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COMPUTER PROGRAM FOR THERMAL ANALYSIS OF TANK-MOUNTED MULTILAYER INSULATION

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16. Abstract

An analysis was done on the space-hold thermal performance of various multilayer insulation configurations on an oblate spheroidal tank. The thermal code CINDA-3G (Chrysler Improved Numerical Differencing Analyzer for Third Generation Computers) was used for the thermal analysis, and several subroutines were written to tailor it for the needs of the problem. A portion of the tailoring is called the pre-preprocessor, which generates the data required as input to CINDA-3G. This pre-preprocessor and allied subroutines comprise a package to obtain a parametric thermal study with a minimum amount of input data. Parameters may be changed with a minimum of effort.

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COMPUTER PROGRAM FOR THERMAL ANALYSIS OF TANK-MOUNTED MULTILAYER INSULATION

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SUMMARY

A computer program was developed to analyze the space-hold thermal performance of various multilayer insulation (MLI) configurations on the upper half of an oblate spheroidal liquid-hydrogen tank. The thermal model considered was an unshrouded tank within a hypothetical sun-oriented vehicle such that the payload was the only heat source in the system.

The thermal code CINDA-3G (Chrysler Improved Numerical Differencing Analyzer for Third Generation Computers) was chosen for the basic thermal analysis, and several subroutines were written to tailor it for the needs of the particular problem. A portion of the tailoring included a program called the pre-preprocessor, which generated the data required as input for the CINDA-3G program.

This pre-preprocessor and allied subroutines comprise a package to obtain a parametric thermal analysis of any multilayer covering on a spheroid. As a result, a minimum amount of input is required to specify the model geometry so that perturbations in the geometry configuration may be introduced with a minimum of effort.

INTRODUCTION

The long-term storage of liquid hydrogen in space can be effectively accomplished by using high-performance multilayer insulation (MLI) systems. A typical system would use a large number of highly reflective shields (aluminized polyester film) separated by low-thermal-conductivity spacers (e.g., silk netting).

A cross-sectional view of a sun-oriented vehicle with an unshrouded liquid-hydrogen tank covered with MLI is shown in figure 1. The payload intercepts all solar energy and thus represents the only high-temperature heat source in the vehicle. The direction of the anticipated heat flows could be as indicated by the arrows in figure 1. The only heat being transferred into any of the tanks is through the MLI on the top half of the liquid-hydrogen tank. Therefore, this discussion will consider the thermal performance of the MLI on the top half of the liquid-hydrogen tank only.

This analysis will be general for a steady-state study of any oblate spheroidal tank and payload geometry. However, to simplify the discussion, the programs herein will be described with respect to a particular problem; that is, a steady-state analysis of a variable-thickness shield of MLI on the top half of an oblate spheroidal tank viewing a constant-temperature payload. A complete discussion and the results of this problem for the geometries considered may be found in reference 1.

A cross-sectional view of the variable-thickness MLI system on the top half of the liquid-hydrogen tank is shown in figure 2. The net heat flow by thermal radiation into the top surface of the MLI is transferred within the MLI by

(1) Conduction in the lateral direction parallel to the shields, Q_{lat}

(2) Combination of radiation and conduction in the normal direction perpendicular to the shields, Q_{norm}

For a steady-state condition to exist, the net thermal radiation received by the top surface of the MLI must be exactly equal to the total heat transferred through the MLI and into the liquid-hydrogen tank. The problem then becomes one of solving for the net heat flows after temperatures resulting from local heat balances throughout the MLI have been established.

There are a number of computer programs available which, when fed the proper input data to describe the model of a physical problem, will perform a thermal analysis and output the temperature distribution. When these programs are used, both building the mathematical model which describes the physical geometry and the preparation of the necessary input data are most tedious. To alleviate this difficulty, the computer subroutines described in this report were written to provide a ready means to generate this input data.

These subroutines are specifically designed to solve the problem described in reference 1, but can be generally applied to any tank in the shape of an oblate spheroid with layers of material covering the tank, or for a shell of varying thickness having the same general shape. These computer programs, then, generate the data required by CINDA-3G (ref. 2), which is the particular thermal analysis program chosen by the authors because of its versatility. The capability to readily effect small changes in geometry added to the versatility and afforded a substantial saving in time and effort.

The routines to be described herein are (1) a pre-preprocessor which takes the input data and converts it to the CINDA-3G data as prescribed by that program, (2) a view factor program which computes the geometric view factors for radiation in an enclosure, (3) an output routine which graphically displays the temperatures, thus making it easier to get an overall view of the temperature distribution, and (4) various other subroutines that are used for special operations by routines (1), (2), and (3).

ANALYSIS

Thermal Model

The thermal model for this problem is shown in figures 3 and 4. It consists of a 45° wedge of the MLI on top of an oblate spheroidal tank. This wedge is divided into a number of internal nodes.

For convenience, the geometry of all the nodes in a given column is assumed to be identical in the normal direction, having numerical values for the node width, node length, the lateral cross-sectional area (ALAT), and the normal area (ANORM) based on the dimensions on the top surface of the MLI. This should introduce no significant error when the maximum MLI thickness is small relative to the minor tank radius.

The node length for each segment (column) is described by specifying the angles $\theta_1, \theta_2, \ldots, \theta_n$ (all θ's must be integers). The depth of all nodes is constant and is specified by two input variables: the number of shields in each node, NSPL, and the thickness of each shield, DELS. The product of NSPL and DELS then is the depth of each internal node. The number of nodes in each column is an input variable, NL, which is a function of the MLI thickness being simulated in that particular column. The program is set up to accept a maximum of 30 segments and up to 50 nodes in each column. For the particular problem under discussion, 10 segments were used with varying numbers of layers (see fig. 3). The computed performance of this wedge is then multiplied by 8 to obtain the results for the entire top half of the tank.

A constant-value boundary node represents the temperature of the tank and the tank surface is held at this constant temperature. The payload is simulated by a flat disk divided into concentric rings (maximum, 10 rings). Space is simulated by a constant-temperature node with temperature at absolute zero and an emissivity equal to unity (blackbody).

Thermal Radiation

An enclosure composed of the payload, the surface of the MLI, and an imaginary surface representing space is used to compute the net thermal radiation received by the top surface of the MLI. The enclosure formed with the various surfaces labeled is shown in figure 5. The enclosure used in this discussion is composed of the 10 tank surface areas, five payload surface areas, and an imaginary surface simulating space, for a total of 16 surfaces.

The payload surface represented by a flat disk is divided into concentric rings of approximately equal area (labeled A_{11} to A_{15} in fig. 5). Each of these rings is considered to be a separate surface of the enclosure, and as such, each ring may have a different surface emissivity and a different constant temperature which is considered to be an infinite heat source. This is then assumed to be a multiple gray surface enclosure and simulates a radiosity network. A CINDA-3G subroutine, IRRAD1, is then used to compute the net radiant heat flow rates to each surface of the enclosure. Subroutine IRRAD1 uses a method described in reference 3 to obtain the net radiant heat flow to each surface.

Computer Program - General

CINDA-3G is a two-pass or double-phase operation consisting of a preprocessor phase and an execution phase. The user input data (description of the model) to CINDA-3G are converted into FORTRAN IV language subroutines by the preprocessor. These subroutines are then passed onto the system FORTRAN compiler for compilation and execution for solution of the problem.

Since the user input data as described in reference 2 are for a fixed geometric model, much extra labor would be necessary to change the input for a slightly modified geometry. Thus, a set of subroutines were written to accept a general description of the model and to generate the user input data so that the geometry can easily be varied by small changes in input data. This set of author-written subroutines was added to the CINDA-3G system as an additional phase of operation, making a three-pass or three-phase operation. This additional phase, called the pre-preprocessor, is executed first to generate all the necessary input data as required by the CINDA-3G preprocessor using a minimum amount of punched card input data. The CINDA-3G data are described in reference 2 (pp. 4.1 to 4.21). Control is then passed to the CINDA-3G preprocessor (phase 2) to process this generated data and to generate the subroutines for the third phase of the operation to perform the execution of the problem.

Because of this method of combining the three phases of operation and the use of certain portions of the computer operating system, this overall program as described is usable only on IBM 7094 II/7044 Direct Couple Systems running under the operating system IBSYS version 13, with a FORTRAN IV compiler. However, the CINDA-3G program is available for other computer configurations, for example UNIVAC 1108; and the routines written by the authors as described in this report could easily be modified to operate on these other computers since they are entirely written in FORTRAN IV.

Finite Difference Equations

The input to CINDA-3G is the description of the model. This description is given by designating each incremental volume, called a node, by a number and then describing the heat paths between nodes by specifying the node numbers of the two adjoining nodes and a value which represents the conductance between these two nodes. Conductance is the area of heat flow times the thermal conductivity divided by the conductor length. Heat flow to boundaries is specified by supplying heat-transfer coefficients or radiation constants as the conductance between the two nodes.

When a network (model) to the problem has been described, the solution is obtained by solving a set of finite difference equations, which are an approximation to the partial differential equations of the diffusion type

$$\frac{\partial T}{\partial t} = \alpha \nabla^2 T + S \tag{1}$$

where T is temperature, t is time, α is diffusivity

$$\alpha = \frac{k}{C_p} \tag{2}$$

∇^2 is the Laplacian operator in x, y, z coordinates, and S is a source term defined as

$$S = \frac{\dot{q}\alpha}{k} \tag{3}$$

where $\dot{q}$ is heat rate per unit volume and k is thermal conductivity.

Since we are interested in only the steady-state solution for this particular problem, the time derivative is equal to zero, and equation (1) reduces to Poisson's equation:

$$\alpha \nabla^2 T + S = 0 \tag{4}$$

Substituting equations (2) and (3) into equation (4) results in

$$\frac{k\nabla^2 T}{\rho C_p} + \frac{\dot{q}k}{k\rho C_p} = 0 \tag{5}$$

Then since ρC_p may be assumed to be a constant for steady-state computation, multiply both sides of equation (5) by ρC_p to get

$$k\nabla^2 T + \dot{q} = k\left(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2}\right) + \dot{q} = 0 \tag{6}$$

Then

$$k\nabla^2 T + \dot{q} \cong \frac{k}{\Delta x}\left(\frac{\partial T}{\partial x^-} - \frac{\partial T}{\partial x^+}\right) + \frac{k}{\Delta y}\left(\frac{\partial T}{\partial y^-} - \frac{\partial T}{\partial y^+}\right) + \frac{k}{\Delta z}\left(\frac{\partial T}{\partial z^-} - \frac{\partial T}{\partial z^+}\right) + \dot{q} \tag{7}$$

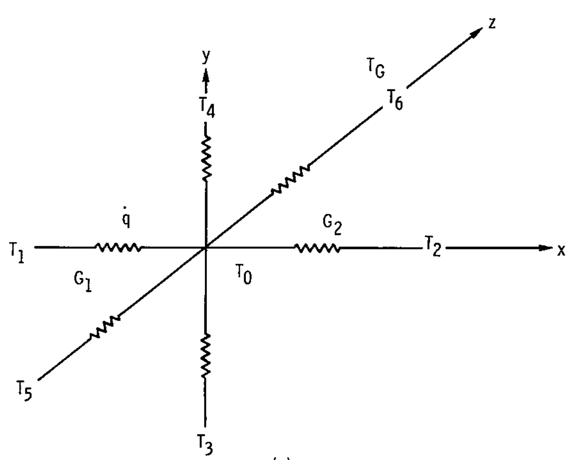
where the plus and minus signs in the first partial term indicate that they are taken on the negative or positive side, respectively, of the point under consideration. If three consecutive points (1, 0, and 2) ascending in the x direction are considered, the finite difference of the x portion of equation (7) is

$$\frac{k}{\Delta x}\left(\frac{\partial T_0}{\partial x^-} - \frac{\partial T_0}{\partial x^+}\right) \cong \frac{k}{\Delta x}\left(\frac{T_1 - T_0}{\Delta x^-} + \frac{T_2 - T_0}{\Delta x^+}\right) \tag{8}$$

applying this to equation (7) for x, y, and z for the points

1, 0, 2 in x direction
3, 0, 4 in y direction
5, 0, 6 in z direction

yields:



(a)

$$k\nabla^2 T_0 + \dot{q} = \frac{k}{\Delta x}\left(\frac{T_1 - T_0}{\Delta x^-} + \frac{T_2 - T_0}{\Delta x^+}\right) + \frac{k}{\Delta y}\left(\frac{T_3 - T_0}{\Delta y^-} + \frac{T_4 - T_0}{\Delta y^+}\right) + \frac{k}{\Delta z}\left(\frac{T_5 - T_0}{\Delta z^-} + \frac{T_6 - T_0}{\Delta z^+}\right) + \dot{q} \tag{9}$$

taking common denominator of volume $V = (\Delta x)(\Delta y)(\Delta z)$ and $A_x = (\Delta y)(\Delta z)$, $A_y = (\Delta x)(\Delta z)$, $A_z = (\Delta x)(\Delta y)$ and combining equation (9) with equation (6) to obtain

$$\frac{kA_x}{\Delta x^-}\left(T_1 - T_0\right) + \frac{kA_x}{\Delta x^+}\left(T_2 - T_0\right) + \frac{kA_y}{\Delta y^-}\left(T_3 - T_0\right) + \frac{kA_y}{\Delta y^+}\left(T_4 - T_0\right) + \frac{kA_z}{\Delta z^-}\left(T_5 - T_0\right)$$

$$+ \frac{kA_z}{\Delta z^+}\left(T_6 - T_0\right) + \dot{q} = 0 \tag{10}$$

now let $G_1 = kA_x/\Delta x^-$, $G_2 = kA_x/\Delta x^+$, $G_3 = kA_y/\Delta y^-$, . . ., etc. Then

$$G_1\left(T_1 - T_0\right) + G_2\left(T_2 - T_0\right) + G_3\left(T_3 - T_0\right) + G_4\left(T_4 - T_0\right) + G_5\left(T_5 - T_0\right)$$

$$+ G_6\left(T_6 - T_0\right) + \dot{q} = 0 \tag{11}$$

$$G_1T_1 + G_2T_2 + G_3T_3 + G_4T_4 + G_5T_5 + G_6T_6 + \dot{q}$$

$$= T_0\left(G_1 + G_2 + G_3 + G_4 + G_5 + G_6\right) \tag{12}$$

or

$$T_0 = \frac{G_1T_1 + G_2T_2 + G_3T_3 + G_4T_4 + G_5T_5 + G_6T_6 + \dot{q}}{G_1 + G_2 + G_3 + G_4 + G_5 + G_6} \tag{13}$$

or, in more general terms,

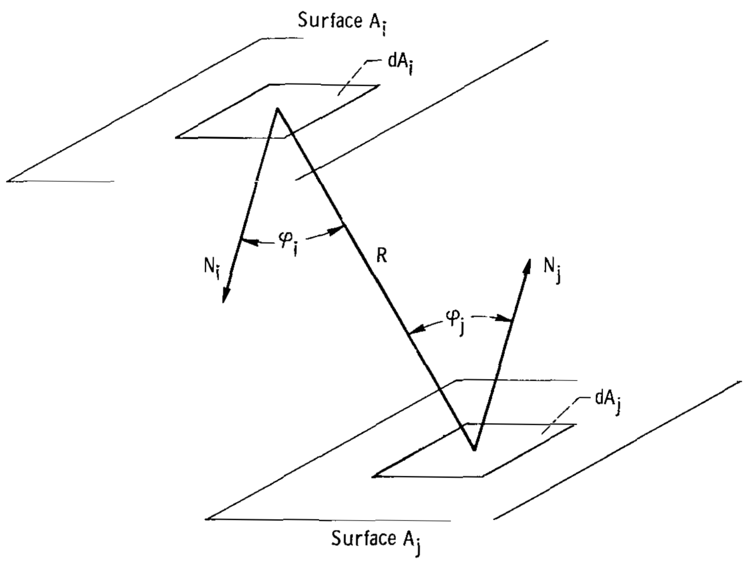
$$T_0 = \frac{\sum G_i T_i + \dot{q}_0}{\sum G_i} \tag{14}$$

where i ranges over all neighboring nodes to T_0.

Since all the temperatures T_i in equation (14) are not known, assume some initial temperatures and solve this equation for T_0; when this is done over all the nodes in the network, a new temperature distribution will be obtained. Iterate in this fashion with equation (14) over all the nodes in the network until the temperatures obtained do not change between two consecutive iterations by more than some prescribed value, called the convergence criterion. This is the method used by the execution routine CINDSS (see ref. 2).

Geometric Radiation View Factors Between Surfaces on a Flat-Surfaced Payload and a Spheroidal Tank

The geometric radiation view factor between any two surfaces A_i and A_j shown in the following sketch is defined by equation (15)



(b)

$$A_i F_{i,j} = \int_{A_i} \int_{A_j} \frac{\cos \varphi_i \cos \varphi_j \, dA_i \, dA_j}{\pi R^2} \tag{15}$$

where $F_{i,j}$ represents the portion of the total energy, either emitted or reflected by surface i, that is intercepted by surface j. As shown in the sketch, φ_i and φ_j are the angles between the respective normals to the surface elements dA_i and dA_j and the connecting line R.

The double integral in equation (15) is approximated by the following double summation in order to obtain a numerical solution on the digital computer:

$$A_i F_{i,j} = \sum_{A_i} \sum_{A_j} \frac{\cos \varphi_i \cos \varphi_j \, \Delta A_i \, \Delta A_j}{\pi R^2} \tag{16}$$

The radiosity subroutine used to calculate the net heat into each surface of the enclosure requires the following numerical input:

A_{N_E} area of each surface in the enclosure

T_{N_E} temperature of each surface in the enclosure

ϵ_{N_E} emissivity of each surface in the enclosure

$A \times F$ area times geometric view factor for each interchange in the enclosure (see ref. 2, p. 6.6.2)

The procedure described in this section first determines the individual values of $A \times F$ for each of the tank surfaces viewing each of the payload surfaces. Once these primary values are determined, all other values of $A \times F$ are readily determined. The equations used to define the other values of $A \times F$ are discussed at the very end of this section.

The view factors, and subsequently the net q into each of the surfaces in the radiosity enclosure, are computed for the entire top half of the tank and the entire payload. As described earlier, in the discussion of the model, the top node of each column of MLI is a 45° segment. These segments are extended completely around the tank to form a ring and the net q is computed for each of these rings. These q's are then divided by 8 to obtain the net q into each node on top of the MLI. The method of computing the view factors described herein further breaks up each of these rings on the MLI and also breaks up the payload surfaces, described on page 3, into smaller rings. Then these small areas with their respective view factors are added together to obtain the $A \times F$ for each payload surface and each MLI surface, where each MLI surface is a ring as described previously.

The actual view factors are calculated as follows: The payload is arbitrarily divided into concentric rings each having a width of 0.1 foot (3.05 cm). Each ring with area A_p is then further divided into incremental areas ΔA_p. As shown in figure 6, the subscript p will pertain to the payload surface, and the subscript t will pertain to the tank surface. The number of incremental areas in each ring N_J is varied so that the numerical value of ΔA_p remains approximately constant over the entire payload. Thus, for the payload ring shown in figure 6, N_J is the nearest whole number determined by the following expression:

$$N_J = 20\pi R_p \tag{17}$$

The number of these rings of 0.1-foot (3.05-cm) width which are to be included in each of the individual payload surfaces is then readily determined.

The MLI surface on the tank is arbitrarily divided into 90 increments of 1° each, measured from the vertical z-axis. As shown in figure 6, the incremental area extends in a ring completely around the tank. The location of this ring is specified by ψ_m, the angular distance from the vertical z-axis. Each ring with area A_t is further divided into incremental areas ΔA_t of constant size over the entire tank surface. The number of individual rings to be included in each of the separate tank surfaces used in the enclosure is then readily determined once the angular size of each of the surfaces is specified.

The variable MLI thickness over any particular tank surface area is accounted for by reading in the number of nodes used at that particular location. The numerical values of a and b (the major and minor semi-axes of the spheroid formed by the surface of the MLI) are determined individually for each of the tank areas used.

$$a = X_r + \Delta S$$

$$b = Y_r + \Delta S$$

where ΔS is the thickness of the MLI and X_r and Y_r are the uninsulated tank dimensions. Thus for any particular surface area of the tank, the existing MLI thickness over that particular area is considered to exist over the entire tank surface.

Both the tank and the payload are symmetrical about their respective z-axes. Because of this symmetry and the fact that the z-axes of both coordinate systems coincide, the geometric view factor of <u>any</u> one element ΔA_t along a given tank ring to any given complete payload ring is independent of position. Thus, equation (16) may be written in the following manner:

$$A_t F_{t,p} = A_t \sum_{A_p} \frac{\cos \varphi_t \cos \varphi_p \, \Delta A_p}{\pi R^2} \tag{19}$$

where A_t and A_p are the tank and payload ring areas, respectively. Thus, the view factor $F_{t,p}$ of any ring on the tank to any ring on the payload is the summation of the view factors to all the incremental areas making up the payload ring.

To simplify the geometry, the typical element ΔA_t on any given tank ring, selected to view all elements ΔA_p on any given payload ring, is located in the yz plane. In this plane, the equation of the MLI surface is

$$\frac{y^2}{a^2} + \frac{z^2}{b^2} = 1 \tag{20}$$

The following geometric relations are then valid:

$$\left.\begin{aligned}
R_t &= ab\sqrt{\frac{1}{b^2 \sin^2 \psi_m + a^2 \cos^2 \psi_m}} \\
y_t &= R_t \sin \psi_m \\
z_t &= R_t \cos \psi_m \\
\Delta h &= b - z_t
\end{aligned}\right\} \tag{21}$$

For each value of ψ_m used, the entire payload will be divided into incremental areas ΔA_p. Thus, R_p will be a function of the payload ring being considered, and γ_n will be a function of the location of ΔA_p. The following relations can be seen from figure 6:

$$\left.\begin{aligned} x_p &= R_p \cos \gamma_n \\ y_p &= R_p \sin \gamma_n \\ \Delta A_p &= \frac{\pi}{N_J}\left[\left(R_p + \frac{\Delta L}{2}\right)^2 - \left(R_p - \frac{\Delta L}{2}\right)^2\right] \end{aligned}\right\} \tag{22}$$

where N_J is determined by equation (17). Differentiating equation (20) gives the slope at any point on the curve:

$$\frac{dz}{dy} = -\frac{b^2}{a^2}\frac{y}{z} \tag{23}$$

The slope of a line normal to that point m_{N_1} can be expressed as

$$m_{N_t} = -\frac{1}{\frac{dz}{dy}} = \frac{a^2}{b^2}\frac{z}{y} = \frac{a^2 z_t}{b^2 y_t} \tag{24}$$

where z_t and y_t are the coordinates of the point shown in figure 6. The vector $\vec{N}_t$ representing the normal from this point is

$$\vec{N}_t = \hat{j} + m_{N_t}\hat{k} \tag{25}$$

and the unit vector $\hat{N}_t$ becomes

$$\hat{N}_t = \frac{\hat{j} + m_{N_t}\hat{k}}{\left|\sqrt{1 + m_{N_t}^2}\right|} \tag{26}$$

Since the payload surface is in the xy plane,

$$\hat{N}_p = -\hat{k} \tag{27}$$

The vector $\vec{R}_{t,p}$ from ΔA_t to ΔA_p can be expressed as

$$\vec{R}_{t,p} = (x_p - x_t)\,\hat{i} + (y_p - y_t)\,\hat{j} + (z_p - z_t)\,\hat{k} \tag{28}$$

Since $x_t = 0$,

$$\vec{R}_{t,p} = x_p\hat{i} + (y_p - y_t)\,\hat{j} + (z_p - z_t)\,\hat{k} \tag{29}$$

$$R = \left| \sqrt{x_p^2 + \left(y_p - y_t\right)^2 + \left(z_p - z_t\right)^2} \right| \tag{30}$$

Thus the unit vector $\hat{R}_{t,p}$ becomes

$$\hat{R}_{t,p} = \frac{x_p\,\hat{i} + (y_p - y_t)\,\hat{j} + (z_p - z_t)\,\hat{k}}{R} \tag{31}$$

and

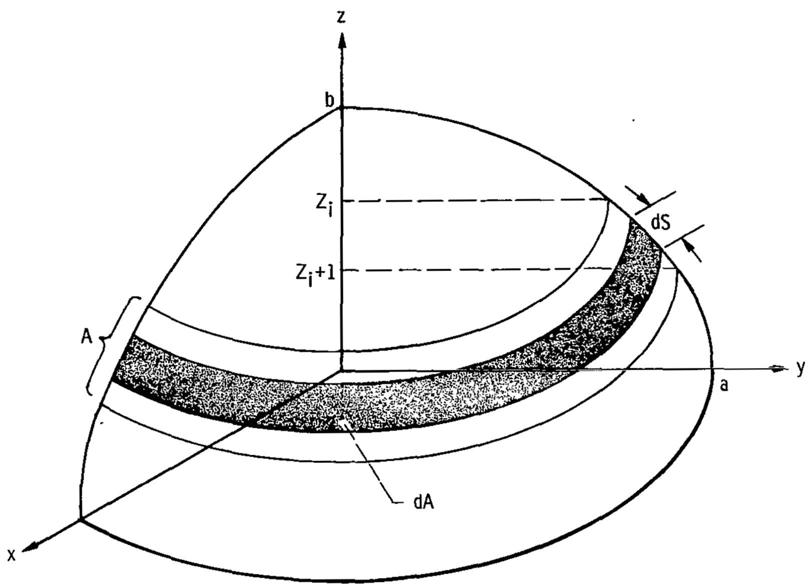
$$\hat{R}_{p,t} = -\hat{R}_{t,p} \tag{32}$$

The angles φ_t and φ_p can now be determined by forming scalar products:

$$\cos\varphi_t = \hat{N}_t \cdot \hat{R}_{t,p} = \frac{(y_p - y_t) + m_{N_t}(z_p - z_t)}{R\left|\sqrt{1 + m_{N_t}^2}\right|} \tag{33}$$

$$\cos\varphi_p = \hat{N}_p \cdot \hat{R}_{p,t} = \frac{z_p - z_t}{R}$$

The tank surface area A of any ring is determined with the equation obtained from the following derivation:



(c)

$$dA = 2\pi y \, ds$$

$$ds = \sqrt{(dy)^2 + (dz)^2}$$

$$\frac{y^2}{a^2} + \frac{z^2}{b^2} = 1$$

$$y = a \sqrt{1 - \frac{z^2}{b^2}}$$

$$dy = \frac{-az \, dz}{b^2 \sqrt{1 - \frac{z^2}{b^2}}}$$

$$\therefore\ dA = (2\pi)\left(a\sqrt{1 - \frac{z^2}{b^2}}\right)\left[\sqrt{\frac{a^2 z^2}{b^4\left(1 - \frac{z^2}{b^2}\right)} + 1}\right] dz$$

$$\therefore\ dA = 2\pi a\left[\sqrt{1 + \left(\frac{a^2}{b^4} - \frac{1}{b^2}\right) z^2}\right] dz$$

$$\therefore\ A = 2\pi a \int_{z_i}^{z_{i+1}} \sqrt{1 + w^2 z^2}\, dz$$

where

$$w^2 = \frac{a^2}{b^4} - \frac{1}{b^2} = \frac{a^2 - b^2}{b^4}$$

Thus

$$A_p = 2\pi a\left[\frac{z}{2}\sqrt{1 + w^2 z^2} + \frac{1}{2w}\ln\left(zw + \sqrt{w^2 z^2 + 1}\right)\right]_{z_i}^{z_{i+1}} \tag{34}$$

Therefore all quantities required in equation (19) are determined.

To obtain the value of $A_m F_{m,n}$ between specific areas m and n is simply an appropriate summation of the results of equation (19):

$$A_m F_{m,n} = \sum_{\substack{\text{All tank} \\ \text{rings in the} \\ m^{th}\text{ segment}}} \ \sum_{\substack{\text{All payload} \\ \text{rings in the} \\ n^{th}\text{ segment}}} A_t F_{t,p} \tag{35}$$

All other values of $A_m F_{m,n}$ can now be generated using the following relations:

(1) Since no surface "sees" itself, $F_{m,m} = 0$ for any m.

(2) Since no two surfaces on the tank "see" each other, $F_{m,n} = 0$ for all tank surfaces m and n.

(3) Since no two surfaces on the payload "see" each other, $F_{m,n} = 0$ for all payload surfaces m and n.

(4) By definition, $\sum_{n=1}^{\text{All surfaces}} F_{m,n} = 1.$

(5) By reciprocity, $A_m F_{m,n} = A_n F_{n,m}$.

DESCRIPTION OF SUBROUTINES

As previously discussed, the program is divided into three phases: (1) the pre-preprocessor, which by using the input data described in appendix A of this report computes the input data needed to run a problem with CINDA-3G and generates a tape according to the formats given on pages 4.1 to 4.2 of reference 2; (2) the preprocessor, as described in reference 2; and (3) the execution phase, which actually computes the temperature distribution.

Pre-preprocessor Phase

The pre-preprocessor is composed of four subroutines which read data cards describing the geometry, compute the data required by the CINDA-3G system, and write this data onto a tape to be used in phase 2.

The subroutines in the pre-preprocessor are as follows:

Subroutine name	FORTRAN call name	Brief description
PREPRE	Main program	Reads the input data, computes the data required by CINDA-3G
VIEWFC	VIEWF	Computes the geometric view factors for the radiation interchange used in subroutine IRRAD1
RAYOUT	RITARY	Called by PREPRE; writes arrays of numbers onto the input tape as prescribed by CINDA-3G, p. 4.10 of ref. 2
COMDAT	BLOCK COMMON	Block common subroutine

Preprocessor Phase

The preprocessor is the second phase of the operation. A list of the subroutines and a description of each is given in reference 2 (pp. 8. 1 to 8. 3). The only variation is that the preprocessor reads the data from the tape that was prepared by the pre-preprocessor phase instead of from cards.

Execution Phase

The actual computing to determine the temperature distribution is done in the execution phase. In this execution phase the following subroutines are used: LINKO, EXECDK, VAR1DK, VAR2DK, OUTDK, which are generated by the preprocessor phase of CINDA-3G.

LINKO is the main program. Its only function is to call the INPUT routines to read in the CINDA input data and call EXECDK.

EXECDK is called the execution block of the program. It retains control until the problem is solved. Subroutines VAR1DK, VAR2DK, and OUTDK are called by EXECDK or by other subroutines called from EXECDK.

VAR1DK, VAR2DK, and OUTDK are the subroutines generated from the VARIABLES 1 block, VARIABLES 2 block, and OUTPUT block, respectively, that are described in reference 2. The order of calculation in the execution phase of the program is described, along with a flow chart, in reference 2 (pp. 3. 12 and 3. 13).

Several subroutines were written by the authors and incorporated into the execution phase in the user subroutine section. These subroutines may be easily modified or rewritten by the user because they must be included into the program deck as FORTRAN source cards. The subroutines are

Subroutine name	FORTRAN call name
CNDCTR	GETG
OUTEND	ENDOUT
DISTRT	TDIST
GRAFIC	PICTR
PUNTEM	PCHT

Subroutine CNDCTR computes the value of all internal conduction connectors G_i between two nodes i and j.

$$G_i = \frac{A_k}{l_{i,j}} \tag{36}$$

where

A area of heat flow

k thermal conductivity

l distance from the center of node i to center of node j

If the thermal conductivity varies with temperature

$$G_i = \frac{A}{\frac{l_i}{k_i} + \frac{l_j}{k_j}} \tag{37}$$

where k_i and k_j are temperature-varying thermal conductivities at nodes i and j. These conductors are computed just prior to each iteration of the network solution.

Subroutine CNDCTR as listed in this report was written to permit the use of very high thermal conductivity shields (pure aluminum as opposed to aluminized mylar) to increase the lateral thermal conductivity of some layers of the MLI. The nodes in these layers with high conductivity will be denoted as hi-k nodes. All other interior nodes with a lower conductivity will be denoted as standard nodes. It should be noted that this is conduction in the lateral direction only. The thermal conductivity for the standard nodes is determined by straight-line curve fit. Input variables CON1 and CON2 are the a and b, respectively, for the line $k = aT + b$. The data for the hi-k nodes are input in a table with variable name AKVST. The format for this table is found in appendix E. For the data used in the sample problem for both the standard nodes and the hi-k nodes see figure 8 of reference 1. The thermal conductivity for conduction in the normal direction $k_{effective}$ is a combination of conduction and radiation (see ref. 1 for details). Subroutine CNDCTR also calls subroutine IRRAD1 to obtain the net Q into each surface of the radiosity enclosure.

Subroutine OUTEND calls subroutine GRAFIC and then computes and prints out the heating rates Q of the fuel tank to MLI, QNORM, and also the net heat into the MLI on the top surface of the MLI, QTS. QNORM and QTS are printed in tabular form to show the Q in or out of each segment on the tank. Further, these values are then multiplied by 8 to obtain the Q in and out for the entire tank. The names of these output variables are QN8 and QTS8. These printouts occur each time the print switch (NPRINT) calls for an output of the temperature distribution.

Subroutine TDIST reads the initial temperature distribution from tape unit SYSUT5 which was written in the pre-preprocessor.

Subroutine GRAFIC is a special subroutine which prints out the temperature distribution pictorially. Blocks are made, simulating the nodes, and are printed to simulate the shape of the shield. Inside each block is printed a node number and the temperature of that node. A node number with a minus sign in front denotes this node is a hi-k node, as described in the section on subroutine CNDCTR. If the top of the box is made up of dollar signs ($$$$$$) instead of asterisks (******) it denotes a surface with a high surface emissivity (see sample output listing on p. 31).

Subroutine PUNTEM punches cards with the current temperatures if either the number of iteration loops or the amount of computer time requested on the TCP card is exceeded.

Lewis Research Center,

National Aeronautics and Space Administration,

Cleveland, Ohio, December 2, 1970,

129-04.

APPENDIX A

COMPUTER PROGRAM SYMBOLS

FORTRAN name	Corresponding mathematical symbol	Units in program	Description
A	A_{norm}	ft^2	Conduction area in normal direction
AFA	$A_i F_{ij}$	ft^2	Product of i^{th} surface area and the geometric view factor between i^{th} and j^{th} surfaces
AKVST	k	Btu/(hr)(ft)(^{o}F)	Thermal conductivity table
ARCLN	---	ft	Arc length
AREAL	A_L	ft^2	Conduction area in lateral direction
BOTLIM	---	---	Integrand of equation (34) evaluated at lower limit z_i
BTA	β	deg	Angle measured from minor axis to segment boundary on tank
C	---	---	Array of user constants to CINDA-3G
CINCON	---	---	Array of control constants to CINDA-3G
CONNAM	---	---	Array of control constant names
CON1	---	---	Constant = a (a straight-line curve fit for k for lateral conduction; k = aT + b)
CON2	---	---	Constant = b (a straight-line curve fit for k for lateral conduction; k = aT + b)
DAMPA	---	---	Damping factor (CINDA control constant)
DAREA	A_t	ft^2	Incremental area on MLI for view factor computation

FORTRAN name	Corresponding mathematical symbol	Units in program	Description
DELDMP	---	---	Delta to add to change damping factor
DELS	---	ft	Thickness of each shield
DMLI	ΔS	ft	Thickness of MLI at a given segment
DPTH	---	ft	Thickness (depth) of each node
EMISP	ϵ	---	Emissivity of each surface of payload
EMISS	ϵ	---	Emissivity of space
EMIST	ϵ	---	Emissivity of each surface on MLI
G	G	Btu/(hr)(^{o}F)	Conductor value for heat transfer
H	h	ft	Tank-to-payload spacing
IEXECN	---	---	Name of CINDA execution routine to be used
LCK2	---	---	Tape unit SYSCK2 CINDA input written on
LUT3	---	---	Tape unit SYSUT3 used as temporary storage for FORTRAN subroutines to be used in execution phase
LUT5	---	---	Tape unit SYSUT5 initial temperatures stored on this unit, to be read in execution phase
MAXNL	---	---	Maximum number of nodes at any segment
NDAMP	---	---	Change damping factor every NDAMP iterations
NHIK	---	---	Number of high-conductivity layers

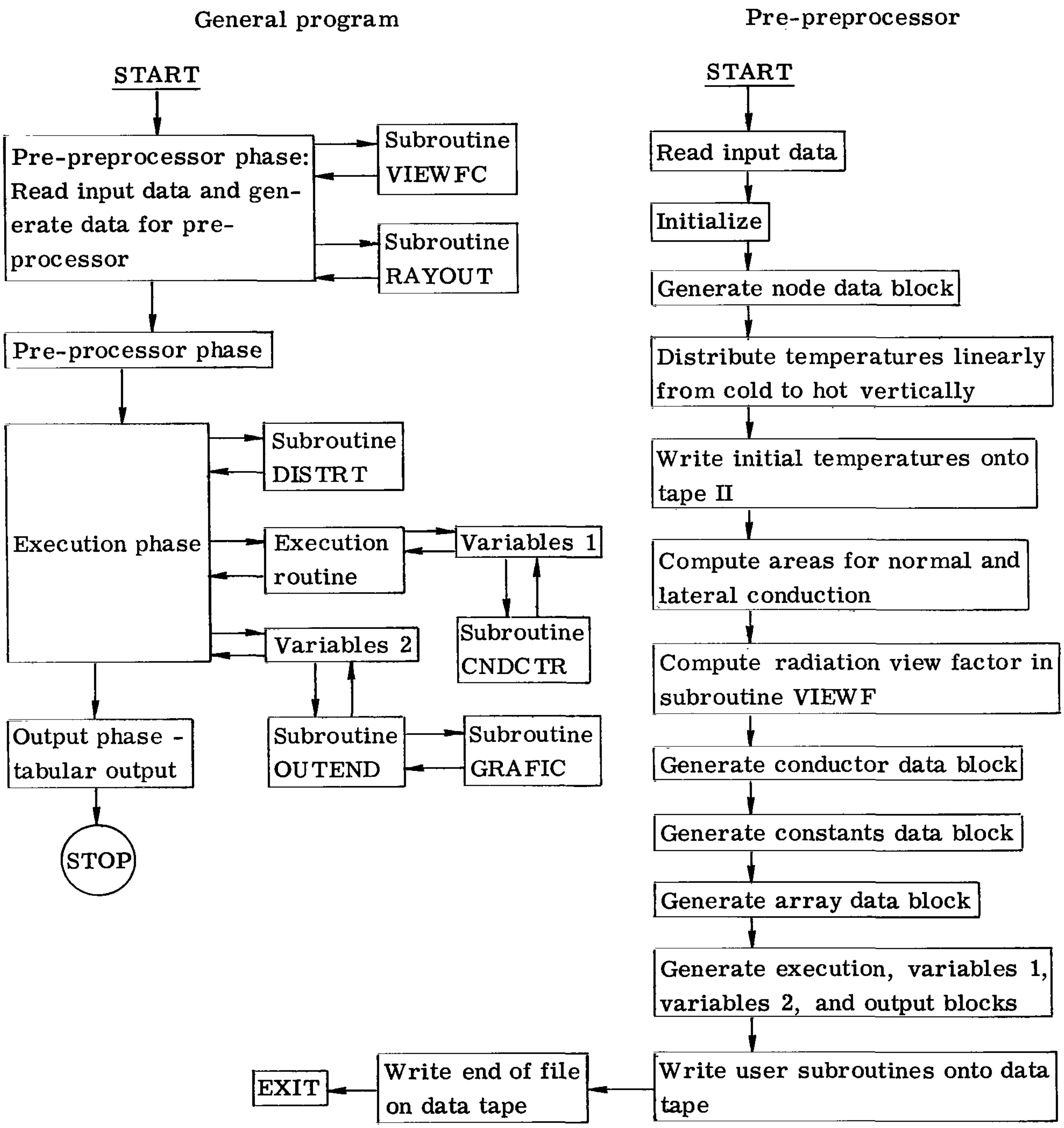
FORTRAN name	Corresponding mathematical symbol	Units in program	Description
NIN	---	---	Tape unit, input unit
NL	---	---	Number of nodes in MLI in normal direction for each segment
NNODES	---	---	Total number of nodes in configuration
NNPAY	---	---	Number of nodes on payload
NNSEG	---	---	Number of segments on tank
NOFA	---	---	Number of entries in view factor matrix
NOUT	---	---	Tape unit, output unit
NPAY	---	---	Same as NNPAY above
NPRINT	---	---	Print temperatures every NPRINT iterations
NSEG	---	---	Same as NNSEG above
NSPL	---	---	Number of shields in each node
NSTMTS	---	---	Number of FORTRAN cards read in as user program to go into SUBROUTINES block of CINDA-3G
NSURF	---	---	Number of surfaces in radiation enclosure
NTAB	---	---	Total number of entries in K-vs-T table (AKVST)
NUMHIK	---	---	Array containing layer numbers of high-conductivity layers
PSI	ψ_m	---	Angle from top of tank to R_1
QNORM	Q	Btu/hr	Heat flow from MLI into tank

FORTRAN name	Corresponding mathematical symbol	Units in program	Description
QTS	Q	Btu/hr	Heat flow from enclosure into top of MLI
R1	R_1	ft	Distance from tank center to incremental surface i
R1X	R_1	ft	Distance from tank center to incremental surface i + 1
RP	R_p	ft	Radius of payload
SLAY	---	---	Number of nodes in MLI in normal direction at each 1^o increment
SPACEE	ϵ	---	Emissivity of space
TCARDS	---	---	Switch: If equal to zero, use temperatures input with input data; then distribute initial temperatures throughout configuration with subroutine TDIST. If not equal to zero, read initial temperature distribution from cards.
THETA	θ	deg	Array of angles specifying angular segments on tank
THIKN	---	---	Same as DPTH above
TPAY	T	^oR	Array temperatures of payload nodes
TSPACE	T	^oR	Temperature of space node
TSURF	T	^oR	Initial temperature on MLI surface
TWALL	T	^oR	Temperature of tank wall
UPLIM	---	---	Integrand of equation (34) evaluated at upper limit
X	X_r	ft	Major semi-axis of tank

FORTRAN name	Corresponding mathematical symbol	Units in program	Description
XM1	m_{N_1}	--	Slope
Y	Y_r	ft	Minor semi-axis of tank

APPENDIX B

FLOW DIAGRAM



APPENDIX C

DECK SETUP

The following is the deck setup to run this program at Lewis Research Center on the IBM 7094-7044 Direct Couple System using IBSYS version 13:

cc1	cc8	cc16
$ID	JO	USER NAME
$TCP		TIME=XX, PAGES=YY
$SETUP	10	CIN3G
$IBJOB		

FORTRAN IV source or binary decks of pre-preprocessor as described in this report. (Includes subroutines PREPRE, VIEWFC, RAYOUT, and COMDAT.)

$DATA

FORTRAN IV source cards of user-written subroutines. For this problem these subroutines include CNDCTR, OUTEND, DISTRT, GRAFIC, and PUNTEM. Any other user-written subroutines may be added here.

ENDX

Input data as described in appendix E.

$IBSYS	
$REWIND	SYSCK2
$SWITCH	SYSIN1, SYSCK2

APPENDIX D

TAPE USAGE

Tape units must be made compatible between CINDA-3G and the computer system. A table of tape usage presently being used at Lewis Research Center only with the CINDA-3G program is included to aid in making this compatible with other systems.

SYSUNI name	FORTRAN number in CINDA-3G	Variable name in program	Lewis system number	Function
UT3	2	LUT3	14	Copy of original problem data
UT4	3	LUT4	15	Parameter change data*
UT8	4	LUT1	3	Data number definitions
IN1	5	NIN	5	Input
OU1	6	NOUT	6	Output
UT2	8	LUT2	13	NA-NB pairs, data number definitions for parameter changes
CK1	9	------	10	CINDA-3G master tape
CK2	10	------	16	New master tape if updating, also used as problem recall data tape*
UT5	11	------	7	Problem store data tape*
UT6	12	LBD3	1	Data tape (original problem and all parameter changes)
PP1(LB4)	13	------	Calcomp	System plot tape
LB3	14	LB4P	9	Program tape (contains generated FORTRAN routines; LINKO, EXECTN, VARBL1, VARBL2, OUTCAL)

SYSUNI name	FORTRAN number in CINDA-3G	Variable name in program	Lewis system number	Function
UT7	15	LUT7	2	Variables 1 calls generated from node and conductor data blocks*
UT9	16	------	4	Internal file for reread
UT9	99	------	4	Internal file for reread
LB2	17	------	8	Overlay tape

The tapes marked by an asterisk need not be assigned if the particular options are not used. The STOREP option in CINDA-3G requires assigning and saving tapes on units LB3 and UT5. The RECALL option requires assigning and mounting these two tapes onto units LB3 and CK2, respectively.

APPENDIX E

DESCRIPTION AND FORMAT OF INPUT DATA TO PRE-PREPROCESSOR

Input Data Description

```
CARD 1   FORMAT( I4, 2I3, 7F10.5)
         NSEG     NO. OF SEGMENTS   (MAXIMUM 30)
         NPAY     NO. OF SURFACES, (SEGMENTS) ON PAYLOAD  (MAXIMUM 10)
         NSPL     NO. OF SHIELDS PER LAYER
         DELS     THICKNESS OF EACH (SHIELD+SPACER)    FT.
         TWALL    TEMPERATURE OF TANKWALL    DEG.R
         TSURF    TEMPERATURE OF TOP SURFACE OF SHIELD   DEG.R
         TSPACE   TEMPERATURE OF SPACE                   DEG.R
         EMISS    EMISIVITY USED IN EQUATION FOR K(EFF),
                     CONDUCTION IN NORMAL DIRECTION
         SPACEE   EMISIVITY OF SPACE
         RP       RADIUS OF PAYLOAD    FT.

CARD 2   FORMAT( 6F10.5, A6)
         TCARDS   SWITCH- TO READ INITIAL TEMPERATURES
                  IF TCARDS =0, CARDS WILL NOT BE READ. THE PROGRAM
                  USES TWALL AND TSURF AND DISTRIBUTES THE TEMPERATURES
                  BETWEEN THESE TWO VALUES AS THE INITIAL TEMPERATURE
                  DISTRIBUTION.
                  IF TCARDS .GT. 0 THE INITIAL TEMPERATURE DISTRIBUTION
                  IS READ FROM CARDS, (DEG. R). SEE CARDS 11 BELOW.
         X        LENGTH OF SEMI-AXIS OF ELIPSE, (TANKWALL),ALONG X AXIS
         Y        LENGTH OF SEMI-AXIS OF ELIPSE, (TANKWALL),ALONG Y AXIS
         H        TANK TO PAYLOAD SPACING    FT.
         CON1     CONSTANTS USED FOR STRAIGHT LINE CURVE FIT TO COMPUTE
         CON2     THERMAL CONDUCTIVITY FOR G VALUES FOR LATERAL
                  CONDUCTION OF STANDARD NODES. K=CON1*T+CON2.
         IEXECN   NAME OF EXECUTION ROUTINE      CINDSS OR CINDSL
CARD 3   FORMAT( 2I10, F10.5)
        NPRINT    DELTA PRINT, PRINT TEMP. DIST. EVERY NPRINT ITERATIONS
        NDAMP     CHANG DAMPING FACTOR EVERY NDAMP ITERATIONS
         DELDMP   DELTA TO ADD TO DAMPING FACTOR

 CARD 4 FORMAT(I8,9F8.3)
         CINCON(I)  CINDA CONTROL CONSTANTS, AS REQUIRED BY EXECUTION
                      ROUTINE BEING USED. CONSTANTS INPUT IN ORDER AS
                      FOLLOWS ACCORDING TO FORMAT GIVEN ABOVE,
                      NLOOP, ARLXCA, DAMPA, DRLXCA, DAMPD, TIMEO,
                      TIMEND, OUTPUT, DTIMEI, CSGFAC.

 CARDS 5 NTAB, (AKVST(I),I=1,NTAB)        FORMAT(I6,12F6.1/(6X,12F6.1))
                  TABLE OF TEMPERATURE VS. THERMAL CONDUCTIVITY FOR
                  LATERAL CONDUCTION OF HIGH CONDUCTIVITY LAYERS.
                  NTAB= TOTAL NO. OF ENTRIES IN TABLE (TEMPS AND K'S)
     DATA FORM      NTAB TEMP1      K1 TEMP2     K2 ---    TEMPN  KN
                  UNITS-- K BTU/HR-FT-DEG.R
                          T DEG.R

 CARDS 6 NL       NUMBER OF LAYERS IN EACH SEGMENT FORMAT ( NI2)
```

CARDS 7 THETAD   ANGLE OF EACH SEGMENT, IN DEGREES, IF ALL SEGMENTS
ARE EQUAL INPUT ONLY THE FIRST.   FORMAT (N I2)
THE SUM OF THE N ANGLES MUST EQUAL 90

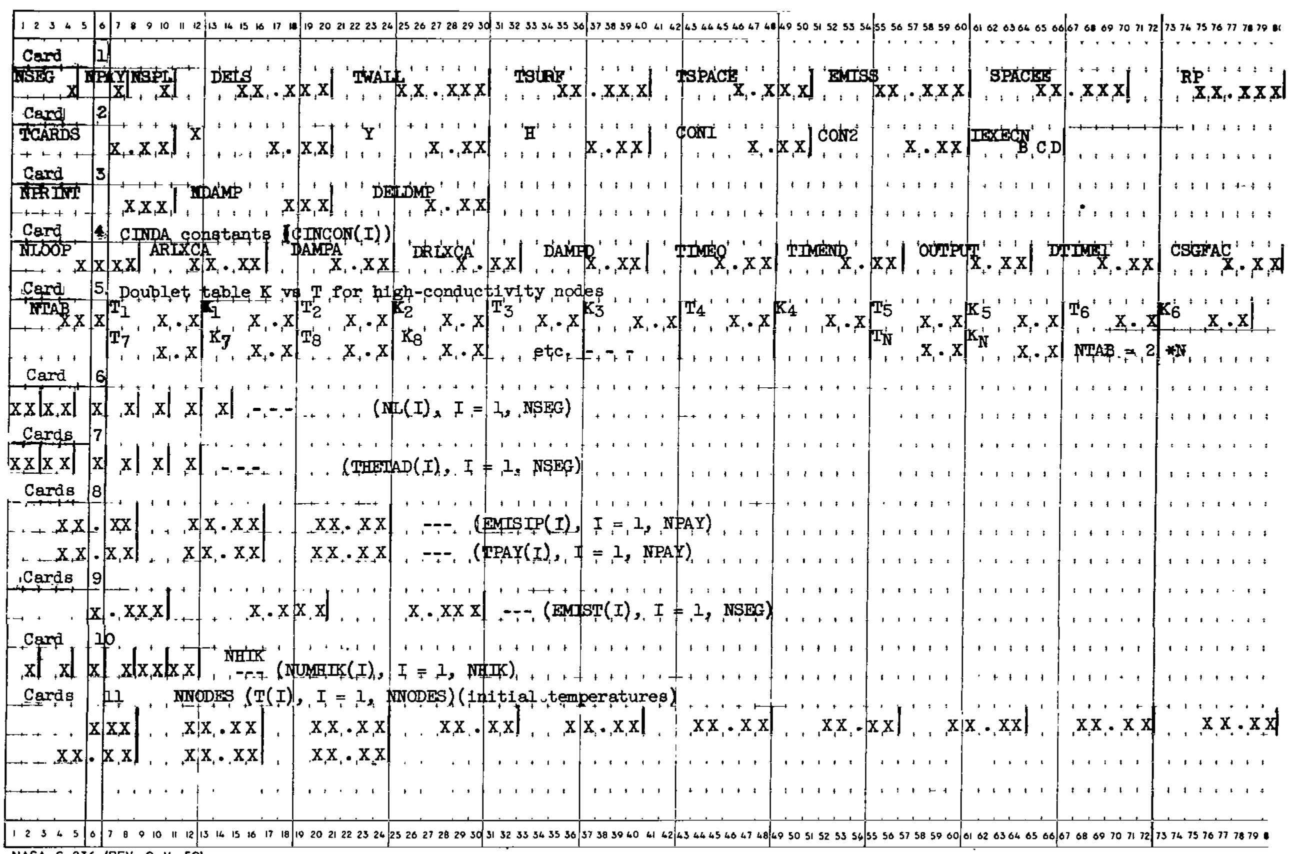
CARDS 8   ON TWO CARDS   (10F8.5)
EMISIP(I) EMISIVITY OF EACH PAYLOAD SEGMENT   (MAXIMUM 10)
TPAY(I)   TEMPERATURE OF EACH PAYLOAD SEGMENT   (MAXIMUM 10)

CARDS 9   EMIST EMISSIVITY OF EACH SURFACE, RADIATION   (8F10.5)

CARD 10   NHIK   NO. OF HIGH CONDUCTIVITY LAYERS   (30I2)
NUMHIK LAYER NUMBERS WHICH ARE HI COND.

CARDS 11 NNODES IF INITIAL TEMPS READ FROM CARDS - NO. OF NODES
T(I)   INITIAL TEMPERATURES, DEG. R   (I8,9F8.1/10F8.1)

Format of Input Data



APPENDIX F

INPUT DATA FOR SAMPLE PROBLEM

```
SHIELDING STUDY CONFIGURATION NO. 24
  10  5  5 .0016667    37.0      295.0       0.0        0.24       1.0         5.0
            4.571      3.233     0.8175     .000047    .0045      CINDSS
       125        2000    0.1
    9999  .0001   0.1
   104  37.  .8       40.  .873     45.  .913     50.  .970     55.  1.010    60.  1.045
        62. 1.055     64. 1.065     66. 1.0875    68. 1.105     70.  1.112    72.  1.114
        74. 1.116     75. 1.117     76. 1.116     78. 1.114     80.  1.112    82.  1.105
        84. 1.090     86. 1.085     88. 1.072     90. 1.062     95.  1.040   100.  1.012
       105.  .985    110.  .955    115.  .925    120.  .900    125.   .880   130.   .857
       135.  .837    140.  .819    145.  .800    150.  .785    155.   .770   160.   .757
       165.  .742    170.  .730    175.  .720    180.  .711    185.   .700   190.   .695
       195.  .687    200.  .683    205.  .675    210.  .672    215.   .668   220.   .665
       225.  .662    230.  .660    235.  .658    240.  .655
242220201717151311 8
2715 9 9 6 6 6 4 4 4
 .11        .11        .11        .11        .11
  520.0 520.0     520.0     520.0      520.0
 .024       .024         .024         .024         .024         .024         .900         .900
 .900       .900
 4 8111315
```

OUTPUT FOR SAMPLE PROBLEM

```
SHIELDING STUDY CONFIGURATION NO. 24
  ****************************************************               ****************
  *                                                  *               *              *
  * PAYLOAD NODES                                    *               * SPACE        *
  * NODE NOS       179       180       181       182       183 *     * NODE NO.  184 *
  *                                                  *               *              *
  * TEMPS=    520.00   520.00   520.00   520.00   520.00 *           * TEMP=     0.   *
  * EMISIV=   0.1100   0.1100   0.1100   0.1100   0.1100 *           * EMISIV 1.0000 *
  ****************************************************               ****************

ANGLE OF EACH
SEGMENT(DEG.)
             27.0     15.0      9.0      9.0      6.0      6.0      6.0      4.0      4.0      4.0

EMISIVITY OF
EACH SEGMENT
           0.0240   0.0240   0.0240   0.0240   0.0240   0.0240   0.9000   0.9000   0.9000   0.9000

TANK TO PAYLOAD SPACING= 0.8175 FT.
 LAYER
 NO.
        *********
    24  *    25 *
        * 340.27*
        *********
    23  *    24 *
        * 331.26*
        *****************
    22  *    23 *    48 *
        * 321.44* 317.63*
        *****************
    21  *    22 *    47 *
        * 310.72* 306.77*
```

Layer										
20	21	46	69	90						
	298.88	294.54	286.25	262.06						
19	20	45	68	89						
	285.58	280.90	272.16	252.90						
18	19	44	67	88						
	270.27	265.30	256.60	240.99						
17	18	43	66	87	108	126				
	252.02	246.77	238.48	225.46	215.58	195.77				
16	17	42	65	86	107	125				
	228.92	223.24	215.80	205.86	197.55	186.02				
15	-16	-41	-64	-85	-106	-124	-142			
	195.88	188.96	183.10	178.40	173.98	170.70	167.44			
14	15	40	63	84	105	123	141			
	176.08	170.70	166.28	162.63	159.38	156.82	154.65			
13	-14	-39	-62	-83	-104	-122	-140	-156		
	146.57	143.90	141.98	140.39	138.87	137.60	136.23	134.96		
12	13	38	61	82	103	121	139	155		
	131.96	130.02	128.59	127.33	126.17	125.16	124.16	123.49		
11	-12	-37	-60	-81	-102	-120	-138	-154	-168	
	110.36	109.60	108.99	108.42	107.84	107.29	106.67	106.05	105.40	
10	11	36	59	80	101	119	137	153	167	
	102.06	101.46	100.94	100.45	99.96	99.51	99.04	98.65	98.51	
9	10	35	58	79	100	118	136	152	166	
	91.32	90.88	90.47	90.09	89.72	89.38	89.04	88.79	88.72	
8	-9	-34	-57	-78	-99	-117	-135	-151	-165	-177
	74.74	74.55	74.37	74.18	73.98	73.76	73.51	73.20	73.00	72.81
7	8	33	56	77	98	116	134	150	164	176
	72.04	71.89	71.74	71.60	71.45	71.31	71.15	71.08	71.03	70.99
6	7	32	55	76	97	115	133	149	163	175
	69.13	69.02	68.91	68.80	68.69	68.65	68.60	68.57	68.54	68.53
5	6	31	54	75	96	114	132	148	162	174
	65.93	65.85	65.78	65.71	65.65	65.63	65.61	65.60	65.59	65.58
4	5	30	53	74	95	113	131	147	161	173
	62.27	62.22	62.18	62.14	62.11	62.10	62.09	62.08	62.08	62.08
3	4	29	52	73	94	112	130	146	160	172
	57.90	57.87	57.84	57.83	57.82	57.81	57.81	57.80	57.80	57.80
2	3	28	51	72	93	111	129	145	159	171
	52.30	52.28	52.27	52.26	52.26	52.26	52.25	52.25	52.25	52.25
1	2	27	50	71	92	110	128	144	158	170
	43.98	43.97	43.97	43.97	43.96	43.96	43.96	43.96	43.96	43.96
TANKWALL	1	26	49	70	91	109	127	143	157	169
SURFACE	37.00	37.00	37.00	37.00	37.00	37.00	37.00	37.00	37.00	37.00

TANKWALL
NODE NO.= 178
TEMP.= 37.00

SHIELDING STUDY CONFIGURATION NO. 24

NO. SEG	QTS	QNORM	QTS*8	QNORM*8
1	0.06936889	0.00018959	0.55495113	0.00151672
2	0.10318061	0.00029260	0.82544488	0.00234082
3	0.09149027	0.00025254	0.73192215	0.00202030
4	0.04330576	0.00032500	0.34644613	0.00260004
5	0.04622486	0.00023741	0.36979891	0.00189930
6	0.00980636	0.00027727	0.07845092	0.00221822
7	-0.20052147	0.00028314	-1.60417175	0.00226517
8	-0.09447652	0.00018922	-0.75581217	0.00151382
9	-0.04718843	0.00019050	-0.37750745	0.00152403
10	-0.01882567	0.00018001	-0.15060541	0.00144006
SUMMATION	0.23647E-02	0.24173E-02	0.18917E-01	0.19339E-01

APPENDIX G

FORTRAN LISTING OF AUTHOR-WRITTEN SUBROUTINES

```
$IBFTC PREPRE
      COMMON/BCD/ NBCD(60)
      COMMON /TAPE/NIN,NOUT,LCK2
      COMMON /RADIO/ NSEG,NPAY,NSURF,X,Y,H,RP,THIKN,PIE,SLAY(90),
     1 THETAD(30),A(41),AFA(1681)
      DIMENSION ID(14),BTA(31),ERAD(31),THETA(30),F(30),ITEST(50),NL(30)
      DIMENSION ARCLN(30),AREAL(30),NSNOD(30),NUMHIK(30),C(36)
      DIMENSION AKVST(200), EMIST(41), TPAY(10), EMISP(10)
       DIMENSION ISTMT(14), T(1545), CONNAM(10), CINCON(10)
      DIMENSION IFMT1(7), IFMT4(4), IFMTH(5)
      DIMENSION Z1(9),Z2(9),Z3(9),Z4(9),Z5(9),Z6(9),Z7(9),Z8(9)
      DIMENSION Z9(9),Z10(9),Z11(9)
      EQUIVALENCE (NNSEG,C),(NNPAY,C(2)),(NSURFS,C(3)),(MNODES,C(4)),
     X (MAXVL,C(5)),(NPRINT,C(6)),(NDAMP,C(7)),(NNL,C(8)),(NAREAL,C(9)),
     X (NAREAN,C(10)),(NARCLN,C(11)),(NTHETA,C(12)),(NITEST,C(13)),
     X (NKHIC,C(14)),(NEMISS,C(15)),(NAFA,C(16)),(NSNT,C(17)),
     X (SIGMA,C(21)),(DPTH,C(22)),(DELS,C(23)),(EMISS,C(24)),
     X (CON1,C(25)),(CON2,C(26)),(DELDMP,C(27)),
     X (TABS,C(29)),(HIKCON,C(30)),(PSWTCH,C(31)),(RAD,C(32))
     X ,(HH,C(33))
      DATA IFMT1(1)/ 42H(           I2/         F2.0/(10F8.5))     /
      DATA IFMTH(1)/ 30H(7X,17HBCD 3THERMA      ,56X )  /
      DATA CONNAM(1)/60H NLOOPARLXCA DAMPADRLXCA DAMPD TIMEOTIMENDOUTPUT
     1DTIMEICSGFAC  /
      DATA ISL,IWBK,IBACK,IVARB,ISPS,ILPS,IENDX
     1 /6HCINDSL,6HCNFWBK,6HCNBACK,6HCNVARB,6HL SPCS,6HL LPCS,6H ENDX /
      DATA M1, ONE, ONEM, TEN20, PI, TABS, SIGMA
     1 /1, 1.0, -1.0, 6H1.E+20, 3.14159265, 460.0, 0.173E-8 /
      DATA
     1 Z1(1)/ 54H NL, NO. OF LAYERS IN EACH SEGMENT                    /
     2,Z2(1)/ 54H AREAL, AREA, LATERAL CONDUCTION, EACH SEGMENT (HORIZ)/
     3,Z3(1)/ 54H A,  AREA, NORMAL CONDUCTION, EACH SEGMENT  (VERT)    /
     4,Z4(1)/ 54H ARCLN, ARC LENGTH, LENGTHS FOR LATERAL CONDUCTION    /
     5,Z5(1)/ 54H THETA (DEG.), ANGLE OF EACH SEGMENT                  /
     6,Z6(1)/ 54H ITEST, NEGATIVE NO. IS HI-COND. LAYER, LATERAL CONDCT/
     7,Z7(1)/ 54H AKVST, K(BTU/HR.FT) VS T(DEG R) FOR HI-K LAYERS      /
     8,Z8(1)/ 54H EMIST, EMMISIVITY OF SHIELD, RADIATION.              /
     9,Z9 (1)/54H AF, AREA*VIEWFACTOR FOR RADIOSITY, FOR EACH SEGMENT  /
     A,Z10(1)/54H TABLE OF SURFACE NODE NUMBERS, SURFACE EACH SEGMENT  /
      PIE=PI
      PIO4= PI/4.
      NIN= 5
      NOUT= 6
      LUT3=2
      LCK2=10
      LUT5= 11
      REWIND LCK2
      REWIND LUT3
      REWIND LUT5
      DO 12 I=1,10
   12 CINCON(I)=0.
C
C  WRITE EXECUTE, ID, IBJOB CARDS, THEN ALL CINDA3G PREPROCESSOR
```

```
C    CARDS ONTO TAPE SYSCK2 (9)
C
      WRITE(LCK2,2000)
C
C
C  READ PRE-PREPROCESSOR DATA AND GENERATE CINDA DATA
C
      I=1
    1 READ(NIN,2018) ISTMT
      WRITE(LUT3) ISTMT
      IF(ISTMT(2) .EQ. IENDX)  GO TO 7
      I= I+1
      GO TO 1
    7 NSTMTS= I
      REWIND LUT3
      READ(NIN,1000) ID
C
C  INPUT DATA DESCRIPTION
C CARD 1  FORMAT( I4, 2I3, 7F10.5)
C         NSEG    NO. OF SEGMENTS   (MAXIMUM 30)
C         NPAY    NO. OF SURFACES, (SEGMENTS) ON PAYLOAD  (MAXIMUM 10)
C         NSPL    NO. OF SHIELDS PER LAYER
C         DELS    THICKNESS OF EACH (SHIELD+SPACER)    FT.
C         TWALL   TEMPERATURE OF TANKWALL    DEG.R
C         TSURF   TEMPERATURE OF TOP SURFACE OF SHIELD   DEG.R
C         TSPACE  TEMPERATURE OF SPACE                   DEG.R
C         EMISS   EMISIVITY USED IN EQUATION FOR K(EFF),
C                    CONDUCTION IN NORMAL DIRECTION
C         SPACEE  EMISIVITY OF SPACE
C         RP      RADIUS OF PAYLOAD    FT.
C
C CARD 2  FORMAT( 6F10.5, A6)
C         TCARDS  SWITCH- TO READ INITIAL TEMPERATURES
C                 IF TCARDS =0, CARDS WILL NOT BE READ. THE PROGRAM
C                 USES TWALL AND TSURF AND DISTRIBUTES THE TEMPERATURES
C                 BETWEEN THESE TWO VALUES AS THE INITIAL TEMPERATURE
C                 DISTRIBUTION.
C                 IF TCARDS .GT. 0 THE INITIAL TEMPERATURE DISTRIBUTION
C                 IS READ FROM CARDS, (DEG. R). SEE CARDS 11 BELOW.
C         X       LENGTH OF SEMI-AXIS OF ELIPSE, (TANKWALL),ALONG X AXIS
C         Y       LENGTH OF SEMI-AXIS OF ELIPSE, (TANKWALL),ALONG Y AXIS
C         H       TANK TO PAYLOAD SPACING    FT.
C         CON1    CONSTANTS USED FOR STRAIGHT LINE CURVE FIT TO COMPUTE
C         CON2    THERMAL CONDUCTIVITY FOR G VALUES FOR LATERAL
C                 CONDUCTION OF STANDARD NODES. K=CON1*T+CON2.
C         IEXECN  NAME OF EXECUTION ROUTINE     CINDSS OR CINDSL
C CARD 3  FORMAT( 2I10, F10.5)
C        NPRINT   DELTA PRINT, PRINT TEMP. DIST. EVERY NPRINT ITERATIONS
C        NDAMP    CHANG DAMPING FACTOR EVERY NDAMP ITERATIONS
C         DELDMP  DELTA TO ADD TO DAMPING FACTOR
C
C  CARD 4 FORMAT(I8,9F8.3)
C         CINCON(I)  CINDA CONTROL CONSTANTS, AS REQUIRED BY EXECUTION
C                       ROUTINE BEING USED. CONSTANTS INPUT IN ORDER AS
C                       FOLLOWS ACCORDING TO FORMAT GIVEN ABOVE,
C                       NLOOP, ARLXCA, DAMPA, DRLXCA, DAMPD, TIMEO,
C                       TIMEND, OUTPUT, DTIMEI, CSGFAC.
C
C  CARDS 5 NTAB, (AKVST(I),I=1,NTAB)        FORMAT(I6,12F6.1/(6X,12F6.1))
C                 TABLE OF TEMPERATURE VS. THERMAL CONDUCTIVITY FOR
C                 LATERAL CONDUCTION OF HIGH CONDUCTIVITY LAYERS.
C                 NTAB= TOTAL NO. OF ENTRIES IN TABLE (TEMPS AND K'S)
```

```
C        DATA FORM   NTAB TEMP1     K1 TEMP2    K2 ---  TEMPN  KN
C                  UNITS-- K BTU/HR-FT-DEG.R
C                           T DEG.R
C
C  CARDS 6 NL     NUMBER OF LAYERS IN EACH SEGMENT FORMAT ( NI2)
C
C  CARDS 7 THETAD   ANGLE OF EACH SEGMENT, IN DEGREES, IF ALL SEGMENTS
C                    ARE EQUAL INPUT ONLY THE FIRST.    FORMAT (N I2)
C                    THE SUM OF THE N ANGLES MUST EQUAL 90
C
C  CARDS 8  ON TWO CARDS  (10F8.5)
C           EMISIP(I) EMISIVITY OF EACH PAYLOAD SEGMENT    (MAXIMUM 10)
C           TPAY(I)   TEMPERATURE OF EACH PAYLOAD SEGMENT  (MAXIMUM 10)
C
C  CARDS 9  EMIST EMISSIVITY OF EACH SURFACE, RADIATION  (8F10.5)
C
C  CARD 10  NHIK  NO. OF HIGH CONDUCTIVITY LAYERS       (30I2)
C           NUMHIK LAYER NUMBERS WHICH ARE HI COND.
C
C  CARDS 11 NNODES IF INITIAL TEMPS READ FROM CARDS - NO. OF NODES
C        T(I)  INITIAL TEMPERATURES,  DEG. R    (I8,9F8.1/10F8.1)
C
      READ(NIN,1001) NSEG,NPAY,NSPL,DELS,TWALL,TSURF,TSPACE,EMISS,
     1 SPACEE,RP,TCARDS,X,Y,H,CON1,CON2,IEXECN,NPRINT,NDAMP,
     2 DELDMP,CINCON
       DPTH=DELS*FLOAT(NSPL)
      THIKN= DPTH
      HH=H .
      NNSEG=NSEG
      NNPAY= NPAY
      TNODE=0.0
      READ(5,1003) NTAB, (AKVST(I),I=1,NTAB)
      HIKCON=AKVST(NTAB)
      IF(NSEG.GT.30) NSEG=30
      IFMT1(2)= NBCD(NSEG)
      IFMT1(4)= NBCD(NSEG)
      READ(NIN,IFMT1) (NL(I),I=1,NSEG),(THETAD(I),I=1,NSEG),EMISP,TPAY
      READ(NIN,1004) (EMIST(I),I=1,NSEG)
      READ(NIN,1002) NHIK,(NUMHIK(I),I=1,NHIK)
      NSURF= NSEG + NPAY + 1
      NSURFS=NSURF
      NOFA= (NSURF*(NSURF+1)/2)+2
      J=NSEG+1
      MAXNL=0
      DO 201 I=1,NSEG
  201 IF(NL(I) .GT. MAXNL) MAXNL=NL(I)
      DO 200 I=J,NSURF
      M=I-J+1
  200 EMIST(I)= EMISP(M)
      EMIST(NSURF)=SPACEE
      DO 2 I=1,50
    2 ITEST(I)= I
      IF(NHIK .LE. 0) GO TO 4
      DO 3 I=1,NHIK
      M= NUMHIK(I)
    3 ITEST(M)= -ITEST(M)
    4 CONTINUE
      IFMTH(4)=ISPS
      IF(IEXECN .EQ. ISL .OR. IEXECN .EQ. IWBK .OR. IEXECN .EQ. IBACK
     1 .OR. IEXECN .EQ. IVARB) IFMTH(4)=ILPS
      IF(THETAD(2) .GT. 0.) GO TO 5
      DO 6  I=2,NSEG
    6 THETAD(I)= THETAD(1)
```

```
    5 BTA(1)= 0.
      DO 9  I=2,NSEG
    9 BTA(I)= BTA(I-1) + THETAD(I-1)
      BTA(NSEG+1)=90.0
      WRITE(LCK2,IFMTH)
      WRITE(LCK2,2001) ID
      NSEGP1= NSEG+1
 7001 NNL= 1
 7002 NAREAL= NSEG+2
 7003 NAREAN= NAREAL+NSEGP1
 7004 NARCLN=NAREAN+NSURF+1
 7005 NTHETA= NARCLN+NSEGP1
 7006 NITEST=NTHETA+NSEGP1
 7007 NKHIC= NITEST+51
 7008 NEMISS= NKHIC+NTAB+1
 7009 NAFA=NEMISS+NSURF+1
 7010 NSNT=NAFA+NOFA+1
C
C  GENERATE NODE DATA
C      NODE NO. FOR SPACE IS     NNODES
C       NODE NO. FOR FIRST PAYLOAD NODE IS  (NNODES-NPAY)
C       NODE NO. FOR TANKWALL IS  (NNODES-NPAY-1)
C
C  SHIELD NODES
C
      WRITE(LCK2,2032)
  101 NNODES=0
C
C  GENERATE INTERIOR NODES
C
      DO 10 I=1,NSEG
   10 NNODES= NNODES + NL(I)
      NINSN=NNODES
C
C  ADD NO. OF SURFACE NODES TO NNODES, SURF NODES ONLY ALONG TANKWALL
C
      NNODES=NNODES+NSEG
      TEMP= TNODE
      WRITE(LCK2,2003)M1  ,NNODES,M1  ,TEMP,ONE,ONE,ONE,ONEM
C
C  TANKWALL NODE
C
      NNODES= -NNODES-1
      TEMP= TWALL
      WRITE(LCK2,2004) NNODES,TEMP,ONE
C
C  PAYLOAD NODES  (BOUNDARY NODES)
C
      DO 105 I=1,NPAY
      NNODES=NNODES-1
      TEMP=TPAY(I)
      WRITE(LCK2,2004) NNODES,TEMP,ONE
  105 CONTINUE
C
C  NODE FOR SPACE   (BOUNDARY NODE)
C
      NNODES = NNODES-1
      TEMP= TSPACE
      WRITE(LCK2,2004) NNODES,TEMP,ONE
  104 WRITE(LCK2,2007)
      NNODES= IABS(NNODES)
      IF(TCARDS .EQ. 0.) GO TO 115
```

```
      READ(NIN,1005) NNSPCH,(T(I),I=1,NNSPCH)
      GO TO 110
  115 CONTINUE
      N=0
      IF(TSURF) 207,207,208
C
C  CONSTANT INITIAL TEMPS
C
  207 TS=ABS(TSURF)
      DELT=0.0
      GO TO 205
C
C  DISTRIBUTE TEMPS BETWEEN TWALL AND TSURF
C
  208 DELT=(TSURF-TWALL)/FLOAT(MAXNL)
      TS=TWALL
  205 DO210 I=1,NSEG
      NLAY=NL(I)+1
      N=N+1
      T(N)=TS
      DO211 J=2,NLAY
      N=N+1
      T(N)=T(N-1) +DELT
  211 CONTINUE
  210 CONTINUE
      DO 212 I=1,N
  212 T(I)=T(I)-TABS
  110 T(NNODES)=TSPACE -TABS
      M=NNODES-NPAY-1
      DO 213 I=1,NPAY
      J=M+I
  213 T(J)=TPAY(I)-TABS
      T(M)=TWALL-TABS
      WRITE(LUT5) (T(I),I=1,NNODES)
C
C  COMPUTE AREAS FOR LATERAL (HORIZ), AND NORMAL (VERT), CONDUCTORS
C  PUT AREAS INTO ARRAYS  AREAL, AND AREAN AND OUTPUT IN ARRAY DATA AS
C  ARRAY 2 AND ARRAY 3 RESPECTIVELY.
C  ARRAY ARCLN, LENGTHS OF NODES, IS ARRAY 4.
C
   80 CONTINUE
      ASQ=X*X
      BSQ=Y*Y
      ASQBSQ= ASQ*BSQ
      ERAD(1)=Y
      K=0
      DO 20 I=1,NSEG
      ANG1= BTA(I)
      ANG2= BTA(I+1)
      THETA(I)= THETAD(I)*0.01745329
      M= THETAD(I)
      DLAY=NL(I)
      DO 81 L=1,M
      K=K+1
   81 SLAY(K)=DLAY
      ANG2= ANG2*0.01745329
      SINAL= SIN(ANG2)
      COSAL= COS(ANG2)
      SSQ= SINAL**2
      CSQ= COSAL**2
      ERAD(I+1)= SQRT(ASQBSQ / (BSQ*SSQ + ASQ*CSQ) )
      DMLI= DPTH*FLOAT(NL(I))
      R1= ERAD(I)+DMLI
      R2= ERAD(I+1)+DMLI
```

```
      RAD= (R1+R2)/2.
      ARCLN(I)= RAD*THETA(I)
      SMALLR= R2* SINAL
      ENDW= SMALLR* PI04
      AREAL(I)= ENDW • DPTH
   20 CONTINUE
      CALL VIEWF
C
C  GENERATE CONDUCTOR DATA ,  ALL CONDUCTANCE VALUES WILL BE COMPUTED
C                             IN VARIABLES 1 (THEREFORE 1.0 WILL BE USED
C                             IN THIS ROUTINE FOR C.)
C
      WRITE(LCK2,2005)
C  NORMAL CONDUCTORS IN SHIELD
C
      NODA=1
      NCOND=1
      DO 11 I=1,NSEG
      NLAY=NL(I)
      NODB=NODA+1
      WRITE(LCK2,2006)NCOND,NLAY,M1,NODA,M1,NODB,M1,ONE,ONE,ONE,ONE
      NODA=NODA+NLAY+1
   11 NCOND=NCOND+NLAY
C
C  LATERAL CONDUCTORS IN SHIELD
C
      NODA=2
      DO 15 I=2,NSEG
      NLAY=NL(I)
      NLM1P2=NL(I-1)+1
      NODB=NODA+NLM1P2
      WRITE(LCK2,2006)NCOND,NLAY,M1,NODA,M1,NODB,M1,ONE,ONE,ONE,ONE
      NODA=NODB
   15 NCOND=NCOND+NLAY
C
C  CONDUCTORS FROM EDGE OF SHIELD TO TANKWALL
C
      NODA=0
      NODB=NNODES-NPAY-1
      NCOND=NCOND-1
  144 DO 14 I=1,NSEG
      NODA=NODA+1
      NCOND=NCOND+1
      WRITE(LCK2,2026) NCOND,NODA,NODB,TEN20
   14 NODA= NODA+NL(I)
C
C  COMPUTE TABLE OF SURFACE NODE NUMBERS
C
      NODA=0
      DO 16 I=1,NSEG
      NODA= NODA+NL(I)+1
      NSNOD(I)= NODA
   16 CONTINUE
      J=NSEG+1
      JJ=NNODES-NPAY-J
      DO 162 I=J,NSURF
  162 NSNOD(I)=JJ+I
      WRITE(LCK2,2007)
C
C  GENERATE CONSTANTS DATA
C
      WRITE(LCK2,2008) (I,C(I),I=1,20)
```

```
      WRITE(LCK2,2024) (I,C(I),I=21,28)
      WRITE(LCK2,2010) (I,C(I),I=29,36)
      WRITE(LCK2,2022) (CONNAM(I),CINCON(I),I=1,10)
      WRITE(LCK2,2007)
C
C  GENERATE ARRAY DATA BLOCK
C              TO OUTPUT ARRAY CALL SUBROUTINE RITARY(N,A,NO,NF,ZN)
C                    WHERE     N=ARRAY NUMBER
C                              A=ARRAY TO BE PUT OUT
C                              NO= NUMBER OF ELEMENTS IN THE ARRAY
C                              NF= EITHER 1 OR 2   NF=1 IF ARRAY IS FLOATI
C                                                  NF=2 IF ARRAY IS INTEGE
C                              ZN=BCD ARRAY WHICH BECOMES A TITLE FOR
C                                 ARRAY N.
C
      WRITE(LCK2,2009)
      CALL RITARY(1,NL,NSEG,2,Z1)
      CALL RITARY(2,AREAL,NSEG,1,Z2)
      CALL RITARY(3,A,NSURF,1,Z3)
      CALL RITARY(4,ARCLN,NSEG,1,Z4)
      CALL RITARY(5,THETAD,NSEG,1,Z5)
      CALL RITARY(6,ITEST, 50 ,2,Z6)
      CALL RITARY(7,AKVST,NTAB,1,Z7)
      CALL RITARY(8,EMIST,NSURF,1,Z8)
      CALL RITARY (9,AFA,NOFA,1,Z9)
      CALL RITARY(10,NSNOD,NSURF,2,Z10)
      WRITE(LCK2,2007)
C
C  GENERATE EXECUTION BLOCK
C
      WRITE (LCK2,2012)
      WRITE(LCK2,2020)
      WRITE(LCK2,2033) IEXECN
      WRITE(LCK2,2007)
C
C  GENERATE VARIABLES 1 BLOCK
C
      WRITE(LCK2,2015)
      WRITE(LCK2,2007)
C
C  GENERATE VARIABLES 2 BLOCK
C
      WRITE(LCK2,2014)
      WRITE(LCK2,2031)
      WRITE(LCK2,2007)
C
C  GENERATE OUTPUT CALLS
C
      WRITE(LCK2,2016)
      WRITE(LCK2,2029)
      WRITE(LCK2,2028)
      WRITE(LCK2,2025)
      WRITE(LCK2,2030)
      WRITE(LCK2,2007)
C
C  WRITE SUPPLIED SUBROUTINES ONTO TAPE LCK2
C
      WRITE(LCK2,2017)
      DO 60 I=1,NSTMTS
      READ(LUT3) ISTMT
   60 WRITE(LCK2,2018) ISTMT
      WRITE(LCK2,2019)
      REWIND 2
```

```
C
C  WRITE SWITCH SYSIN1 TO SYSUT6, TO READ CINDA DATA BY CINDA
C
      END FILE LCK2
      WRITE(LCK2,2021)
      END FILE LCK2
      END FILE LCK2
      END FILE LCK2
      REWIND LCK2
      WRITE(NOUT,5000)
 5000 FORMAT(51H   END OF PREPRE PGM. NOW SWITCHTO INPUT FOR PREPRO)
      WRITE(6,5001) NSTMTS
 5001 FORMAT(45H   NO. OF STATEMENTS IN SUBROUTINES LOADED =    I5)
      CALL EXIT
      READ(NIN,1000) ID
 1000 FORMAT(13A6,A2)
 1001 FORMAT(I4,2I3,7F10.5/6F10.5,A6/2I10,F10.5/I8,9F8.3)
 1002 FORMAT(30I2)
 1003 FORMAT(I6,12F6.1/(6X,12F6.1))
 1004 FORMAT(8F10.5)
 1005 FORMAT(I8,9F8.1/(10F8.1))
 2000 FORMAT(20H$EXECUTE        IBJOB, 64X /
     1 34H$ID   COWGILL                PREPRO, 50X/ 6H$IBJOB ,78X /
     2 27H$IEDIT          SYSCK1,SCHF2 ,57X / 13H$IBLDR PREPRO ,71X /
     2 13H$IBLDR TAPDEF,71X/ 13H$IBLDR FVIO. ,71X/
     3 27H$ORIGIN         ALPHA,SYSLB2 ,57X / 13H$IBLDR GENLNK ,71X /
     4 27H$ORIGIN         ALPHA,SYSLB2 ,57X / 13H$IBLDR PSEUDO ,71X /
     5 13H$IBLDR PACK43 , 71X / 13H$IBLDR ORMIN , 71X /
     6 27H$ORIGIN         ALPHA,SYSLB2 ,57X /
     7 13H$IBLDR CODERD , 71X / 13H$IBLDR DATARD , 71X /
     8 27H$ORIGIN         ALPHA,SYSLB2 ,57X / 13H$IBLDR PRESUB ,71X /
     9 13H$IBLDR CINDA4 , 71X / 13H$IBLDR SEARCH, 71X /
     A 27H$ORIGIN         ALPHA,SYSLB2 ,57X / 13H$IBLDR COPYSB, 71X /
     B 13H$IBLDR LOCATE , 71X / 13H$IBLDR FIBLDR , 71X /
     C 13H$IBLDR READTP , 71X / 13H$IBLDR CIN90  , 71X /
     D 27H$ORIGIN         ALPHA,SYSLB2 ,57X / 13H$IBLDR INITAL , 71X /
     E 27H$ORIGIN         ALPHA,SYSLB2 ,57X / 13H$IBLDR FINAL  , 71X /
     F 27H$ORIGIN         ALPHA,SYSLB2 ,57X /
     G 13H$IBLDR SKIP   , 71X / 13H$IBLDR SPLIT , 71X /
     H  5H$DATA , 79X / 80X )
 2001 FORMAT(7X,5HBCD 9,9A6,14X/7X,5HBCD 5,5A6,38X/7X,3HEND,70X )
 2003 FORMAT(
     1 7X,4HGEN ,I1,1H,,I4,1H,,I1,1H,,F7.2,1H,,F3.1,1H,,F3.1,1H,,F3.1,
     2 1H,,F4.1,36X)
 2004 FORMAT(11X,I5,1H,,F6.1,1H,,F4.1,52X)
 2005 FORMAT(7X,19HBCD 3CONDUCTOR DATA ,54X)
 2006 FORMAT(7X,4HGEN ,7(I4,1H,),3(F3.1,1H,),F3.1,19X)
 2007 FORMAT(7X,3HEND,70X)
 2008 FORMAT(7X,19HBCD 3CONSTANTS DATA,54X /
     1 (11X,4(I3,1H,,I5,1H,,),I3,1H,,I5,20X))
 2009 FORMAT(7X,15HBCD 3ARRAY DATA,58X)
 2010 FORMAT((11X,3(I2,1H,,F13.5,1H,,),I2,1H,,F13.5,2X))
 2012 FORMAT(7X,14HBCD 3EXECUTION,59X/23HF      DIMENSION X(3000),57X /
     1 15HF      NDIM=3000,65X / 12HF      NTH=0,68X   )
 2014 FORMAT(7X,16HBCD 3VARIABLES 2,57X)
 2015 FORMAT(7X,16HBCD 3VARIABLES 1, 57X /15HF      CALL GETG,65X)
 2016 FORMAT(7X,17HBCD 3OUTPUT CALLS,56X)
 2017 FORMAT(7X,16HBCD 3SUBROUTINES ,57X )
 2018 FORMAT(13A6,A2)
 2019 FORMAT(7X,16HBCD 3END OF DATA ,57X)
 2020 FORMAT(11HF      NN=10,69X/22HF      IF(NN.GT.0)GOTO3,58X /
     1 11X,24HLAGRAN(RTEST,STEST,A7,7) ,45X/
```

```
     2 11X,22HIRRADI(A3,A8,A9,STEST)  ,47X          /
     2 14HF    3 CONTINUE,66X /
     2 16HF      CALL TDIST,64X)
 2021 FORMAT(6H$IBSYS,74X/21H$REWIND          SYSLB3,59X/
     1 21H$REWIND          SYSUT6,59X/28H$SWITCH          SYSIN1,SYSLB3,52X/
     2  28H$SWITCH          SYSIN1,SYSCK2,52X)
 2022 FORMAT(11X,A6,1H,,I4,3(1H,,A6,1H,,F9.6),7X /
     1 11X,A6,1H,,F9.6,3(1H,,A6,1H,,F9.4),2X /
     2 11X,A5,1H,,F9.6,1H,,A6,1H,,F9.6,36X)
 2023 FORMAT(12X,3HEND,65X)
 2024 FORMAT((11X,3(I2,1H,,1PE13.6,1H,,),I2,1H,,1PE13.6,2X))
 2025 FORMAT(26HF      WRITE(6,1000) LOOPCT,54X /
     1   28HF1000 FORMAT(9HL LOOPCT= I6),52X)
 2026 FORMAT(11X,3(I5,1H,),3X,A6,42X)
 2027 FORMAT(11X,3(I5,1H,),E16.8,35X)
 2028 FORMAT(11X,6HPRNTMP,63X)
 2029 FORMAT(13HF      NN=K(4),67X/
     1    18HF      DO 10 I=1,NN, 62X /
     2    22HF   10 T(I)=T(I)+460.0 ,58X)
 2030 FORMAT(18HF      DO 11 I=1,NN,62X/
     2    22HF   11 T(I)=T(I)-460.0 ,58X)
 2031 FORMAT(17HF      CALL ENDOUT,63X)
 2032 FORMAT(7X,14HBCD 3NODE DATA,59X)
 2033 FORMAT(11X,A6,63X)
      END
```

```
$IBFTC VIEWFC

      SUBROUTINE VIEWF
C RADIATION VIEW FACTOR BETWEEN FLAT SURFACED PAYLOAD AND SPHEROIDAL
C TANK WITH VARYING MLI THICKNESS.
C INPUT REQUIRED
C        SLAY - NO. OF NODES IN EACH 1 DEGREE SEGMENT
C        RP   - PAYLOAD RADIUS
C        X AND Y - MAJOR AND MINOR RADII OF TANK (WITHOUT COVERING)
C        NSEG - NO. OF SEGMENTS ON TANK
C        NPAY - NO. OF RINGS ON PAYLOAD
C        NSURF- TOTAL NO. OF SURFACES IN RADIATION ENCLOSURE
C        H    - TANK TO PAYLOAD SPACING
      COMMON /RADIO/ NSEG,NPAY,NSURF,X,Y,H,RP,THIKN,PI,SLAY,THETA,A,AFA
      COMMON /TAPE/ NIN,NOUT,LCK2
      DIMENSION SLAY(90),A(41),AFA(1681),THETA(30)
      DIMENSION SAREA(90),DAREA(90),SEGA(100),DF(600),F(600),R(10)
      DIMENSION SAF(90,100),AF(41,41),RVF(41,41)
      DATA W1,W2,W3,W4,W5,W6,EY1,EY2     /6H     A,6H     R,6H DAREA,
     1 6H  SEGA,6H   RFV,6H    AF,6H(I)    ,6H(I,J)    /
      TOPI=2.*PI
      ONED= PI/180.
      HALFD=ONED/2.
      RPSQ=RP*RP
      N=10.*RP
      PSI=-HALFD
      DO 28 K=1,90
      PSI=PSI+ONED
   10 DMLI= SLAY(K)*THIKN
      AX=X+DMLI
      BX=Y+DMLI
      AXSQ=AX*AX
```

```
      BXSQ=BX*BX
      SPSI=SIN(PSI)
      CPSI=COS(PSI)
      SSQ=SPSI*SPSI
      CSQ=CPSI*CPSI
      AXBX=AX*BX
      R1= AXBX*SQRT(1./(BXSQ*SSQ+AXSQ*CSQ))
      Y1=R1*SPSI
      Z1=R1*CPSI
      DH=BX-Z1
      XM1=(AXSQ*Z1)/(BXSQ*Y1)
      WSQ=(AXSQ-BXSQ)/BXSQ/BXSQ
      W=SQRT(WSQ)
      HOW=0.5/W
      SRQB=SQRT(1.+WSQ*BXSQ)
      RJ=BX/2.*SRQB
      S=  HOW*ALOG(BX*W+SRQB)
      UPLIM=RJ+S
      PSIX=PSI+HALFD
      SPX=SIN(PSIX)
      CPX=COS(PSIX)
      SPXSQ=SPX*SPX
      CPXSQ=CPX*CPX
      R1X= AXBX*SQRT(1./(BXSQ*SPXSQ+AXSQ*CPXSQ))
      Z1X=R1X*CPX
      SRQZX=SQRT(WSQ*Z1X**2+1.)
      T=Z1X/2.*SRQZX
      U= HOW*ALOG(Z1X*W+SRQZX)
      BOTLIM= T+U
      SAREA(K)=TOPI*AX*(UPLIM-BOTLIM)
      IF(K.EQ.1) GO TO 12
      DAREA(K)=SAREA(K)-SAREA(K-1)
      GO TO 14
   12 DAREA(K)=SAREA(K)
   14 DO 28 I=1,N
      RING=I
      RHO=.1*(RING-.5)
      SIXRNG=6.*RING
      SEGA(I)=PI*((.1*RING)**2-(.1*(RING-1.))**2)/SIXRNG
      NSGT=6*I
      GAMA=0.
      DO 24 J=1,NSGT
      IF(J.EQ.1) GO TO 16
      GAMA=GAMA+(TOPI/SIXRNG)
   16 X2=RHO*COS(GAMA)
      Y2=RHO*SIN(GAMA)
      XA= X2
      YB= Y2-Y1
      ZC= H-DMLI+DH
      RV=SQRT(XA**2+YB**2+ZC**2)
      SM= SQRT(1.+XM1**2)
      COSP1= (YB+XM1*ZC)/(RV*SM)
      COSP2= ZC/RV
      IF(COSP1.LE.0.)  GO TO 18
      DF(J)=(COSP1*COSP2*SEGA(I))/(PI*RV*RV)
       GO TO 20
   18 DF(J)=0.
   20 IF(J.EQ.1) GO TO 22
      F(J)=DF(J)+F(J-1)
      GO TO 24
   22 F(J)=DF(J)
   24 CONTINUE
      SAF(K,I)=DAREA(K)*F(NSGT)
```

```
 28 CONTINUE
    XNPAY=NPAY
    DO 30 II=1,NPAY
    XI=II
    RR=SQRT((RPSQ*XI)/XNPAY)
    NDELR=10.*RR
    XNDELR=NDELR
    R(II)=.1*XNDELR
    JJ=II+NSEG
    IF(II.EQ.1) GO TO 29
    A(JJ)= PI*(R(II)**2-R(II-1)**2)
    GO TO 30
 29 A(JJ)=PI*R(II)**2
 30 CONTINUE
    DO 304 KK=1,NSEG
    IF(KK.EQ.1) GO TO 301
    NDEG1=NDEG2+1
    NDEG=THETA(KK)
    NDEG2=NDEG1+NDEG-1
    GO TO 302
301 NDEG1=1
    NDEG2=THETA(KK)
302 ASUM=0.
    DO 303 K=NDEG1,NDEG2
    ASUM=ASUM+DAREA(K)
303 CONTINUE
    A(KK)=ASUM
304 CONTINUE
    A(NSURF)= 122.211
    DO 40 KK=1,NSEG
    IF(KK.EQ.1) GO TO 32
    NDEG1=NDEG2+1
    NDEG=THETA(KK)
    NDEG2=NDEG1+NDEG-1
    GO TO 34
 32 NDEG1=1
    NDEG2=THETA(KK)
 34 DO 40 II=1,NPAY
    IF(II.EQ.1) GO TO 36
    NDR1=NDR2+1
    NDR2=10.*R(II)
    GO TO 37
 36 NDR1=1
    NDR2=10.*R(II)
 37 SUM=0.
    DO 38 K=NDEG1,NDEG2
    DO 38 I=NDR1,NDR2
    SUM=SUM+SAF(K,I)
 38 CONTINUE
    JJ=II+NSEG
    AF(KK,JJ)=SUM
 40 CONTINUE
    DO 42 I=1,NSEG
    DO 42 J=I,NSEG
 42 AF(I,J)=0.
    NS1=NSEG+1
    NS2=NSURF-1
    DO 44 I=NS1,NS2
    DO 44 J=I,NS2
 44 AF(I,J)=0.
    AF(NSURF,NSURF)=0.
    DO 48 I=1,NSEG
    SUM=0
```

```
      DO 46 K=NS1,NS2
   46 SUM=SUM+AF(I,K)
   48 AF(I,NSURF)=A(I)-SUM
      DO 52 I=NS1,NS2
      SUM=0
      DO 50 K=1,NSEG
   50 SUM=SUM+AF(K,I)
   52 AF(I,NSURF)=A(I)-SUM
      DO 60 KK=1,NSEG
      DO 60 JJ=NS1,NSURF
   60 RVF(KK,JJ)=AF(KK,JJ)/A(KK)
      AFA(1)=0.0
      AFA(2)=0.0
      I=2
      DO 100 KK=1,NSURF
      DO 100 JJ=KK,NSURF
      I= I+1
  100 AFA(I)= AF(KK,JJ)
      Z1=W1
      Z2=EY1
      WRITE(NOUT,1001) Z1,Z2,(A(I),I=1,NSURF)
      Z1=W2
      WRITE(NOUT,1001) Z1,Z2,(R(I),I=1,NPAY)
      Z1=W3
      WRITE(NOUT,1001) Z1,Z2,(DAREA(I),I=1,90)
      Z1=W4
      WRITE(NOUT,1001) Z1,Z2,(SEGA(I),I=1,N)
      Z1=W5
      Z2=EY2
      WRITE(NOUT,1001) Z1,Z2
      DO 200 KK=1,NSEG
      WRITE(NOUT,1002) (RVF(KK,JJ),JJ=NS1,NSURF)
  200 CONTINUE
      Z1=W6
      WRITE(NOUT,1001) Z1,Z2
      DO1100 KK=1,NSURF
      WRITE(NOUT,1002) (AF(KK,JJ),JJ=KK,NSURF)
 1100 CONTINUE
      RETURN
 1001 FORMAT(1HK,2A6/(1X,1P10E13.5))
 1002 FORMAT(1X,1P10E13.5)
      END
```

```
$IBFTC RAYOUT

      SUBROUTINE RITARY(NA,A,N,J,HEAD)
      DIMENSION A(1), IFMT1(5), IFMT2(7)
      DIMENSION HEAD(9)
      COMMON/BCD/ NBCD(60)
      COMMON /TAPE/ NIN,NOUT,LCK2
      DATA IFMT1(1) /30H(12X,4      ,1H,),       4X)      /
      DATA IFMT2(1) /42H(12X,                                X)      /
      DATA IFLOT1 ,    IFLOT2 ,    IFLOT3
     1 / 6H(F12.7 , 6HF12.7, , 6H,1H,),      /
      DATA IFIX1  ,    IFIX2  ,    IBLANK
     1 / 6H (I12  , 6H I12,  , 6H            /
      DATA IE1  ,    IE2
```

```
      1 /  6H(E12.5   ,   6HE12.5,    /
       NSEG= N
       JJ= J
       IFMT2(3)= IBLANK
       IFMT2(4)= IBLANK
       ITEM2= IFLOT3
       GO TO (10,11,12),JJ
    12 IFMT1(2)=IE1
       IFMT1(4)=IE2
       IFMT2(5)=IE2
       ITEM1=IE1
       GO TO 21
    10 IFMT1(2)= IFLOT1
       IFMT1(4)= IFLOT2
       IFMT2(5)= IFLOT2
       ITEM1= IFLOT1
       GO TO 21
    11 IFMT1(2)= IFIX1
       IFMT1(4)= IFIX2
       IFMT2(5)= IFIX2
       ITEM1= IFIX1
    21 N1= 1
       N2= 5
       WRITE(LCK2,2011) NA,(HEAD(I),I=1,9)
    31 IF (N2 .GE. NSEG) GO TO 40
       WRITE (LCK2,IFMT1) (A(I),I=N1,N2)
       N1= N1+5
       N2= N2+5
       GO TO 31
    40 NN= NSEG-N1
       N2= NSEG
       IF(NN .LE. 0) GO TO 39
       IFMT2(3)= ITEM1
       IFMT2(4)= ITEM2
       IFMT2(2)= NBCD(NN)
       NBL= 56-13*NN
    42 IFMT2(6)= NBCD(NBL)
       WRITE(LCK2,IFMT2) (A(I),I=N1,N2)
       WRITE (LCK2,2013)
       RETURN
    39 NN=1
       IFMT2(2)=NBCD(NN)
       NBL=56
       GO TO 42
  2011 FORMAT(11X,I2,3H  $,9A6,10X)
  2013 FORMAT(12X,3HEND,65X)
       END
```

```
$IBFTC COMDAT

       BLOCK DATA
       COMMON /BCD/ NBCD(60)
       DATA NBCD(1) /360H     1     2     3     4     5     6     7     8
      1     9    10    11    12    13    14    15    16    17    18    19
      2    20    21    22    23    24    25    26    27    28    29    30
      3    31    32    33    34    35    36    37    38    39    40    41
      4    42    43    44    45    45    47    48    49    50    51    52
      5    53    54    55    56    57    58    59    60            /
       END
```

```
$IBFTC CNDCTR
      SUBROUTINE GETG
      COMMON /KONST/ NSEG,NPAY,NSURF,NNODES,MAXNL,NPRINT,NDAMP,NNL,
     1 NAREAL,NAREAN,NARCLN,NTHETA,NITEST,NKHIC,NEMISS,NAFA,NSNT,
     2 NEXTRA(3),
     3 SIGMA,DPTH,DELS,EMISS,CON1,CON2,DELDMP,X,TABS,HIKCON,NPSWCH,RAD,H
      COMMON /COND/ G(1)
      COMMON /TEMP/ T(1)
      COMMON /SOURCE/ Q(1)
      COMMON /ARRAY/ A(1)
      COMMON /FIXCON/ KA(1)
      COMMON/QCOM/ QTS(30),QNORM(30)
      DIMENSION SAREA(41),EMISIV(41),TQ(41),NTQ(1),NARY(1)
      EQUIVALENCE (A,NARY), (TQ,NTQ)
      EQUIVALENCE (NLOOP,KA(5)),(DAMPA,KA(9)),(LOOPCT,KA(20))
      EQUIVALENCE (ARLXCC,KA(30))
      DATA  NTIME /1/
      NPSWCH=0
      IF(LOOPCT.GE.NLOOP) CALLPCHT(1)
      IF(NPSWCH .GT. 0) GO TO 9998
      IF(ARLXCC .LT. .01) DAMPA=DAMPA+DELDMP
      IF(DAMPA .GT. 1.0) DAMPA=1.0
      IF(MOD(LOOPCT,100 ) .NE. 0 ) GO TO 32
      CALL TIMLFT(TLEFT)
      TLEFTM=TLEFT/3600.
      WRITE(6,9999) TLEFTM,LOOPCT
      IF(TLEFT .LT. 14400.0) CALL PCHT(2)
      IF(NPSWCH .GT. 0) GO TO 9998
   32 CONTINUE
      IF(MOD(LOOPCT,NPRINT) .NE. 0) GO TO 33
   35 NSP1=NSURF+1
      CALL ENDOUT
      WRITE(6,1001) LOOPCT,DAMPA,(TQ(I),I=1,NSP1)
   33 CONTINUE
      NRAD=RAD
C
C   GET G FOR ALL NORMAL (VERTICAL) CONNECTORS
C
      AKPART= DELS*SIGMA/((2./EMISS)-1.)
      NODA= 0
      NCOND= 0
      N1= 1
      DO 11 I=1,NSEG
      M=NNL+I
      NLAY= NARY(M)
      MA= NAREAN+I
      AOD=A(MA)/DPTH /8.
      N2=N1+NLAY-1
   30 DO 12 J=N1,N2
      NODA= NODA+1
      NODB= NODA+1
      T1= T(NODA)   +TABS
      T2= T(NODB)   +TABS
      TPART= (T1+T2)*(T1*T1+T2*T2)
      AK= AKPART*TPART
      G(J)=AOD*AK
   12 CONTINUE
      NT2=NODA
   41 N3=NODB-NLAY
      N4=N3+1
      G(N1)=G(N1)*2.
      QNORM(I)=G(N1)*(T(N4)-T(N3))
```

```
   43 CONTINUE
      N1= N2+1
   40 TSURF=T(NT2)
   11 NODA= NODA+1
C
C  COMPUTE G FOR LATERAL CONNECTORS
C
      NODA= 1
      NCOND= N2
      DO 15 I=2,NSEG
      M=NNL+I
      NLAY= NARY(M)
      NLM1P2=NARY(M-1)+1
      L=NARCLN+I
      EL1=A(L-1)/2.
      EL2=A(L)/2.
      LL=NAREAL+I-1
      AREA=A(LL)
      DO 13 J=1,NLAY
      NODA= NODA+1
      NODB= NODA+NLM1P2
      NCOND= NCOND+1
      T1= T(NODA)   +TABS
      T2= T(NODB)   +TABS
      MM=NITEST+J
      ITEST=NARY(MM)
      IF(ITEST)20,19,19
   20 MMM=NKHIC
      IF(T1 .GT. 240.) GO TO 18
      CALL LAGRAN(T1,AK1,A(MMM),7)
   17 IF(T2 .GT. 240.) GO TO 16
      CALL LAGRAN(T2,AK2,A(MMM),7)
      GO TO 21
   18 AK1=HIKCON
      GO TO 17
   16 AK2=HIKCON
      GO TO 21
   19 AK1=CON1*T1 + CON2
      AK2=CON1*T2 + CON2
   21 DEN= EL1/AK1 + EL2/AK2
      G(NCOND)= AREA/DEN
   13 CONTINUE
   15 NODA=NODA+1
C
C  COMPUTE SOURCE TERMS FOR NET Q, RADIOSITY, USING SUBR. IRRADI FOR
C  INTERCHANGE BETWEEN FACE OF SHIELD AND PAYLOAD
C
      GO TO (600,601),NTIME
  600 NTIME=2
      J=NSURF+1
      M=NAREAN-1
      K=NEMISS-1
      DO 602 I=1,J
      MM=M+I
      KK=K+I
      SAREA(I)=A(MM)
      EMISIV(I)=A(KK)
  602 CONTINUE
      NARY(NAFA+1)=NSURF
      A(NAFA+2)=SIGMA
      WRITE(6,1000) (SAREA(I),I=1,J)
      WRITE(6,1000) (EMISIV(I),I=1,J)
```

```
  601 CONTINUE
      DO 500 I=1,NSURF
      K=NSNT+I
      J=NARY(K)
  500 TQ(I+1)=T(J)
      NTQ(1)=NSURF
      CALL IRRADI(SAREA,EMISIV,A(NAFA),TQ)
      DO 505 I=1,NSEG
      K=NSNT+I
      J=NARY(K)
      Q(J)=Q(J)+TQ(I+1) /8.
      QTS(I)=Q(J)
  505 CONTINUE
 9998 RETURN
 1000 FORMAT(1X,10G13.5)
 1001 FORMAT(10HL LOOPCT=  I6, 5X,6HDAMPA= F6.4,
     1 /22H  NET Q FROM RADIOSITY/(1X,10G13.5))
 9999 FORMAT(12H  TIME LEFT= F15.2, 10H   LOOPCT= I8)
      END
```

```
$IBFTC OUTEND

      SUBROUTINE ENDOUT
      COMMON/TITLE/ HEAD(20)
      COMMON /KONST/ K(1)
      COMMON/FIXCON/ X(27),L,NP
      COMMON/QCOM/ QTS(30),QNORM(30)
      DIMENSION QTS8(30),QN8(30)
      NSEG=K(1)
      STS=0.
      SNO=0.
      CALL PICTR
      DO 10 I=1,NSEG
      QTS8(I)= QTS(I)*8.
      QN8(I) = QNORM(I)*8.
      STS=STS+QTS(I)
   10 SNO=SNO+QNORM(I)
      STS8=STS*8.
      SNO8=SNO*8.
      WRITE(6,2000) (HEAD(I),I=1,20),(I,QTS(I),QNORM(I),
     1 QTS8(I),QN8(I),I=1,NSEG)
      WRITE(6,2001) STS,SNO,STS8,SNO8
      N=K(31)
      L=0
      NP=0
      IF(N .EQ. 0) GO TO 4
      GO TO (1,2),N
    1 WRITE(6,2003)
      GO TO 3
    2 WRITE(6,2002)
    3 WRITE(6,2004)
    4 RETURN
 2000 FORMAT(1H1,10X,20A6/9HL NO. SEG,8X,3HQTS,11X,5HQNORM,
     1 24X,5HQTS*8,9X,7HQNORM*8 //
     2 (I8,4X,2F14.8,15X,2F14.8))
 2001 FORMAT(12HLSUMMATION   ,2G14.5,15X,2G14.5)
 2002 FORMAT( 71HLNOTE....THIS CASE STOPPED FOR TIME EXCEEDED, IT HAS NO
     1T YET CONVERGED. )
 2003 FORMAT(52HL....THIS CASE STOPPED FOR ITERATION COUNT EXCEEDED. )
 2004 FORMAT(53HK  ....CARDS WERE PUNCHED TO RESTART FROM THIS POINT.  )
      END
```

```
$IBFTC DISTRT

      SUBROUTINE TDIST
      COMMON /KONST/ K(1)
      COMMON /TEMP/ T(1)
      LUT5=11
      REWIND LUT5
      NNODES=K(4)
   12 READ (LUT5) (T(I),I=1,NNODES)
      RETURN
      END
```

```
$IBFTC GRAFIC

      SUBROUTINE PICTR
      COMMON/TITLE/ HEAD(20)
      COMMON /TEMP/ T(1)
      COMMON /ARRAY/ IA(1)
      COMMON /KONST/ NSEG,NPAY,NSURF,NNODES,MAXNL,NPRINT,NDAMP,NNL,
     1 NAREAL,NAREAN,NARCLN,NTHETA,NITEST,NKHIC,NEMISS,NAFA,NSNT,
     2 NEXTRA(3),
     3 SIGMA,DPTH,DELS,EMISS,CON1,CON2,DELDMP,X,TABS,HIKCON,PSWTCH,RAD,H
      DIMENSION NODNO(15),TOUT(15), LINE(30), NBCD(50), IFMT(13)
      DIMENSION NRENDN(15), NRENDT(15), IFMT1(96), A(1)
      EQUIVALENCE (IA,A)
      DATA  ILINE,IBLANK /6H******, 6H      /
      DATA ITARG /6H$$$$$$/
      DATA NBCD(1)/ 300H     1     2     3     4     5     6     7     8
     1     9    10    11    12    13    14    15    16    17    18    19
     2    20    21    22    23    24    25    26    27    28    29    30
     3    31    32    33    34    35    36    37    38    39    40    41
     4    42    43    44    45    46    47    48    49    50     /
      DATA  IFMT(1)/ 78H(2HP 8X,A1,30A4/2HP A6,A2,A1,      (I6,1X,A1)/2
     1HP A6,A2,A1,      (F7.2,A1))  /
      DATA IFMT1(1)/576H(1H1,5X,20A6/8X,10(1H*),      (8H********),2H**,
     110X,17(1H*)/8X,1H*,9X,       (8H        ),2H *,10X,1H*,15X,1H*/8X
     2,18H* PAYLOAD NODES   ,      (8H        ),2H *,10X,7H* SPACE,9X,
     31H* /8X,10H* NODE NOS,        I8 ,2H *,10X,10H* NODE NO.,I5,2H */
     48X,1H*,9X,       (8H        ),2H *,10X,1H*,15X,1H*/8X,10H* TEMPS=
     5  ,           F8.2 ,2H *,10X,7H* TEMP=,F8.2,2H */8X,10H* EMISIV= ,
     6       F8.4 ,2H *,10X,8H* EMISIV,F7.4,2H */8X,10(1H*),      (8H***
     7*****),2H**,10X,17(1H*)/14HKANGLE OF EACH/14H SEGMENT(DEG.)/10X,
     8      F8.1/14HKEMISIVITY OF /14H EACH SEGMENT /10X,        F8.4)
     9  /
      DATA ISU1,ISU2,ITW1,ITW2
     1 / 6HSURFAC ,6HE      , 6HTANKWA ,6HLL     /
      DO 5 I=1,NNODES
```

```
    5 T(I)=T(I)+TABS
      MAXL= MAXNL+1
      NSPACE=NNODES
      NWALL=NSPACE-NPAY-1
      NCINIT=0
      NS1= 1
      NS2= NSEG
      IF(NSEG .GT. 15) NS2=15
    8 NTH1 = NTHETA+NS1
      NTH2 = NTHETA+NS2
      NP1=NSPACE-NPAY
      NP2=NSPACE-1
      NET1=NEMISS+NS1
      NET2=NEMISS+NS2
      NEP1=NET1+NSEG
      NEP2=NEP1+NPAY-1
      NESPAC=NEMISS+NSEG+NPAY+1
      IFMT1( 5)= NBCD(NPAY)
      IFMT1(13)= NBCD(NPAY)
      IFMT1(24)= NBCD(NPAY-1)
      IFMT1(35)= NBCD(NPAY)
      IFMT1(44)= NBCD(NPAY)
      IFMT1(54)= NBCD(NPAY)
      IFMT1(64)= NBCD(NPAY)
      IFMT1(73)= NBCD(NPAY)
      IFMT1(86)= NBCD(NSEG)
      IFMT1(95)= NBCD(NSEG)
      WRITE(6,IFMT1)HEAD,(J,J=NP1,NP2),NSPACE,(T(I),I=NP1,NP2),T(NSPACE)
     1 ,(A(I),I=NEP1,NEP2),A(NESPAC), (A(I),I=NTH1,NTH2),
     2  (A(I),I=NET1,NET2)
       WRITE(6,2004) H
      WRITE(6,2003)
      DO 10 I=1,MAXL
      M=MAXL-I+1
      IM=M-1
    9 DO 11 L=1,15
      LINE(L)= IBLANK
      LINE(L+15)= IBLANK
      NODNO(L)= 0
   11 TOUT(L)= 0.0
      NS1P1= NS1-1
      NC=NCINIT
      N= 0
      ISNSW=1
   50 IF(M .EQ. 1) GO TO 12
      MM1=M-1
   52 MM=NITEST+MM1
      ITEST=IA(MM)
      IF(ITEST .LT. 0) ISNSW=-1
   12 DO 20 J=NS1,NS2
      N2= 2*(J-NS1P1)
      N1= N2-1
      JJ=NNL+J
      JN=J-NS1+1
      NLAY=IA(JJ)+1
      IF(NLAY .LT. M) GO TO 19
      N= N+1
C
C   CHECK FOR TOP SURFACE TARGETING
C
   26 IF(NLAY .GT. M) GO TO 21
C
```

```
C NLAY =M  THIS IS A TOP SURFACE, CHECK TO SEE IF TARGETED
C
   24 JJ=NEMISS+J
      EMISIV=A(JJ)
      IF(EMISIV .LT. 0.1) GO TO 21
      LINE(N1)=ITARG
      LINE(N2)=ITARG
      GO TO 27
C
C NL(JJ) M  THIS IS AN INTERIOR NODE OR TANKWALL SURFACE.
C
   21 LINE(N1)= ILINE
      LINE(N2)= ILINE
   27 ISIGN=1
      IF(I .LT. MAXL) GO TO 23
      NRENDN(N)=IBLANK
      NRENDT(N)=IBLANK
      LEND=IBLANK
      LLEND=ILINE
      NAM1=ITW1
      NAM2=ITW2
      NAM3=ISU1
      NAM4=ISU2
      GO TO 18
   23 ISIGN=ISNSW
      LEND=ILINE
      LLEND=ILINE
      NAM1=NBCD(IM)
      NAM2=IBLANK
      NAM3=IBLANK
      NAM4=IBLANK
      NRENDN(N)=ILINE
      NRENDT(N)=ILINE
   18 NN= NC+M
      NODNO(JN)= NN*ISIGN
      TOUT(JN)=T(NN)
   19 NC= NC+NLAY
   20 CONTINUE
      IF(N .GT. 0) GO TO 22
      WRITE(6,2001)
      GO TO 10
   22 IFMT( 6)= NBCD(N)
      IFMT(11)= NBCD(N)
      WRITE(6,IFMT)LLEND, ( LINE(L),L=1,30), NAM1,NAM2,LEND,
     1 (NODNO(L),NRENDN(L),L=1,N), NAM3,NAM4,LEND,
     2 (TOUT(L),NRENDT(L),L=1,N)
   10 CONTINUE
      DO 31 I=1,3
   31 LINE(I)=ILINE
      WRITE(6,2002) (LINE(I),I=1,3), NWALL, T(NWALL), (LINE(I),I=1,3)
      IF(NS2 .GE. NSEG) GO TO 40
      NS1= NS2+1
      NS2= NSEG
      NCINIT=NC
      GO TO 8
   40 DO 41 I=1,NNODES
   41 T(I)=T(I)-TABS
      RETURN
 2000 FORMAT(1H1, 5X,20A6/41X,17(1H*),10X,17(1H*)/
     1  41X,1H*,15X,1H*,10X,1H*,15X,1H* /
     2  41X,    9H* PAYLOAD,7X,1H*,10X,7H* SPACE,9X,1H* /
     3  41X,10H* NODE NO.,I5,2H *,10X,10H* NODE NO.,I5,2H */
```

```
    4  41X,1H*,15X,1H*,10X,1H*,15X,1H*/
    5  41X,7H* TEMP=,F8.2,2H *,10X,7H* TEMP=,F8.2,2H */
    6  41X,1H*,15X,1H*,10X,1H*,15X,1H*/
    7  41X,17(1H*),10X,17(1H*) /
    8 14HKANGLE OF EACH / 14H SEGMENT(DEG.) / 10X,15F8.1)
 2001 FORMAT(2HP /2HP /2HP   )
 2002 FORMAT(2HP /2HP /2HP  ,41X,3A6/2HP  ,41X,1H*,16X,1H*/
    1 2HP  ,41X,1H*,9H TANKWALL,7X,1H* /
    2 2HP  ,41X,1H*,10H NODE NO.=,I5,2H */
    3 2HP  ,41X,1H*,7H TEMP.= F8.2,2H */
    4 2HP  ,41X,1H*,16X,1H*/2HP  ,41X,3A6 )
 2003 FORMAT(7H  LAYER /6H  NO.    )
 2004 FORMAT(25HKTANK TO PAYLOAD SPACING= F7.4, 4H FT. /)
      END
```

```
$IBFTC PUNTEM

      SUBROUTINE PCHT(N)
      COMMON /TEMP/ T(1)
      COMMON /FIXCON/ FC(1)
       COMMON/KONST/ K(1)
C   SET NPSWCH TO NON-ZERO TO INDICATE CARDS BEING PUNCHED
      K(31)=N
      NNODES=K(4)
      FC(19)=10000.
      WRITE(6,101)
      PUNCH 100, NNODES,(T(I),I=1,NNODES)
  100 FORMAT(I8,9F8.1/(10F8.1))
  101 FORMAT( 36HL   TEMPERATURE  CARDS BEING PUNCHED)
      RETURN
      END
```

APPENDIX H

SYMBOLS USED IN ANALYSIS

A	area, ft^2; m^2
ΔA	incremental area, ft^2; m^2
A_x	incremental area in x direction in finite difference equation, ft^2; m^2
A_y	incremental area in y direction in finite difference equation, ft^2; m^2
A_z	incremental area in z direction in finite difference equation, ft^2; m^2
a	major semi-axis of tank plus shield, ft; m
$A_iF_{i,j}$	product of i^{th} surface area times geometric radiation view factor between i^{th} and j^{th} surface, ft^2; m^2
b	minor semi-axis of tank plus shield, ft; m
C_p	specific heat, Btu/(lb)(^{o}R); J/(kg)(K)
$F_{i,j}$	geometric radiation view factor - portion of total energy, either emitted or reflected diffusely from surface i, that is intercepted by surface j
G	conductor value for heat transfer, Btu/(lb)(^{o}F); J/(sec)(K)
h	tank-to-payload spacing, ft; m
k	thermal conductivity, Btu/(hr)(ft)(^{o}R); J/(sec)(m)(K)
ΔL	payload ring width, ft; m
m_{N_1}	slope of normal N_1
N	normal to center of an incremental surface
N_E	number of surfaces in radiation enclosure
N_J	number of incremental areas in j^{th} payload ring
Q	heat flow, Btu/hr; J/sec
q	incremental heat flows, either across a plane of any segment or into (or out of) any surface segment, Btu/hr; J/sec
$\dot{q}$	internal heat generation rate at each node, Btu/hr; J/sec
R	distance between any two incremental surfaces, ft; m
R_p	payload radius, ft; m
R_1	distance from tank center to incremental surface, ft; m

R_2	distance from payload center to incremental surface, ft; m
S	source term, $\dot{q}\alpha/k$, $(ft^3)(^oR)/hr$; $(m^3)(K)/sec$
ΔS	thickness of MLI, ft; m
T	temperature, ^oR; K
t	time, sec
V	volume, ft^3; m^3
x, y, z	coordinate system, point coordinates
x_r	major semi-axis of tank, ft; m
Δx	incremental distance in x direction
y_r	minor semi-axis of tank, ft; m
Δy	incremental distance in y direction, ft; m
Δz	incremental distance in z direction, ft; m
α	thermal diffusivity, ft^2/hr; m^2/sec
β	angle measured from minor axis to segment boundary on tank
γ	location angle on payload
ϵ	emissivity
θ	angle on tank to specify segments
ρ	density, lb/ft^3; kg/m^3
φ	angle between the normal to a surface and the vector R from that surface
ψ_m	angle from top of tank to R_1

Subscripts:

i	index or counter
j	index or counter
k	index or counter
lat	lateral
m, n	reference or index
norm	normal
p	refers to payload surface increment
t	refers to tank surface increment

Notation:

$\rightarrow$	vector
$\hat{}$	unit vector
∇^2	Laplacian operator, $\frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2} + \frac{\partial^2}{\partial z^2}$
$\hat{i}, \hat{j}, \hat{k}$	unit vectors in x, y, z directions

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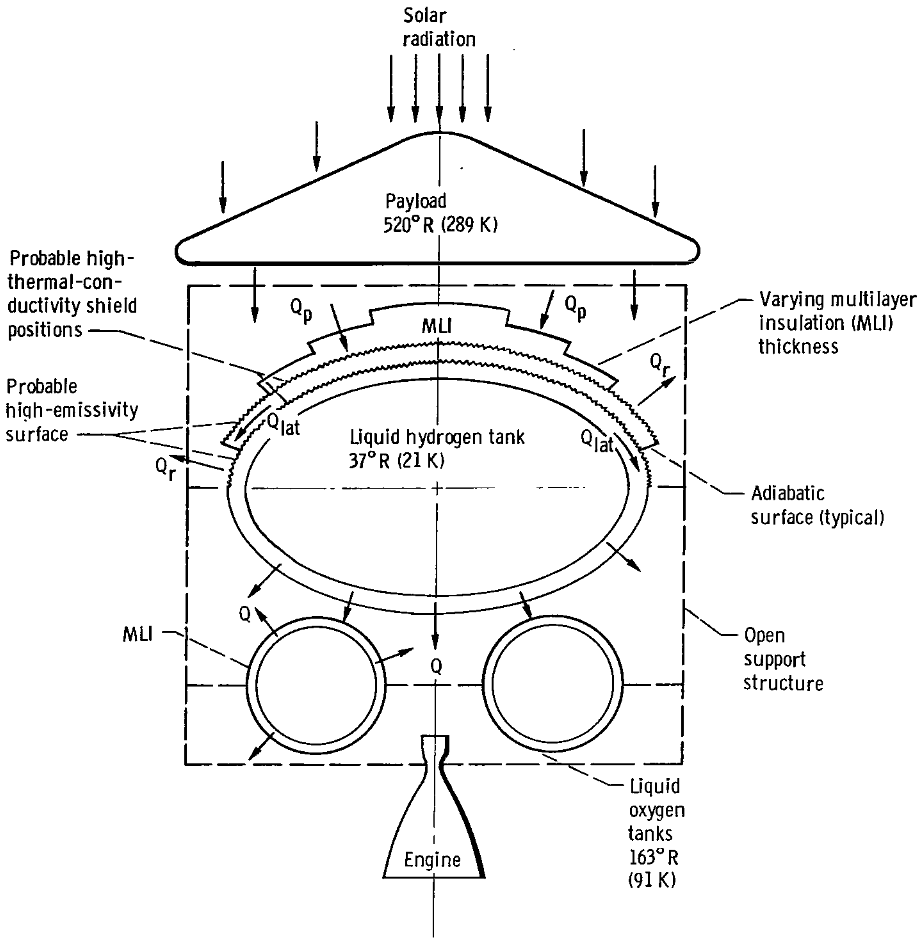

Figure 1. - Vehicle configuration.

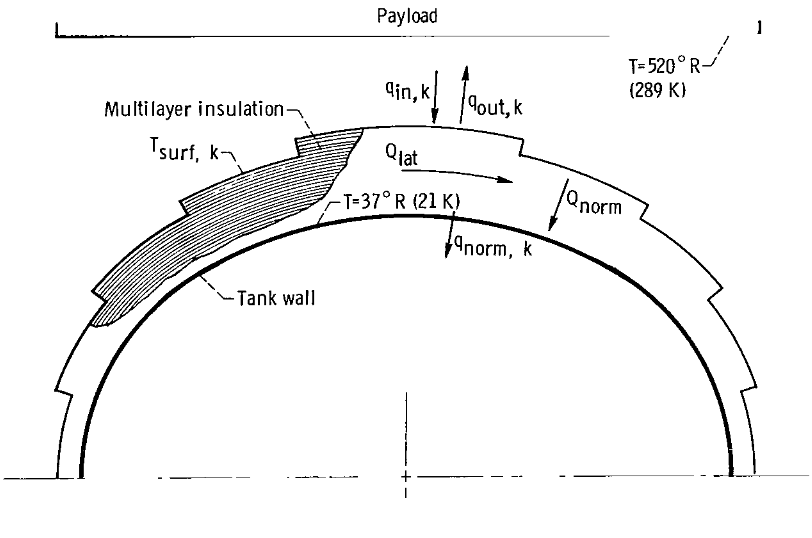

Figure 2. - Cross-sectional view of model.

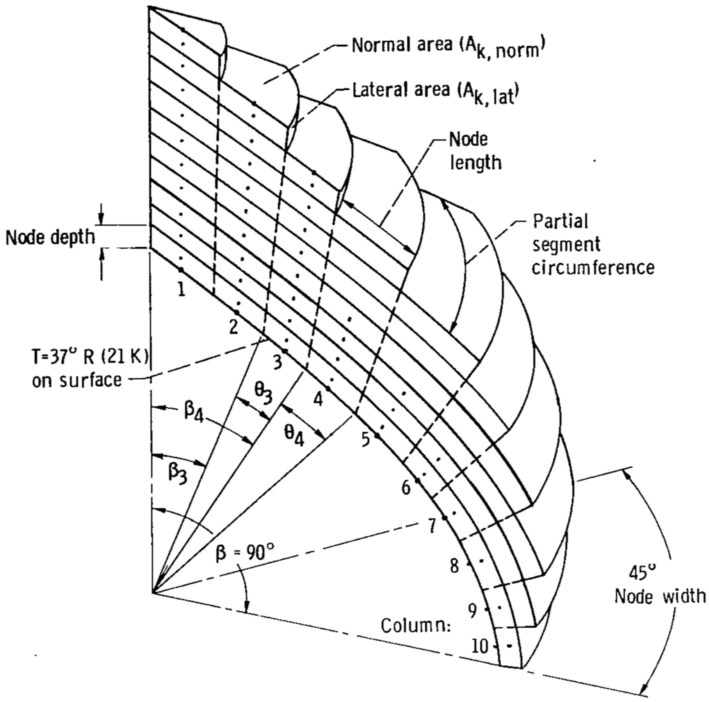

Figure 3. - 45° segment of the multilayer insulation (MLI) divided into nodes.

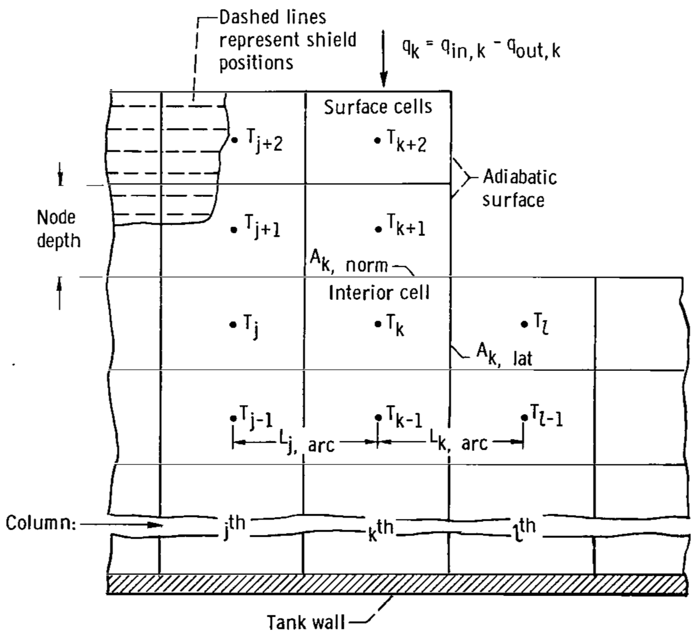

Figure 4. - Cross-sectional view of several nodes.

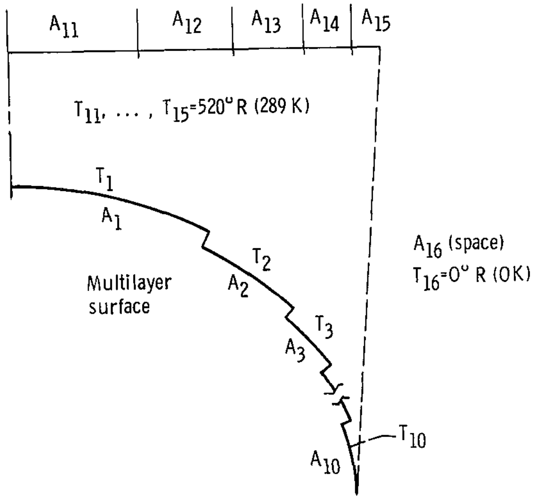

Figure 5. - Enclosure for radiation exchange.

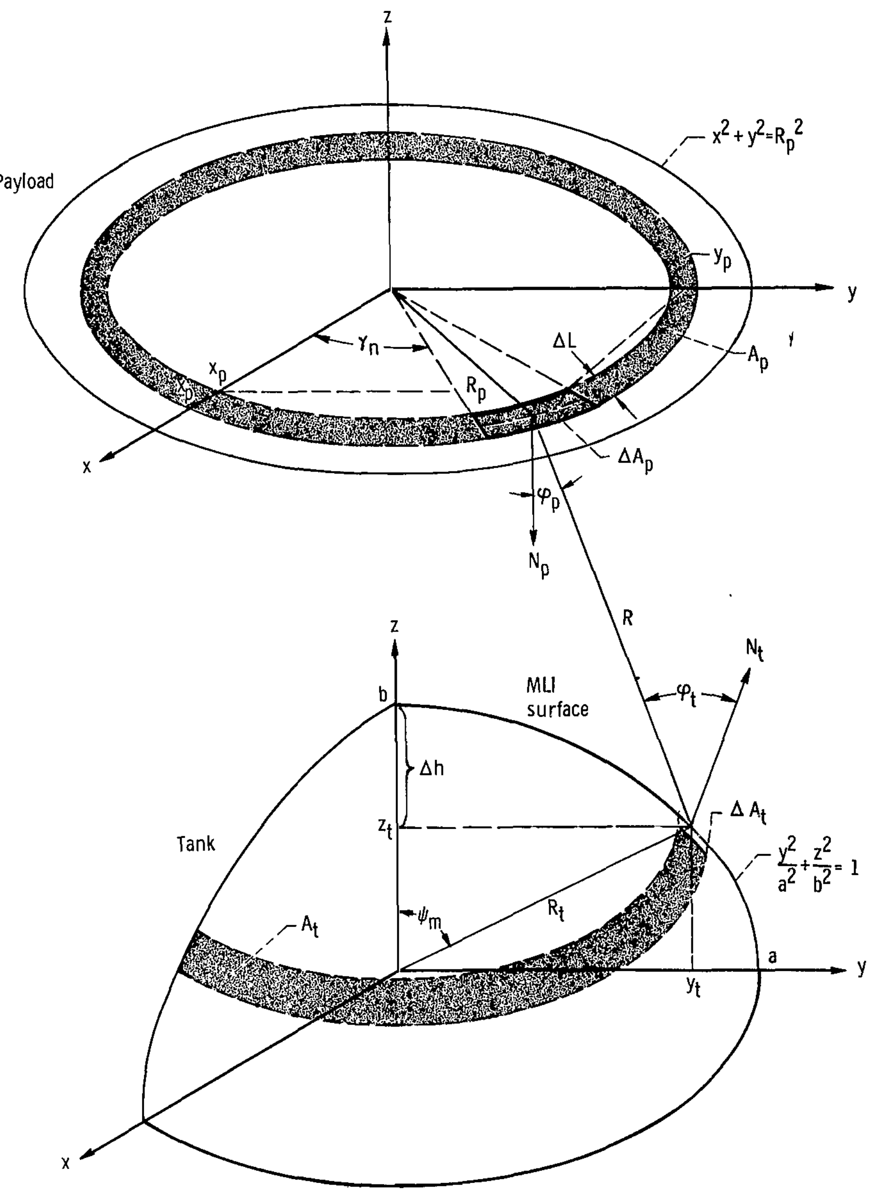

Figure 6. - Geometric configuration for determining radiation view factors between tank and payload.

NASA-Langley, 1971 — 8 E-5911

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