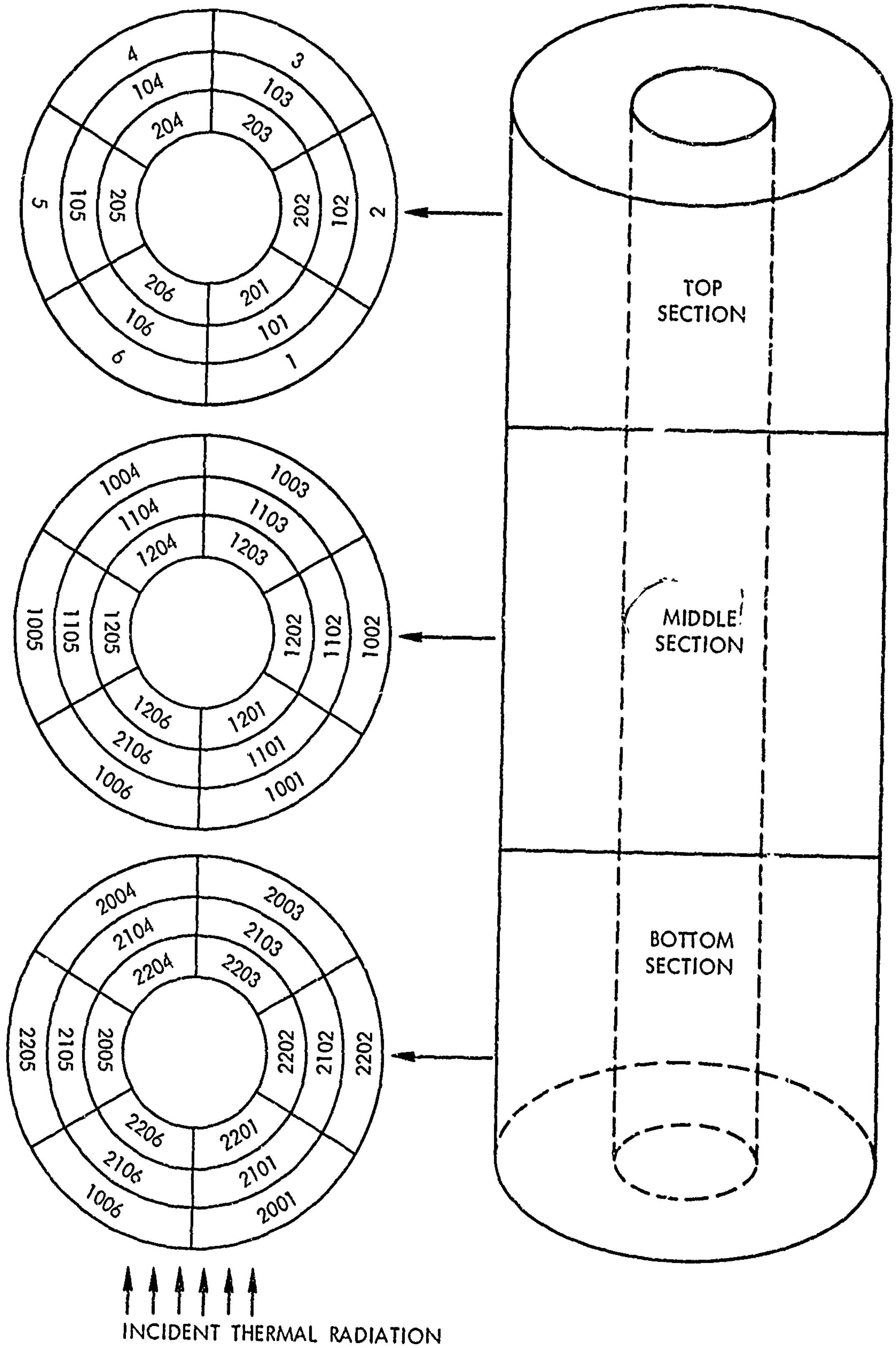

FIG. 4 NUMBERING CONVENTION FOR THREE-DIMENSIONAL CYLINDRICAL PROBLEMS.

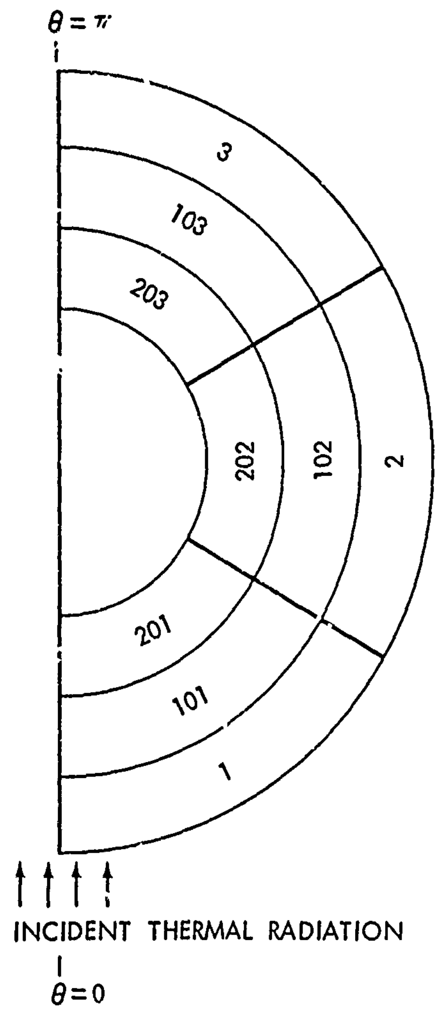

FIG. 5 NUMBERING CONVENTION FOR STATIONARY CYLINDRICAL PROBLEMS

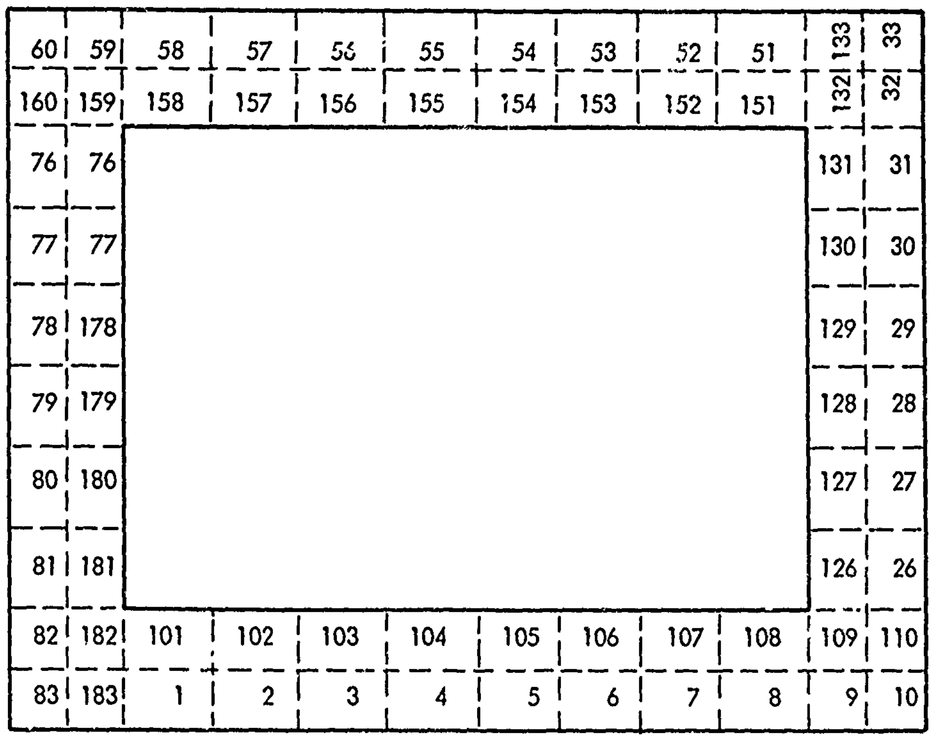

FIG. 6 NUMBERING CONVENTION FOR TWO-DIMENSIONAL RECTANGULAR PROBLEMS

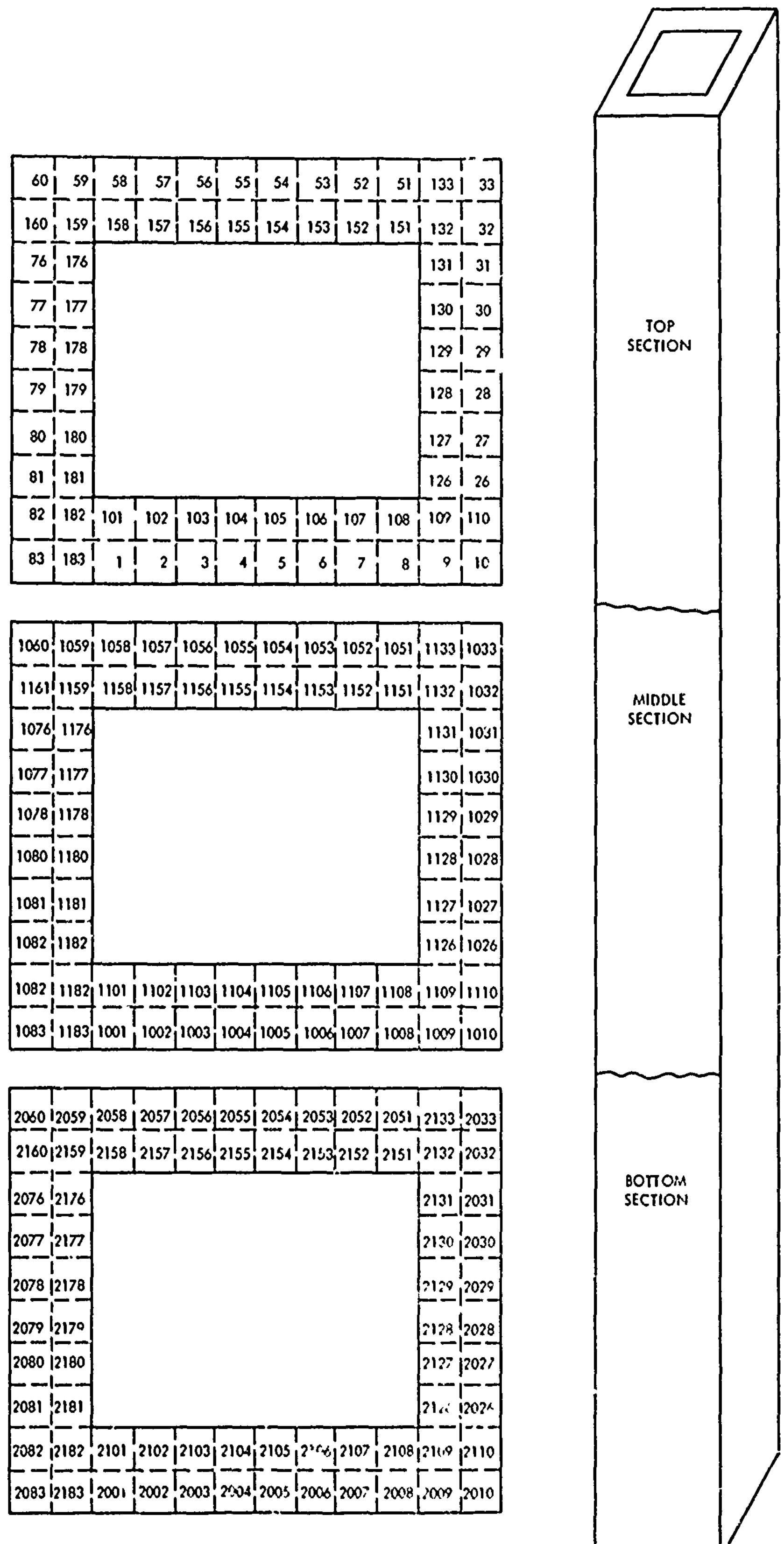

FIG. 7 NUMBERING CONVENTION FOR THREE-DIMENSIONAL RECTANGULAR PROBLEMS.

APPENDIX A

LISTING OF THE TRIN PROGRAM

```
      PROGRAM TRIN (INPUT, OUTPUT, TAPE4 = INPUT, TAPE3 = OUTPUT, TAPE2)
C THIS IS TRIN (12APR72)
      DIMENSION CATP(10), TVARC(10), CONT(10), TVARK(10), TEMPB(20),
     1 TIMEB(20), TIMEE(8), H(51), T(51), TI(51), TE(51), NOHEAT(100)
      EQUIVALENCE (LTABHS, LTABT), (HB, CONBTM), (OMEGA, ROTSP),
     1 (HI, CONINT), (ANI, POWINT),
      DATA (H(I), I=1,51) / 0.,.026, .105,.201, .357, .54, .717, .84,
     1 .926, .988, .997, 1., .997, .988, .88, .79,.670, .59, .53,
     2 .483, .445, .415, .384, .36, .34, .32, .3, .284, .27, .256, .23,
     3 .19, .157, .133, .114, .1, .085, .074, .065, .058, .051, .047,
     4 .040, .036, .0175, .011, .0057, .0036, .0025, .001/
      DATA (T(I),I=1,51) / 0., .1, .2, .3, .4, .5, .6, .7, .8, .9, .95,
     1 1., 1.05, 1.1, 1.2, 1.3, 1.4, 1.5, 1.6, 1.7, 1.8, 1.9, 2., 2.1,
     2 2.2, 2.3, 2.4, 2.5, 2.6, 2.7, 2.8, 3., 3.4, 3.8, 4.2, 4.6, 5.,
     3 5.5, 6., 6.5, 7., 7.5, 8., 9., 10., 15., 20., 30., 40., 50., 90./
      DATA NO, N1,N2,N3,N4,N5,N6,N7,NADD,NADDD/ 1,25,100,1000,50,1000,
     1 98001,26,1,1/
      DATA N8,N9/ 100,1000/
      DATA KDATA,NDOT,NPUNCH/ -1,0,0/
      DATA HINTI,I90/1.,0/
      IUTIL9 = -N2
   15 FORMAT (6HBLOCK ,I1)
   16 FORMAT (1H )
    1 FORMAT(8E10.3)
    2 FORMAT(16I5)
    4 FORMAT(5I6,2E12.4)
    6 FORMAT(6I6,3E12.4)
    7 FORMAT(4I6,4E12.4)
    8 FORMAT(8E10.4)
    9 FORMAT(4I6,3E12.4)
      ISYM
      N = 2
      DUMMY3 = 0.
      IDUM2 = 1
      NODMAT = 1
      KS = 0
      IDUMM = 0
      KD = 1
      TAU = 0.
      TMIN = -1.0E+12
      TMAX = 1.0E+12
      DIM = 1.
      MAT = 1
      DUMMY = 0.
   17 CONTINUE
```

```
      HINT = 1.0E+12
      RINT = 0.
      READ(4,1003) (NAMEEE(I),I = 1,7)
      IF (EOF(4) .NE. 0) STOP 111
      READ(4,6)IINPUT,IPRINT,IGEON,LTABC,LTABK,LTABHS,DELTI,TIMAX,TONE
      READ(4,7)NELTH,NELZ,NELY,NELX,THICK,Z,Y,X
      READ(4,8)TM,HM,THETA1,OMEGA,THETA2,ABSORP,DENS,HB
      READ(4,8) (CAPT(I),TVARC(I),I=1,LTABC)
      READ(4,8) (CONT(I),TVARK(I),I=1,LTABK)
      READ(4,8) (TEMPB(I),TIMEB(I),I=1,LTABHS)
      IF(IGEOM.EQ.1.AND.OMEGA.LT.1.0E-12) ISYM = 1
      IF(IINPUT.GE.1) GO TO 55
      READ(4,9)ILIST,KSPEC,MCYC,    ITEMP,DELTO,SMALL,TVARY
      READ(4,8)HI,ANI,TINT,HE,ANE,TEXT,FE,SIGM
      READ(4,4)LOCTOP,LOCBTM,LOCOF,LOCIF,LOCCIR,TMELT,HMELT
      GO TO 60
   55 LOCTOP = 0
      LOCBTM = 1
      LOCOF = 0
      LOCIF = 0
      LOCCIR = 1
      ISYM = 0
      KSPEC = 1
      HI = 0.
      ANI = 0.
      TINT = 0.
      HE = 0.
      ANE = 0.
      TEXT = 0.
      ITEMP = 0
      MCYC=0
      ILIST=0
      SIGM = 0.
      FE = 0.
      TMELT = 0.
      HMELT = 0.
      DELTO = DELTI
      SMALL = DELTI
      TVARY = 5.
   60 CONTINUE
      IL = IABS(LOCOF) + IABS(LOCIF)
      IF (IL .GT. 0 .AND. IGEOM .EQ. 0 .AND. NELTH .GT. 1) STOP 101
      IF (HI .GT. 1.0E-12 .AND. ANI .LT. 1.0) STOP 102
      IF (HE .GT. 1.0E-12 .AND. ANE .LT. 1.0) STOP 103
      ALOCBT = LOCBTM
      ALOCTP = LOCTOP
```

```
      ALOCOF = LOCOF
      ALOCIF = LOCIF


      ALOCCI = LOCCIR
      KT = ITEMP
      IF (IGEOM .EQ. 0) GO TO 75
      NELA = NELY
      NELR - NELTH
      NSEQR = NELR - 1
      NSEQA = NELA - 1
      NSEQAA = NELA - 2
      ROUT = Y
      ANELR = NELR
      DELR = THICK /ANELR
      DELRR = DELR / 2.
      ANELA = NELA
      DELA = 6.28318/ANELA
      IF (ISYM .GT. 0) DELA = DELA/2.
      DELAA = DELA/2.
 75   CONTINUE
      GO TO(81,82,83,84,85,86) ,KT
 81   TBASE = 273.15
       SIGMA = 1.355E-12
       GO TO 90
 82   TBASE = 0.0
       SIGMA = 1.355E-12
       GO TO 90
 83   TBASE = 460.0
       SIGMA = 0.173E-8
       GO TO 90
 84   TBASE = 0.0
       SIGMA = 0.173E-8
       GO TO 90
 85   TBASE = 0.0
       SIGMA = 1.0
      GO TO 90
 86   TBASE = 0.0
      SIGMA = 5.673E-08
 90   CONTINUE
      RADEXT = FE * SIGM/SIGMA
       HM1=HM*ABSORP*SIN(1.5708-THETA2)/HINT1
      DO 92 I = 1,51
 92   TI(I) = TM*T(I)
      DO 95 I = 1,51
      IF (TI(I) .LT. TIMAX) GO TO 95
      LH = I
      GO TO 96
 95   CONTINUE
      LH = 51
 96   CONTINUE
      NADDDD = NELTH *NADDD
      ANELZ = NELZ
      DELZ = Z/ANELZ
```

```
      DELZZ = DELZ/2.
          NSEQZ = NELZ - 1
      NSEQZZ = NELZ - 2
      IF (IGEOM .GT. 0) GO TO 94
      NSEQX = NELX -1
      NSEQY =NELY - 1
      NSEQTH = NELTH -1
      ANELX = NELX
      ANELY = NELY
      ANELTH = NELTH
      DELX = (X - 2. *THICK) /ANELX
      DELY = (Y - 2. *THICK) /ANELY
      DELTH = THICK/ ANELTH
      DELXX = DELX/2.
      DELYY = DELY/2.
      DELTHH = DELTH/ 2.
      NSEQXX=NELX - 2
      NDEQYY = NELY - 2
      NSEQTT = NELTH- 2
   94 CONTINUE
 1003 FORMAT (7A10)
      WRITE(N,1013) (NAMEEE(I),I =1,7)
 1013 FORMAT (1H*,7A10)
      IBLOCK = 1
      WRITE (N,15) IBLOCK
      WRITE (N,2) IPRINT,IDUMM,KDATA,KSPEC,MCYC,IDUMM,NPUNCH,NDOT
      WRITE(N,1001) KD,KT,DELTO,SMALL,TVARY,TAU,TIMAX,TMIN,TMAX
 1001 FORMAT(2I5,7E10.3)
      WRITE(N,1) TONE
      WRITE(N,16)
      IBLOCK = 2
      WRITE(N,15) IBLOCK
      WRITE(N,1002) MAT,LTABC,LTABK,DENS,CAPT(1),CONT(1,,TMELT.EMELT
 1002 FORMAT(5HMAT1 ,I5,10X,2I5,5E10.3)
      IF (LTABC .GT. 1)
     1WRITE(N,1) (CAPT(I),TVARC(I),I=1,LTABC)
      IF (LTABK .GT. 1)
     1WRITE(N,1) (CONT(I),TVARK(I),I=1,LTABK)
C NOW ONTO BLOCK 7
      WRITE(N,16)
      IBLOCK = 7
      WRITE(N,15) IBLOCK
      IF (CONBTM .LT. 1.0E-12) GO TO 4030
      LLL = LTABT
      IF (LLL .GT. 3) LLL = 3
      NODB = N6 +1000
      WRITE(N,1004) NODB,LTABT,(TEMPB(I),TIMEB(I),I=1,LLL)
 1004 FORMAT (2I5,10X,6E10.3)
      IF (LTABT .GT. 3) WRITE(N,1) TEMPB(I),TIMEB(I),I=4,LTABT)
 4030 CONTINUE
      IF (CONEXT .LT. 1.0E-12 .AND. RADEXT .LT. 1.0E-12) GO TO 4035
```

```
      NODB = N6 + 1001
      WRITE(N,1004) NODB,IDUMM,TEXT,DUMMY3
 4035 CONTINUE
      IF (CONINT .LT. 1.0E-12) GO TO 4040
      NODB = N6 + 1002
      WRITE(N,1004) NODB,IDUMM,TINT,DUMMY3
 4040 CONTINUE
      IF (HM .LT. 1.0E-12) GO TO 5000
      NODB = N6 +1003
      IF (I90 .EQ. 0)
     1WRITE(N,1004) NODB
      IF (IGEOM .EQ. 0) J2 = 4
      IF (IGEOM .GT. 0) J2 = NELA
      DO 4099 J = 1,J2
      TEMAX = 0.
      AJ = J
      AJ = AJ -.5
      IF (IGEOM .LE. 0) AJ = AJ -.5
      DO 4098 I = 1,LH
      IF (IGEOM .EQ. 0)
     1ANG = THETA1 +ROTSP *TI(I) +AJ*1.570796
      IF (IGEOM .GT. 0)
     1ANG = AJ*DELA +ROTSP *TI(I)
      ANGF = COS(ANG)
      IF (ANGF .LT. 0.) ANGF = 0.
      TE(I) = HM1 *H(I) *ANGF
      TE1 = ABS(TE(I))
      TEMAX = AMAX1(TEMAX,TE1)
 4098 CONTINUE
      IF (TEMAX .GT. 1.0E-05) GO TO 4096
      NOHEAT(J)=1
      GO TO 4099
 4096 NOHEAT(J) = 0
      NODB = N6 +1003+ J
      LH1= MINO(3,LH)
      WRITE(N,1004) NODB,LH,(TE(I),TI(I),I=1,LH1)
      IF (LH .GT. 3) WRITE(N,1) (TE(I),TI(I),I=4,LH)
 4099 CONTINUE
 5000 CONTINUE
      WRITE(N,16)
      IBLOCK = 6
      WRITE(N,15) IBLOCK
      HSURE = 1.0E+12
      IF (CONBTM .LT. 1.0E-12) GO TO 4010
      NODS = N6
      NODSB = NODS + 1000
      WRITE(N,1005) NODS,NODSB,IDUMM,IDUMM,IDUMM,DIM,DIM,HSURE,DUMMY,
     1 DUMMY
 1005 FORMAT(5I5,5X,5E10.3)
 4010 CONTINUE
```

```
      IF (CONEXT .LT. 1.0E-12 .AND. RADEXT .LT. 1.0E-12) GO TO 4015
      NODS = N6 +1
      NODSB = NODS + 1000
      WRITE(N,1005) NODS,NODSB,IDUMM,IDUMM,IDUMM,DIM,DIM,HSURE,DUMMY,
     1 DUMMY
 4015 CONTINUE
      IF (CONINT .LT. 1.0E-12) GO TO 4020
      NODS = N6 +2
      NODSB = NODS + 1000
      WRITE(N,1005) NODS,NODSB,IDUMM,IDUMM,IDUMM,DIM,DIM,HSURE,DUMMY,
     1 DUMMY
 4020 CONTINUE
      IF (HM .LT. 1.0E-12) GO TO 4029
      NODS = N6 +3
      NODSB = NODS + 1000
      IF (I90 .EQ. 0)
     1WRITE(N,1005) NODS,NODSB,IDUMM,IDUMM,IDUMM,DIM,DIM,HSURE,DUMMY,
     1 DUMMY
      IF (IGEOM .EQ. 0) J = 4
      IF (IGEOM .GT. 0) J = NELA
      DO 4028 I = 1,J
      IF (NOHEAT(I) .GT. 0) GO TO 4028
      NODS = N6 + 3 + I
      NODSB = NODS + 1000
      WRITE(N,1005) NODS,NODSB,IDUMM,IDUMM,IDUMM,DIM.DIM,HSURE,DUMMY,
     1 DUMMY
 4028 CONTINUE
 4029 CONTINUE
C
C
      WRITE(N,16)
      IBLOCK = 4
      WRITE(N,15) IBLOCK
C NOW DESCRIBE THE ZERO VOLUME NODES
      DO 198 I = 1,4
      GO TO (197,195,193,190) ,I
  197 IF (CONBTM ,LT. 1.0E-12) GO TO 198
      NODE = N6
      J = 0
      GO TO 196
  195 IF (CONEXT .LT. 1.0E-12 .AND. RADEXT .LT. 1.0E-12) GO TO 198
      NODE = N6 + 1
      J = 0
      GO TO 196
  193 IF (CONINT .LT. 1.0E-12) GO TO 198
      NODE = N6 + 2
```

```
      J = 0
      GO TO 196
  190 IF (HM .LT. 1.0E-12) GO TO 198
      NODE = N6 + 3
      IF (IGEOM .EQ. 0) J = 4
      IF (IGEOM .GT. 0) J = NELA
  196 CONTINUE
      IF (I .NE. 4 .OR. I90 .EQ. 0)
     1WRITE(N,5) NODE,IDUMM,IDUMM,NODMAT
      IF (J .LE. 0) GO TO 198
      DO 188 II = 1,J
      NODE = NODE + 1
      IF (NOHEAT(II) .GT. 0) GO TO 188
      WRITE(N,5) NODE,IDUMM,IDUMM,NODMAT
  188 CONTINUE
  198 CONTINUE
      IF (IGEOM .GT. 0) GO TO 3000
      DO 99 J =1,2
      DO 99 I1 =1,NELZ
      DO 99 I2 =1,NELTH
      NODE =N0+N1*2 *(J-1) +N3  *(I1-1) +N2 *(I2-1)
      WRITE(N,5) NODE,NSEQX,NADD,NODMAT,KS,DELX,DELTH,DELZ
      NODEE = NODE + NELX *NADD
      WRITE(N,5) NODEE,NSEQTH,NADD,NODMAT,KS,DELTH,DELTH,DELZ
      NODE = NODE + N1
      WRITE(N,5) NODE,NSEQY,NADD,NODMAT,KS,DELY,DELTH,DELZ
      NODEE = NODE + NELY *NADD
      WRITE(N,5) NODEE,NSEQTH,NADD,NODMAT,KS,DELTH,DELTH,DELZ
    5 FORMAT (5I5,5X,3E10.3)
   99 CONTINUE
C
C NOW WRITE THE BLOCK 5 DATA  START WITH CONNECTIONS IN THE Z DIRECTION
C
      WRITE(N,16)
      IBLOCK = 5
      WRITE(N,15) IBLOCK
      IF (NSEQZ .LT. 1) GO TO 400
      DO 299 J = 1,2
      DO 299 I1 = 1,NSEQZ
      IF (I1 .EQ. 1) GO TO 295
      IF (I1 .EQ. NSEQZ) GO TO 296
      GO TO 297
  295 DEL1 = DELZZ * (1. + ALOCTP)
      DEL2 = DELZZ
      GO TO 298
  296 DEL2 = DELZZ * (1. +ALOCBT)
      DEL1 = DELZZ
      GO TO 298
```

```
  297 DEL1 = DELZZ
      DEL2 = DELZZ
  298 CONTINUE
      DO 299 I2 =1,NELTH
      NOD1 = N0+N1 *2 *(J-1) + N3 * (I1-1) + N2 *(I2-1)
      NOD2 = NOD1 +N3
      WRITE(N,10) NOD1,NOD2,NSEQX,NADD,NADD,   DEL1, DEL2, DELX,DELTH,
     1 HINT,RINT
   10 FORMAT(2I5,3I3,1X,6E10.3)
      NOD11 = NOD1 +NELX *NADD
      NOD2 = NOD11 +N3
      WRITE(N,10) NOD11,NOD2,NSEQTH,NADD,NADD,DEL1,DEL2,DELTH,DELTH,
     1 HINT,RINT
      NOD1 = NOD1 +N1
      NOD2 = NOD1+N3
      WRITE(N,10) NOD1,NOD2,NSEQY,NADD,NADD,  DEL1, DEL2, DELY,DELTH,
     1 HINT,RINT
      NOD11 = NOD1 +NELY *NADD
      NOD2 = NOD11 +N3
      WRITE(N,10) NOD11,NOD2,NSEQTH,NADD,NADD,DEL1,DEL2,DELTH,DELTH,
     1 HINT,RINT
  299 CONTINUE
  400 CONTINUE
C NOW CONNECT NODES IN THE CIRCUMFERENTIAL DIRECTION
      DO 499 J =1,2
      DO 499 I1 =1,NELZ
      DO 499 I2=1,NELTH
      NOD1 = N0+ N1 * 2 *(J-1) + N3*(I1-1) + N2 * (I2-1)
      IF (NSEQXX .LT. 0) GO TO 440
      NOD2 = NOD1 +NADD
      WRITE(N,10) NOD1,NOD2,NSEQXX,NADD,NADD,  DELXX,DELXX,DELTH,DELZ,
     1 HINT,RINT
  440 CONTINUE
      NOD11 = NOD1 +NSEQX*NADD
      NOD2 = NOD11 +NADD
      WRITE(N,10) NOD11,NOD2,IDUMM,IDUMM,IDUMM,DELXX,DELTHH,DELTH,DELZ,
     1 HINT,RINT
      IF (I2 .LT. NELTH) GO TO 445
      DO 444 J9 = 1,NELTH
      NOD11 = NOD2 +NADD*(J9-1)
      NOD22= NOD1 + N1 +IUTIL9*(J9-1)
  444 WRITE(N,10) NOD11,NOD22,IDUMM,IDUMM,IDUMM,DELTHH,DELYY,DELTH,DELZ,
     1 HINT,RINT
  445 CONTINUE
      IF (NSEQTT .LT. 0) GO TO 450
      NOD11 = NOD2
      NOD2 = NOD11 +NADD
      WRITE(N,10) NOD11,NOD2,NSEQTT,NADD,NADD,DELTHH,DELTHH,DELTH,DELZ,
     1 HINT,RINT
```

```
  450 CONTINUE
      NOD1 = NOD1 + N1
      IF (NSEQYY .LT. 0) GO TO 490
      NOD2 = NOD1 +NADD
      WRITE(N,10) NOD1,NOD2,NSEQYY,NADD,NADD,  DELYY,DELYY,DELTH,DELZ,
     1 HINT,RINT
  490 CONTINUE
      NOD11 = NOD1 + NSEQY*NADD
      NOD2 = NOD11 +NADD
      WRITE(N,10) NOD11,NOD2,IDUMM,IDUMM,IDUMM,DELYY,DELTHH,DELTH,DELZ,
     1 HINT,RINT
      IF (I2  .LT. NELTH) GO TO 495
      DO 494 J9 = 1,NELTH
      NOD11 = NOD2 +NADD*(J9-1)
      IF (J.EQ. 1) NOD22= NOD1 +N1 +IUTIL9*(J9-1)
      IF (J.EQ. 2) NOD22= NOD1 -3*N1 +IUTIL9 *(J9-1)
  494 WRITE(N,10) NOD11,NOD22,IDUMM,IDUMM,IDUMM,DELTHH,DELXX,DELTH,DELZ,
     1 HINT,RINT
  495 CONTINUE
      IF (NSEQTT .LT. 0) GO TO 499
      NOD11 = NOD2
      NOD2 = NOD11 +NADD
      WRITE(N,10) NOD11,NOD2,NSEQTT,NADD,NADD,DELTHH,DELTHH,DELTH,DELZ,
     1 HINT,RINT
  499 CONTINUE
C NOW CONNECT THENODES IN THE RADIAL DIRECTION
      IF (NSEQTH .LT. 1) GO TO 700
      DO 699 J =1,2
      DO 699 I1 =1,NELZ
      DO 699 I2 =1,NSEQTH
      NOD1 = N0+N1*2*(J-1) + N3*(I1-1) + N2*(I2-1)
      NOD2 = NOD1 +N2
      WRITE(N,10) NOD1,NOD2,NSEQX,NADD,NADD,  DELTHH,DELTHH,DELX,DELZ,
     1 HINT,RINT
      NOD11 = NOD1 +NELX *NADD
      NOD2 = NOD11 + N2
      WRITE(N,10) NOD11, NOD2,NSEQTH,NADD,NADD,NADD,DELTHH,DELTHH,DELTH,
      DELZ,
     1 HINT,RINT
      NOD1 = NOD1 + N1
      NOD2 = NOD1 + N2
      WRITE(N,10) NOD1,NOD2,NSEQY,NADD,NADD,  DELTHH,DELTHH,DELY,DELZ,
     1 HINT,RINT
      NOD11 = NOD1 +NELY *NADD
      NOD2 = NOD11 + N2
      WRITE(N,10) NOD11,NOD2,NSEQTH,NADD,NADD,DELTHH,DELTHH,DELTH,DELZ,
     1 HINT,RINT
  699 CONTINUE
  700 CONTINUE
```

```
      DEL1 = 0.
      IF (CONBTM .LT. 1.0E-12) GO TO 900
      RINT = 0.
      HSURE = CONBTM
      NOD2 = N6
      DO 850 J =1,2
      DO 850 I2 =1,NELTH
      NOD1 = N0 +N1 *2 * (J-1) +N2*(I2-1) +N3*(NELZ-1)
      WRITE(N,10) NOD1,NOD2,NSEQX,NADD,IDUMM,  DEL1,DUMMY,DELX,DELTH,
     1 CONBTM,RINT
      NOD11 = NOD1 +NELX*NADD
      WRITE(N,10) NOD11,NOD2,NSEQTH,NADD,IDUMM,DEL1,DUMMY,DELTH,DELTH,
     1 CONBTM,RINT
      NOD1 = NOD1 + N1
      WRITE(N.10) NOD1,NOD2,NSEQY,NADD,IDUMM,  DELI,DUMMY,DELY,DELTH,
     1 CONBTM,RINT
      NOD11 = NOD1 +NELY*NADD
      WRITE(N,10) NOD11,NOD2,NSEQTH,NADD,IDUMM,DEL1,DUMMY,DELTH,DELTH,
     1 CONBTM,RINT
  850 CONTINUE
  900 CONTINUE
      J2 = 0
      DELCOR = DELTH
      DO 999 J9 =1,5
      IF (J9 .NE. 2) J2 = J2 + 1
      GO TO (915,909,910,907,905) ,J9
  905 IF (HM .LT. 1.0E-12) GO TO 999
      HINT = HINT1
      RINT = 0.
      J4 = 0
      J3 = 1
      GO TO 920
  909 IF (RADEXT .LT. 1.0E-12) GO TO 999
      HINT = 0.
      RINT = RADEXT
      J4 = 0
      J3 = 0
      GO TO 920
  907 IF (HM .LT. 1.0E-12) GO TO 999
      IF (I90 .GT. 0) GO TO 999
      HINT = -HINT1
      RINT = 0.
      J4 = 0
      J3 = 0
      GO TO 920
  910 IF (CONINT .LT. 1.0E-12) GO TO 999
      HINT = CONINT
```

```
      RINT = -POWINT +1.
      J4 = NELTH -1
      J3 = 0
      GO TO 920
  915 IF (CONEXT .LT. 1.0E-12) GO TO 999
      HINT = CONEXT
      RINT = -POWEXT +1.
      J4 = 0
      J3 = 0
      IF (POWEXT .LT. 1.0001) GO TO 918
      RINT = RADEXT
      RADEXT = 0.
      GO TO 920
  918 RINT = -POWEXT + 1.
  920 CONTINUE
      DO 998 J =1,2
      DO 998 I1 =1, NELZ
      J13 = 1 + (J-1)*2
      NOD1 = N0 +N1 *2*(J-1) +N3*(I1-1) +N2*J4
      NOD2 = N6 +J2 +2*(J-1)*J3
      IF (J9 .GE. 4 .AND. NOHEAT(J13) .GT. 0) GO TO 950
      WRITE(N,10) NOD1,NOD2,NSEQX,NADD,IDUMM,  DEL1, DUMMY,DELX,DELZ,
     1 HINT,RINT
      GO TO (925,925,950,925,925) ,J9
  925 CONTINUE
      NOD11 = NOD1 +NELX*NADD
      WRITE(N,10) NOD11,NOD2,NSEQTH,NADD,IDUMM,DEL1,DUMMY,DELCOR,DELZ,
     1 HINT,RINT
      IF (J.EQ. 1) NOD11 = NOD1 +3*N1 +(NELY+NSEQTH)*NADD
      IF (J.EQ. 2) NOD11 = NOD1 -N1   +(NELY+NSEQTH)*NADD
      WRITE(N,10) NOD11,NOD2,NSEQTH,N2,  IDUMM,DEL1,DUMMY,DELTH,DELZ,
     1 HINT,RINT
  950 CONTINUE
      J13 = J*2
      IF (J9 .GE. 4 .AND. NOHEAT(J13) .GT. 0) GO TO 998
      NOD1 = NOD1 +N1
      NOD2 = NOD2 +J3
      WRITE(N,10) NOD1,NOD2,NSEQY,NADD,IDUMM,  DEL1, DUMMY,DELY,DELZ,
     1 HINT,RINT
      GO TO (975,975,998,975,975) ,J9
  975 CONTINUE
      NOD11 = NOD1 +NELY*NADD
      WRITE(N,10) NOD11,NOD2,NSEQTH,NADD,IDUMM,DEL1,DUMMY,DELCOR,DELZ,
     1 HINT,RINT
                   NOD11 = NOD1 -N1   +(NELX+NSEQTH)*NADD
      WRITE(N,10) NOD11,NOD2,NSEQTH,N2,  IDUMM,DEL1,DUMMY,DELTH,DELZ
     1 HINT,RINT
  998 CONTINUE
```

```
  999 CONTINUE
      GO TO 4000
 3000 CONTINUE
      DO 3099 I = 1,NELA
      DO 3099 I1 = 1,NELR
      AI1 = I1
      RAVG = ROUT - (AI1 -.5) *DELR
      DR = RAVG *DELA
      NODE =NO +N8*(I1-1) + I - 1
      WRITE(N,5) NODE,NSEQZ,N9,NODMAT,KS,DR,DELR,DELZ
 3099 CONTINUE
C NOW WRITE THE BLOCK 5 DATA  START WITH CONNECTIONS IN THE Z DIRECTION
      WRITE(N.16)
      IBLOCK = 5
      WRITE(N,15) IBLOCK
      IF (NSEQZ .LE. 0) GO TO 3400
      DO 3299 I1 = 1,NSEQZ
      IF (I1 .EQ. 1) GO TO 3295
      IF (I1 .EQ. NSEQZ) GO TO 3296
      GO TO 3297
 3295 DEL1 = DELZZ * (1. + ALOCTP)
      DEL2 - DELZZ
      GO TO 3298
 3296 DEL2 = DELZZ * (1. +ALOCBT)
      DEL1 = DELZZ
      GO TO 3298
 3297 DEL1 = DELZZ
      DEL2 = DELZZ
 3298 CONTINUE
      DO 3299 12 =1,NELR
      AI2 = I2
      NOD1 = N0+N8*(I2-1) +N9*(I1-1)
      NOD2 = NOD1 +N9
      RAVG = ROUT -(AI2-.5) *DELR
      DR = RAVG * DELA
      WRITE(N,10) NOD1,NOD2,NDEQA,NADD,NADD,  DEL1,DEL2,DR,DELR,HINT
     1 RINT
 3299 CONTINUE
 3400 CONTINUE
      IF (NDEQAA .LT. 0) GO TO 3600
      DO 3499 I1 = 1,NELZ
      DO 3499 I2 = 1,NELR
      AI2 = I2
      NOD1 = N0+N9 *(I1-1) +N8 * (I2-1)
      NOD2 = NOD1 +NADD
      RAVG = ROUT -(AI2 -.5) *DELR
```

```
      DRR = RAVG *DELA/2.
      DR1 = DRR *(1.+ALOCCI)
      DR2 = DRR * (1.-ALOCCI)
      WRITE(N,10) NOD1,NOD2,NSEQAA,NADD,NADD,  DR1,DR2,DELR,DELZ,HINT,
     1 RINT
      IF (ISYM .GT. 0) GO TO 3499
      NOD2 = NOD2 + NSEQAA *NADD
      WRITE(N,10) NOD1,NOD2,IDULL,IDUMM,IDUMM, DR2,DR1,DELR,DELZ,HINT,
     1 RINT
 3499 CONTINUE
 3600 CONTINUE
C NOW CONNECT THE NODES IN THE RADIAL DIRECTION
      IF (NELR .LT. 2) GO TO 3700
      DO 3699 I1 =1,NELZ
      DO 3699 I2 =1,NSEQR
      AI2 = I2
      IF (I2 .EQ. 1) GO TO 3695
      IF (I2 .EQ. NSEQR) GO TO 3696
      GO TO 3697
 3695 DEL1 - DELRR * (1. + ALOCOF)
      DEL2 = DELRR
      GO TO 3698
 3696 DEL2 = DELRR * (1. +ALOCIF)
      DEL1 = DELRR
      GO TO 3698
 3697 DEL2 = DELRR
      DEL1 = DELRR
 3698 CONTINUE
      NOD1 = NO +N9 * (I1 - 1) +N8*(I2 -1)
      NOD2 = NOD1 + N8
      RIN = ROUT - DELR *AI2
      DR = RIN * DELA
      WRITE(N,10) NOD1,NOD2,NSEQZ,NADD,NADD,  DEL1,DEL2,DR,DELZ,
     1 HINT,RINT
 3699 CONTINUE
 3700 CONTINUE
      DEL = 0.
      IF (CONBTM .LT. 1.0E-12) GO TO 3900
      RINT = 0.
      HSURE = CONBTM
      NOD2 = N6
      DO 3850 I2 = 1,NELR
      AI2 = I2
      NOD1 = NO + N8*(I2-1) +N9*NSEQZ
      RAVG = ROUT -(AI2-.5) *DELR
      DR = RAVG *DELA
      WRITE(N.10) NOD1,NOD2,NSEQA,NADD,IDUMM,  DEL1,DUMMY,DR,DELR,
     1 CONBTM,RINT
```

```
3850 CONTINUE
3900 CONTINUE
     J2 = 0
     DO 3999 J9 = 1,5
     IF (J9 .NE. 2) J2 = J2 + 1
     GO TO (3915,3905,3910,3902,3901) , J9
3901 IF (HM .LT. 1.0E-12) GO TO 3999
     HINT = HINT1
     DR = ROUT *DELA
     RINT = 0.
     J3 = 1
     J4 = 0
     GO TO 3920
3902 IF (HM .LT. 1.0E-12) GO TO 3999
     IF (I90 .GT. 0) GO TO 3999
     HINT = -HINT1
     RINT = 0.
     DR = ROUT *DELA
     J3 = 0
     J4 = 0
     GO TO 3920
3905 IF (RADEXT .LT. 1.0E-12) GO TO 3999
     HINT = 0.
     DR = ROUT * DELA
     RINT = RADEXT
     J3 = 0
     J4 = 0
     GO TO 3920
3910 IF (CONINT .LT. 1.0E-12) GO TO 3999
     DR = (ROUT -THICK) *DELA
     HINT = CONINT
     RINT = -POWINT +1.
     J3 = 0
     J4 = NSEQR
     GO TO 3920
3915 IF (CONEXT .LT. 1.0E-12) GO TO 3999
     DR = ROUT * DELA
     HINT = CONEXT
     J3 = 0
     J4 = 0
     IF (POWEXT .LT. 1.0001) GO TO 3918
     RINT = RADEXT
     RADEXT = 0.
     GO TO 3920
3918 RINT = -POWEXT + 1.
3920 CONTINUE
     NOD22= N6 + J2
     DO 3996 I17 = 1,NELA
     IF (J9 .GE. 4 .AND. NOHEAT(I17).GT. 0) GO TO 3996
```

```
      DO 3998 I1 = 1,NELZ
      NOD1 = NO +N9 *(I1-1) + N8*J4 +NADD * (I17-1)
      NOD2 = NOD22 +             (I17-1) *J3
      WRITE(N,10) NOD1,NOD2,IDUMM,IDUMM,IDUMM,DEL1,DUMMY,DR,DELZ,HINT,
     1 RINT
 3998 CONTINUE
 3996 CONTINUE
 3999 CONTINUE
 4000 CONTINUE
      WRITE(N,16)
      WRITE(N,1006)
 1006 FORMAT(7HENDED-1)
 9999 CONTINUE
      ENDFILE N
      IF (ILIST .LT. 1) GO TO 9991
      REWIND N
      IF (ILIST -2) 9998,9996,9994
 9998 READ(N,9992) (NAMEEE(I),I=1,8)
      IF (EOF(N)) 9991,9997
 9997 PRINT 9990, (NAMEEE(I),I=1,8)
      GO TO 9998
 9996 READ(N,9992) (NAMEEE(I),I=1,8)
      IF (EOF(N)) 9991,9995
 9995 PRINT 9990, (NAMEEE(I),I=1,8)
      PUNCH 9992, (NAMEEE(I),I=1,8)
      GO TO 9996
 9994 READ(N,9992)  (NAMEEE(I),I=1,8)
      IF (EOF(N)) 9991,9993
 9993 PUNCH 9992, (NAMEEE(I),(=1,8)
      GO TO 9994
 9992 FORMAT(8A10)
 9991 CONTINUE
      REWIND N
      CALL TRUMP
 9990 FORMAT(1X,8A10)
      REWIND N
      GO TO 17
      END
```

APPENDIX B

EXAMPLES FOR THE SET-UP AND USE OF THE TRIN PROGRAM

The section will present five examples which illustrate the set-up and use of the TRIN program. Three of these examples will also be used to compare the results of TRIN with results from two other numerical programs and one analytical solution. This is done to verify the correctness and accuracy of TRIN in obtaining temperature distribution histories for either cylindrical or box beam structural members. The final two examples will illustrate the use of TRIN in solving more complicated problems. The set-up of TRIN will be exemplified by listing the values of the variables which appear on the basic input cards. (See section "Use of the Computer Program TRIN" for the definitions of these variables.) In all of the following examples, the initial temperature is zero, the absorptance of the surface is 1.0, and the material thermophysical properties are assumed constant.

Example 1: Temperature Distribution History in a Stationary Box Beam

A stationary box beam is exposed to the thermal radiation pulse of a nuclear weapon detonation. The convective coefficient between the base plane of the box beam and the external heat sink is zero and the box beam is not inclined with respect to the vertical. Therefore the temperature distribution is two-dimensional with changes occurring in the x and y directions only. The box beam dimensions, material thermophysical properties and the weapon heating properties are given in Table (B-1). The TRIN program was run with each leg of the box beam divided into 20 elements and with a time increment of 0.01 seconds. The following table presents the input variable values required to set-up and run the TRIN program for this problem.

CARD	INPUT VARIABLE VALUE								
1	STATIONARY BOX BEAM								
Col.	6	12	18	24	30	36	48	60	72
2	1	16	0	1	1	1	0.004	6.40	0.0
Col.	6	12	18	24	36	48	60	72	
3	1	1	20	20	0.516	1.0	6.279	6.279	
Col.	10	20	30	40	50	60	70	80	
4	0.320	162.3	0.0	0.0	0.0	1 0	2.68	0.0	
Col.	10								
5	0.225								
Col.	10								
6	0.428								
Col.	10	20							
7	0.0	0.0							

The results of the TRIN program are compared in Table (B-1) with results generated by the computer program described in Reference (6) for the above box beam problem. In this comparison, heat is applied only to the leg y=0 and x=x and the temperature distribution is symmetric about the line x = Lx/2. An examination of Table (B-1) shows excellent agreement of the two temperature distribution histories.

Example 2: Temperature Distribution History in a Rotating Cylinder

A circular cylinder rotating at 6 rpm (0.628 radians/sec) is exposed to the thermal radiation pulse of a nuclear weapon detonation. The convective coefficient between the base of the cylinder and the external heat sink is zero and the cylinder is not inclined with respect to the vertical. Hence, the temperature distribution is two-dimensional with changes occurring in the radial and circumferential direction only. The cylinder dimensions, material thermophysical properties and the weapon heating properties are given in Table (B-2). The TRIN program was run with the circumferential distance divided into 24 elements and the thickness into five layers of elements. A time increment of 0.0078 seconds was chosen. The following table presents the input variable values required to set-up and run the TRIN program for this problem.

CARD	INPUT VARIABLE VALUE								
1	2-D ROTATING CYLINDER								
Col.	6	12	18	24	30	36	48	60	72
2	0	20	1	1	1	1	0.0078	15.6	0.0
Col.	6	12	18	24		36	48	60	
3	5	1	24	0		0.95	1.0	6.33	
Col.	10	20	30	40	50	60	70	80	
4	0.78	50.0	0.0	0.628	0.0	1.0	2.71	0.0	
Col.	10								
5	0.230								
Col.	10								
6	0.370								
Col.	10	20							
7	0.0	0.0							

Optional cards will be used to obtain the temperature at the outer surface (variable, LOCOF) and the backface surface (variable, LOCIF). The following table lists the input variable values required on the optional cards.

CARD	INPUT VARIABLE VALUE						
Col.	6	12	18	24	36	48	60
8	0	1	0	1	0.0	0.0	0.0
9	BLANK (No convection or radiation)						
Col.	6	12	18	24	30	42	54
10	0	0	1	1	1	0.0	0.0

The results of the TRIN program are compared in Table (B-2) with results generated by the computer program described in Reference (5) for the above rotating cylinder problem. In this example, the position $\theta = 0^{\circ}$ initially receives the thermal radiation and the cylinder rotates in a clockwise direction when viewed from the top. An examination of Table (B-2) shows good general agreement of the two temperature distribution histories, but the agreement is not as good as in the previous example. The lack of agreement is due to the way in which the thermal radiation pulse is applied to the cylindrical elements. The method of Reference (5) applies the heat pulse to the left edge of the element while the TRIN program applies the heat to the center. The method of TRIN is preferable in this case.

Example 3: Temperature Distribution in a Stationary Cylinder Cooled by Convection and Conduction

This example compares the results of the TRIN program with an analytic solution. A stationary right circular cylinder is simultaneously cooled by uniform convection over its outer surface and uniform conduction to a heat sink attached to its base. The top plane and the inner surface of the cylinder are insulated against heat flow. Therefore, the temperature distribution is two-dimensional with changes occurring in the r and z directions only. The cylinder dimensions, material thermophysical properties and boundary conditions are given in Table (B-3). The TRIN program was run with the altitude divided into 21 elements and the thickness divided into nine elements. A time step of 0.001 was chosen. In this problem, the units are deliberately omitted to emphasize that any consistent set of units may be used. The following table presents the input variable values required to set-up and run the TRIN program for this problem.

CARD	INPUT VARIABLE VALUE								
1	2-D STATIONARY CYLINDER WITH CONVECTION								
Col.	6	12	18	24	30	36	48	60	72
2	0	5	1	1	1	1	0.001	0.50	1.0
Col.	6	12	18	24		36	48	60	
3	9	21	1	0	0.20	1.0	1.0		
Col.	10	20	30	40	50	60	70	80	
4	0.0	0.0	0.0	0.0	0.0	1.0	1.0	1.0E+12	
Col.	10								
5	1.0								
Col.	10								
6	1.0								
Col.	10	20							
7	0.0	0.0							
Col.	6	12	18	24		36	48	60	
8	0	1	0	0	0.0	0.0	0.0		
Col	10	20	30	40	50	60	70	80	
9	0.0	0.0	0.0	1.0	1.0	0.0	0.0	0.0	
Col	6	12	18	24	30	42	54		
10	0	0	0	0	1	0.0	0.0		

This problem is one whose analytic solution can be expressed as the product of solutions of two simpler problems (reference (13)). The two simpler problems are: (1) An infinitely long flat plate, initially at a temperature of 1.0, insulated at its backface (z = 1.0) but cooled by convection at its bottom face (z = 0.0) after a sudden change in front face temperature from 1.0 to 0.0 and (2) a hollow cylinder infinite in length insulated against heat flow at its inner surface (Ri = 0.8) but uniformly cooled from an initial temperature of 1.0 by convection on its outer surface. The convective coefficient is 1.0 and the outer surface medium is at a temperature of 0.0. The solution for each of the two simple problems is available from the charts of Reference (12). These two solutions are multiplied together to obtain the solution to the stationary cylinder cooled by convection and conduction as described above. The results of the TRIN program are compared in Table (B-3) with the analytic solution. An examination of Table (B-3) shows excellent agreement of the two temperature distribution histories. The slight random differences that do occur are due to inaccuracies in reading the charts to obtain the analytic solution.

Example 4: Temperature Distribution in a Rotating Cylinder Cooled By Conduction

A right circular cylinder rotating at 6 rpm is exposed to the thermal radiation pulse of a nuclear weapon detonation. The cylinder is cooled by conduction to a heat sink which remains at 0^{o}C, the initial temperature of the cylinder. Hence, the temperature distribution is three-dimensional with temperature changes occurring in the radial, circumferential and longitudinal directions. However, for simplicity only the circumferential and longitudinal temperature changes will be considered in this example. The cylinder dimensions, material thermophysical properties and weapon heating properties are as follows: (1) weapon heating properties: Hm = 91.8 cal/sec cm^2 tm = 0.78 sec (2) cylinder dimensions Ro = 2.22 cm Ri = 2.08 cm Lz = 2.22 cm (3) material thermophysical properties ρ = 2.71 gm/cm^3 c = 0.23 cal/gm^{o}C K = 0.397 cal/sec cm ^{o}C. Note that all units are in the cgs system and the temperature computed will be in degrees Centigrade. The TRIN program was run with 24 circumferential elements, seven altitude elements and with a time increment of 0.01 seconds. The following table presents the input variable values required to set-up and run the TRIN program for this problem.

CARD	INPUT VARIABLE VALUE								
1	3-D Rotating Cylinder								
Col.	6	12	18	24	30	36	48	60	72
2	1	10	1	1	1	1	0.01	2.0	0.0
Col.	6	12	18	24		36	48	60	
3	1	7	24	0		0.140	2.22	2.22	
Col.	10	20	30	40	50	60	70	80	
4	0.78	91.8	0.0	0.628	0.0	1.0	2.71	1.0E+12	
Col.	10								
5	0.230								
Col.	10								
6	0.397								
Col.	10	20							
7	0.0	0.0							

The results of the TRIN program for this problem are shown in Figure (B-1). In this example, the position $\theta = 0$ initially receives the thermal radiation and the cylinder rotates in a clockwise direction when viewed from the top. The temperature distribution in the radial direction could be found by specifying a value for NELTH other than one. However, little differences in radial temperatures exist in this problem due to the small cylinder wall thickness (0 14 cm).

<u>Example 5: Temperature Distribution in a Rotating Box Beam Cooled by Conduction</u>

A box beam rotating at 6 rpm is exposed to the thermal radiation pulse of a nuclear weapon detonation. The box beam is cooled by conduction to a heat sink which remains at $0^{o}F$, the initial temperature of the box beam. Here, the temperature distribution is three-dimensional with temperature changes occurring in the x, y, and z directions. However, for simplicity, changes occurring in the thickness of the box beam will not be considered in this example. The box beam is not inclined with respect to the vertical but the incoming thermal radiation strikes the face initially exposed at a 45^{o} angle. The box beam dimensions, material thermophysical properties and weapon heating properties are as follows:

(1) Weapon heating properties. Hm 2.33 BTU/sec-in^2 tm = 0.78 sec
(2) Box beam dimensions. length = 1.10 in, Width = 1.10 in
    Thickness = 0.10 inch, Altitude = 2.20 in
(3) Material thermophysical properties. ρ = 0.098 lbs/in^3
    C = 0.23 BTU/ lb^{o}F, K = 0 00222 BTU/sec-in-^{o}F

The weapon heating properties and the material thermophysical properties are identical to those used in Example 4 with only the system of units changed. In this example, BTU, pounds, seconds and inches are used and the temperatures will be computed in degrees Fahrenheit. The TRIN program was run with each leg divided into seven elements and the altitude divided into five elements. A time increment of 0.0078 seconds was chosen. The following table presents the input variable values required to set-up and run the TRIN program for this problem.

CARD	INPUT VARIABLE VALUE								
1	3-D Rotating Box Beam								
Col.	6	12	18	24	30	36	48	60	72
2	1	20	0	1	1	1	0.0078	2.0	0.0
Col.	6	12	18	24		36	48	60	72
3	1	5	7	7	0.100		2.20	1.10	1.10
Col.	10	20	30	40	50	60	70	80	
4	0.78	2.35	0.0	0.628	0.0	1.0	0.098	1.0E+12	
Col.	10								
5	0.230								
Col.	10								
6	0.00222								
Col.	10	20							
7	0.0	0.0							

The results of the TRIN program for this problem are shown in Figure (B-2). In this example, the box beam is rotating in a clockwise direction when viewed from the top. As in Example 4, there are little differences in temperatures through the thickness due to the thickness being small (0.10 in.).

TABLE (B-1) TEMPERATURE DISTRIBUTION HISTORY IN A STATIONARY BOX BEAM

WEAPON HEATING PROPERTIES Hm = 162.3 $\frac{cal}{sec-cm^2}$ tm = 0.32 sec

BOX BEAM DIMENSIONS LENGTH = 6.279 cm. WIDTH = 6.279 cm. THICKNESS = 0.516 cm.

MATERIAL THERMOPHYSICAL PROPERTIES ρ = 2.68 $\frac{gms}{cm}$ 3 C = 0.225 $\frac{cal}{gm-°c}$ K = 0.428 $\frac{cal}{sec-cm-°c}$

AVERAGE TEMPERATURE HISTORY - REFERENCE 6					AVERAGE TEMPERATURE HISTORY TRIN-TRUMP PROGRAM				
t/tm	x=0 y=Ly/4	x=0 y=0	x=Lx/4 y=0	x=Lx/2 y=0	t/tm	x=0 y=Ly/4	x=0 y=0	x=Lx/4 y=0	x=Lx/2 y=0
0.	0. °C	0. °C	0. °C	0. °C	0.	0. °C	0. °C	0. °C	0. °C
0.6	0.0°C	23.9°C	27.3°C	27.3°C	0.6	0.0°C	23.5°C	26.6°C	26.7°C
1.0	0.3°C	72.2°C	88.0°C	88.0°C	1.0	0.3°C	71.5°C	86.5°C	87.0°C
1.4	1.7°C	115.0°C	150.0°C	150.0°C	1.4	1.6°C	114.0°C	148.0°C	149.0°C
2.0	6.8°C	144.0°C	203.0°C	205.0°C	2.0	6.7°C	144.0°C	203.0°C	204.0°C
4.0	34.3°C	177.0°C	271.0°C	285.0°C	4.0	34.3°C	177.0°C	271.0°C	285.0°C
8.0	75.6°C	195.0°C	291.0°C	321.0°C	8.0	75.5°C	195.0°C	291.0°C	321.0°C
12.0	99.2°C	201.0°C	287.0°C	317.0°C	12.0	99.2°C	201.0°C	287.0°C	317.0°C
16.0	114.0°C	204.0°C	278.0°C	306.0°C	16.0	114.0°C	204.0°C	278.0°C	305.0°C
20.0	125.0°C	203.0°C	267.0°C	291.0°C	20.0	124.0°C	203.0°C	267.0°C	291.0°C

TABLE (B-2) TEMPERATURE DISTRIBUTION HISTORY IN A ROTATING CIRCULAR CYLINDER

WEAPON HEATING PROPERTIES $H_m = 50.0 \frac{cal}{sec - cm^2}$ $T_m = 0.78$ sec

CYLINDER DIMENSIONS RO = 6.33 cm. Ri - 5.38 cm.

MATERIAL THERMOPHYSICAL PROPERTIES

$\rho = 2.71 \frac{gm}{cm^2}$ $C = 0.23 \frac{cal}{gm - °c}$ $k = 0.370 \frac{cal}{sec - cm - °c}$

I TEMPERATURE DISTRIBUTION HISTORY - METHOD OF REFERENCE 5

t/tm	SURFACE TEMPERATURE (°C) θ = 0°	θ = 30°	θ = 60°	θ = 90°	θ = 180°	θ = 270°	BACK FACE TEMPERATURE (°C) θ = 0°	θ = 30°	θ = 60°	θ = 90°	θ = 180°	θ = 270°
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.6	32.4	31.3	21.7	6.5	0.	0.1	2.5	2.3	1.4	0.3	0.	0.
1.0	71.7	74.1	56.7	24.2	0.	0.1	16.7	16.3	11.4	3.6	0.	0.1
1.4	88.5	97.9	81.0	42.7	0.	0.2	39.8	40.9	31.0	13.1	0.	0.2
2.0	87.7	103.	90.3	54.1	0.	0.4	66.1	72.5	59.5	30.9	0.	0.4
4.0	82.2	107.	106.	77.4	2.9	1.3	82.1	104.	98.0	67.5	0.7	1.3
8.0	79.5	101.	100.	79.8	21.7	6.6	79.5	101.	100.	79.8	19.2	4.8
12.0	80.7	97.7	96.4	78.4	23.1	16.8	79.1	96.8	96.4	78.4	23.1	15.9
16.0	82.4	99.0	97.8	80.4	24.1	18.7	82.2	98.2	96.7	79.3	24.1	18.7
20.0	80.4	95.5	95.2	80.6	28.1	20.8	80.4	95.5	95.2	80.6	27.4	20.7

II TEMPERATURE DISTRIBUTION HISTORY - TRIN-TRUMP PROGRAM

t/tm	SURFACE TEMPERATURE (°C) θ = 0°	θ = 30°	θ = 60°	θ = 90°	θ = 180°	θ = 270°	BACK FACE TEMPERATURE (°C) θ = 0°	θ = 30°	θ = 60°	θ = 90°	θ = 180°	θ = 270°
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.6	27.6	27.3	19.7	6.8	0.	0.	2.3	2.2	1.5	0.4	0.	0.
1.0	66.0	70.4	55.9	26.6	0.	0.1	15.1	15.2	11.3	4.3	0.	0.1
1.4	84.9	96.5	82.3	46.2	0.	0.1	36.6	38.9	30.8	14.6	0.	0.1
2.0	85.0	103.	93.4	59.1	0.	0.3	62.5	70.9	60.3	33.9	0.	0.3
4.0	78.6	105.	107.	80.8	3.6	0.9	78.5	103.	101.	72.8	1.3	0.9
8.0	76.2	99.6	102.	83.7	22.5	6.1	76.2	99.5	102.	83.7	20.6	4.5
12.0	75.3	96.2	98.9	82.5	24.3	16.6	75.4	95.9	98.5	82.1	24.4	15.5
16.0	76.6	96.1	99.1	84.2	25.8	19.8	76.2	95.4	98.3	83.5	25.7	19.8
20.0	74.9	92.8	96.4	84.4	29.9	21.7	74.9	92.8	96.4	84.4	29.6	21.5

TABLE (B-3) TEMPERATURE DISTRIBUTION HISTORY IN A STATIONARY CIRCULAR CYLINDER COOLED BY CONVECTION AND CONDUCTION

BOUNDARY CONDITIONS: $h_e = 1.0$ $h_i = 0.0$ Te = Ti = 0.0
INITIAL TEMPERATURE = 1.0 BASE TEMPERATURE = 0.0
CYLINDER DIMENSIONS $R_o = 1.0$ $R_i = 0.8$ $L_z = 1.0$
MATERIAL THERMOPHYSICAL PROPERTIES
$\rho = 1.0$ C = 1.0 K = 1.0

I TEMPERATURE DISTRIBUTION HISTORY - CHARTS OF REFERENCE 12

TIME	SURFACE TEMPERATURE					BACK FACE TEMPERATURE				
	Z=0.1	Z=0.3	Z=0.5	Z=0.7	Z=1.0	Z=0.1	Z=0.3	Z=0.5	Z=0.7	Z=1.0
0.01	0.466	0.859	0.894	0.894	0.894	0.511	0.941	0.979	0.979	0.979
0.02	0.323	0.729	0.831	0.841	0.841	0.330	0.805	0.916	0.928	0.928
0.04	0.212	0.544	0.700	0.746	0.760	0.234	0.606	0.772	0.824	0.839
0.06	0.159	0.424	0.587	0.657	0.682	0.175	0.468	0.650	0.726	0.755
0.08	0.124	0.341	0.486	0.566	0.610	0.136	0.375	0.536	0.625	0.672
0.10	0.100	0.278	0.410	0.487	0.529	0.109	0.305	0.449	0.534	0.579
0.15	0.060	0.176	0.264	0.326	0.362	0.066	0.194	0.292	0.361	0.400
0.20	0.038	0.114	0.175	0.220	0.246	0.042	0.125	0.192	0.243	0.271
0.30	0.018	0.054	0.084	0.105	0.117	0.019	0.056	0.088	0.110	0.122
0.50	0.004	0.010	0.020	0.025	0.029	0.005	0.011	0.021	0.027	0.030

II TEMPERATURE DISTRIBUTION HISTORY - TRIN-TRUMP PROGRAM

TIME	SURFACE TEMPERATURE					BACK FACE TEMPERATURE				
	Z=0.1	Z-0.3	Z=0.5	Z=0.7	Z=1.0	Z=0.1	Z=0.3	Z=0.5	Z=0.7	Z= 1.0
0.01	0.460	0.858	0.899	0.901	0.901	0.499	0.939	0.976	0.977	0.977
0.02	0.315	0.722	0.835	0.850	0.851	0.345	0.789	0.913	0.930	0.931
0.04	0.203	0.528	0.695	0.752	0.765	0.222	0.577	0.760	0.822	0.837
0.06	0.150	0.408	0.573	0.652	0.683	0.164	0.446	0.627	0.713	0.747
0.08	0.117	0.326	0.476	0.561	0.602	0.128	0.357	0.521	0.613	0.659
0.10	0.094	0.267	0.398	0.481	0.526	0.103	0.292	0.436	0.526	0.575
0.15	0.059	0.170	0.262	0.326	0.365	0.065	0.186	0.286	0.356	0.400
0.20	0.039	0.113	0.175	0.221	0.250	0.043	0.123	0.192	0.241	0.273
0.30	0.018	0.051	0.080	0.101	0.115	0.019	0.056	0.087	0.111	0.126
0.50	0.004	0.011	0.017	0.021	0.024	0.004	0.012	0.019	0.023	0.027

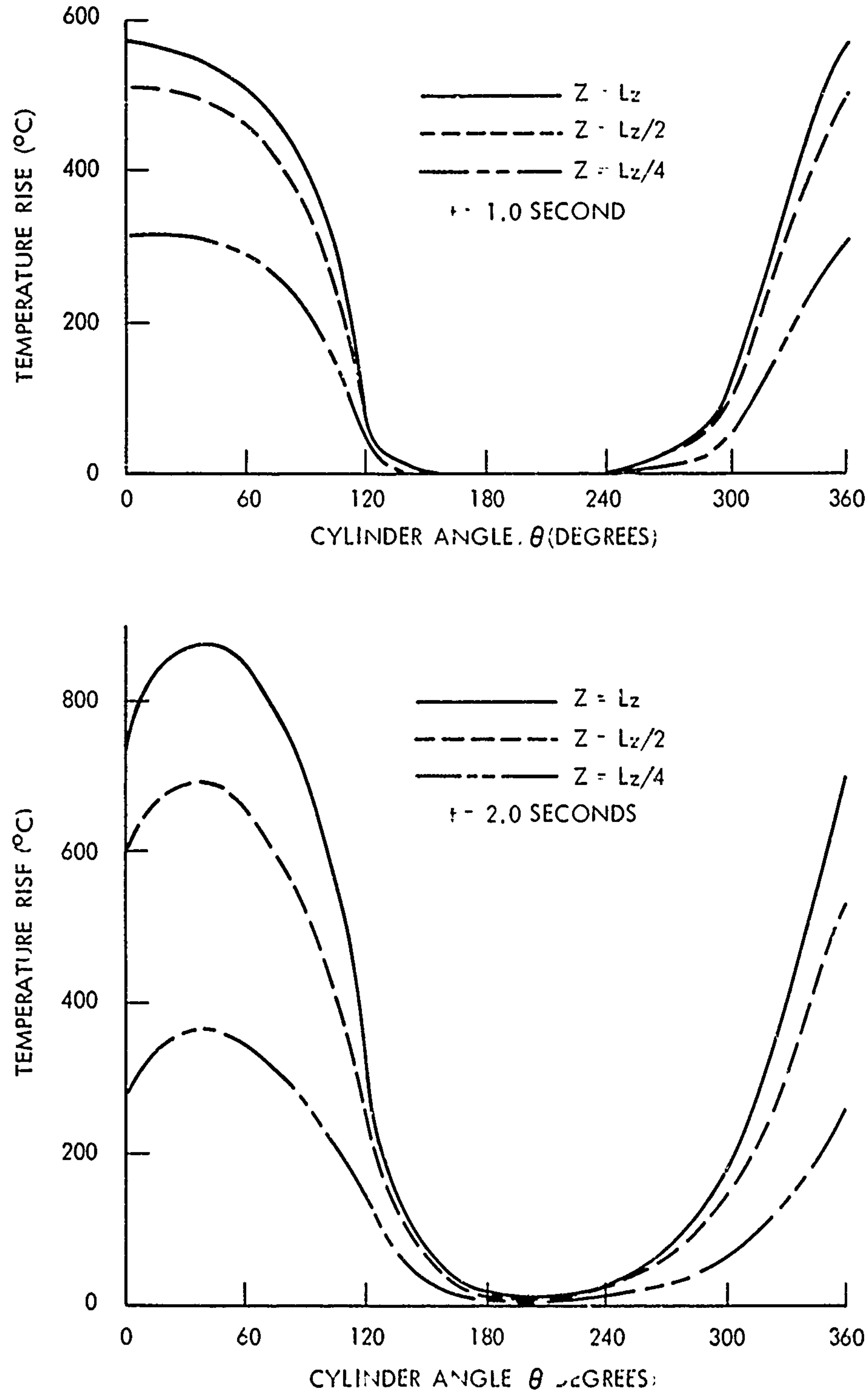

FIG. (B-1) TEMPERATURE DISTRIBUTION HISTORY IN A ROTATING CIRCULAR CYLINDER WITH BASE CONDUCTION

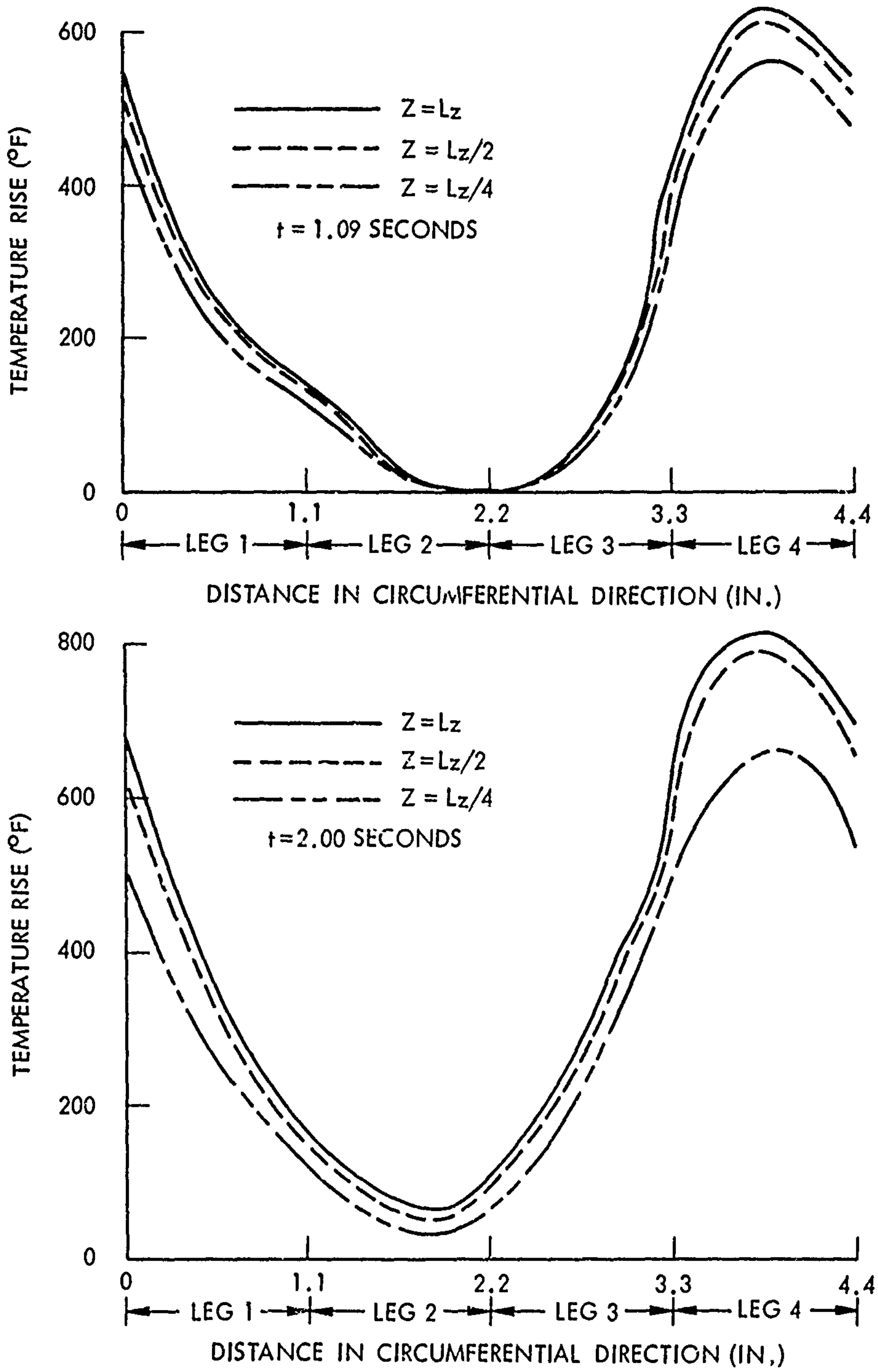

FIG. B-2) TEMPERATURE DISTRIBUTION HISTORY IN A ROTATING BOX BEAM WITH BASE CONDUCTION.