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VOLUME 5

SYNTHESIS OF CALCULATIONAL METHODS
FOR THE DESIGN AND ANALYSIS OF RADIATION
SHIELDS FOR NUCLEAR ROCKET SYSTEMS

TIC-TOC-TOE

A FORTRAN PROGRAM FOR THE TEMPERATURE IN THE
COOLANT TANK AND OTHER CALCULATIONS AND FOR THE
THERMAL NEUTRON ORIGINATING ENERGY

by

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ABSTRACT

This report is Volume 5 of nine volumes of the final report on "Synthesis of Computational Methods for the Design and Analysis of Radiation Shields for Nuclear Rocket Systems". Presented in this volume is a description of the TIC-TOC-TOE program for the Temperature In the Coolant Tank and Other Calculations and for the Thermal neutron Originating Energy.

The TIC-TOC-TOE program, which is written in FORTRAN IV language, performs rapid calculations of heating rate distributions in on-axis liquid hydrogen propellant tanks. Neutron and photon sources from the reactor are expressed as multigroup, angular equivalent point sources. The propellant tank geometry is described by a series of axisymmetric truncated cones and/or cylinders. Basic heating rate data are interpolated from curve-fits of M. O. Burrell's Monte Carlo data which are built into the program.

Quantities calculated by the TIC-TOC-TOE program for specified points in the tank include:

- 1) gamma ray heating by energy group,
- 2) neutron kinetic heating by fast energy group,
- 3) capture gamma ray heating due to neutron captures in liquid hydrogen, and
- 4) capture gamma ray heating due to neutron captures in tank wall.

These same quantities are also obtained for points at the corners of the volume elements employed in performing volume integrations over the tank. Quantities obtained from the volume integration include:

- 1) total gamma and neutron heating rate as a function of propellant height,
- 2) radial and volume averaged heating rates as a function of propellant height,
- 3) radial averaged temperature rise as a function of time for a no-mix fluid model,
and
- 4) temperature rise as a function of time for a complete mix fluid model.

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SECTION

1.0 INTRODUCTION

The TIC-TOC-TOE program is written in FORTRAN IV for the IBM 7094 and CDC 6600 computers. This program utilizes curve-fit Monte Carlo heating rate data⁽¹⁾ generated by M. O. Burrell of the Marshall Space Flight Center (MSFC), to obtain heating rates in an on-axis liquid hydrogen propellant tank whose geometry is described by a series of truncated cones and cylinders. The radiation source is expressed as an equivalent point angular dependent source for three pre-selected gamma ray energy groups, and five pre-selected neutron energy groups (three fast, one epithermal and one thermal).

TIC-TOC-TOE is an integral part of the "early" design method provided for the Marshall Space Flight Center under this contract. A simplified schematic diagram of the "early" design method is shown in Figure 1 and is described in detail in Volume 1. The starting point for the method is the POINT program (Volume 2) which prepares cross section and other basic data for use in the transport programs. In the "early" design method (Figure 1), the TAPAT program system (Volume 3) computes one dimensional neutron and photon fluxes in the reactor geometry. From these fluxes, neutron and photon sources and distributions are obtained and are used as input to the KAP-V program. The KAP-V program (Volume 4) provides gamma ray and fast neutron radiation levels at locations external to the reactor. Radiation levels from the KAP-V program at a specific radial distance from the center of the reactor can then be employed in the TIC-TOC-TOE program (Volume 5) for calculating radiation quantities of interest in an on-axis liquid hydrogen propellant tank.

Quantities calculated by the TIC-TOC-TOE program for specified points in the tank include:

- 1) gamma ray heating by energy group,
- 2) neutron kinetic heating by fast energy group,
- 3) capture gamma ray heating due to neutron captures in the liquid hydrogen, and
- 4) capture gamma ray heating due to neutron captures in the tank wall.

These quantities are also obtained for points at the corners of the volume elements employed in performing volume integrations over the tank. Quantities obtained from the volume integration include:

- 1) total gamma and neutron heating rate as a function of propellant height,
- 2) radial and volume averaged heating rates as a function of propellant height,
- 3) radial averaged temperature rise as a function of time for a no-mix* fluid model, and
- 4) temperature rise as a function of time for a complete mix* fluid model.

Typical computer runs on the IBM 7094 require approximately 10 milliseconds per point if the capture gamma ray heating (from both the wall and propellant) is not computed. If these capture gamma ray heating rate components are calculated, a volume integration over the entire tank is performed for each point and the computer time per point becomes proportional to the number of points used in this numerical volume integration.

Section 2.0 of this report presents the equations involved in this program. The program logic is discussed in Section 3.0. Detailed input instructions are given in Section 4.0. Section 5.0 contains a sample problem and a description of the output format. The program listing is given in an appendix.

* In a no-mix fluid model, the heat deposited in the liquid hydrogen is assumed to remain in the same area until that incremental volume of coolant is pumped out of the tank. In a complete mix fluid model, the total heat deposited is assumed to be instantaneously mixed throughout the tank.

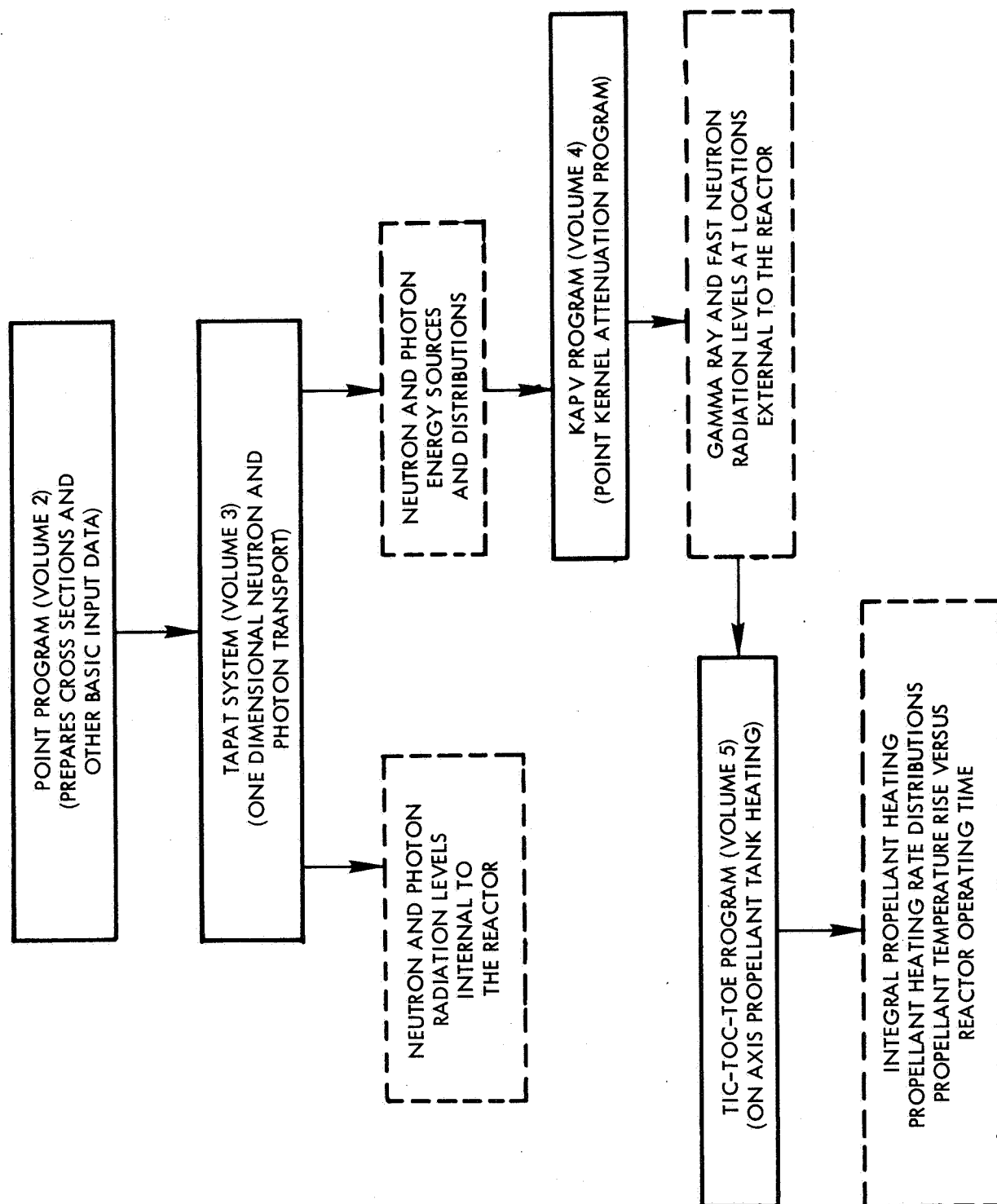


Figure 1. Schematic Diagram of the "Early" Design Method

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SECTION

2.0 PROGRAM DESCRIPTION

This section describes the seven essential parts of the TIC-TOC-TOE programs which are:

- 1) The Monte Carlo data built into the program
- 2) The point angular source
- 3) The propellant tank geometry
- 4) Gamma ray and neutron kinetic heating calculations
- 5) Capture gamma ray heating calculations
- 6) Total heating rate calculations
- 7) Temperature rise calculations.

2.1 BASIC DATA

The basic data used in this program are based on the Monte Carlo calculations of M. O. Burrell reported in Reference 1. These data include propellant heating rates and thermal neutron capture rates as a function of depth, z' , and radius, r , in a flat bottomed cylindrical tank for unit monoenergetic sources. All of these data have been empirically fitted, as a function of the two spatial parameters r and z' , in the general form:

$$F(r, z') = \sum_{k=0}^1 A_k(r) \exp \left[-B_k(r) \min(z_0, z') + C_k(r) \max(0, z' - z_0) \right] \quad (2.1)$$

where:

z_0 = a constant depth into the tank defining a breakpoint in the empirical fit of the z dependence.

$$A_k(r) = \sum_{l=0}^2 a_{l,k} r^l ; a_{l,k} , l = 0, 1, 2 \text{ are constants} \quad (2.2)$$

$$B_k(r) = \sum_{l=0}^2 b_{l,k} r^l \quad ; \quad b_{l,k} \quad , l = 0, 1, 2 \text{ are constants} \quad (2.3)$$

$$C_k(r) = \sum_{l=0}^2 c_{l,k} r^l \quad ; \quad c_{l,k} \quad , l = 0, 1, 2 \text{ are constants} \quad (2.4)$$

r = the radial distance from the tank centerline.

z' = the distance into the tank parallel to the centerline.

$\min(z_0, z')$ = the smaller of the numbers z_0 and z'

$\max(0, z_0 - z')$ = the larger of the numbers 0.0 and $z_0 - z'$

The functions curve fit using Eq. 2.1 are:

$h_1(r, z')$, the volumetric energy deposition from 6 Mev Gamma Rays

$h_2(r, z')$, the volumetric energy deposition from 3 Mev Gamma Rays

$h_3(r, z')$, the volumetric energy deposition from 1 Mev Gamma Ray

$h_4(r, z')$, the volumetric energy deposition from 7 Mev Neutrons

$h_5(r, z')$, the volumetric energy deposition from 3 Mev Neutrons

$h_6(r, z')$, the volumetric energy deposition from 1 Mev Neutrons

$\dot{g}_1(r, z')$, the volumetric capture rate from 7 Mev Neutrons

$\dot{g}_2(r, z')$, the volumetric capture rate from 3 Mev Neutrons

$\dot{g}_3(r, z')$, the volumetric capture rate from 1 Mev Neutron

$\dot{g}_4(r, z')$, the volumetric capture rate from 0.1 Mev Neutrons

$\dot{g}_5(r, z')$, the volumetric capture rate from 2 ev Neutrons

A comparison between the empirical fit and the Monte Carlo energy deposition and capture rate data is given in Reference 2. In general, accuracy within 5 percent of the "smoothed" Monte Carlo data is obtained.

The above functions are extrapolated from the conditions used in the original Monte Carlo study. In particular, this data is extrapolated to account for:

- 1) different tank bottom shape (flat in the Monte Carlo calculations), and
- 2) different source to propellant tank separation distance (11.25 feet in the Monte Carlo calculations).

The extrapolation techniques are discussed in connection with equations presented later.

2.2 POINT ANGULAR SOURCES

The point sources required for TIC-TOC-TOE are determined from flux calculations performed at a fixed radial distance, R (in feet), from the center of the reactor sources (usually assumed to be the core geometric center). These fluxes are assumed to be azimuthally symmetric and are supplied for a series of energy groups as a tabulated function of the polar angle, θ , measured from the center-line axis of the reactor-propellant tank configuration:

$$\begin{aligned}\theta_i &= \text{the } i\text{th polar angle (degrees)} \\ \phi_{i,i} &= \text{the flux in the } i\text{th energy group at the } i\text{th polar angle (particles/cm}^2\text{/sec)}\end{aligned}$$

These data define the equivalent point source, $S_i(\mu)$ for each group i , where μ is the cosine of the polar angle, θ . The angular dependence is then obtained by a linear interpolation in μ :

$$S_i(\mu) = \frac{(\mu - \mu_{i+1}) S_{i,i} + (\mu_i - \mu) S_{i,i+1}}{\mu_i - \mu_{i+1}} \quad (2.5)$$

for $\mu_i \geq \mu > \mu_{i+1}$

where

$$\mu_i = \cos \theta_i \quad i = 1, 2, \dots \quad (2.6)$$

$$S_{i,i} = 4\pi (30.48R)^2 \phi_{i,i} \quad i = 1, 2, \dots; \quad j = 1, 2, \dots, 8 \quad (2.7)$$

R = the reference radius at which the fluxes are given (feet)

The source group structure is fixed by the Monte Carlo energy deposition and capture distribution data with the notation:

Group 1	6 Mev gamma rays
Group 2	3 Mev gamma rays
Group 3	1 Mev gamma rays
Group 4	7 Mev neutrons
Group 5	3 Mev neutrons
Group 6	1 Mev neutrons
Group 7	0.1 Mev neutrons
Group 8	thermal neutrons

2.3 PROPELLANT TANK GEOMETRY

The propellant tank geometry as shown in Figure 2 is described by a series of truncated cones and/or cylinders with center lines on the z-axis of the coordinate system. The i th section of the tank is the volume bounded by:

$z = z_i$, the z - plane at the bottom of the section,

$z = z_{i+1}$, the z - plane at the top of the section, and

$R_{\max}(z) = a_i + b_i z$, the equation of the cone or cylinder at the side of the section. (2.8)

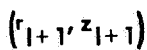


Figure 2. Propellant Tank Geometry

The constants a_i and b_i determine the equation of the line between the points (r_i, z_i) and (r_{i+1}, z_{i+1})

$$b_i = \frac{r_{i+1} - r_i}{z_{i+1} - z_i} \quad (b_i = 0 \text{ for cylindrical tank sections})$$

$$a_i = r_i - b_i z_i \quad (a_i = r_i = r_{i+1} \text{ for cylindrical tank sections})$$

The complete tank geometry is specified by a tabulation of the points (r_i, z_i) , $i = 1, 2, \dots, l+1$ where l is the total number of volume sections required to describe the shape of the tank.

The tank wall is assumed to have a constant thickness, t_w , over the outer boundary of the tank; its finite thickness is not treated explicitly in the geometric calculations. Instead, the tank wall effect is approximated using the outward unit vector, $\vec{n}$, normal to the tank surface as described below.

All distance calculations required by the TIC-TOC-TOE program are performed by the function subprogram PATH. The geometric calculations generally involve a point $\vec{r}$ in the tank and a unit direction vector $\vec{\Omega}$ from this point where:

$$\begin{aligned} \vec{r} &= x\vec{i} + y\vec{j} + z\vec{k} \\ \vec{\Omega} &= \alpha\vec{i} + \beta\vec{j} + \gamma\vec{k} \end{aligned} \quad (2.9)$$

$\vec{i}, \vec{j}, \vec{k}$ are unit vectors parallel to the coordinate system axis.

x, y, z are rectangular coordinates

α, β, γ are direction cosines with respect to the x, y , and z axes, respectively.

The distance s_w from $\vec{r}$ along $\vec{\Omega}$ to the surface of the tank is computed as:

$$s_w = \min \left\{ \frac{z_{i+1} - z}{\gamma}, s_i, s_{i+1}, \dots, s_l \right\} \quad \text{if } \gamma > 0$$

$$s_w = \min \left\{ \frac{z_1 - z}{\gamma}, s_1, s_2, \dots, s_i \right\} \quad \text{if } \gamma < 0$$
(2.10)

where

$z_{i+1} \geq z \geq z_i$, i.e. the point $\vec{r}$ is in the i th section of the tank,

$(z_{i+1} - z)/\gamma$ is the distance to the top of the tank from $\vec{r}$ along $\vec{\Omega}$

$(z_1 - z)/\gamma$ is the distance to the bottom of the tank from $\vec{r}$ along $\vec{\Omega}$

s_i is the smaller of the positive distances (if any) to the i th conical or cylindrical boundary of the tank.

The distances s_i , $i = 1, 2, \dots, l$, are computed, as required, from equation 2.8 by noting that for points on the boundary:

$$R_{\max}(z + \gamma s_i) = a_i + b_i(z + \gamma s_i) = \left[(x + \alpha s_i)^2 + (y + \beta s_i)^2 \right]^{1/2} \quad (2.11)$$

An expansion gives:

$$\left[\alpha^2 + \beta^2 - \gamma^2 b_i^2 \right] s_i^2 + 2 \left[\alpha x + \beta y - \gamma b_i (a_i + b_i z) \right] s_i$$

$$+ x^2 + y^2 - (a_i + b_i z)^2 = 0$$

or:

$$s_i = \frac{-B \pm \sqrt{B^2 - AC}}{A} \quad (2.12)$$

where

$$\left. \begin{aligned} A &= \alpha^2 + \beta^2 - \gamma^2 b_i^2 \\ B &= \alpha x + \beta y - \gamma b_i (a_i + b_i z) \\ C &= x^2 + y^2 - (a_i + b_i z)^2 \end{aligned} \right\} \quad (2.13)$$

The cosine of the angle between $\vec{\Omega}$ and the outward normal $\vec{n}$ at the tank surface is given by

$$\mu_w = |\gamma| \quad \text{if the top or bottom of the tank yields the minimum distance } s_w. \quad (2.14a)$$

$$\mu_w = \left| \vec{\Omega} \cdot \vec{n}_i \right| \quad \text{if the } i \text{th conical or cylindrical boundary yields the minimum distance } s_w. \quad (2.14b)$$

In the latter case the normal vector is computed as:

$$\vec{n}_i = \frac{C_1 \vec{i} + C_2 \vec{j} + C_3 \vec{k}}{[C_1^2 + C_2^2 + C_3^2]^{1/2}} \quad (2.15)$$

where

$$\left. \begin{aligned} C_1 &= x + \alpha s_i \\ C_2 &= y + \beta s_i \\ C_3 &= -b_i [a_i + b_i (z + \gamma s_i)] \end{aligned} \right\} \quad (2.16)$$

2.4 DIRECT GAMMA RAY AND FAST NEUTRON HEATING

The heating rate from direct gamma rays and fast neutrons at a specified point $\vec{r}$, at a radius r and height z , is determined by an extrapolation of the curve-fit Monte Carlo data. For the i th group, this extrapolation is:

$$\dot{H}_i(r, z) = S_i(\mu) \dot{h}_i(r, z') \frac{s_o^2}{s_t^2} \exp \left[- \sum_i^w \Delta s_w \right] \quad (2.17)$$

where

$$s_o^2 = 11.25^2 + r^2, \text{ the square of the distance to the volume element in the original Monte Carlo calculation} \quad (2.18)$$

$$\dot{h}_i(r, z') = \text{the heating rate from the } i \text{ th energy group}$$

$$\vec{r}_o = \text{the angular point source position}$$

$$s_t = \text{the total distance from the source point to the point in the tank}$$

$$s_t = \left| \vec{r}_o - \vec{r} \right| \quad (2.19)$$

$$\vec{\Omega} = \text{the unit direction vector from } \vec{r} \text{ to } \vec{r}_o$$

$$\vec{\Omega} = (\vec{r}_o - \vec{r}) / s_t \quad (2.20)$$

$$\mu = -\vec{k} \cdot \vec{\Omega} = |\gamma| \quad (2.21)$$

$$s_w = \text{the distance from the point } \vec{r} \text{ to the tank wall along the direction } \vec{\Omega}$$

$$z' = \mu s_w, \text{ the axial penetration distance into the tank.} \quad (2.22)$$

$$\sum_i^w = \text{the total attenuation cross section of the tank wall for particles in the } i \text{ th group.}$$

$$\Delta s_w = \text{the distance in the tank wall, approximated by}$$

$$\Delta s_w = t_w / \vec{\Omega} \cdot \vec{n} \quad (2.23)$$

2.5 CAPTURE GAMMA RAY HEATING

The energy deposition due to the liquid hydrogen capture gammas at a point $\vec{r}$ in the tank is computed by a volume integration over these capture sources. This volume integration is performed by subroutine TOE using spherical coordinates with the coordinate system centered at the point $\vec{r}$. The equation used for the propellant capture gamma ray heating is:

$$\dot{H}_p(r, z) = \mu_p^a E_p^\gamma C \int_{-1}^1 \int_0^{2\pi} \int_0^{s_w} \frac{S_p(\vec{r}')}{4\pi s^2} \exp[-\mu_p^t s] B_p(\mu_p^t s) s^2 ds d\theta d\mu \quad (2.24)$$

where

$\dot{H}_p(r, z)$ = the propellant capture gamma heating rate at $\vec{r}$, i.e. at r , and z ,

μ_p^a = the energy absorption coefficient,

E_p^γ = the capture gamma ray energy (2.23 Mev),

C = a units conversion factor,

μ = the cosine of the polar angle,

θ = the azimuthal angle,

s = the distance from $\vec{r}$ along $\vec{\Omega}$

$\vec{\Omega}$ = $\vec{i} \sqrt{1-\mu^2} \cos \theta + \vec{j} \sqrt{1-\mu^2} \sin \theta + \vec{k} \mu$

$\vec{r}'$ = $\vec{r} + s \vec{\Omega}$, the capture gamma ray source point, (2.25)

μ_p^t = the mass attenuation coefficient,

$B_p(\mu_p^t s)$ = a polynomial buildup factor, and

$S_p(\vec{r}')$ = the volumetric capture gamma ray source strength at the source point.

The capture gamma ray source strength is determined from the curve fit Monte Carlo data as:

$$S_p(\vec{r}') = \sum_{i=4}^8 \frac{(11.25 + z')^2 + r'^2}{|\vec{r}' - \vec{r}_o|^2} g_{i-3}(r, z') S_i(\mu') \exp[-\Sigma_i^w \Delta s_w] \quad (2.26)$$

The same procedures used in this source strength calculation are used in defining the point wise heating rates from direct gamma rays and fast neutrons, i.e. eq. 2.17.

2.5.1 Wall Capture Gamma Ray Heating

The energy deposition from capture gamma rays produced in the tank wall is computed concurrent with the calculation of the liquid hydrogen capture gamma component. A single capture gamma ray energy is allowed and the energy deposition is computed at points in the propellant tank as:

$$\dot{H}_w(r, z) = \mu_w^a E_w^{\gamma C} \int_{\frac{-1}{\Omega}}^1 \int_{\frac{0}{n}}^{2\pi} \int_{\substack{s_w \\ > 0}}^{s_w + \Delta s_w} \frac{S_w(\vec{r}')}{4\pi} \frac{\exp[-\mu_w^t s]}{s^2} B_w(\mu_w^t s) s^2 ds d\theta d\mu \quad (2.27a)$$

where

C is a units conversion factor

μ_w^a is the energy absorption coefficient of liquid hydrogen for the wall capture gammas

E_w^γ is the energy (Mev) of the wall capture gammas

μ_w^t is the mass attenuation coefficient of the liquid hydrogen for the wall capture gammas

$B_w(\mu_w^t s)$ is a polynomial buildup factor for the wall capture gammas in liquid hydrogen

Δs_w is the slant thickness of the wall as seen by the point, $\vec{r}$

$S_w(\vec{r}')$ is the volumetric source strength of capture gammas in the tank wall

$\vec{\Omega}'$ is the unit direction vector from the capture point to the angular point source

Note: this integration is limited to portions of the tank wall which can "see" the equivalent angular point source.

The attenuation of these capture gamma rays by the tank wall is neglected so that the integration reduces to

$$\dot{H}_w(r, z) = C \mu_w^a E_w^\gamma \int_{-1}^1 \int_0^{2\pi} \left\{ \int_{s_w}^{s_w + \Delta s_w} S_w(\vec{r}') ds \right\} \frac{\exp \left[-\mu_w^t s \right]}{4\pi} B_w(\mu_w^t s) d\theta d\mu \quad (2.27b)$$

$\vec{\Omega}' \cdot \vec{n} > 0$

The capture gamma source is obtained from the neutron fluxes at the tank wall as:

$$s_w(\vec{r}') = \sum_{i=4}^8 \Sigma_i^c \frac{S_i(\mu')}{4\pi t^2} \exp \left[- \Sigma_i^t \Delta s_w' \right] \quad (2.28)$$

where

Σ_i^c is the neutron capture cross section for source group i

t is the distance from the angular point sources to the tank wall

$\Delta s_w'$ is the distance into the tank wall of the capture source point measured along the line from the angular point source to the capture point.

From Figure 2, the distance $\Delta s_w'$ is given by

$$t_w - \vec{n} \cdot \vec{\Omega} (s - s_w) = \vec{n} \cdot \vec{\Omega}' \Delta s_w'$$

or

$$\Delta s_w' = \frac{t_w - \vec{n} \cdot \vec{\Omega} (s - s_w)}{\vec{n} \cdot \vec{\Omega}'}$$

Since the attenuation of the wall capture gammas by the tank wall is neglected, the source term in eq. 2.27b is obtained analytically:

$$\int_{s_w}^{s_w + \Delta s_w} S_w(\vec{r}') ds = \sum_{i=4}^8 \frac{\Sigma_i^c}{4\pi t^2} S_i(\mu') \int_{s_w}^{s_w + \Delta s_w} \exp \left[- \Sigma_i^t \left(\frac{t_w - \vec{n} \cdot \vec{\Omega} (s - s_w)}{\vec{n} \cdot \vec{\Omega}'} \right) \right] ds$$

$$= \sum_{i=4}^8 \frac{\Sigma_i^c}{\Sigma_i^t} \frac{S_i(\mu')}{4\pi t^2} \left(1 - \exp \left[-\Sigma_i^t t_w / \vec{n} \cdot \vec{\Omega}' \right] \right) \frac{\vec{n} \cdot \vec{\Omega}'}{\vec{n} \cdot \vec{\Omega}} \quad (2.29)$$

Substitution into eq. 2.27b yields the final equation evaluated in subroutine TOE:

$$\begin{aligned} \dot{H}_w(r, z) = C \mu_w^a E_w^Y \int_{-1}^1 \int_0^{2\pi} \left(\sum_{i=4}^8 \frac{\Sigma_i^c}{\Sigma_i^t} S_i(\mu') \right. \\ \left. \left(1 - \exp \left[-\Sigma_i^t t_w / \vec{n} \cdot \vec{\Omega}' \right] \right) \right) \\ \times \frac{1}{4\pi t^2} \frac{\vec{n} \cdot \vec{\Omega}'}{\vec{n} \cdot \vec{\Omega}} \frac{\exp \left[-\mu_w^t \right]}{4\pi} B_w(\mu_w^t) d\theta d\mu \quad (2.30) \end{aligned}$$

2.6 Average Energy Deposition

The total heating rate at a point is given by a summation over the various heating rate components.

$$\dot{H}(r, z) = \sum_{i=1}^6 \dot{H}_i(r, z) + \dot{H}_p(r, z) + \dot{H}_w(r, z) \quad (2.31)$$

The total energy deposited in the tank per unit time is then obtained by an integration over the tank volume. The energy deposition rate for propellant levels up to z is denoted by $\dot{H}(z)$ and is given by

$$\dot{H}(z) = \int_{z_1}^z 2\pi \int_0^{R_{\max}(z'')} \dot{H}(r'', z'') d\left(\frac{r''^2}{2}\right) dz'' \quad (2.32)$$

where r'' is the variable radius and z'' is the variable axial coordinate. The volume averaged heating rate for the propellant below z is simply:

$$\dot{H}_v(z) = \frac{1}{V(z)} \dot{H}(z) \quad (2.33)$$

where

$$V(z) = 2\pi \int R_{\max}^2(z'') dz'' \quad (2.34)$$

The radial averaged heating rate at the propellant height z is given by:

$$\dot{H}_A(z) = \frac{2\pi}{A(z)} \int_0^{R_{\max}(z)} \dot{H}(r'', z) d\left(\frac{r''^2}{2}\right) \quad (2.35)$$

$$\text{where } A(z) = \pi R_{\max}^2(z) \quad (2.36)$$

2.7 Propellant Temperature Rise

Neglecting the fact that heating rates are perturbed by the total amount of propellant in the tank, the temperature rise can be computed as a function of the time, after which the tank starts to empty.

No Mix Model

The radial averaged temperature rise of propellant, initially at a height z at time $\tau = 0$, can be determined by integrating the heating rate over the time required to reach the tank outlet. Assuming no mixing of the propellant, then:

$$\Delta T(z) = \frac{1}{C_p} \int_0^{\tau(z)} \dot{H}_A(z''(\tau')) d\tau' \quad (2.37)$$

where C_p is the specific heat.

$$\text{But } \frac{dz''}{d\tau'} = \dot{V}/A(z'')$$

where $\dot{V}$ is the volumetric flow rate

so that

$$\Delta T(z) = \frac{1}{C_p} \int_0^z \dot{H}_A(z''(\tau')) \frac{d\tau'}{dz''} dz'' = \frac{1}{C_p \dot{V}} \int_0^z A(z'') \dot{H}_A(z'') dz'' \quad (2.38)$$

$$= \dot{H}(z)/C_p \dot{V} \quad (2.39)$$

where τ is given by

$$\tau = V(z)/\dot{V} \quad (2.40)$$

Complete Mix Model

The temperature rise under the assumption of a complete and instantaneous mix of the energy deposited in the tank can be determined by solving a differential equation

$$\frac{dH(z)}{d\tau} = \dot{H}(z) - \dot{V} H(z)/V(z) \quad (2.41)$$

where $H(z)$ is the total energy contained in the tank when the propellant level has dropped to a height z . The time at this condition is

$$\tau = \frac{V_0 - V(z)}{\dot{V}} \quad (2.42)$$

or alternatively

$$V(z) = V_0 - \dot{V}\tau$$

where V_0 is the total tank volume.

Solution of eq. 2.41 yields the temperature rise when the propellant has dropped to the height z :

$$\Delta T(z) = \frac{1}{C_p \dot{V}} \int_z^{z_I+1} \dot{H}_V(z'') A(z'') dz'' \quad (2.43)$$

with the corresponding time

$$\tau(z) = \frac{1}{\dot{V}} \int_z^{z_I+1} A(z'') dz'' = \frac{V_0 - V(z)}{\dot{V}} \quad (2.44)$$

SECTION

3.0 PROGRAM LOGIC

The TIC-TOC-TOE program accepts all input data before proceeding to the calculation of propellant heating rates. Detailed input instructions are given in Section 4.0. Some of the input data are altered as they are input. In particular, the point angular source is defined from input fluxes tabulated at discrete polar angles.

3.1 POINT CALCULATIONS

Heating rate calculations are first performed for discrete points in the tank as specified in the input. The point heating calculations are performed in subroutine POINT. This subroutine is also utilized in the volume integrations, discussed in Section 3.2, where the discrete points are specified by the numerical integration procedures.

3.1.1 Direct Heating

The POINT subroutine computes the direction and total distance from the point in the tank to the source point. The distance in the propellant and the normal derivative at the surface are then computed by the function subprogram PATH. Next, the angular point source is interpolated to obtain the groupwise source for the direction from the source point to the point in the tank. The axial penetration, z' , is computed and the heating rate obtained for each group by eq. 2.1 using the function subprogram CURVE to evaluate eq. 2.2, 2.3, and 2.4.

3.1.2 Capture Heating

The option indicator for capture gamma ray calculations is checked. If requested, these capture calculations are performed by subroutine TOE.

The TOE subroutine performs an integration over the tank volume to obtain capture gamma ray heating rates. The volume integration is performed in a spherical coordinate system centered at the point in the tank as indicated in eq. 2.24 and 2.27.

The first procedure in this volume integration is to define a discrete direction through the tank based on the discrete directions obtained from the solid angle portion of the

integration. The distance to the tank surface and the outward normal are then computed for this direction by PATH. The volume integration then involves a spatial integration along the path to the wall. Each of the discrete points generated along the path by the numerical spatial integration is a point source of hydrogen capture gammas. The source strength at each of these point sources is obtained from equation 2.1 using subroutine GAMMAS in conjunction with the function subprogram CURVE.

After evaluating the point sources along the line to tank wall, the tank wall capture gamma heating contribution is obtained using eq. 2.30

3.2 VOLUME CALCULATIONS

The volume integration option is checked after all point calculations have been performed. If requested, this integration is performed in a cylindrical coordinate system.

The outermost integration involves the integration along the length of the tank. The inner integration is an area integration. Discrete points are generated for the area integration and the pointwise heating rates are obtained by subroutine POINT.

The radial averaged heating rate, eq. 2.35, is obtained from the inner area integration and volume averaged heating rates are obtained from eq. 2.33 by the integration of the area averages over the axial distance.

The no-mix temperature rise is computed during the volume integration using eq. 2.39. Appropriate quantities are saved for the complete mix temperature rise, eq. 2.43 after the volume integration is completed.

SECTION

4.0 INPUT DATA INSTRUCTIONS

The TIC-TOC-TOE program utilizes standard FORTRAN input statements. A variety of formats are used. Each format utilizes various combinations of the following data fields:

- 1) hollerith information: A4 field (4 columns)
- 2) integer data: I3 field (3 columns)
- 3) floating point data: E9.0 field (9 columns)

NOTE: For floating point data entered without a decimal point, the decimal point is assumed to be to the right of the data field.

In preparing data, it should be remembered that all blanks in integer or floating point fields are interpreted as zeros. Therefore, all integers (including exponents of floating point numbers) must be right adjusted.

Each physical data card is written on the output file as soon as it is read from the input file. The resulting printout includes the information in card columns (cc) 73 through 80 of the data cards. Since TIC-TOC-TOE does not print details of problem data except for the input cards, prolific use of card labeling is desirable. A note of warning: in obtaining the card identification from cc 73-80, all unused data fields in cc 1-72 are interpreted as data and these unused fields should be blank or contain valid data punches.

CARD A, First title card for labeling the printout

NOTE: This card is always required

COLUMN	FORMAT	SYMBOL	DEFINITION
1-80	20A4	---	Any desired information for problem identification--this will appear on the first line of each output page.

CARD B, Second title card for labeling the printout

NOTE: This card is always required

COLUMN	FORMAT	SYMBOL	DEFINITION
1-80	20A4	---	Any desired information for problem identification. This will appear on the second line of each output page.

CARD 0, Input controls for data cards

NOTE: This card is always required

COLUMN	FORMAT	SYMBOL	DEFINITION
1-3	I3	IN1	Input control for Card 1, comments. $IN1 \leq 0$, do not input Card 1. $IN1 > 0$, input Card 1.
4-6	I3	IN2	Input control for Card 2, limits and options. $IN2 \leq 0$, do not input Card 2. $IN2 > 0$, input Card 2.
7-9	I3	IN3	Input control for Card 3, point source location. $IN3 \leq 0$, do not input Card 3. $IN3 > 0$, input Card 3.
10-12	I3	IN4	Input control for Card 4, polar angles for fluxes. $IN4 \leq 0$, omit Card 4. $IN4 > 0$, input Card 4.
13-15	I3	IN5	Input control for Card 5, polar fluxes. $IN5 \leq 0$, omit Card 5. $IN5 > 0$, input Card 5.
16-18	I3	IN6	Input control for Card 6, flux scaling factors. $IN6 \leq 0$, omit Card 6. $IN6 > 0$, input Card 6.
19-21	I3	IN7	Input control for Card 7, tank wall cross section. $IN7 \leq 0$, omit Card 7. $IN7 > 0$, input Card 7.
22-24	I3	IN8	Input control for Card 8, tank wall source. $IN8 \leq 0$, omit Card 8. $IN8 > 0$, input Card 8.
25-27	I3	IN9	Input control for Card 9, cubic buildup. $IN9 \leq 0$, omit Card 9. $IN9 > 0$, input Card 9.
28-30	I3	IN10	Input control for Card 10, tank geometry. $IN10 \leq 0$, omit Card 10. $IN10 > 0$, input Card 10.
31-33	I3	IN11	Input control for Card 11, point detectors. $IN11 \leq 0$, omit Card 11. $IN11 > 0$, input Card 11.

CARD 0, Input controls for data cards (continued)

COLUMN	FORMAT	SYMBOL	DEFINITION
34-72	13I3	---	These columns are not used and should be left blank.
73-80	2A4	---	Any desired information for card identification.

CARD 1, Comments

- NOTES:
- a) omit this card if $IN1 \leq 0$
 - b) supply $IN1$ physical cards if $IN1 > 0$.

COLUMN	FORMAT	SYMBOL	DEFINITION
1-72	18A4	---	Any information for description of problem.
73-80	2A4	---	Any information for card identification.

CARD 2, Limits and options.

- NOTES:
- a) omit this card if $IN2 \leq 0$.
 - b) supply this card if $IN2 > 0$.

COLUMN	FORMAT	SYMBOL	DEFINITION
1-3	I3	NAMAX	Number of angles used to tabulate fluxes defining point angular sources $2 \leq NAMAX \leq 25$.
4-6	I3	NRMAX	Number of conical and cylindrical sections of the tank $1 \leq NRMAX \leq 24$.
7-9	I3	NTOE	Capture gamma ray calculation option. NTOE = 0, do not calculate. NTOE = 1, calculate.
10-12	I3	NPOINT	Number of discrete points in the tank--described on Card 11. $0 \leq NPOINT \leq 100$.
13-15	I3	NVOLYM	Volume integration option to obtain heating distributions, total heating and temperature rise. NVOLYM = 0, do not integrate. NVOLYM = 1, integrate.

CARD 2, continued

COLUMN	FORMAT	SYMBOL	DEFINITION
16-18	I3	NIZMAX	Number of intervals in the axial integration to obtain heating distributions.
19-21	I3	NIRMAX	Number of intervals in the radial integration to obtain heating distributions.
22-24	I3	NITMAX	Number of intervals in the azimuthal integration to obtain heating distributions. Use NITMAX = 1.
25-27	I3	IPMAX	Number of intervals in the polar integration to obtain capture gamma ray heating (discrete points on Card 11 have their own limit).
28-30	I3	ITMAX	Number of intervals in the azimuthal integration to obtain capture gamma ray heating.
31-33	I3	ISMAX	Number of intervals in the distance integration to obtain capture gamma ray heating.
34-72	13I3	---	These columns are not used and should be left blank.
73-80	2A4	---	Any information for card identification.

CARD 3, Point source location and other parameters.

NOTES: a) omit this card if $IN3 \leq 0$.
 b) supply this card if $IN3 > 0$.

COLUMN	FORMAT	SYMBOL	DEFINITION
1-9	E9.0	XS(1)	X-coordinate of the source point (ft). use XS(1) = 0.0.
10-18	E9.0	XS(2)	Y-coordinate of the source point (ft). use XS(2) = 0.0.
19-27	E9.0	XS(3)	Z-coordinate of the source point (ft).
28-36	E9.0	RADIUS	Distance from source point for which polar fluxes are tabulated (ft).
37-45	E9.0	WALL	Tank wall thickness (ft).
46-54	E9.0	ADUM1	Volumetric flow rate (ft ³ /sec)

CARD 3, continued

COLUMN	FORMAT	SYMBOL	DEFINITION
55-63	E9.0	ADUM2	Specific heat of propellant (watt sec·cm ⁻³ . degree ⁻¹)
64-72	E9.0	---	These columns are not used and should be left blank.
73-80	2A4	---	Any information for card identification.

CARD 4, Polar angles at which polar fluxes are tabulated

- NOTES: a) omit this card if $IN3 \leq 0$.
b) supply this card if $IN3 > 0$.

COLUMN	FORMAT	SYMBOL	DEFINITION
1-72	8E9.0	CSA(1)	First polar angle at which fluxes are tabulated. CSA(1) = 0.0.
		CSA(2)	Second polar angle at which fluxes are tabulated. CSA(2) > CSA(1)
		⋮	⋮
		CSA(NAMAX)	Last polar angle at which fluxes are tabulated.
73-80	2A4	---	Any information for card identification.

CARD 5, Fluxes at discrete polar angles

- NOTES: a) omit these cards if $IN5 \leq 0$.
b) supply these cards if $IN5 > 0$, one for each polar angle and in the order of the increasing polar angles (NAMAX physical cards).

COLUMN	FORMAT	SYMBOL	DEFINITION
1-72	8E9.0	FLUX(1,I)	6 Mev photon flux at polar angle CSA(I) (photons/cm ² sec).
		FLUX(2,I)	3 Mev photon flux at polar angle CSA(I) (photons/cm ² sec).
		FLUX(3,I)	1 Mev photon flux at polar angle CSA(I) (photons/cm ² sec).

CARD 5, continued

COLUMN	FORMAT	SYMBOL	DEFINITION
		FLUX(4,I)	7 Mev neutron flux at polar angle CSA(I) ($\frac{\text{neutrons}}{\text{cm}^2 \text{ sec}}$)
		FLUX(5,I)	3 Mev neutron flux at polar angle CSA(I) (neutrons/cm ² - sec)
		FLUX(6,I)	1 Mev neutron flux at polar angle CSA(I) (neutrons/cm ² - sec)
		FLUX(7,I)	0.1 Mev neutron flux at polar angle CSA(I) (neutrons/cm ² - sec)
		FLUX(8,I)	thermal neutron flux at polar angle CSA(I) (neutrons/cm ² - sec)
73-80	2A4	---	Any information for card identification.

CARD 6, Flux scaling factors.

NOTES:

- omit this card if $IN6 \leq 0$.
- supply this card if $IN6 > 0$.
- all numbers on this card are used and should be non-zero.

COLUMN	FORMAT	SYMBOL	DEFINITION
1-72	8E9.0	FAC(1)	Multiplicative scaling factor for group 1 input fluxes (6 Mev gammas) if they were not in the right units.
		FAC(2)	Multiplicative scaling factor for group 2 input fluxes (3 Mev gammas) in case they were not in the right units.
		•	
		•	
		•	
		FAC(8)	Multiplicative scaling factor for group 8 input fluxes (thermal neutrons) in case they were not in the right units.
73-80	2A4	---	Any information for card identification.

CARD 7, Tank wall cross sections

- NOTES: a) omit this card if $IN7 \leq 0$.
 b) supply this card if $IN7 > 0$

COLUMN	FORMAT	SYMBOL	DEFINITION
1-72	8E9.0	SGT(1)	Attenuation coefficient of tank wall for group 1 sources (cm^{-1})
		SGT(2)	Attenuation coefficient of tank wall for group 2 sources (cm^{-1})
		•	
		•	
73-80	2A4	•	
		SGT(8)	Attenuation coefficient of tank wall for group 8 sources (cm^{-1})

			any information for card identification

CARD 8, Tank wall capture gamma source

- NOTES: a) omit this card if $IN8 \leq 0$
 b) supply this card if $IN8 > 0$

COLUMN	FORMAT	SYMBOL	DEFINITION
1-72	8E9.0	ENG	Tank wall capture gamma ray energy (Mev)
		ACF	Attenuation coefficient of liquid hydrogen for tank wall capture gamma (cm^{-1})
		EAC	Energy absorption coefficient of liquid hydrogen for tank wall capture gamma (cm^{-1})
		FRA(1)	Fraction of 7 Mev neutrons removed by tank wall that are captured in wall
		FRA(2)	Fraction of 3 Mev neutrons removed by tank wall that are captured in the wall
		•	
		•	

CARD 8 (Continued)

COLUMN	FORMAT	SYMBOL	DEFINITION
		FRA(5)	Fraction of thermal neutrons removed by tank wall that are captured in the wall
73-80	2A4	---	Any information for card identification

CARD 9, Tank wall capture gamma buildup factor

- NOTES: a) omit this card if $IN9 \leq 0$
b) supply this card if $IN9 > 0$

COLUMN	FORMAT	SYMBOL	DEFINITION
1-36	4E9.0	BUF(1)	Constant term in cubic build representation
		BUF(2)	Coefficient of linear term in buildup
		BUF(3)	Coefficient of squared term in buildup
		BUF(4)	Coefficient of cubed term in buildup
37-72	4E9.0	---	These columns are not used and should be left blank
73-80	2A4	---	Any information for card identification

CARD 10, Tank geometry description

- NOTES: a) omit this card if $IN10 \leq 0$
b) supply this card (s) if $IN10 > 0$

COLUMN	FORMAT	SYMBOL	DEFINITION
1-72	8E9.0	ARE(1)	Radius of bottom of first tank section (ft)
		ZEE(1)	Height of bottom of first tank section (ft)
		ARE(2)	Radius of top of first tank section (ft) (= radius of bottom of second tank section)
		ZEE(2)	Height of top of first tank section (ft) (= height of bottom of second tank section)
		.	
		.	
		.	

CARD 10 (Continued)

COLUMN	FORMAT	SYMBOL	DEFINITION
		ARE(NRMAX + 1)	Radius of top of last tank section (ft)
		ZEE(NRMAX + 1)	Height of top of last tank section (ft)
73-80	2A4	----	Any information for card identification

CARD 11, Detector point parameters

NOTES: a) omit this card if $IN11 \leq 0$

b) supply this card for $IN11$ points if $IN11 > 0$

COLUMN	FORMAT	SYMBOL	DEFINITION
1-3	I3	I	Index of point being described
4-6	I3	INT(1, I)	Intervals in polar integration for capture gammas
7-9	I3	INT(2, I)	Intervals in azimuthal integration for capture gammas
10-12	I3	INT(3, I)	Intervals in distance integration for capture gammas
13-18	---	---	These columns are not used
19-27	E9.0	XD(1, I)	x coordinate of point (ft)
28-36	E9.0	XD(2, I)	y coordinate of point (ft)
37-45	E9.0	XD(3, I)	z coordinate of point (ft)
54-72	3E9.0	----	These columns are not used
73-80	2A4		Any information for card identification

NOTE: Use either $x = 0.0$ and $y = \text{radius}$
or $x = \text{radius}$ and $y = 0.0$

SECTION

5.0 SAMPLE PROBLEM

This sample problem is one of several calculations performed in the checkout of the TIC-TOC-TOE program. This particular problem does not employ all of the options coded in the program.

5.1 PROBLEM DESCRIPTION

This problem employed the propellant tank model described in Volume 1 of this report. The equivalent angular point sources were defined from fluxes obtained from the KAP-V point kernel program described in Volume 4.

The data cards for this problem are not shown since the data on the cards appear in the printout shown in Table 1. The first page of the printout, labeled CASE 1, PAGE 1 in the upper right hand corner, contains the input data. The first two lines of the printout contain the descriptive information as supplied on data cards A and B.

The remainder of the lines on this first printout page correspond to data cards 0 through 11. The printout contains the data in the same form as it was entered -- with one exception; the card identification in card columns 73-80 appears on the left side of the printout and is followed by three periods. Note: some of the data cards did not contain identification punches.

Two major characteristics of this problem are noted: (1) the neutron sources are input as zeros, and (2) the tank wall was not treated.

5.2 CALCULATED RESULTS

Discrete Points

The remainder of the Table 1 contains selected pages of the printout of the computed heating rates. The page identified as CASE 1, PAGE 2 contains pointwise heating rates for the individual points defined via card type 11. The columns on this printout page contain the point number, the point coordinates (radius and height) and the heating rates in watts/cm³

TABLE 1
TIC-TOC-TOE SAMPLE PROGRAM

TIC-TOC FOR NR-1 MSFC TANK 15 FEET SEPARATION CASE 1										**TIC-TOC AND TOE**CASE										1
GAMMA ONLY--GAMMA FROM KAP 10 FEET CORE + SEC										*ASTRONUCLEAR LAB*PAGE										1
0	1	1	1	1	1	1	1	1	1	1	10	-0	-0	-0	-0	-0	-0	-0	-0	-0
7	7	0	10	1	100	33	0	-0	-0	-0	-0	-0	-0	-0	-0	-0	-0	-0	-0	-0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	1	9	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	2	9	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	3	9	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	4	1	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	5	1	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	6	1	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	7	2	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	8	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	7	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	7	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	7	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	7	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	7	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	7	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	3	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	5	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	6	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	7	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	8	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	9	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	10	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

TIC-TOC FOR NR-1 MSFC TANK 15 FEET SEPARATION CASE 1										**TIC-TOC AND TOE**CASE			
GAMMA ONLY--GAMMA FROM KAP 10 FEET CORE + SEC										*ASTRONUCLEAR LAB*PAGE			
POINT INDEX	RADIUS (FEET)	HEIGHT (FEET)	6 MEV G	3 MEV G	1 MEV G	7 MEV N	3 MEV N	1 MEV N	HYDROGEN	WALL	TOTAL	1	2
			WATT/CC	WATT/CC	WATT/CC	WATT/CC	WATT/CC	WATT/CC	WATT/CC	WATT/CC	WATT/CC		
1	0.0000	15.1000	7.37E-04	1.75E-03	1.34E-03	0.	0.	0.	0.	0.	3.83E-03		
2	0.0000	15.5000	7.00E-04	1.66E-03	1.23E-03	0.	0.	0.	0.	0.	3.59E-03		
3	0.0000	16.0000	6.55E-04	1.55E-03	1.11E-03	0.	0.	0.	0.	0.	3.32E-03		
4	0.0000	18.0000	4.99E-04	1.17E-03	7.20E-04	0.	0.	0.	0.	0.	2.39E-03		
5	0.0000	20.0000	3.76E-04	8.65E-04	4.60E-04	0.	0.	0.	0.	0.	1.70E-03		
6	0.0000	26.5000	1.49E-04	3.09E-04	1.01E-04	0.	0.	0.	0.	0.	5.59E-04		
7	0.0000	31.5000	7.60E-05	1.35E-04	3.05E-05	0.	0.	0.	0.	0.	2.42E-04		
8	7.2000	17.5000	4.90E-04	1.12E-03	7.81E-04	0.	0.	0.	0.	0.	2.39E-03		
9	12.4000	22.4000	3.81E-04	7.43E-04	4.92E-04	0.	0.	0.	0.	0.	1.62E-03		
10	16.0000	30.0000	1.12E-04	1.43E-04	4.58E-05	0.	0.	0.	0.	0.	3.01E-04		

TIC-TOC FOR NR-1 MSFC TANK 15 FEET SEPARATION CASE 1														**TIC-TOC AND TOE**CASE				3
GAMMA ONLY--GAMMA FROM KAP 10 FEET CORE + SEC														*ASTRONUCLEAR LAB*PAGE				
POINT INDEX	RADIUS (FEET)	HEIGHT (FEET)	6 MEV G WATT/CC	3 MEV G WATT/CC	1 MEV G WATT/CC	7 MEV N WATT/CC	3 MEV N WATT/CC	1 MEV N WATT/CC	HYDROGEN WATT/CC	WALL WATT/CC	TOTAL WATT/CC							
1	0.0000	15.0000	7.46E-04	1.77E-03	1.37E-03	0.	0.	0.	0.	0.	3.89E-03							
2	0.1768	15.0000	7.41E-04	1.77E-03	1.36E-03	0.	0.	0.	0.	0.	3.87E-03							
3	0.2501	15.0000	7.38E-04	1.77E-03	1.36E-03	0.	0.	0.	0.	0.	3.86E-03							
4	0.3063	15.0000	7.37E-04	1.76E-03	1.35E-03	0.	0.	0.	0.	0.	3.85E-03							
5	0.3537	15.0000	7.35E-04	1.76E-03	1.35E-03	0.	0.	0.	0.	0.	3.85E-03							
6	0.3954	15.0000	7.34E-04	1.76E-03	1.35E-03	0.	0.	0.	0.	0.	3.84E-03							
7	0.4332	15.0000	7.33E-04	1.76E-03	1.35E-03	0.	0.	0.	0.	0.	3.84E-03							
8	0.4679	15.0000	7.32E-04	1.76E-03	1.34E-03	0.	0.	0.	0.	0.	3.83E-03							
9	0.5002	15.0000	7.31E-04	1.76E-03	1.34E-03	0.	0.	0.	0.	0.	3.83E-03							
10	0.5305	15.0000	7.30E-04	1.75E-03	1.34E-03	0.	0.	0.	0.	0.	3.82E-03							
11	0.5592	15.0000	7.29E-04	1.75E-03	1.34E-03	0.	0.	0.	0.	0.	3.82E-03							
12	0.5865	15.0000	7.28E-04	1.75E-03	1.34E-03	0.	0.	0.	0.	0.	3.82E-03							
13	0.6126	15.0000	7.28E-04	1.75E-03	1.34E-03	0.	0.	0.	0.	0.	3.82E-03							
14	0.6376	15.0000	7.27E-04	1.75E-03	1.34E-03	0.	0.	0.	0.	0.	3.81E-03							
15	0.6617	15.0000	7.26E-04	1.75E-03	1.33E-03	0.	0.	0.	0.	0.	3.81E-03							
16	0.6849	15.0000	7.26E-04	1.75E-03	1.33E-03	0.	0.	0.	0.	0.	3.81E-03							
17	0.7074	15.0000	7.25E-04	1.75E-03	1.33E-03	0.	0.	0.	0.	0.	3.80E-03							
18	0.7291	15.0000	7.24E-04	1.75E-03	1.33E-03	0.	0.	0.	0.	0.	3.80E-03							
19	0.7503	15.0000	7.24E-04	1.75E-03	1.33E-03	0.	0.	0.	0.	0.	3.80E-03							
20	0.7708	15.0000	7.23E-04	1.74E-03	1.33E-03	0.	0.	0.	0.	0.	3.80E-03							
21	0.7909	15.0000	7.23E-04	1.74E-03	1.33E-03	0.	0.	0.	0.	0.	3.79E-03							
22	0.8104	15.0000	7.22E-04	1.74E-03	1.33E-03	0.	0.	0.	0.	0.	3.79E-03							
23	0.8295	15.0000	7.22E-04	1.74E-03	1.33E-03	0.	0.	0.	0.	0.	3.79E-03							
24	0.8481	15.0000	7.21E-04	1.74E-03	1.32E-03	0.	0.	0.	0.	0.	3.79E-03							
25	0.8664	15.0000	7.21E-04	1.74E-03	1.32E-03	0.	0.	0.	0.	0.	3.78E-03							
26	0.8842	15.0000	7.20E-04	1.74E-03	1.32E-03	0.	0.	0.	0.	0.	3.78E-03							
27	0.9017	15.0000	7.20E-04	1.74E-03	1.32E-03	0.	0.	0.	0.	0.	3.78E-03							
28	0.9189	15.0000	7.19E-04	1.74E-03	1.32E-03	0.	0.	0.	0.	0.	3.78E-03							
29	0.9358	15.0000	7.19E-04	1.74E-03	1.32E-03	0.	0.	0.	0.	0.	3.77E-03							
30	0.9523	15.0000	7.18E-04	1.74E-03	1.32E-03	0.	0.	0.	0.	0.	3.77E-03							
31	0.9686	15.0000	7.18E-04	1.73E-03	1.32E-03	0.	0.	0.	0.	0.	3.77E-03							
32	0.9846	15.0000	7.17E-04	1.73E-03	1.32E-03	0.	0.	0.	0.	0.	3.77E-03							
33	1.0004	15.0000	7.17E-04	1.73E-03	1.32E-03	0.	0.	0.	0.	0.	3.77E-03							
RADIAL AVERAGES		15.0000	7.26E-04	1.75E-03	1.33E-03	0.	0.	0.	0.	0.	3.81E-03							
VOLUME AVERAGES		15.0000	7.26E-04	1.75E-03	1.33E-03	0.	0.	0.	0.	0.	3.81E-03							
RADIAL AVERAGES NO-MIX TEMPERATURE RISE TO OUTLET AND CORRESPONDING TIME		15.0000	7.04E-04	1.67E-03	1.25E-03	0.	0.	0.	0.	0.	3.62E-03							
34	0.0000	15.4500	7.04E-04	1.67E-03	1.25E-03	0.	0.	0.	0.	0.	3.62E-03							

TIC-TOC FOR NR-1 MSFC TANK 15 FEET SEPARATION CASE 1											1	
GAMMA ONLY--GAMMA FROM KAP 10 FEET CORE + SEC											**TIC-TOC AND TOE**CASE	
											*ASTRONUCLEAR LAB*PAGE	
											101	
POINT INDEX	RADIUS (FEET)	HEIGHT (FEET)	6 MEV G	3 MEV G	1 MEV G	7 MEV N	3 MEV N	1 MEV N	HYDROGEN	WALL	TOTAL	
			WATT/CC	WATT/CC	WATT/CC	WATT/CC	WATT/CC	WATT/CC	WATT/CC	WATT/CC	WATT/CC	
3327	14.4222	60.0000	2.26E-06	4.93E-07	1.09E-08	0.	0.	0.	0.	0.	2.76E-06	
3328	14.6969	60.0000	2.22E-06	4.76E-07	1.04E-08	0.	0.	0.	0.	0.	2.70E-06	
3329	14.9666	60.0000	2.18E-06	4.60E-07	1.00E-08	0.	0.	0.	0.	0.	2.65E-06	
3330	15.2315	60.0000	2.14E-06	4.44E-07	9.57E-09	0.	0.	0.	0.	0.	2.59E-06	
3331	15.4919	60.0000	2.10E-06	4.29E-07	9.18E-09	0.	0.	0.	0.	0.	2.54E-06	
3332	15.7480	60.0000	2.06E-06	4.14E-07	8.79E-09	0.	0.	0.	0.	0.	2.49E-06	
3333	16.0000	60.0000	2.03E-06	3.98E-07	8.39E-09	0.	0.	0.	0.	0.	2.44E-06	
RADIAL AVERAGES		60.0000	2.86E-06	6.69E-07	1.58E-08	0.	0.	0.	0.	0.	3.55E-06	
VOLUME AVERAGES		60.0000	6.11E-05	1.12E-04	4.85E-05	0.	0.	0.	0.	0.	2.21E-04	
RADIAL AVERAGED NO-MIX TEMPERATURE RISE TO OUTLET AND CORRESPONDING TIME.....											2.70E-01	4.61E+02
TOTALS (WATTS).....											0.	1.94E+05
COMPLETE MIX TEMPERATURE RISE AND CORRESPONDING TIME.....											0.	0.
COMPLETE MIX TEMPERATURE RISE AND CORRESPONDING TIME.....											1.05E-03	5.39E+00
COMPLETE MIX TEMPERATURE RISE AND CORRESPONDING TIME.....											5.30E-03	1.08E+01
COMPLETE MIX TEMPERATURE RISE AND CORRESPONDING TIME.....											7.45E-03	1.62E+01
COMPLETE MIX TEMPERATURE RISE AND CORRESPONDING TIME.....											1.18E-02	2.15E+01
COMPLETE MIX TEMPERATURE RISE AND CORRESPONDING TIME.....											1.40E-02	2.69E+01
COMPLETE MIX TEMPERATURE RISE AND CORRESPONDING TIME.....											1.85E-02	3.23E+01
COMPLETE MIX TEMPERATURE RISE AND CORRESPONDING TIME.....											2.07E-02	3.77E+01
COMPLETE MIX TEMPERATURE RISE AND CORRESPONDING TIME.....											2.53E-02	4.31E+01
COMPLETE MIX TEMPERATURE RISE AND CORRESPONDING TIME.....											2.76E-02	4.85E+01
COMPLETE MIX TEMPERATURE RISE AND CORRESPONDING TIME.....											3.23E-02	5.39E+01
COMPLETE MIX TEMPERATURE RISE AND CORRESPONDING TIME.....											3.47E-02	5.92E+01
COMPLETE MIX TEMPERATURE RISE AND CORRESPONDING TIME.....											3.95E-02	6.46E+01
COMPLETE MIX TEMPERATURE RISE AND CORRESPONDING TIME.....											4.19E-02	7.00E+01
COMPLETE MIX TEMPERATURE RISE AND CORRESPONDING TIME.....											4.69E-02	7.54E+01
COMPLETE MIX TEMPERATURE RISE AND CORRESPONDING TIME.....											4.94E-02	8.08E+01
COMPLETE MIX TEMPERATURE RISE AND CORRESPONDING TIME.....											5.44E-02	8.62E+01
COMPLETE MIX TEMPERATURE RISE AND CORRESPONDING TIME.....											5.70E-02	9.16E+01
COMPLETE MIX TEMPERATURE RISE AND CORRESPONDING TIME.....											6.22E-02	9.69E+01
COMPLETE MIX TEMPERATURE RISE AND CORRESPONDING TIME.....											6.49E-02	1.02E+02
COMPLETE MIX TEMPERATURE RISE AND CORRESPONDING TIME.....											7.03E-02	1.08E+02
COMPLETE MIX TEMPERATURE RISE AND CORRESPONDING TIME.....											7.30E-02	1.13E+02
COMPLETE MIX TEMPERATURE RISE AND CORRESPONDING TIME.....											7.85E-02	1.18E+02
COMPLETE MIX TEMPERATURE RISE AND CORRESPONDING TIME.....											8.13E-02	1.24E+02
COMPLETE MIX TEMPERATURE RISE AND CORRESPONDING TIME.....											8.70E-02	1.29E+02
COMPLETE MIX TEMPERATURE RISE AND CORRESPONDING TIME.....											8.99E-02	1.35E+02

for the 3 gamma ray groups, the 3 fast neutron groups (zero for this problem), the propellant capture gammas, and the tank wall capture gammas, respectively. The last column is the total heating rate.

Volume Integration

The next part of the printout contains quantities obtained from the volume integration. The page identified by CASE 1, PAGE 3 contains the first part of the results of this integration. The major portion of this page is the pointwise heating rate as obtained during the area integration over the bottom of the tank. These results are read in the same manner as the preceding page for points entered via Card type 11.

The three lines following the discrete points 1 through 33 contain the area averaged heating rates (watts/cm^3) at the tank bottom, the volume averaged heating rates (watts/cm^3) for all the propellant below the indicated height of 15 feet, and the radial averaged temperature rise and corresponding time (seconds) assuming no mixing of the propellant.

The printout for the volume integration proceeds in this manner for each z-plane generated during the volume integration. The page labeled CASE 1, PAGE 101 contains the final points generated in the area integration at the upper propellant level. After the usual summaries of radial and volume averaged heating rates and of no mix temperature rise, there is a summary of the total heating rate (watts) by energy group obtained from the volume integration.

After the summary line containing volume integrated heating rates, the complete mix temperature rise and time (seconds), respectively, are printed for each of the axial positions generated during the volume integration. The remainder of the printout for this problem consisted of similar complete-mix temperature rise results.

6.0 REFERENCES

1. M. O. Burrell, "Nuclear Radiation Transfer and Heat Deposition Rates in Liquid Hydrogen", NASA-TND-1115, August 1962.
2. H. C. Woodsum, P. C. Heiser, "Tank Heating Codes, TIC-TOC and TOE for the IBM-7090 Computer", WANL-TNR-083, January 1963.
3. "IBM 7090/7094 Programming Systems FORTRAN IV Language", C23-6274-1, May 1963.

APPENDIX A

LISTING OF PROGRAM

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$IBFTC TIC TAC M94/2,XR7
CTIC TOC*(T)TEMPERATURE (I)N (C)OOLANT (T)ANK AND (O)THER (C)ALCULATIONS
DATA PI/3.1415927/
COMMON/INPUTS/IN1 ,IN2 ,IN3 ,IN4 ,IN5 ,IN6 ,IN7 ,
IN8 ,IN9 ,IN10 ,IN11 ,IN12 ,IN13 ,IN14 ,
IN15 ,IN16 ,IN17 ,IN18 ,IN19 ,IN20 ,IN21 ,
IN22 ,IN23 ,IN24 ,
COMMON/TAPEID/M1 ,M2
COMMON/CASEID/KASE ,NPAG ,LINES ,LINEX ,YTILEA(20) ,YTILEB(20)
COMMON/LIMITS/NAMAX ,NRNA ,NTOE ,NPOINT,NVOLYM,NIZMAX,NIRMAX,
NITMAX,IPMAX ,ITMAX ,ISMAX ,LIM(13)
1 COMMON/SOURCE/XS(3) ,RADIUS,WALL ,ADUM1 ,ADUM2 ,ADUM3 ,CSA(25),
FLUX(8,25)
1 COMMON/REGION/ARE(25) ,ZEE(25)
DIMENSION INT(3,100),XD(3,100),ALP(3,100)
DIMENSION X(3),C(3),FAC(8),ADM(18),H(2),OUT(9),HEAT(9)
EQUIVALENCE (X(1),X1),(X(2),X2),(X(3),X3),(C(1),C1),(C(2),C2)
1,(C(3),C3)
COMMON/WALLAL/SGT(8),ENG,ACF,EAC,FRA(5),BUF(4)
DIMENSION HRAD(9),VOL(1000),TIME(1000),DEP(1000)
SIMSON(I,J) = FLOAT(4 - 2*(I - 2*(I/2)) - 1/I - 1/J)
M1 = 5
M2 = 6
KASE = 0
LINEX = 40
DO 5 I=1,10
5 XYZ = (1.0E-30)**2
10 READ(M1,1000)YTILEA,YTILEB
KASE = KASE + 1
NPAGE = 0
LINES = LINEX + 1
CALL READI(24,IN1)
IF(IN1.LE.0)GO TO 30
DO 20 I=1,IN1
20 CALL READA(18,ADM)
30 IF(IN2.GT.0)CALL READI(24,NAMAX)
IF(IN3.GT.0)CALL READE(8,XS)
IF(IN4.LE.0)GO TO 50
CALL READE(NAMAX,CSA)
DO 40 I=1,NAMAX
40 CSA(I) = COS(CSA(I)*PI/180.0)
50 IF(IN5.LE.0)GO TO 70
FST = 4.0*PI*(2.54*12.0*RADIUS)**2
DO 60 I=1,NAMAX
CALL READE(8,FLUX(1,I))
DO 60 J=1,8
60 FLUX(J,I) = FST*FLUX(J,I)

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048 70 IF(IN6.LE.0)GO TO 90
049   CALL READE(8,FAC)
050   DO 80 I=1,NAMAX
051     DO 80 J=1,8
052       80 FLUX(J,I) = FAC(J)*FLUX(J,I)
053     90 IF(IN7.GT.0)CALL READE(8,SGT)
054     IF(IN8.GT.0)CALL READE(8,ENG)
055     IF(IN9.GT.0)CALL READE(4,BUF)
056     IF(IN10.GT.0) CALL READEE(NRMAX+1,ARE,ZEE)
057     IF(IN11.LE.0) GO TO 110
058     DO 100 N=1,IN11
059     READ(M1,1010)I,(INT(J,I),J=1,3),(XD(J,I),J=1,3),(ALP(J,I),J=1,3),H
060     IF(LABEL(1).GE.0)WRITE(M2,2000)H,I,(INT(J,I),J=1,3),(XD(J,I),J=1,3
061     1),(ALP(J,I),J=1,3)
062   100 CONTINUE
063   1000 FORMAT(20A4)
064   1010 FORMAT(4I3,6X,6E9.0,2A4)
065   2000 FORMAT(1X,2A4,3(1H.),4I4,8X,1P6E12.4)
066   110 IF(NPOINT.LE.0)GO TO 130
067     LINES = LINEX + 1
068   C POINT DETECTORS
069     DO 120 I=1,NPOINT
070     120 CALL POINT(INT(1,I),ALP(1,I),XD(1,I),OUT,I)
071     130 IF(NVOLYM.EQ.0)GO TO 10
072     LINES = LINEX + 1
073     N = 0
074   C VOLUME INTEGRATION
075     NIZMOD = MAX0(3,2*(NIZMAX/2)+1)
076     NIRM0D = MAX0(3,2*(NIRM0X/2)+1)
077     NITMOD = MAX0(1,2*(NITMAX/2)+1)
078     DZ = (ZEE(NRMAX+1) - ZEE(1))/FLOAT(NIZMOD - 1)
079     DT = PI/FLOAT(MAX0(1,NITMOD-1))
080     X3 = ZEE(1) - DZ
081     DO 140 J=1,9
082     140 HEAT(J) = 0.0
083     RSQUAP = 0.0
084     VOLTOT = 0.0
085     DO 160 III=1,NIZMOD
086     X3 = X3 + DZ
087     DO 145 J=1,9
088     145 HRAD(J) = 0.0
089     SRZ = SIMSON(III,NIZMOD)*DZ*30.48/3.0
090     X1 = 0.0
091     X2 = 0.0
092     C1 = 1.0
093     C2 = 0.0
094     C3 = 0.0

```



```
095 RSQUAR = PATH(X,C)**2
096 DRS = RSQUAR/FLOAT(NIRMOD - 1)
097 RSQ = -DRS
098 DO 150 JJJ=1,NIRMOD
099 RSQ = RSQ + DRS
100 R = SQRT(AMAX1(0.0,RSQ))
101 SRR = SIMSON(JJJ,NIRMOD)*DRS*30.48**2/6.0
102 THE = -DT
103 DO 150 KKK=1,NITMOD
104 THE = THE + DT
105 X1 = R*COS(TH)
106 X2 = R*SIN(TH)
107 SRT = 2.0*PI
108 IF(NITMOD.GT.1) SRT = SIMSON(KKK,NITMOD)*DT/1.5
109 N = N + 1
110 CALL POINT(IPMAX,ADUM1,X,OUT,N)
111 SRA = SRT*SRR
112 SRB = SRA*SRZ
113 DO 150 J=1,9
114 HRAD(J) = HRAD(J) + SRA*OUT(J)
115 HEAT(J) = HEAT(J) + SRB*OUT(J)
116 AREA = PI*RSQUAR*30.48**2
117 DO 155 J=1,9
118 HRAD(J) = HRAD(J)/AREA
119 IF(LABEL(1).GE.0) WRITE(M2,2010)X3,HRAD
120 FORMAT(1X,16HRADIAL AVERAGES ,OPF10.4,1P9E9.2)
121 VOLUME = PI*DZ*(RSQUAR + SQRT(RSQUAR*RSQUAP) + RSQUAP)*30.48**3/3.
122 RSQUAP = RSQUAR
123 IF(III.EQ.1) VOLUME = 0.0
124 VOLTOT = VOLTOT + VOLUME
125 FST = DZ*30.48*AREA/3.0
126 IF(III.GT.1) FST = VOLTOT
127 DO 156 J=1,9
128 HRAD(J) = HEAT(J)/FST
129 IF(LABEL(1).GE.0) WRITE(M2,2020) X3,HRAD
130 FORMAT(1X,16HVOLUME AVERAGES ,OPF10.4,1P9E9.2)
131 TIME(III) = VOLTOT/(ADUM1*30.48**3)
132 TEMP = HEAT(9)/(ADUM1*ADUM2)
133 IF(III.EQ.1) TEMP = 0.0
134 IF(LABEL(1).GE.0) WRITE(M2,2030)TEMP,TIME(III)
135 FORMAT(1X,72HRADIAL AVERAGED NO-MIX TEMPERATURE RISE TO OUTLET AND
136 1 CORRESPONDING TIME,17(1H.),1P2E9.2)
137 DEP(III) = HRAD(9)*AREA *SRZ
138 IF(III.GT.1) DEP(III) = DEP(III) + DEP(III - 1)
139 160 CONTINUE
140 CALL OUTPUT(0.0,0.0,0.0,HEAT)
141 J = NIZMOD + 1
```

```

142 DO 170 I=1,NIZMOD
143 J = J - 1
144 DELT = TIME(NIZMOD) - TIME(J)
145 TEMP = (DEP(NIZMOD) - DEP(J))/(ADUM1*ADUM2)
146 IF(LABEL(1).GE.0) WRITE (M2,2050)TEMP,DELT
147 2050 FORMAT(1X,53HCOMPLETE MIX TEMPERATURE RISE AND CORRESPONDING TIME,
148 136(1H.),1P2E9.2)
149 170 CONTINUE
150 GO TO 10
151 END
152
153 $IBFTC XPOINT M94/2,XR7
154 CPOINT VALUES OF HEATING
155 SUBROUTINE POINT(INT,ALP,X,OUT,N)
156 COMMON/RRRRRR/RADMAX
157 COMMON/WALLAL/SGT(8),ENG,ACF,EAC,FRA(5),BUF(4)
158 COMMON/TAPEID/NI,M2
159 COMMON/CASEID/KASE,NPAGE,LINES,LINEX,TITLEA(20),TITLEB(20)
160 COMMON/LIMITS/NAMAX,NRMAX,NTOE,NPOINT,NVOLYM,NIZMAX,NIRMAX,
161 NITMAX,IPMAX,ITMAX,ISMAX,LIM(13)
162 1 COMMON/SOURCE/XS(3),RADIUS,WALL,ADUM1,ADUM2,ADUM3,CSA(25),
163 FLUX(8,25)
164 EQUIVALENCE (WALL,TWALL)
165 COMMON/REGION/ARE(25),ZEE(25)
166 COMMON/ROTATE/THETAZ
167 DIMENSION FLX(6),OUT(9),X(3),C(3)
168 EQUIVALENCE (C(3),C3)
169 DIMENSION AAA(72),AA(12,6)
170 EQUIVALENCE (AA,AAA)
171 DATA AAA
172 10.0,-0.0844,1.7,0.0,0.0,0.1828,
173 20.000391,0.004375,0.18,3.555E-5,0.001592,0.0714,
174 1-0.0017,-0.02,1.2,0.0,0.0,0.1755,
175 20.0,0.0,0.0,0.0,0.0,0.0,0.0,
176 1-0.0005,-0.025,0.72,0.0,0.0,0.25,
177 20.0,0.0,0.0,0.0,0.0,0.0,0.0,
178 10.0,-5.7,88.0,0.00434,-0.0411,1.547,
179 20.05,3.95,-58.0,0.0089,-0.02,2.725,
180 1-0.25,-0.15,66.0,0.0044,0.022,2.55,
181 20.21,-0.25,-42.0,0.0085,-0.0285,3.91,
182 1-0.275,-0.1,66.0,0.003,0.125,5.18,
183 20.26,-0.3,-52.0,0.0054,0.148,7.23,
184 COMMON/NORMAL/DSN
185 DO 115 J=1,9
186 115 OUT(J) = 0.0
187 STD = VECTOR(X,XS,C)
188 STW = PATH(X,C)
189 R = 0.0

```

```

189 DO 130 J=1,2
190 130 R = R + X(J)**2
191 R = SQRT(R)
192 THE = 0.0
193 IF(R.GT.0.0) THE = ATAN2(X(2),X(1))
194 THETAZ = THE
195 PSI = -C3
196 Z = PSI*STW
197 FST = ((Z + 11.25)**2 + R**2)/STD**2
198 Q = R
199 DO 140 J=2,NAMAX
200 IF(PSI.GE.CSA(J))GO TO 150
201 140 CONTINUE
202 J = NAMAX
203 150 K = J - 1
204 FST = FST/(CSA(K) - CSA(J))
205 AST = FST*(PSI - CSA(J))
206 BST = FST*(CSA(K) - PSI)
207 TTW = 30.48*TWALL/DSN
208 DO 160 L=1,6
209 160 OUT(L)=6.43E-22*CURVE(R,Z,AA(1,L),0.0)
210 *{AST*FLUX(L,K)+BST*FLUX(L,J)}
211 1*EXP(-TTW*SGT(L))
212 IF(INTOE.GT.0) CALL TOE(INT,ALP,X,OUT(7))
213 CALL OUTPUT(N,Q,THE,X(3),OUT)
214 180 CONTINUE
215 RETURN
216 END
217 $IBFTC TOEHOE M94/2,XR7
218 CTOE *CAPTURE GAMMA RAY HEATING
219 SUBROUTINE TOE(INP,ALP,XX,OUT)
220 COMMON/ROTATE/THETAZ
221 COMMON/LIMITS/NAMAX,LIM(23)
222 COMMON/SOURCE/XS(3),RZERO,ADUMMY(4),CSA(25),FLUX(8,25)
223 EQUIVALENCE (ADUMMY(1),TWALL)
224 DIMENSION INP(3),ALP(3),XX(3),HOUT(5),INT(3),ALF(3),XD(3),UZERO(3)
225 1,DEL(3),C(3),XMIN(3),XMAX(3),X(3),CP(3),CAP(5)
226 DATA XMIN/-1.0,0.0,0.0/XMAX/1.0,3.141593,1.0/
227 EQUIVALENCE (INT(1),INTU),(INT(2),INTV),(INT(3),INTW)
228 COMMON/NORMAL/DSN
229 COMMON/WALLAL/SGT(81),EWG,ACF,EAC,FRA(5),BUF(4)
230 SIMSON(I,J) = FLOAT(4 - 2*(I - 2*(I/2)) - 1/I - I/J)/3.0
231 DIMENSION OUT(2)
232 COMMON/RRRRRR/RACMAX
233 DO 10 I=1,3
234 ALF(I) = ALP(I)
235 XD(I) = XX(I)
236

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237 INT(I) = INP(I) + 1
239 UZERO(I) = XMIN(I)
240 10 DEL(I) = (XMAX(I) - XMIN(I))/FLOAT(INT(I) - 1)
241 FLXUVW = 0.0
242 CAPUVW = 0.0
243 DO 250 NNN=1,INTU
244 U = UZERO(I) + FLOAT(NNN-1)*DEL(I)
245 C(3) = U
246 SNP = SQRT(1.0 - C(3)**2)
247 FLXVW = 0.0
248 CAPVW = 0.0
249 DO 200 MM=1,INTV
250 V = UZERO(2) + FLOAT(MM-1)*DEL(2)
251 THE = V + THETAZ
252 C(1) = SNP*COS(THE)
253 C(2) = SNP*SIN(THE)
254 XMAX(3) = PATH(XD,C)
255 DSNW = DSN
256 DEL(3) = (XMAX(3) - XMIN(3))/FLOAT(INT(3) - 1)
257 FLXW = 0.0
258 DO 150 LLL=1,INTW
259 W = UZERO(3) + FLOAT(LLL - 1)*DEL(3)
260 S = W
261 IF(LLL.GT.1.OR.(MMH+ NNN).LE.2) GO TO 30
262 CAPT = FLUXZ
263 GO TO 100
264
265 30 STS = 0.0
266 DO 40 I=1,3
267 X(I) = XD(I) + C(I)*S
268 CP(I) = XS(I) - X(I)
269 40 STS = STS + CP(I)**2
270 STM = SQRT(STS)
271 DO 50 I=1,3
272 CP(I) = CP(I)/STM
273 STB = PATH(X,CP)
274 RSQ = X(1)**2 + X(2)**2
275 RAD = SQRT(RSQ)
276 ZPR = -STB*CP(3)
277 CALL GAMMAS(RAD,ZPR,CAP)
278 PSI = -CP(3)
279 DO 60 I=2,NAMAX
280 IF(PSI .GT.CSA(I))GO TO 70
281 60 CONTINUE
282 I = NAMAX
283 70 AST =(PSI - CSA(I))/(CSA(I-1) - CSA(I))
284 BST =(CSA(I-1) - PSI)/(CSA(I-1) - CSA(I))
285 ITW = 30.48*TWALL/DSN

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286 CAPW = 0.0
287 CAPT = 0.0
238 DO 80 J=1,5
288 ATN = EXP(-TTW*SGT(J+3))
289 FLX = ATN*(AST*FLUX(J+3,I-1) + BST*FLUX(J+3,I))
290 CAPT = CAPT + FLX*CAP(J)
291 80 CAPW = CAPW + FLX*(1./ATN-1.)*FRA(J)
292 C CAPTURES IN TANK
293 CAPT=CAPT*5.46E-15*(1.+S*(.13636+S*5.33E-4))*EXP(-.1771*S)
294 1 *(RSQ*(ZPR+11.25)*2)/STS
295
296 IF(LLL.EQ.1) FLUXZ = CAPT
297 100 FLXW = FLXW + CAPT *DEL(3)*SIMSON(LLL,INTW)
298 140 CAPZ = 0.0
299 IF(LLL.LT.INTW) GO TO 150
300 IF(STB.GT.0.01) GO TO 150
300 IF(DSNW.LT.0.01) GO TO 150
301 C CAPTURES IN WALL, BUILDUP AND ATTENUATION
302 BUP = BUF(4)
303 XMP = S*ACF*30.48
304 DO 141 I=1,3
305 J = 4 - I
306 141 BUP = XMP*BUP + BUF(J)
307 CAPZ=CAPW*2.17E-18*ENG*EAC*BUP*EXP(-XMP)*DSN/(DSNW*STS)
308
309 C 150 CONTINUE
310 SRC = DEL(2)*SIMSON(MMM,INTV)
311 FLXVW = FLXVW + SRC*FLXW
312 CAPVW = CAPVW + SRC*CAPZ
313 190 VP = V
314 200 CONTINUE
315 IF(FLXVW.EQ.0.0) GO TO 999
316 SRC = DEL(1)*SIMSON(NNN,INTU)
317 FLXUVW = FLXUVW + SRC*FLXVW
318 CAPUVW = CAPUVW + SRC*CAPVW
319 240 UP = U
320 250 CONTINUE
321 999 OUT(1) = FLXUVW
322 OUT(2) = CAPUVW
323 RETURN
324 END
325 $IBFTC CAPGAM M94/2,XR7
326 CGAMMAS*CAPTURE GAMMA SOURCES
327 SUBROUTINE GAMMAS(R,Z,S)
328 DIMENSION S(5),AAA(60),AA(12,5),BBB(6),BB(3,2) ,CUT(5)
329 EQUIVALENCE (AA,AAA),(BB,BBB)
330 DATA CUT,BBB,AAA
```

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11.0E+30 ,1.0 ,0.833 ,1.0E+30 ,1.0E+30 ,
20.0 ,0.032 ,2.47 ,0.0088 ,0.048 ,8.34
10.0 ,0.058 ,1.14 ,0.0 ,0.036 ,1.42
20.0 ,0.057 ,1.11 ,0.0 ,0.046 ,1.82
10.0 ,0.041 ,0.9 ,0.001368 ,0.0382 ,2.107
20.0 ,0.039 ,0.85 ,0.000295 ,0.0683 ,3.547
10.0 ,0.115 ,2.27 ,0.0 ,0.134 ,3.44
20.0 ,0.113 ,2.22 ,0.0 ,0.196 ,4.8
10.00498 ,0.245 ,3.12 ,0.0 ,0.0 ,7.67
2-0.00448 ,0.22 ,2.83 ,0.0 ,0.0 ,12.38
10.0183 ,0.683 ,10.0 ,0.0573 ,0.233 ,22.2
2-0.0153 ,0.483 ,6.5 ,0.108 ,0.5 ,30.6
DO 10 I=1,5
FST = 0.0
IF((I-2)*(I-3)).NE.0) GO TO 10
ZP = CUT(I) - Z
IF(ZP.GE.0.0) GO TO 10
DO 20 J=1,3
20 FST = R*FST + B8(J,I-1)
10 S(I) = 1.0E-7*CURVE(R,AMIN1(CUT(I),Z),AA(1,I),ZP*FST)
RETURN
END

$IBFTC OUTPUT M94/2,XR7
COUTPUT*PRINTOUT OF PCINT HEATING RATES*T.M.JORDAN*WANL*DECEMBER 1966***
SUBROUTINE OUTPUT(N,ARE,THE,ZEE,DOT)
COMMON/TAPE10/M1 ,M2
DIMENSION DOT(9)
THE = THE
DOT(9) = 0.0
DO 10 J=1,8
DOT(J) = AMAX1(0.0,DOT(J))
10 DOT(9) = DOT(9) + DOT(J)
IF(LABEL(1).GT.0) WRITE(M2,2000)
IF(N.EQ.0) GO TO 20
WRITE(M2,2010)N,ARE,ZEE,DOT
GO TO 40
20 WRITE(M2,2020)DOT
40 RETURN
2000 FORMAT(1X,10THPOINT ,RADIUS ,HEIGHT ,6 MEV G ,3 MEV G ,1 MEV
IG 7 MEV N ,3 MEV N ,1 MEV N HYDROGEN ,WALL ,TOTAL/1X,6INDEX
2 ,2(10H (FEET)),9(9H WATT/CC))
2010 FORMAT(16,OPF11.4,F10.4,1P9E9.2)
2020 FORMAT(1X,14HTOTALS (WATTS),12(1H.),1P9E9.2)
END

$IBFTC TRACE M94/2,XR7
CPATH * PATH LENGTH IN TANK
FUNCTION PATH(XP,CP)

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378 COMMON/LIMITS/NAMAX,NRMAX,NPOINT,LI(21)
379 COMMON/REGION/ARE(25),ZEE(25)
380 DIMENSION XP(3),CP(3),X(3),C(3)
381 COMMON/RRRRRR/RADMAX
382 DIMENSION XN(3),CN(3)
383 COMMON/NORMAL/DSN
384 DSN = ABS(CP(3))
385 DO 10 I=1,3
386   X(I) = XP(I)
387   C(I) = CP(I)
388   X(3) = AMAX1(ZEE(I)+0.0001,X(3))
389   X(3) = AMIN1(ZEE(NRMAX+1)-0.0001,X(3))
390 DO 20 I=1,NRMAX
391   IF(ZEE(I+1)-GT.X(3))GO TO 30
392 20 CONTINUE
393 I = NRMAX
394 RADMAX = ARE(I) + (X(3) - ZEE(I))*(ARE(I+1)-ARE(I))/(ZEE(I+1) -
395   ZEE(I))
396 IF(C(3)) 40,50,60
397 40 MIN = 1
398 MAX = I
399 STM = (ZEE(I) - X(3))/C(3)
400 GO TO 70
401 50 MIN = I
402 MAX = I
403 STM = 1.0E+30
404 GO TO 70
405 60 MIN = I
406 MAX = NRMAX
407 STM = (ZEE(NRMAX+1) - X(3))/C(3)
408 RADACT = SQRT(X(1)**2 + X(2)**2)
409 IF(RADACT.LT.RADMAX) GO TO 79
410 FST =(RADMAX - 0.0001)/RADACT
411 DO 75 I=1,2
412   X(I) = X(I)*FST
413 79 DO 110 I = MIN,MAX
414   AA = (ARE(I+1) - ARE(I))/(ZEE(I+1) - ZEE(I))
415   BB = ARE(I) - AA*ZEE(I)
416   Z = AA*X(3) + BB
417   ZC = AA*C(3)
418   AQ = C(1)**2 + C(2)**2 - ZC**2
419   BQ = Z*ZC - X(1)*C(1) - X(2)*C(2)
420   CQ = X(1)**2 + X(2)**2 - Z**2
421   IF(AQ.NE.0.0)GO TO 80
422   IF(BQ.EQ.0.0)GO TO 110
423   SP = 2.0*CQ/BQ
424   GO TO 90

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424 80 BQ = BQ/AQ
425 CQ = BQ**2 - CQ/AC
426 IF(CQ.LE.0.0)GO TO 110
427 CQ = SQRT(CQ)
428 SP = BQ - CQ
429 IF(SP.GT.0.0)GO TO 1C0
430 SP = BQ + CQ
431 90 IF(SP.LT.0.0)GO TO 110
432 100 IF(SP.GT.STM) GO TO 110
433 DO 101 J=1,3
434 XN(J) = X(J) + SP*C(J)
435 101 CN(J) = XN(J)
436 CN(3) = - AA*(AA*XN(3) + BB)
437 FST = 0.0
438 GST = 0.0
439 DO 102 J=1,3
440 FST = FST + C(J)*CN(J)
441 102 GST = GST + CN(J)**2
442 IF(FST.LE.0.0) GO TO 110
443 JJ = J
444 STM = SP
445 DSN = FST/SQRT(GST)
446 110 CONTINUE
447 PATH = STM
448 RETURN
449 END
450 $IBFTC LABEL M94/2,XR7
451 CLABEL *OUTPUT PAGE HEADINGS FOR PROGRAM FASTER* T.M.JORDAN*WANL*OCT.1966
452 FUNCTION LABEL(LINE)
453 COMMON/TAPEID/M1,M2
454 COMMON/CASEID/KASE,NPAGE,LINES,LINEX,TITLEA(20),TITLEB(20)
455 L = IABS(LINE)
456 IF(LINE.LE.0)GO TO 10
457 LINES = LINES + L
458 LABEL = 0
459 IF(LINES.LE.LINEX)GO TO 20
460 10 LINES = L + 3
461 NPAGE = NPAGE + 1
462 LABEL = 1
463 WRITE(M2,2000)TITLEA,KASE,TITLEB,NPAGE
464 2000 FORMAT(1H1,20A4,22H**TICTOC AND TOE**CASE,15/1X,20A4,22H**ASTRONUCL
465 1EAR LAB*PAGE,15/1X,1H )
466 20 RETURN
467 END
468 $IBFTC VECTR M94/2,XR7
469 CVECTOR *UNIT VECTOR
470 FUNCTION VECTOR(X,Y,C)

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471 DIMENSION X(3),Y(3),C(3)
472 FST = 0.0
473 DO 10 I=1,3
474   C(I) = Y(I) - X(I)
475   10 FST = FST + C(I)**2
476   FST = SQRT(FST)
477   DO 20 I=1,3
478     20 C(I) = C(I)/FST
479   VECTOR = FST
480   RETURN
481   END
482 $IBFTC IREAD M94/2,XR7
483 CREADI *INTEGER INPUT, 24I3 FORMAT
484 SUBROUTINE READI(MAX,IDM)
485 COMMON/TAPEID/M1,M2
486 DIMENSION IDM(10000),H(2)
487 DO 30 I=1,MAX,24
488   MOD = I + 23
489   IF(MOD.GT.MAX)GO TO 10
490   READ(M1,1000)(IDM(J),J=I,MOD),H
491   GO TO 20
492   10 JMX = MOD - MAX
493   MOD = MAX
494   READ(M1,1000)(IDM(J),J=I,MOD),(K,J=1,JMX),H
495   20 IF(LABEL(1).GE.0)WRITE(M2,2000)H,(IDM(J),J=I,MOD)
496   30 CONTINUE
497   1000 FORMAT(24I3,2A4)
498   2000 FORMAT(1X,2A4,3H....,24I4)
499   RETURN
500   END
501 $IBFTC EREAD M94/2,XR7
502 CREADI *FLOATING INPUT, 8E9.0 FORMAT
503 SUBROUTINE READE(MAX,ADM)
504 COMMON/TAPEID/M1,M2
505 DIMENSION ADM(10000),H(2)
506 DO 30 I=1,MAX,8
507   MOD = I + 7
508   IF(MOD.GT.MAX)GO TO 10
509   READ(M1,1000)(ADM(J),J=I,MOD),H
510   GO TO 20
511   10 JMX = MOD - MAX
512   MOD = MAX
513   READ(M1,1000)(ADM(J),J=I,MOD),(X,J=1,JMX),H
514   20 IF(LABEL(1).GE.0)WRITE(M2,2000)H,(ADM(J),J=I,MOD)
515   30 CONTINUE
516   1000 FORMAT(8E9.0,2A4)
517   2000 FORMAT(1X,2A4,3H....,1P8E12.4)

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518 RETURN
519 END
520 $IBFTC AREAD M94/2,XR7
521 CREADA *HOLLERITH INPUT, 18A4 FORMAT
522 SUBROUTINE READA(MAX,ADM)
523 COMMON/TAPE10/M1,M2
524 DIMENSION ADM(10000),H(2)
525 DO 30 I=1,MAX,18
526 MOD = I + 17
527 IF(MOD.GT.MAX)GO TO 10
528 READ(M1,1000)(ADM(J),J=I,MOD),H
529 GO TO 20
530 10 JMX = MOD - MAX
531 MOD = MAX
532 READ(M1,1000)(ADM(J),J=I,MOD),(X,J=1,JMX),H
533 20 IF(LABEL(1).GE.0)WRITE(N2,2000)H,(ADM(J),J=I,MOD)
534 30 CONTINUE
535 1000 FORMAT(20A4)
536 2000 FORMAT(1X,2A4,27(1H.),18A4)
537 RETURN
538 END
539 $IBFTC EEREAD M94/2,XR7
540 CREADEE*ALTERNATING FLOATING INPUT, 8E9.0 FORMAT
541 SUBROUTINE READEE(MAX,ADM,BDM)
542 DIMENSION ADM(10000),BDM(10000),CDM(2,4)
543 K= 0
544 DO 10 I=1,MAX,4
545 MOD = MIN0(4,MAX-K)
546 CALL READE(2*MOD,CDM)
547 DO 10 J=1,MOD
548 K = K + 1
549 ADM(K) = CDM(1,J)
550 BDM(K) = CDM(2,J)
551 RETURN
552 END
553 $IBFTC CURVFT M94/2,XR7
554 CCURVE FIT EVALUATION FOR TIC TOC AND TOE
555 FUNCTION CURVE(R,Z,A,ARG)
556 DATA KOUNT/O/
557 DIMENSION A(3,2,2),RAD(2)
558 EQUIVALENCE (RAD(1),GST),(RAD(2),HST)
559 FST = 0.0
560 DO 20 I=1,2
561 DO 10 J=1,2
562 RAD(J) = 0.0
563 DO 10 K=1,3
564 10 RAD(J) = R*RAD(J) + A(K,J,I)

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X = ARG - Z*HST
IF(X.LT.-200.0) X = -200.0
IF(X.LE.100.0) GO TO 20
KOUNT = KOUNT + 1
IF(KOUNT.GT.100) GO TO 20
IF(LABEL(3).GE.0) WRITE(6,2000)R,Z,ARG,GST,HST,X,A
2000 FORMAT(1X,1P6E14.6)
20 FST = FST + GST*EXP(X)
CURVE = FST
RETURN
END
```