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**TRANZIT: A Program for Multigroup
Time-Dependent Transport in
(ρ, z) Cylindrical Geometry**

by

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TRANZIT, A PROGRAM FOR MULTIGROUP TIME-
DEPENDENT TRANSPORT IN (ρ, z) CYLINDRICAL GEOMETRY

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ABSTRACT

Finite difference equations are derived for the time-dependent Boltzmann equation in (ρ, z) geometry. Generalized weighted-diamond difference equations are used to provide recursive solution of the difference equations. A formulation is given for a first collision source due to an energy-distributed point source on the axis of a system with material properties non-uniform in the z direction. The TRANZIT program to solve the difference equations and (optionally) evaluate the uncollided flux is described. Input and usage instructions for the program are given. Comparisons of calculations with Monte Carlo results are made and used to illustrate typical problem output.

I. INTRODUCTION

In this report we describe the theory and use of a program designed to solve the multigroup, discrete ordinates approximation to the time-dependent Boltzmann equation in finite (ρ, z) cylindrical geometry. Features of the program include:

1. Weighted-diamond difference approximation in all five variables.
2. A first collision source option that evaluates the analytic uncollided flux due to a point source on the cylinder axis in a medium which may have z -dependent cross sections, and uses this flux to compute a first collision source.
3. Coarse-mesh rebalancing acceleration of the within-group iterations required by the implicit time differencing algorithm.
4. Wholesale use of extended core storage to permit the storage of the entire angular flux array at each time step.
5. Pointwise (fine-mesh) z -dependence of cross sections.

6. A variety of boundary conditions including albedos and specification of the incoming angular flux at the right, top, or bottom of the cylinder.

7. Restart, dump, and periodic balance edit options.

No provision is made in the program for including a fission source, but a time-dependent, inhomogeneous, distributed source that is separable in space-time may be used.

In the first sections below we give the finite difference equations used in the program. In subsequent sections we describe the program and the preparation of input. Our notation is as consistent as possible with that used in the TWOTRAN manual.¹

In a final section we display a comparison of results for a test problem with data computed by a Monte Carlo program.

II. DIFFERENCE APPROXIMATIONS

A. Analytic Transport Equation

The time-dependent Boltzmann equation can be written

$$\frac{1}{v} \frac{\partial \psi}{\partial t} + \nabla \cdot \underline{\Omega} \psi + \sigma_t \psi(\underline{r}, E, \underline{\Omega}, t) = \iiint dE' d\Omega' \psi(\underline{r}, E', \underline{\Omega}', t) \sigma_s(E' \rightarrow E, \underline{\Omega} \leftarrow \underline{\Omega}') + Q(\underline{r}, E, \underline{\Omega}, t), \quad (1)$$

in which ψ is the particle flux (density times speed v) such that $\psi dv dE d\Omega/v$ is the number of particles in the volume dv about $\underline{r}$, in the solid angle element $d\Omega$ about the direction $\underline{\Omega}$, in the energy range dE about E at time t . Similarly $Q dv dE d\Omega dt$ is the number of particles emitted in the phase space volume in time dt by sources independent of ψ . The macroscopic total interaction cross section is denoted by σ_t , and the scattering transfer probability from $dE' d\Omega'$ to $dE d\Omega$ by σ_s . These cross sections can depend on $\underline{r}$ but not t in the TRANZIT program. No provision is made for delayed emission of particles or fission sources.

1. Form of the Divergence Operator. In cylindrical coordinates we measure distance from the origin by the coordinate ρ and distance from the (x, y) plane by the coordinate z . The direction $\underline{\Omega}$ is represented in an orthogonal coordinate system locally aligned with $\hat{e}_\rho$ and $\hat{e}_z$ at the point $\underline{r}$, $r^2 = \rho^2 + z^2$. The $\hat{e}_\rho$ component of $\underline{\Omega}$ is called μ , $\mu = \hat{e}_\rho \cdot \underline{\Omega}$ and the $\hat{e}_z$ component of $\underline{\Omega}$ is η , $\eta = \hat{e}_z \cdot \underline{\Omega}$. The third direction cosine is $\xi = -\hat{e}_\phi \cdot \underline{\Omega}$ where $\hat{e}_\phi$ is the third unit vector of the local orthogonal system. In the local system we call the angle of revolution about the $\hat{e}_z$ axis ω so that

$$\mu = (1 - \eta^2)^{1/2} \cos \omega, \quad (2)$$

$$\xi = (1 - \eta^2)^{1/2} \sin \omega.$$

We also use an angle of revolution, φ , about the local $\hat{e}_\rho$ axis so that

$$\xi = (1 - \mu^2)^{1/2} \sin \varphi, \quad (3)$$

$$\eta = (1 - \mu^2)^{1/2} \cos \varphi.$$

These coordinates are shown in Fig. 1. In this geometry we use the divergence operator

$$\nabla \cdot (\underline{\Omega} \psi) = \frac{\mu}{\rho} \frac{\partial (\rho \psi)}{\partial \rho} + \frac{1}{\rho} \frac{\partial (\xi \psi)}{\partial \omega} + \eta \frac{\partial \psi}{\partial z}. \quad (4)$$

Fig. 1. Coordinates in (ρ, z) geometry.

2. Spherical Harmonic Expansion of the

Source Terms. We represent the scattering transfer probability by a finite Legendre polynomial expansion:

$$\sigma_s(E' \rightarrow E, \mu_0) = \sum_{n=0}^{ISCT} \frac{2n+1}{4\pi} P_n(\mu_0) \sigma_{sn}(E' \rightarrow E), \quad (5)$$

where

$$\mu_0 = \underline{\Omega} \cdot \underline{\Omega}' = \mu \mu' + (1 - \mu^2)^{1/2} (1 - \mu'^2)^{1/2} \cos(\varphi - \varphi'). \quad (6)$$

Because ψ is an even function of φ , we can make the expansion

$$\iiint d\Omega' \psi(\underline{r}, E', \underline{\Omega}') \sigma_s(E' \rightarrow E, \mu_0) = \sum_{n=0}^{ISCT} \frac{2n+1}{2\pi} \sigma_{sn}(E' \rightarrow E) \sum_{k=0}^n R_n^k(\mu, \varphi) \int_{-1}^1 d\mu' \int_0^\pi d\varphi' R_n^k(\mu', \varphi') \psi(\underline{r}, E', \underline{\Omega}'), \quad (7)$$

by using the spherical harmonics addition theorem. The functions R_n^k are defined by

$$R_n^k = \left[\frac{(2-\delta_{ko})(n-k)!}{(n+k)!} \right]^{\frac{1}{2}} P_n^k(\mu) \cos k\omega, \quad (8)$$

and are orthogonal:

$$\int_{-1}^1 d\mu \int_0^\pi d\omega R_n^k(\mu, \omega) R_m^l(\mu, \omega) = \frac{2\pi}{2n+1} \delta_{nm} \delta_{kl}. \quad (9)$$

If the flux is expanded in a series of these functions,

$$\psi = \sum_{n=0}^{\infty} (2n+1) \sum_{k=0}^n R_n^{k,k}, \quad (10)$$

then the expansion coefficients are given by

$$\psi_n^k = \frac{1}{2\pi} \int_{-1}^1 d\mu \int_0^\pi d\omega R_n^{k,k} \psi. \quad (11)$$

We can therefore write

$$\int_{\Omega} d\Omega' \psi(\underline{r}, \Omega', \Omega') \sigma_g(E' \rightarrow E, \mu_0) = \sum_{n=0}^{\text{ISCT}} (2n+1) \sigma_{sn}(E' \rightarrow E) \sum_{k=0}^n R_n^{k,k}. \quad (12)$$

Provision is made in TRANZIT to allow a distributed source Q to be represented by IQAN terms of an expansion like (10). The program accepts the expansion coefficients Q_n^k as input.

B. Multigroup Difference Equations

1. Energy Group Representation. The energy domain is partitioned into IGM intervals of width ΔE_g , $g = 1, 2, \dots$, IGM with the convention that increasing g represents decreasing energy. We represent the energy group average of our transport equation by

$$\frac{1}{v_g} \frac{\partial \psi_g}{\partial t} + \nabla \cdot (c \psi_g) + \sigma_{tg} \psi_g = \sum_{h=1}^{\text{IGM}} \sum_{n=0}^{\text{ISCT}} (2n+1) \sigma_{snh \rightarrow g} \sum_{k=0}^n R_n^{k,k} \psi_h^k + \sum_{n=0}^{\text{IQAN}} (2n+1) \sum_{k=0}^n R_n^{k,k} Q_n^k. \quad (13)$$

In this equation ψ_g is the energy integral of ψ and v_g is an appropriate average speed in the range ΔE_g . The flux ψ_g is no longer a distribution in energy, and energy integrals in TRANZIT are evaluated by simple sums.

2. Space-Time Differencing of the Transport

Equation. We partition the domain into IT ρ intervals, JT z intervals, MT solid angle intervals and ITM time intervals such that

$$\begin{aligned} \rho_{i-\frac{1}{2}} < \rho_i < \rho_{i+\frac{1}{2}} & \quad i = 1, 2, \dots, \text{IT}, \\ z_{j-\frac{1}{2}} < z_j < z_{j+\frac{1}{2}} & \quad j = 1, 2, \dots, \text{JT}, \\ \Omega_{m-\frac{1}{2}} < \Omega_m < \Omega_{m+\frac{1}{2}} & \quad m = 1, 2, \dots, \text{MT}, \\ t_{s-\frac{1}{2}} < t_s < t_{s+\frac{1}{2}} & \quad s = 1, 2, \dots, \text{ITM}. \end{aligned} \quad (14)$$

We then represent (13) by the following difference equation, dropping the subscript g from fluxes for clarity,

$$\begin{aligned} \frac{\psi_{ijm, s+\frac{1}{2}} - \psi_{ijm, s-\frac{1}{2}}}{v \Delta t_s} + \mu_m \frac{(A_{i+\frac{1}{2}, j+\frac{1}{2}, m, s} - A_{i-\frac{1}{2}, j-\frac{1}{2}, m, s})}{V_{ij}} \\ + \frac{(A_{i+\frac{1}{2}, j-\frac{1}{2}, m, s} - A_{i-\frac{1}{2}, j+\frac{1}{2}, m, s})}{V_{ij}} \frac{(\alpha_{m+\frac{1}{2}, i, j, m+\frac{1}{2}, s} - \alpha_{m-\frac{1}{2}, i, j, m-\frac{1}{2}, s})}{w_m} \\ + \eta_m \frac{(B_{i, j+\frac{1}{2}, m, s} - B_{i, j-\frac{1}{2}, m, s})}{V_{ij}} \\ + \sigma_{t_{ijms}} \psi_{ijms} = S_{ijms}. \end{aligned} \quad (15)$$

Here we have lumped all sources of (13) under the heading S , $\Delta t_s = t_{s+\frac{1}{2}} - t_{s-\frac{1}{2}}$, V is a volume element, and A and B are area elements. These are given by

$$\begin{aligned} V_{ij} &= (\rho_{i+\frac{1}{2}}^2 - \rho_{i-\frac{1}{2}}^2) \Delta z_j, \\ A_{i\pm\frac{1}{2}, j} &= 2\pi \rho_{i\pm\frac{1}{2}} \Delta z_j, \\ B_{i, j\pm\frac{1}{2}} &= \pi (\rho_{i+\frac{1}{2}}^2 - \rho_{i-\frac{1}{2}}^2). \end{aligned} \quad (16)$$

We can think of the subscripted fluxes either as evaluated at the noncentered subscript and averaged over the remaining variables or simply as evaluations of ψ at particular points. For example, we can define ψ_{ijms} to be $\psi(\rho_i, z_j, \Omega_m, t_s)$.

It can be shown² that an appropriate choice of the coefficients α is determined by the recursion

$$\alpha_{m+\frac{1}{2}} = \alpha_{m-\frac{1}{2}} - w_m \mu_m, \quad (17)$$

with first and last α values vanishing on each η level. That is, the α terms in (15) represent the $\partial(\xi\psi)/\partial w$ terms in (4) so we pick a partitioning of solid angle such that only w changes for subsets

of μ values. This is accomplished by using subsets of μ values each having the same η value, and for each of these subsets, first and last α values are zero. A typical choice of directions on the unit sphere is shown in Fig. 2 for the S_6 directions ($MT = 24$). Directions 4, 5, 6, 10, 11, and 12 have the same value of η ; the first and last values of α for this set are zero.

3. Definition of the Source Term. The angular integral of (11) for the spherical harmonic expansion coefficient of the flux is approximated by a weighted sum over the discrete directions:

$$R_{njs}^k = \int_{-1}^1 d\mu \int_0^\pi d\varpi R_n^k \psi / 2\pi \cong \sum_{m=1}^{MT} w_m R_n^k(\mu_m, \varpi_m) \psi_{ijms}. \quad (18)$$

The angle ϖ_m is defined by

Fig. 2. Orientation of S_6 directions in (ρ, z) geometry.

$$\varpi_m = \begin{cases} \tan^{-1}[(1 - \mu_m^2 - \eta_m^2)^{1/2} / \eta_m] & \eta_m > 0 \\ \tan^{-1}[(1 - \mu_m^2 - \eta_m^2)^{1/2} / \eta_m] + \pi/2 & \eta_m < 0 \end{cases}. \quad (19)$$

Like TWOTRAN,¹ TRANZIT is organized so that only one quadrant of directions is used at any one time. The proper signs of μ and η are assigned by using four functions:

$$R_n^k(\mu_m, \varpi_m) = \begin{cases} P1_{nm}^k & \mu < 0, \eta < 0 \\ P2_{nm}^k & \mu > 0, \eta < 0 \\ P3_{nm}^k & \mu < 0, \eta > 0 \\ P4_{nm}^k & \mu > 0, \eta > 0 \end{cases}. \quad (20)$$

Using the definition of (18), the source in (13) for group g is written

$$S_{ijmsg} = \sum_{h=1}^{ICM} \sum_{n=0}^{ISCT} (2n+1) \sigma_{snh-g} \sum_{k=0}^n R_{nm}^k \psi_{nijsh}^k + \sum_{n=0}^{IQAN} (2n+1) \sum_{k=0}^n R_{nm}^k Q_{nijsg}^k. \quad (21)$$

C. Solution of the Difference Equations

Using the convention that centered subscripts (i, j, m, s, g) are omitted except to indicate sums or to clarify equations, we can write our difference equations as

$$\begin{aligned} & \frac{\psi_{s+\frac{1}{2}, j-\frac{1}{2}} - \psi_{s-\frac{1}{2}, j-\frac{1}{2}}}{v \Delta t} + \mu \frac{(A_{i+\frac{1}{2}, j+\frac{1}{2}} \psi_{i+\frac{1}{2}, j+\frac{1}{2}} - A_{i-\frac{1}{2}, j-\frac{1}{2}} \psi_{i-\frac{1}{2}, j-\frac{1}{2}})}{V} + \\ & \frac{(A_{i+\frac{1}{2}, j-\frac{1}{2}} - A_{i-\frac{1}{2}, j-\frac{1}{2}})}{V} \frac{(\alpha_{m+\frac{1}{2}, j+\frac{1}{2}} \psi_{m+\frac{1}{2}, j+\frac{1}{2}} - \alpha_{m-\frac{1}{2}, j-\frac{1}{2}} \psi_{m-\frac{1}{2}, j-\frac{1}{2}})}{w} + \\ & \eta \frac{B(\psi_{j+\frac{1}{2}, j-\frac{1}{2}} - \psi_{j-\frac{1}{2}, j-\frac{1}{2}})}{V} + \sigma_t \psi = S. \end{aligned} \quad (22)$$

Here, we have indicated that B is independent of j . The equation contains nine different fluxes; one of these ($\psi_{s-\frac{1}{2}, j-\frac{1}{2}}$) is given by the initial condition (only $\psi_{s-\frac{1}{2}, j-\frac{1}{2}} = 0$ is allowed) or computation at previous times; three others can be gotten from boundary conditions or computations in adjoining phase space cells.

The following boundary conditions are allowed in TRANZIT:

1. vacuum,
2. specular reflection,
3. isotropic return,
4. group dependent albedo (space independent),
5. group and space dependent albedo,
6. specification of the incoming flux on the

top, right, or bottom of the cylinder.

None of these conditions is changed with time. Only specular reflection is allowed on the left ($\rho = 0$) boundary, i.e., at the center of the cylinder.*

Four additional relations are used with (22) to determine the five remaining unknown fluxes. We use the weighted diamond relations³

$$\begin{aligned} \psi_i^+ &= a' \psi_{i+\frac{1}{2}}^+ + (1 - a') \psi_{i-\frac{1}{2}}^+, \\ \psi_j^+ &= b' \psi_{j+\frac{1}{2}}^+ + (1 - b') \psi_{j-\frac{1}{2}}^+, \\ \psi_m^+ &= c' \psi_{m+\frac{1}{2}}^+ + (1 - c') \psi_{m-\frac{1}{2}}^+, \\ \psi_s^+ &= d' \psi_{s+\frac{1}{2}}^+ + (1 - d') \psi_{s-\frac{1}{2}}^+, \end{aligned} \quad (23)$$

in which the weights are chosen to insure positivity. The formulas for choosing these weights are given by

$$\begin{aligned} a &= \max(\frac{1}{2}, 1 - a'), \\ b &= \max(\frac{1}{2}, 1 - b'), \\ c &= \max(\frac{1}{2}, 1 - c'), \\ d &= \max(\frac{1}{2}, 1 - d'), \end{aligned} \quad (24)$$

where, for μ and $\eta > 0$

$$\begin{aligned} a' &= \frac{\mu AI^- + (\eta B J \psi_{j-\frac{1}{2}}^+ + \alpha_{m-\frac{1}{2}} AD \psi_{m-\frac{1}{2}}^+ + RVT \psi_{s-\frac{1}{2}}^+ + S) / (\psi_{i-\frac{1}{2}}^+ + \epsilon)}{\sigma_t + 2(\eta B J + \alpha_{m+\frac{1}{2}} AD + RVT)}, \\ b' &= \frac{\eta B J + (\mu AI^- \psi_{i-\frac{1}{2}}^+ + \alpha_{m-\frac{1}{2}} AD \psi_{m-\frac{1}{2}}^+ + RVT \psi_{s-\frac{1}{2}}^+ + S) / (\psi_{j-\frac{1}{2}}^+ + \epsilon)}{\sigma_t + 2(\mu AI^+ + \alpha_{m+\frac{1}{2}} AD + RVT)}, \\ c' &= \frac{\alpha_{m-\frac{1}{2}} AD + (\mu AI^- \psi_{i-\frac{1}{2}}^+ + \eta B J \psi_{j-\frac{1}{2}}^+ + RVT \psi_{s-\frac{1}{2}}^+ + S) / (\psi_{m-\frac{1}{2}}^+ + \epsilon)}{\sigma_t + 2(\mu AI^+ + \eta B J + RVT)}, \\ d' &= \frac{RVT + (\mu AI^- \psi_{i-\frac{1}{2}}^+ + \eta B J \psi_{j-\frac{1}{2}}^+ + \alpha_{m-\frac{1}{2}} AD \psi_{m-\frac{1}{2}}^+ + S) / (\psi_{s-\frac{1}{2}}^+ + \epsilon)}{\sigma_t + 2(\mu AI^+ + \eta B J + \alpha_{m+\frac{1}{2}} AD)}. \end{aligned} \quad (25)$$

In these equations

* Vacuum boundary conditions must be used with the uncollided flux option.

$$RVT = 1/v\Delta t,$$

$$AI^+ = A_{i+\frac{1}{2}}/V = 2\rho_{i+\frac{1}{2}}/(o_{i+\frac{1}{2}}^2 - o_{i-\frac{1}{2}}^2), \quad (26)$$

$$AD = (A_{i+\frac{1}{2}} - A_{i-\frac{1}{2}})/V = 2/(o_{i+\frac{1}{2}} + o_{i-\frac{1}{2}}),$$

$$BJ = B/V = 1/\Delta z.$$

For negative values of μ and η , the absolute values of μ and η are used in the formulae. If $\eta < 0$, $\psi_{j+\frac{1}{2}}$ is used instead of $\psi_{j-\frac{1}{2}}$, and if $\mu < 0$, $\psi_{i+\frac{1}{2}}$ is used instead of $\psi_{i-\frac{1}{2}}$, and AI^+ is used instead of AI^- .

Equations (24) and (25) are designed to choose the value of the weights a , b , c , and d as close to $\frac{1}{2}$ as possible and still guarantee positive fluxes when (23) is used to solve (22). The coefficients a' , b' , c' , and d' are calculated using values of angular fluxes from previous iterations and the value of ϵ (equal to the inner iteration convergence precision) is used to prevent division by zero. The values of a' , b' , c' , and d' change as iteration progresses.

In TRANZIT, (23) is used to eliminate unknowns from (22) to obtain a formula for ψ_i^+ ; then, given ψ_i^+ , (23) is used to extrapolate the unknown fluxes. Unless $d = 1$, the resulting scheme is implicit in time. Experience has shown that it is stable; however, the truncation error in any variable is first order unless the weights of (24) are equal to $\frac{1}{2}$. Then, the truncation error is second order.

The above system of equations has proved to be very reliable: it provides a solution for extreme variations of size of the parameters $v\Delta t$, $\sigma_t \Delta o$, and $\sigma_t \Delta z$. However, it is computationally expensive and the accuracy of the scheme depends on the flux variation itself. It also has the property of any positive scheme that some particles appear at locations not physically possible. For example, some small number of particles will escape from a system before the minimum flight time from source to boundary.

D. Convergence Acceleration

Because the scattering source in S in (22) depends on the angular flux being calculated, we iterate the solution by assuming S to be known, calculating all fluxes, recalculating S from new fluxes, etc. The iteration is performed in each group at

each time step. If upscatter is present we must also make iterative passes through the groups to update the upscattering source. Both of these iterative processes are accelerated by a coarse-mesh rebalancing algorithm.

If we multiply (22) by w and sum over all directions, we obtain

$$\frac{\phi_{s+\frac{1}{2},s-\frac{1}{2}} - \phi_{s-\frac{1}{2},s-\frac{1}{2}}}{v\Delta t} + \frac{A_{i+\frac{1}{2},i+\frac{1}{2}} - A_{i-\frac{1}{2},i-\frac{1}{2}}}{V} + \frac{B(J_{j+\frac{1}{2},j-\frac{1}{2}} - J_{j-\frac{1}{2},j-\frac{1}{2}})}{V} + \sigma_t \phi = \sigma_{\text{sog-}t} \phi^p + Q, \quad (27)$$

where we denote the scalar flux by

$$\phi_{ijs} = \phi_{0ijs}^0 = \sum_{m=1}^{MT} w_m \psi_{m,ijs}, \quad (28)$$

the i -direction current by

$$I_{i\pm\frac{1}{2},js} = I_{1,i\pm\frac{1}{2},js}^0 = \sum_{m=1}^{MT} w_m \mu_m \psi_{m,i\pm\frac{1}{2},js}, \quad (29)$$

and the j -direction current by

$$J_{i,j\pm\frac{1}{2},s} = J_{1,i,j\pm\frac{1}{2},s}^1 = \sum_{m=1}^{MT} w_m \eta_m \psi_{m,i,j\pm\frac{1}{2},s}. \quad (30)$$

On the right side of (27) we split the isotropic portion of S into a within-group scattering ($\sigma_{\text{sog-}t}$) portion and a remainder Q .

The balance equation (27) is the same as that used in static calculations except that a time derivative of the scalar flux appears. We add the portion of this derivative from previous times ($t_{s-\frac{1}{2}}$) to the coarse-mesh source and include the portion at present times ($t_{s+\frac{1}{2}}$) in the coarse-mesh absorption. We then proceed to form coarse-mesh flows and find coarse-mesh balance factors exactly as for static calculations in the TWOTRAN program.⁴ Upscattering iteration is also accelerated as in the TWOTRAN program, allowing for the presence of the time derivative.

III. CALCULATION OF THE UNCOLLIDED FLUX

Because discrete ordinates treatments of streaming from localized sources leads to flux distortions,⁵ we have introduced a first collision source option in TRANZIT. By evaluating the analytic expression for the uncollided flux as a function of time, we produce a much less localized

source (the source due to first collisions) to treat by the discrete ordinates method. If the scattering cross section is small (void or absorbing medium), nearly all the flux is uncollided so the accuracy of the computation should be increased.

There are several difficulties associated with the evaluation of the analytic expression for the uncollided flux due to a point source at $t = 0$. While the analytic expression can be written neatly in spherical coordinates, we must evaluate it for a set of discrete time and cylindrical geometry mesh boxes. We must also perform particle balance tallies, not only for user information but also to insure that our approximate evaluation of the analytic expression is properly normalized. Because these tallies involve computing quantities like the number of particles leaking from a cylinder as a spherical wave front moves from its position at t to its position at $t + \Delta t$, we must evaluate several different analytic expressions. Finally, we want to allow cross sections to vary with position which complicates the simple analytic expression for the uncollided flux.

In our expressions below we use both spherical coordinates (r, μ_{sph}) and cylindrical coordinates $(\rho, z, \mu_{\text{cyl}}, \eta_{\text{cyl}})$. We assume that a point burst of particles is emitted at $t = 0$ at a height z_0 on the axis ($\rho = 0$) of a cylinder. The cross sections of the medium are allowed to vary in the z directions.* If the center of the spherical coordinate system is located at the point $\rho = 0, z = z_0$, the analytic expression for the uncollided flux is given by

$$\psi_{uc} = \frac{Q_g v e^{-\sigma_t \int_0^r f(z) dz}}{4\pi r^2} \delta(r - vt) \delta(\mu_{\text{sph}} - 1), \quad (31)$$

where Q_g is the strength of the source in the g^{th} group, v is the group speed, $\sigma_t f(z)$ is the space dependence of the macroscopic total interaction cross section, and the integral is evaluated along the line from the source to the point r . Because the cross section varies only with z , we can write

$$\sigma_t \int_0^r f(z) dz = \frac{\sigma_t r \int_{z_0}^z f(z') dz'}{z - z_0}. \quad (32)$$

*Vacuum boundary conditions must be used with the uncollided flux option.

The solution (31) satisfies the equation
 $\psi^{uc}(t=0) = 0$

$$\frac{1}{v} \frac{\partial \psi^{uc}}{\partial t} + \nabla \cdot \vec{\Gamma}^{uc} + \sigma_t f(z) \psi^{uc} = \frac{Q_g \delta(t) \delta(\vec{r})}{4\pi} \quad (33)$$

Integrating over directions $\vec{\Omega}$ we have the time dependent balance equation

$$\frac{1}{v} \frac{\partial \phi^{uc}}{\partial t} + \nabla \cdot \vec{\Gamma}^{uc} + \sigma_t f(z) \phi^{uc} = Q_g \delta(t) \delta(\vec{r}), \quad (34)$$

where ϕ is the scalar flux and $\vec{\Gamma}$ is the current. We wish not only to evaluate the average value of ψ^{uc} in Δt , in a cell, in a direction approximating $\mu_{sph} = 1$, but also to evaluate the volume time average of (34) to normalize our approximation to ψ^{uc} .

We consider first the average value of ψ^{uc} in time $\Delta t = t_2 - t_1$, in the space cell $\rho_{i-\frac{1}{2}} < \rho < \rho_{i+\frac{1}{2}}$, $z_{j-\frac{1}{2}} < z < z_{j+\frac{1}{2}}$ with volume V_{ij} . We have

$$\langle \psi^{uc} \rangle = \frac{2\pi}{V_{ij} \Delta t} \int_{\rho_{i-\frac{1}{2}}}^{\rho_{i+\frac{1}{2}}} \rho d\rho \int_{z_{j-\frac{1}{2}}}^{z_{j+\frac{1}{2}}} dz \int_{t_1}^{t_2} dt \psi^{uc} \quad (35)$$

We also must find an average value for the discrete direction $\vec{\Omega}_m$ corresponding to $\mu_{sph} = 1$. At the point $r = [\rho^2 + (z - z_0)^2]^{\frac{1}{2}}$, the direction corresponding to $\mu_{sph} = 1$ has cosines

$$\mu_{cyl} = \rho/r \quad (36)$$

$$r_{cyl} = (z - z_0)/r.$$

When we evaluate the space integral in (35), we pick an $\vec{\Omega}_m$ with cosines "closest" to those given by (36) and use $1/w_m$ times ψ^{uc} for the approximate angular flux in this direction. Denoting this process by a subscript m and evaluating the time integral in (35), we have

$$\langle \psi^{uc} \rangle_m = \frac{1}{2V_{ij} \Delta t w_m} \int_{z_{j-\frac{1}{2}}}^{z_{j+\frac{1}{2}}} dz \int_{\rho_{i-\frac{1}{2}}}^{\rho_{i+\frac{1}{2}}} \rho d\rho \frac{-\sigma_t r \int_{z_0}^z f(z') dz' / (z - z_0)}{r^2}, \quad (37)$$

where the integrand exists only for values of r such that $vt_1 \leq r \leq vt_2$. Changing variables from ρ to r we have

$$\langle \psi^{uc} \rangle_m = \frac{1}{2V_{ij} \Delta t w_m} \int_{z_{j-\frac{1}{2}}}^{z_{j+\frac{1}{2}}} dz \int_{\max(vt_1, r_{i-\frac{1}{2}}(z))}^{\min(vt_2, r_{i+\frac{1}{2}}(z))} \frac{-\sigma_t r \tau(z) dr}{r}, \quad (38)$$

where

$$\tau(z) = \int_{z_0}^z f(z') dz' / (z - z_0), \quad (39)$$

$$r_{i\pm\frac{1}{2}}(z) = [(z - z_0)^2 + \rho_{i\pm\frac{1}{2}}^2]^{\frac{1}{2}}. \quad (40)$$

The double integral of (38) is evaluated by subdividing the r and z ranges into at least 10 equal points. If $v\Delta t$ is small compared to $\Delta z/10$ we use a finer z mesh. Angular moments of (38) are calculated by

$$\psi_{nk}^{uc} = \sum_{m=1}^{MT} w_m R_{nm}^k \langle \psi^{uc} \rangle_m, \quad (41)$$

for use in the first collision scattering source.

Using the isotropic flux from (41), we can calculate the total collision rate in the system

$$TC = \Delta t \sum_{i,j} V_{ij} (\sigma_t f_j) \psi_{00}^{uc}, \quad (42)$$

or

$$TC = \sum_{i,j} \frac{\sigma_t f_j}{2} \int_{z_{j-\frac{1}{2}}}^{z_{j+\frac{1}{2}}} \int_{\max(vt_1, r_{i-\frac{1}{2}})}^{\min(vt_2, r_{i+\frac{1}{2}})} \frac{-\sigma_t r \tau}{r} dr dz. \quad (43)$$

Other terms for the whole-system balance equation are generated in a similar manner. For the net time flow (NTF), we have

$$NTF = \frac{1}{v} \int_{t_1}^{t_2} dt \int_V dV \frac{\partial \phi^{uc}}{\partial t}, \quad (44)$$

where we take ϕ^{uc} to be the same function as (31) except for the angular delta function. Thus,

$$NTF = \frac{1}{V} \int dV [\phi^{uc}(t_2) - \phi^{uc}(t_1)]$$

$$\equiv TF - TFP. \quad (45)$$

Because we assume an initial condition of $\phi^{uc}(0)$ equal zero, we need only evaluate one such integral per time step. Evaluating TF, we have

$$TF = \frac{Q_g}{2} \int_0^{\rho_{\max}} \rho d\rho \int_{z_{\min}}^{z_{\max}} \frac{e^{-\sigma_t r \tau(z)} \delta(r - vt_2)}{r^2} dz, \quad (46)$$

where $\tau(z)$ is given in (39). It is now convenient to use the delta function to do the z integration by using the relation

$$\delta[f(z)] = \sum_{i=1}^N \frac{\delta(z - z_i)}{\left| \frac{df}{dz} \right|_{z_i}}, \quad (47)$$

where z_i are the N roots of $f(z) = 0$. Here we have two roots

$$z_{1,2} = z_0 \pm [(vt_2)^2 - \rho^2]^{\frac{1}{2}}, \quad (48)$$

and

$$\delta(r - vt_2) = \frac{vt_2 [\delta(z - z_1) + \delta(z - z_2)]}{[(vt_2)^2 - \rho^2]^{\frac{1}{2}}}. \quad (49)$$

Using this result we find

$$TF = \frac{Q_g}{2vt_2} \int_0^{\min(z_{\max}, vt_2)} \frac{\rho d\rho}{[(vt_2)^2 - \rho^2]^{\frac{1}{2}}} \left\{ e^{-\sigma_t vt_2 \tau(z_1)} + e^{-\sigma_t vt_2 \tau(z_2)} \right\}, \quad (50)$$

as long as z_1 and z_2 are in the range $z_{\min} < z < z_{\max}$. The upper limit of integration shifts from vt_2 to $\rho_{\max}$ at the time t_2 such that the wave front emerges from the cylinder. The requirement that z_1 be in the range is

$$z_{\min} < z_0 + [(vt_2)^2 - \rho^2]^{\frac{1}{2}} < z_{\max}, \quad (51)$$

which (for z_0 in the range) is satisfied at the lower inequality for all ρ . But to stay at values of $z_1 < z_{\max}$ we must have

$$\rho^2 \geq (vt_2)^2 - (z_{\max}^2 - z_0^2). \quad (52)$$

This is no restriction provided $vt_2 < z_{\max} - z_0$ because ρ is always greater than zero anyway. Such arguments are made simpler if we change to the variables $x = z_0 + [(vt_2)^2 - \rho^2]^{\frac{1}{2}}$. We find

$$TF = \frac{Q_g}{2vt_2} \left\{ \int_{[(vt_2)^2 - \min(\rho_{\max}^2, (vt_2)^2)]^{\frac{1}{2}}}^{\min(vt_2, z_{\max} - z_0)} dx e^{-\sigma_t vt_2 \tau(x)} + \int_{[(vt_2)^2 - \min(\rho_{\max}^2, (vt_2)^2)]^{\frac{1}{2}}}^{\min(vt_2, z_0 - z_{\min})} dx e^{-\sigma_t vt_2 \tau(x)} \right\}. \quad (53)$$

If the wave front is inside the cylinder at t_2 and cross sections are constant [$\tau(x) = 1$], this complicated expression reduces to

$$TF = Q_g e^{-\sigma_t vt_2}. \quad (54)$$

To evaluate the leakage terms in (34), we use the facts that

$$\int_V dV \nabla \cdot \vec{I}^{uc} = \int_A dA \cdot \vec{I}^{uc}, \quad (55)$$

and that the angle between the normal to the surface and $\vec{n}$ is just the direction cosine. For example, for the right leakage at the cylindrical surface

$\rho = \rho_{\max}$, we find

$$RL = \int_{t_1}^{t_2} dt \int_V dV \nabla \cdot \vec{I}^{uc} = \int_{t_1}^{t_2} dt \rho_{\max} \int_{z_{\min}}^{z_{\max}} dz \frac{\mu_{cyl} Q_g v e^{-\sigma_t r \tau}}{2r^2} \delta(r - vt). \quad (56)$$

At this surface $\mu_{cyl} = \rho_{\max}/r$ and

$$RL = \frac{Q_g \rho_{\max}^2}{2} \int_{z_{\min}}^{z_{\max}} \frac{dz e^{-\sigma_t r \tau}}{r^3}, \quad (57)$$

for $vt_1 < r < vt_2$. The integral exists provided

$$z_0 + z_1 \leq z \leq \min\{z_{\max}, z_0 + z_2\}$$

$$\max\{z_{\min}, z_0 - z_2\} \leq z \leq z_0 - z_1, \quad (58)$$

where

$$z_1 = \left\{ (vt_1)^2 - \min[(vt_1)^2, \rho_{\max}^2] \right\}^{\frac{1}{2}},$$

$$z_2 = \left\{ (vt_2)^2 - \min[(vt_2)^2, \rho_{\max}^2] \right\}^{\frac{1}{2}}. \quad (59)$$

Here, as elsewhere, there is no contribution to the integral if the lower limit of integration is equal to or larger than the upper limit. Suppose t_1 and t_2 are very large. Then, the first expression of (58) becomes $z_1 < z < z_{\max}$ but z_1 can be larger than $z_{\max}$. In this situation the wave front has left the system and there is no right leakage.

By similar manipulations, we find the expressions for the Top Leakage (TL) and Bottom Leakage (BL):

$$TL = \frac{z_{\max} - z_0}{2} \int_{L_1} \frac{dx}{x^2} e^{-\sigma_t x r(z_{\max})}, \quad (60)$$

$$BL = \frac{z_{\min} - z_0}{2} \int_{L_2} \frac{dx}{x^2} e^{-\sigma_t x r(z_{\min})}, \quad (61)$$

where L_1 is given by

$$\max\{z_{\max} - z_0, vt_1\} < x < \min\{vt_2, [(z_{\max} - z_0)^2 + \rho_{\max}^2]^{\frac{1}{2}}\}, \quad (62)$$

and L_2 is given by

$$\max\{z_0 - z_{\min}, vt_1\} < x < \min\{vt_2, [(z_{\min} - z_0)^2 + \rho_{\max}^2]^{\frac{1}{2}}\}. \quad (63)$$

The integrals for TF and RL are evaluated in at least 10 equal intervals for each fine-mesh z interval, while the top and bottom leakages are evaluated at 50 equal intervals on their x ranges.

In terms of the integrals defined above, the volume-time average of (34) can be written

$$TF = TFP + RL + TL + BL + TC = Q_g \delta_{s1}, \quad (64)$$

where $s = 1, 2, \dots$, is the time step number. To

insure that the uncollided flux is properly normalized, we multiply all fluxes by the factor

$$TN = (Q_g \delta_{s1} + TFP)/(TC + TF + RL + TL + BL), \quad (65)$$

for each group at each time step. The leakage, absorption, etc., due to the uncollided flux are added to the appropriate system balance tables. The coarse-mesh balance tables do not include the uncollided flux.

In multigroup problems, the lower group speeds may be so small that the uncollided flux does not enter the finite space mesh until after many time steps. In this or other situations when the wave front is inside the system but the finite integration scheme above does not detect its presence, we pass all particles into the next time step, setting $TF = Q_g$ if it is the first time step. Otherwise, we set $TF = TFP$.

IV. PROGRAM DESCRIPTION

Because of its specialized nature, TRANZIT is smaller than general purpose, two-dimensional transport programs used for static computations. The normal flow of the program involves input and initialization, then outer (over-all-groups when up-scattering is present) and inner (within-group) iterations for all groups at each time step. Certain edit information and summary prints are made at each time step. Contour flux plots are optional

at each time step.

In the sections below, we describe the subroutines, convergence tests, and data storage procedures of TRANZIT.

A. Subroutines

The names of the major TRANZIT subroutines and a brief description of their functions are given in Table I. Similar information is given for service subroutines in Table II and system subroutines in Table III.

TABLE I
MAJOR SUBROUTINES OF TRANZIT

TRANZIT	Main program which identifies I/O systems and sets parameters which are normally constant but are treated as variables so that if they are changed, the only change necessary is in this program. This is the only routine in which the main storage vector A is dimensioned. After calling INPUT, the program controls the progression through time, calling OUTER and EDIT at each time step. At the end of a problem, the program attempts to fetch a new problem.
INPUT	The subroutine reads, checks, and prints the control data for the problem, including the number of fine-mesh intervals in each coarse-mesh interval. These input numbers include the numbers necessary to allocate storage which INPUT does by computing the first word address of core and ECS (Extended Core Storage) data blocks. The program calls SNCON, CSPREP, READX and READQF to read data and begins computation of needed functions by calling GENANG and GEOfUN. The subroutine clears core and ECS storage areas and draws a picture of the system geometry by calling MAPPER.
OUTER	This subroutine controls the progression through the energy groups. It begins by initializing the angular flux bulk storage units. The entire angular flux from one time step is saved for use in the next time step, and this block of storage can exceed the size of ECS. The subroutine initializes group dependent arrays, calls FCOLL and BAL if a first collision source option is used, and begins the progression through groups. At the beginning of the calculation in each group, a periodic or time limit dump may be taken. Subroutine OUTER calls INNER and computes system particle balance information in each group (GSUMS). At the end of the energy group calculation, uncollided fluxes are added to collided fluxes, if a first collision source computation has been performed.
FCOLL	The first collision source for each group is generated and stored in ECS by this routine which evaluates the formulas of Section III.
INNER	This routine solves the difference system of (22) and (23), repeatedly evaluating the source due to within-group scattering until convergence criteria are met. The program calls SETBC to set boundary conditions and REBAL to compute the coarse-mesh acceleration factors. At the beginning of INNER, all angular fluxes from the previous time step are read from bulk storage and placed in ECS. During an iteration, these fluxes are read from ECS, one fine-mesh z interval at a time. A special iteration is made after a group is converged to write the new angular flux into ECS, one fine-mesh z interval at a time. Finally, these fluxes are read from ECS and placed in bulk storage. Coarse-mesh balance table information is also printed from INNER when a converged flux is obtained.

TABLE II
SERVICE SUBROUTINES OF TRANZIT

1. Input Routines

CSPREP	reads, prints, mixes, and stores cross section data from cards.
READQF	reads and prints input flux guess or distributed source data. The routine normalizes the distributed source to NORM, an input number, if NORM $\neq$ 0 and the source is not zero.
SNCON	contains S_N constants for $N = 2, 4, 6, 8, 10, 12, 14,$ and 16 .
READX	reads and prints input fixed or floating point data.
LAXSF	prepares to read cross sections from the special input format used in the ANISN program.

Table II (cont)

FIDOX special read routine from ANISN program.
 MAPPER prints a picture of geometric system input including cross section arrangement.

2. Computational Routines

GEOFUN generates geometric coefficients.
 GENANG generates angular functions.
 SETBC sets allowable boundary conditions.
 BAL initializes particle balance information when first collision source option is used.
 PNGEN generates spherical harmonics functions P₁, P₂, P₃, and P₄.
 REBAL determines coarse-mesh rebalance factors by iterative solution of a block tridiagonal matrix.
 GSUMS calculates group and sum-over-all-group balance information.

3. Dump Routines

SPFDMP controls dumping of core when a CDC mode error occurs.
 MODDMF prints IA array and A vector when a CDC mode error occurs.
 RZDUMP reads and/or writes time-limit and periodic restart dumps. Periodic dumps are written alternately on tape units NDMP1 and NDMP2. Restart dumps are read from unit NDMP1.

4. Miscellaneous Routines

ERROR prints messages, error messages, and services error indicators.
 CLEAR sets a given span of core to a constant.
 ECREAD fetches a data block from ECS.
 ECRITE stores a data block in ECS.

5. Output Routines

EDIT prints system balance information, fluxes and (optionally) calls flux plot routine at the end of each time step.
 PLOTBZ provides a contour plot of fluxes in each group.
 CONTRFB special subroutine to perform contour plot.
 WRITE prints 1, 2, or 3 dimensional arrays according to a variety of formats.

TABLE III

TRANZIT SYSTEM SUBROUTINES

TRANZIT requires the following system routines:

1. ECS System Routines

- a. ECRD fetches a vector from ECS.
- b. ECWR stores a vector in ECS.

2. General System Routines

- a. DATE1 obtains the current date in an ALO format.
- b. MAXM finds the maximum of a matrix.
- c. MAXV finds the maximum of a vector.
- d. MEPPH initializes the arithmetic mode error return.
- e. MINM finds the minimum of a matrix.

Table III (cont)

- f. MINV finds the minimum of a vector.
- g. REMARK places a remark found in an ALO format in the day file.
- h. SECOND obtains the current time.
- i. SHIFT shifts a number.

3. SC-4020 Plot Routines

- a. ADV advances the plot film frame.
- b. DLCH writes large characters on a film.
- c. DRV draws a vector between two points on a film.
- d. EXL sets lighter exposure than normal on a film.
- e. EXH returns normal exposure on a film.
- f. PLOJB plots the points of an independent and a dependent variable vector set as well as labeling the graph.
- g. TRICJB plots a contour.

B. Convergence Tests

For iteration in INNER, we require the maximum relative pointwise change in the scalar flux from one iteration to the next to be less than EPSI, an input precision. In REBAL, the iterative process used for computation of rebalance factors is required to converge so that the maximum relative change in any factor is less than EPSI. In the upscattering iterative process, outer iterations are continued until the maximum derivation from one of any rebalance factors is less than EPSI.

C. Data Storage

As in many of our transport programs, we compactly store all arrays in a single blank common vector, A. First word addresses of these arrays, input control numbers, and commonly used numbers are stored in a blank common array named IA. A table of contents of this array is given in Table IV. Similar information is given in Table V for named common blocks. Logical unit assignment is given in Table VI.

D. Flux Dumps and Problem Restart

Two types of flux dumps are taken. Both types have the same form. A periodic dump is taken every fifteen minutes to back up the calculation. A time limit dump is taken after a user-specified period of time. Each of these dumps is written alternately on unit 5 or 7 depending on which is

free; a message is written to inform the user which unit contains the latest dump.

1. Restart Procedures. Problem execution can be continued using restart dumps. The restart deck is composed of the problem input cards through the floating point parameter section. Certain input parameters can be changed at the time of problem restart by changing their values in the parameter input. The integers that may be changed are IPLOT (plot fluxes on film), IPF (print fluxes) and IPBT (print coarse-mesh balance tables). The floating point input parameter that may be changed is TIMLIM (time limit dump). The restart dump tape must be assigned to the initial unit number of NDMP1.

2. Restart Tape Composition. The restart tape must contain data from main core, from ECS core storage, from the old angular flux file and from the new angular flux file. With the exception of the "vital parameter restart information" record and the "ECS core storage" records, the first word of a record on the restart tape contains the count of the actual data in the record.

The "vital parameter restart record" consists of three words which contain the number of groups (IGM), the number of angular flux records per group (4*JT) and the current group number (G).

The "ECS core storage" records contain three additional words besides actual data. These first

TABLE IV
CONTENTS OF BLANK COMMON BLOCK IA

<u>Position</u>	<u>Name</u>	<u>Pointer for Array</u>	<u>Remarks</u>
1	ITM		Number of time steps
2	ISCT		Scattering order
3	ISN		Order of S_n approximation
4	IGM		Number of groups
5	IM		Number of radial coarse-mesh intervals
6	JM		Number of axial coarse-mesh intervals
7	IBR		Right boundary specification
8	IBB		Bottom boundary specification
9	IBT		Top boundary specification
10	ISTART		Flux input option
11	IQOPT		Source input option
12	IPILOT		Plot option
13	MT		Total number of materials
14	MIN		Number of input materials
15	MS		Length of mixture tables
16	IHT		Position in table of total cross section
17	IHS		Position in table of self-scatter cross section
18	IHM		Cross section table length
19	IQCOL		First collision source indicator
20	IQAN		Distributed source anisotropy order
21	IQR		Right boundary source indicator
22	IQB		Bottom boundary source indicator
23	IQT		Top boundary source indicator
24	ITTM		Maximum number of inner iterations allowed in any group
25	IPF		Flux print frequency indicator
26	IPET		Coarse-mesh balance table print frequency indicator
27			Not used
28			Not used
29			Not used
30	IITOT		Inner iteration total for each outer iteration
31	EPSI		Convergence precision
32	NORM		Normalization amplitude
33	SHGT		Height of source in first collision source option
34	TIMLIM		Time limit after which problem will be terminated by taking a dump
35	LTQ	TQ(ITM)	Time dependent source variation
36	MINF		When MIN < 0, MINF is used for loading special format cross sections (ANISN format)
37	IUP		Upscatter indicator (=1 if IHS.GT.IHT+1)
38	IHA		Sum IHT-2: Position of σ^a in cross section table
39	IMJM		Product IM * JM
40	MM		Product ISN*(ISN+2)/8
41	NM		Product (ISCT+1)*(ISCT+2)/2

Table IV (cont)

<u>Position</u>	<u>Name</u>	<u>Pointer for Array</u>	<u>Remarks</u>
42	NMQ		Product $(IQAN+1)*(IQAN+2)/2$
43	NN		Product $ISN/2$
44	IP		Sum $IM + 1$
45	JP		Sum $JM + 1$
46	IGP		Sum $IGM + 1$
47	IHMT		Product $MT * IHM$
48	ISCP		Sum $ISCT + 1$
49	MM2		Sum $MM + MM$
50	IT		Total number of radial fine-mesh intervals
51	JT		Total number of axial fine-mesh intervals
52	ITJT		Product $IT * JT$
53	ITMM		Product $IT * MM2$
54	JTMM		Product $JT * MM2$
55	NMIJ		Product $NM * ITJT$
56	NMM		Product $NM * MM$
57	IPJM		Product $IP * JM$
58	IMJP		Product $IM * JP$
59	ITP		Sum $IT + 1$
60	JTP		Sum $JT + 1$
61	LENQ		Length of source array (1 group)
62	LENF		Length of flux array (1 group)
63	LENAL		Length of albedo array (1 group)
64	KC		ECS cross section block first word address. Length of block is $(IHM*IGM)$
65	KQ		ECS source block first word address. Length of block is $(LENQ*IGM)$
66	KF		ECS flux block first word address. Length of block is $(LENF*IGM)$
67	KAL		ECS albedo block first word address. Length of block is $(LENAL*IGM)$
68	KAF		ECS angular flux block first word address. Length of block is $(2*ITMM*JT)$
69	KLAST		Total ECS storage requirement
70	LIHR	IHR(IM)	Number of radial fine-mesh intervals per coarse-mesh interval
71	LIHZ	IHZ(JM)	Number of axial fine-mesh intervals per coarse-mesh interval
72	LW	W(MM)	Direction weights
73	LU		Not used
74	LCM	U(MM)	Direction cosines (μ). (Called UM in INNER)
75	LCE	E(MM)	Direction cosines (η). (Called UE in INNER)
76	LWM	WM(MM)	Product $W * U$
77	LWE	WE'	Product $W * E$
78	LP1	P ₁ (NMM)	Spherical harmonic functions for in-down sweep
79	LP2	P ₂ (NMM)	Spherical harmonic functions for out-down sweep
80	LP3	P ₃ (NMM)	Spherical harmonic functions for in-up sweep

Table IV (cont)

Position	Name	Pointer for Array	Remarks
81	LP4	PH(NMM)	Spherical harmonic functions for out-up sweep
82	LAL	AL(MM)	$\alpha_{m+\frac{1}{2}}/w_m$
83	LMN	MIXNUM(MS)	Mixture numbers
84	LMC	MIXCOM(MS)	Mixture commands
85	LMD	MIXDEN(MS)	Mixture densities
86	LA	AI(ITP)	$2\rho_i/(\rho_{i+1}^2 - \rho_i^2)$
87	LB	BJ(JT)	$1./\Delta z_j$
88	LAD	AD(ITP)	$2./(\rho_{i+1} + \rho_i)$
89	LT	AT(ITM)	$1./\Delta t$
90	LTB	TB(ITM+1)	Time points
91	LDZ	DZ(JT)	Δz_j
92	LAA	AA(ITP)	$2\pi\rho_i$
93	LAB	AB(ITP)	$\pi(\rho_{i+1}^2 - \rho_i^2)$
94	LZDEN	DEN(JT)	Density factors for cross section variation
95	LDR	DR(IT+1)	$\Delta\rho_i$
96	LIR	IDR(IT+1)	Radial index multiples
97	LALM	ALM(MM)	$\alpha_{m-\frac{1}{2}}/w_m$
98	LIZ	IDZ(JT+1)	Axial index multiples
99	LDZA	IDZA(JT+1)	Axial zone level numbers
100	LDC	IDCS(IM,JM)	Cross section identification numbers
101	LC	C(IM,MT)	Input cross sections
102	LQ	Q(NM,IT,JT)	Source array
103	LQR	QR(MM2,JT)	Right boundary source (conditional on IQR.NE.O)
104	LQB	QB(MM2,IT)	Bottom boundary source (conditional on IQB.NE.O)
105	LQT	QT(MM2,IT)	Top boundary source (conditional on IQT.NE.O) (called QP in INNER)
106	LFL	FLUX(NM,IT,JT)	Flux components
107	LBR	BR(MM2,JT)	Right boundary fluxes
108	LBT	BT(MM2,IT)	Top boundary fluxes
109	LFLA	FLUXA(IT,JT)	Scalar flux from previous inner iteration
110	LAFL	ALFL(NN,IT)	Angular flux due to curvature streaming
111	LRA	RLBDO(0,1 or JT)	Right albedo
112	LRL	BLBDO(0,1 or IT)	Bottom albedo
113	LTA	TLBDO(0,1 or IT)	Top albedo
114	LANG	ANGFLU(MM,IT)	Angular flux from previous time step
115	LF	F(IM,JM)	Coarse-mesh rebalance factors
116	LFU	FU(IM,JP)	Partial upward current
117	LFD	FD(IM,JP)	Partial downward current
118	LFR	FR(IP,JM)	Partial rightward current
119	LFLI	FL(IP,JM)	Partial leftward current
120	LAS	AS(IM,JM)	Coarse-mesh absorption rate
121	LQQ	QQ(IM,JM)	Coarse-mesh source for each group
122	LQQC	QQG(IM,JM)	Coarse-mesh source for all groups. (Conditional on IUP > 0)
123	LFUT	FUT(IM,JP)	Sum of FU over all groups. (Conditional on IUP > 0)
124	LFDT	FDT(IM,JP)	Sum of FD over all groups. (Conditional on IUP > 0)

Table IV. (cont)

Position	Name	Pointer for Array	Remarks
125	LFRT	FRT(IP, JM)	Sum of FR over all groups. (Conditional on IUP > 0)
126	LFLT	FLT(IP, JM)	Sum of FL over all groups. (Conditional on IUP > 0)
127	LABT	ABT(IM, JM)	Sum of absorption rate for all groups. (Conditional on IUP > 0)
128	LHA	H(IM)	Array used in subroutine REBAL
129	LGA	G(IM)	Array used in subroutine REBAL
130	LQG	QG(IGP)	Source for balance table print
131	LSIN	SIN(IGP)	Inscatter for balance table print
132	LSS	SS(IGP)	Self-scatter for balance table print
133	LSOUT	SOUT(IGP)	Outscatter for balance table print
134	LHL	HL(IGP)	Not used
135	LVL	VL(IGP)	Bottom leakage for balance table print
136	LTL	TL(IGP)	Top leakage for balance table print
137	LNL	NL(IGP)	Net leakage for balance table print
138	LRL	RL(IGP)	Right leakage for balance table print
139	LABG	ABG(IGP)	Absorption for balance table print
140	LBAL	BAL(IGP)	Neutron balance
141	LVEL	VEL(IGP)	Group speeds
142	LQCS	QCS(IGP)	First collision source spectrum (IQCOL = 1 only)
143	LSL	SL(JTP)	Point wise cross section density integral (IQCOL = 1 only)
144	LR	R(IP)	Coarse radial mesh
145	LZ	Z(JP)	Coarse axial mesh
146	LAP	AIP(ITP)	$2\rho_{i+1}/(\rho_{i+1}^2 - \rho_i^2)$
147	LUB	UB(NNP)	Mu bounds used to define first collision source
148	LFLS	FLUXS(IT, JT)	Flux component
149	LQIM	QCIM(MM, IT)	Array used for uncollided angular flux
150	NNP		Sum NN + 1
151	TS		Total integrated source to group
152	KPHI		ECS first word address for time scalar flux. Block is ITJIT*IGM long
153	T1		$\sum w_m * \mu_m$
154	T2		$\sum w_m * \eta_m$
155			Not used
156			Not used
157	DT		$\Delta t = t_{s+\frac{1}{2}} - t_{s-\frac{1}{2}}$
158	FQ		Float (IQCOL)
159	G		Current group number (fixed point)
160	LDPT	DPT(IGP)	$\Delta\phi = \sum V_{ij}(\phi_{ijs+\frac{1}{2}} - \phi_{ijs-\frac{1}{2}})$
161	ICONV		Convergence trigger
162	IITNO		Inner iteration count
163	RVT		Reciprocal of v Δt
164	OITNO		Outer iteration number
165	ITM2		Product MM * IT
166	V		Speed for group g
167	MIJ		Product MM * ITJT

Table IV (cont)

<u>Position</u>	<u>Name</u>	<u>Pointer for Array</u>	<u>Remarks</u>
168	ITMP		Sum ITM + 1
169	KQC		ECS first word address for uncollided angular flux. Block is $4*IT*JT*MM$ long
170	T		Value of current time
171	ITIM		Current time step number
172	KS		ECS first word address for source-to-group. Block is NMLJ long
173	MAXEC		Maximum dimension of extended core storage
174	MAX		Maximum dimension of A data storage
175	LAST		Total core storage requirement for all data
176	TIME		Time in minutes
177	TIN		Starting time of problem
178	TOUT		Starting time of subroutine OUTER
179	TACC		Total accumulated running time
180	TSLDMP		Time since last dump
181	TIMBDP		Time between dumps
182	IGCDMP		Number of group at which dump was taken
183	IDUMP		Final dump indicator
184	TSS		Uncollided self-scatter rate
185	TF		Uncollided time flow at $t_{s+\frac{1}{2}}$
186	TFP		Uncollided time flow at $t_{s-\frac{1}{2}}$
187	TA		Uncollided absorption rate
188	RL		Uncollided right leakage
189	BL		Uncollided bottom leakage
190	TL		Uncollided top leakage
191	LFP	FP(IGM)	Uncollided time flow array
192	TC		Uncollided total collision rate
193	TQ		Uncollided group source amplitude before normalization
194	TFN		Net group time flow (collided flux only)
195	IUPTOT		Trigger for input of cross sections without σ^{up}
196	IPFT		Trigger for print of isotropic flux only
197			
198			
199			
200			

TABLE V

NAMED COMMON BLOCKS

1. Units

NIMP	problem input decimal unit.
NOUT	system output decimal unit.
NAFLX1	angular flux from previous time step.
NAFLX2	angular flux from current time step.

Table V (cont)

NDMP1 first unit for restart dumps.
 NDMP2 second unit for restart dumps.

2. FWENT

IFWENT(14) used by subroutine LAXSF to pass address of cross section block to subroutine FIDOX.

3. FWBCT

IFWBCT(14) used by subroutine LAXSF to pass total length of cross section block to subroutine FIDOX.

4. CNTRCOM

ISYM(50) used by subroutine CNTRCOM and CONTRFB for plotting.

5. LOCAL

NERROR data input error indicator.

6. FWBRZD

FWBRZD information necessary for restarting from a dump.
 TTT used to initialize coarse-mesh group totals.
 K1 ECS pointer for current group of cross sections.
 K2 ECS pointer for current group of flux.
 K3 ECS pointer for current group of Q-source.
 K4 ECS pointer for current group of angular flux.
 IGRST number of current group.
 NTNOW number of current dump tape (NDMP1).

TABLE VI

ASSIGNMENT OF FILES

<u>File Name</u>	<u>Logical Unit</u>	<u>Contents</u>	<u>Remarks</u>
NINP	10	Problem input decimal unit	Generally this unit is equivalent to the system input unit.
NOUT	9	System output decimal unit	
NAFLX1	3	Angular flux from previous time step	
NAFLX2	4	Current angular flux	
NDMP1	7	First unit for restart dumps	Serves as an initial flux dump unit.
NDMP2	5	Second unit for restart dumps	Restart dumps are taken alternately upon NDMP1 and this unit during the execution of a problem.
NFLUX	8	Edit information for each time step written on this unit	Used only for problems with first collision source.

three words are the read-length of the record, the ECS core storage pointer of the record, and the actual data length. Should the actual data length be zero, the resulting record would have the read-length of one and a zero data word.

The ECS core storage of group dependent data is divided into five sections. Each section results in a total of IGM records of the form de-

scribed above. The order of the records is from group one through group IGM. The five sections of group dependent data are the time dependent scalar flux block, the cross section block, the Q source block, the flux component block and the albedo block.

The order of the records on the dump tape is as follows:

<u>Data Length of Record</u>	<u>Number of Records</u>	<u>Remarks</u>
3	1	Vital restart parameters.
Length of named common block FWERZD	1	The named common block FWERZD contains variables from subroutine OUTER such as the current ECS block pointers needed for the continuation of a case.
Length of the common block IA	1	The common block IA contains the case parameter information.
Length (LAST) of common block A	1	Only the actual amount of the common data block A that is required by the case is saved.
ITJT (product of the total number of fine radial intervals and the total number of fine axial intervals)	IGM	ECS time-dependent scalar flux series.
IHMT (product of the cross section table length and the total number of materials)	IGM	ECS cross section series.
LENQ (length of the Q source and any additional boundary sources from the right, bottom, or top)	IGM	ECS Q source series.
LENF (length of the flux data)	IGM	ECS flux component series.
LENAL (length of the albedo data)	IGM	ECS albedo series. This series may result in the "zero data count" record form.
MM*IT (product of number of directions and total number of fine radial intervals)	4*JT*IGM	Old angular flux file processed as ordered from start of the file.
MM*IT	Variable with a maximum of 4*JT*IGM	New angular flux file processed as ordered from start of the file until an end of file is encountered.

E. Source Input Options

If a source of anisotropy IQAN is designated, the $NMQ = ((IQAN+1)(IQAN - 2))/2$ components of the source must be entered for each group. This may be accomplished with the use of five options designated by the input value of IQOPT. For IQOPT=0, a value of zero is automatically entered for all elements of the distributed source, and then input boundary fluxes are read. In other options, the various arrays described below are supplied for each group, first for group 1, then for group 2, and so forth, ending with group IGM (the lowest energy group if the Los Alamos cross section format is used). For each group the boundary sources (if any) are entered after the distributed source. If distributed or boundary sources are specified in any group, values must be entered in all groups. The ordering of source input within each group is

1. $((Q_{gijn}, i = 1, IT), j = 1, JT)$ for $n = 1, NMQ$
2. Optionally: $((QR_{gmj}, m = 1, MM2), j = 1, JT)$ where $MM2 = MM + MM$
3. Optionally: $((QB_{gmi}, m = 1, MM2), i = 1, IT)$ where $MM2 = MM + MM$
4. Optionally: $((QT_{gmi}, m = 1, MM2), i = 1, IT)$ where $MM2 = MM + MM$.

The above notation is that of standard FORTRAN. For example, the source Q is entered in NMQ blocks of $IT \times JT$ numbers, in a continuous stream, the first IT numbers for $j = 1$, the next IT numbers for $j = 2$, etc., all for $n = 1$. Then, for $n = 2$, IT numbers are entered for $j = 1$, and so on.

The user is also allowed to specify the value of the incoming flux along the right and/or bottom and/or top boundaries, but only if these boundaries are specified as vacuum boundaries (IBR and/or IBB and/or IBT = 0).

The user must supply values for the entire range of the index m as specified above. The range of this index is separated into two equal parts -- the first range running from 1 through MM and the second range running from $MM + 1$ through $MM + MM$. In the QR block, the values which are entered with the first range of the index m are the in-down directions ($\mu < 0, \eta < 0$) and the values that are entered with the second range of the index m are the in-up directions ($\mu < 0, \eta > 0$) for

the z value as defined by the index j . The entire block is then specified by entering $MM2$ values for $j = 1$, $MM2$ values for $j = 2$, etc. For the QB block, the entered values of the first index range of m correspond to the in-up directions and the entered values of the second index range of m correspond to the out-up directions. For the QT block, the entered values of the first index range of m correspond to the in-down directions and the entered values of the second index range of m correspond to the out-down directions.

In addition to IQOPT=0 in which Q_{gijn} is automatically set to zero, there are four other options to simplify the reading of Q_{gijn} . These options are all executed for each anisotropic component of Q , i.e., for $n = 1, 2, \dots, NMQ$. These options are:

- IQOPT=1 Enter an energy spectrum ($GR_{g,n}, g = 1, IGM$) for each n . Then
 $Q_{gijn} = GR_{g,n}$ for all i and j for each g and n .
- IQOPT=2 Enter the complete array Q_{gijn} as described above.
- IQOPT=3 Enter first a spectrum ($GR_{g,n}, g = 1, IGM$) as in option 1. Then enter a shape $((F_{ijn}, i = 1, IT), j = 1, JT)$ in a continuous block of $IT \times JT$ numbers. Then the source is made by
 $Q_{gijn} = GR_{g,n} F_{ijn}$ for all i and j for each g and n .
- IQOPT=4 Enter a spectrum ($GR_{g,n}, g = 1, IGM$), an i -direction spatial shape ($X_{i,n}, i = 1, IT$), and a j -direction spatial shape ($Y_{j,n}, j = 1, JT$). The source is then given by
 $Q_{gijn} = GR_{g,n} X_{i,n} Y_{j,n}$ for all i and j for each g and n .

V. INPUT SPECIFICATION

A. Special Input and Output Routines

Except for the control parameters and cross sections, all floating-point numbers and integers are read into TRANZIT in special formats. These formats are $[6(I1, I2, E9, 4)]$ for reading floating-point numbers and $[6(I1, I2, I9)]$ for

integers. In each word of both of these formats, the first integer field, I1, designates the options listed below. The second integer field, I2, controls the execution of the option, and the remainder of the field, I9 or E9.4, is for the input data. All data blocks read with these formats must end with a 3 in the I1 field after the last word of the block. The available options are given in Table VII.

TABLE VII
OPTIONS FOR SPECIAL READ FORMATS

<u>Value of I1</u>	<u>Nature of Option</u>
0 or blank	No action
1	Repeat data word in 9 field number of times indicated in I2 field.
2	Place number of linear interpolants indicated in I2 field between data word in 9 field and data word in next 9 field. <u>Not allowed for integers.</u>
3	Terminate reading of data block. <u>A 3 must follow last data word of all blocks.</u>
4	Fill remainder of block with data word in 9 field. This operation must be followed by a terminate (3).
5	Repeat data word in 9 field 10 times the value in the I2 field.
9	Skip to next data card.

Five illustrations of the use of the special formats are given below. These illustrate:

- 1 - Zero is repeated 47 times.
- 2 - Zero is repeated 470 times.
- 3 - Four interpolants are inserted between 0.0 and 5.0 giving six data numbers: 0.0, 1.0, 2.0, 3.0, 4.0, 5.0.
- 4 - Four interpolants are inserted between 0.0 and 5.0, two between 5.0 and 7.0, and 7.0 is repeated 10 times.
- 5 - After reading 0 and 4 we skip to next card and read 7.

A special routine, WRITE, is used to print most of the two- and three-dimensional arrays that occur in the program. This routine can be used for one-, two-, or three-dimensional arrays and has an

I1I2	I1I2	I1I2	I1I2
1NN	1NN	1NN	1NN
147 0.0	3		EXAMPLE 1
247 0.0	3		EXAMPLE 2
24 0.0	5.0	3	EXAMPLE 3
24 0.0	2 5.0	3 10 0.0	EXAMPLE 4
	0	4 9	EXAMPLE 5
	7 3		

option for printing a portion of an array, e.g., the mixed cross section blocks, if any. When fluxes, sources, and fission rates are printed, they are oriented with the origin at the lower left of the page, corresponding to the picture drawn by MAPPER.

In the following pages the input data for TRANZIT are listed in exactly the order in which they are entered in the code. The data are divided into three categories: (1) job title cards, (2) control integers on cards 1 through 3 and control floating-point numbers on cards 4 and 5, and (3) problem-dependent data on subsequent cards.

B. Job Title Cards

The user begins by indicating on a card in an I6 format the number of title or job description cards he wants to use. He then enters the descriptive material on these cards which are read with a I2A6 format.

C. Input of Control Numbers

On cards 1 through 3, the user enters the following control integers which are read in a I2I6 format:

<u>Number of Word on Card</u>	<u>Name of Variable</u>	<u>Comments</u>
-----------------------------------	-----------------------------	-----------------

CONTROL INTEGERS-----CARD 1

1	ITM	Number of time steps.
2	ISCT	O/N (isotropic/Nth-order anisotropic) order of scattering calculation. There are $NM = (ISCT+1)(ISCT+2)/2$ spherical harmonics flux components computed. These are not used to compute a scattering source unless some zone material identification number is negative. See IDCS below.
3	ISN	S_n order. Even integer only. If negative, user must supply his own quadrature coefficients. Otherwise (for ISN = 2 through 16) built-in constants are used.
4	IGM	Number of groups.
5	IM	Number of <u>coarse</u> -mesh intervals in the ρ direction.
6	JM	Number of <u>coarse</u> -mesh intervals in the z direction.
7	IBR	Right boundary condition. 0-vacuum/1-reflective/2-white/3-constant albedo/4-group dependent albedo.
8	IBB	Bottom boundary condition. Options same as IBR above.
9	IBT	Top boundary condition. Options same as IBR above.
10	ISTART	Input flux guess and starting options. See below under Flux Guess.
11	IQOPT	Input inhomogeneous source options. See Section IV.
12	IPILOT	O/N Contour plot of flux at each Nth time step. No plot if zero.

CONTROL INTEGERS-----CARD 2

1	MT	Total number of materials. (Cross section blocks including anisotropic cross sections in the problem.)
2	MIN	Number of input materials. If MIN < 0, FIDO (ANISN) cross section format is read.
3	MS	Number of mixture instructions.
4	IHT	Row of total cross section in the cross section format. If IHT < 0, code assumes that there is no σ^{up} in cross section table.
5	IHS	Row of within-group scattering cross section in the cross section format.
6	IHM	Total number of rows in the cross section format.
7	IQCOL	0/1 (no/yes) first collision source present.
8	IQAN	Order of anisotropy of inhomogeneous distributed source. There are $NMQ = (IQAN+1)(IQAN+2)/2$ components of the distributed source to be entered.
9	IQR	0/1 (no/yes) right boundary source to be specified as input. This source is the value of the incoming flux on the boundary.
10	IQB	Bottom boundary source. Same options as IQR.
11	IQT	Top boundary source. Same options as IQR.
12	IITM	Maximum number of inner iterations allowed per group.

CONTROL INTEGERS-----CARD 3

1	IPF	O/N Print flux at each Nth time step. Not printed if zero. If negative only isotropic flux is printed.
2	IPBT	O/N Print coarse-mesh balance tables at each Nth time step. Not printed if zero.

Card 4 consists of control floating-point numbers read in a E12.5 format.

CONTROL FLOATING-POINT DATA-----CARD 4

1	EPSI	Convergence precision.
2	NORM	Normalization factor.
3	SHOT	Source height. Used only if IQCOL > 0. Must be located on a fine mesh boundary.
4	TIMLIM	Time limit (in seconds) after which a restart dump will be taken and problem terminated.

Input of remaining data

With the exception of the cross sections, all the following data are read by the special formats discussed in Section V.A. We denote these formats by S(I) for integers and S(E) for floating-point numbers. All group dependent quantities are input in order of increasing group number.

<u>Block Name and Dimension</u>	<u>Format</u>	<u>Number of Entries</u>	<u>Comments</u>
IHR(IM)	S(I)	IM	Integers defining the number of fine-mesh ρ -intervals in each coarse-mesh ρ -interval.
IHZ(JM)	S(I)	JM	Integers defining the number of fine-mesh z-intervals in each coarse-mesh z-interval.
MIXNUM(MS)	S(I)	MS	Numbers identifying cross section block being mixed. <u>Do not enter if MS = 0.</u>
MIXCOM(MS)	S(I)	MS	Numbers controlling cross section mixture process. <u>Do not enter if MS = 0.</u>
MIXDEN(MS)	S(E)	MS	Mixture densities. <u>Do not enter if MS = 0.</u>
C(IHM, IGM, MIN)	6(E12.5)		MIN blocks of IHM*IGM numbers. Cross section blocks from cards. Each block is preceded by a header (identification) card read with 12A6 format. MIN blocks are read in this fashion.
W(MM)	S(E)	MM	Quadrature weights. <u>Do not enter unless ISN < 0.</u>
U(MM)	S(E)	MM	Quadrature Mu cosines. <u>Do not enter unless ISN < 0.</u>
E(MM)	S(E)	MM	Quadrature Eta cosines. <u>Do not enter unless ISN < 0.</u>
TQ(ITM)	S(E)	ITM	Time variation of distributed source. Distribution is normalized to one after input. If distribution becomes zero, source remains zero thereafter.
TB(ITMP)	S(E)	ITM+1	Time interval boundaries.
R(IP)	S(E)	IM+1	Coarse ρ -mesh boundaries which must form increasing sequence.
Z(JP)	S(E)	JM+1	Coarse z-mesh boundaries which must form increasing sequence.
DEN(JT)	S(E)	JT	Density factors for z direction modification of cross sections.
IDCS(IMJM)	S(I)	IM*JM	Cross section zone identification numbers. These numbers assign a cross section block to each zone defined by the coarse-mesh boundaries. If these numbers are negative, an anisotropic scattering source is calculated in the zone. These numbers need not be negative if ISCT=0.

Input FLUX	S(E)		Number of entries depends on option. See Section IV which describes similar options for the source.																						
Guess																									
FLUX(NM,IT,JT)			<table><tr><th>Option</th><th>Number of Entries</th></tr><tr><td>-4</td><td>IGM + IT + JT</td></tr><tr><td>-3</td><td>IGM + IT*JT</td></tr><tr><td>-2</td><td>IGM blocks of IT*JT</td></tr><tr><td>-1</td><td>IGM</td></tr><tr><td>0</td><td>None</td></tr><tr><td>1</td><td>NM sets of IGM</td></tr><tr><td>2</td><td>IGM groups of NM sets of IT*JT</td></tr><tr><td>3</td><td>NM sets of IGM + IT*JT</td></tr><tr><td>4</td><td>NM sets of IGM + IT + JT</td></tr><tr><td>5</td><td>Read restart dump from Tape 7.</td></tr></table>	Option	Number of Entries	-4	IGM + IT + JT	-3	IGM + IT*JT	-2	IGM blocks of IT*JT	-1	IGM	0	None	1	NM sets of IGM	2	IGM groups of NM sets of IT*JT	3	NM sets of IGM + IT*JT	4	NM sets of IGM + IT + JT	5	Read restart dump from Tape 7.
Option	Number of Entries																								
-4	IGM + IT + JT																								
-3	IGM + IT*JT																								
-2	IGM blocks of IT*JT																								
-1	IGM																								
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3	NM sets of IGM + IT*JT																								
4	NM sets of IGM + IT + JT																								
5	Read restart dump from Tape 7.																								
Input Source	S(E)		Number of entries depends on option. See Section IV.																						
Q(NMQ,IT,JT)			<table><tr><th>Option</th><th>Number of Entries</th></tr><tr><td>0</td><td>None</td></tr><tr><td>1</td><td>NMQ sets of IGM</td></tr><tr><td>2</td><td>IGM groups of NMQ blocks of IT*JT</td></tr><tr><td>3</td><td>NMQ sets of IGM + IT*JT</td></tr><tr><td>4</td><td>NMQ sets of IGM + IT + JT</td></tr></table>	Option	Number of Entries	0	None	1	NMQ sets of IGM	2	IGM groups of NMQ blocks of IT*JT	3	NMQ sets of IGM + IT*JT	4	NMQ sets of IGM + IT + JT										
Option	Number of Entries																								
0	None																								
1	NMQ sets of IGM																								
2	IGM groups of NMQ blocks of IT*JT																								
3	NMQ sets of IGM + IT*JT																								
4	NMQ sets of IGM + IT + JT																								
QR(2*MM,JT)	S(E)	2*JT*MM	Right boundary source (flux) in the in-down and in-up directions. Enter MM values for in-down directions, then MM values for in-up directions for first (smallest) z values, then repeat for increasing z values. <u>Do not enter unless IQR = 1.</u>																						
QB(2*MM,IT)	S(E)	2*IT*MM	Bottom boundary source (flux) in the in-up and out-up directions. Enter MM values for inward directions and MM values for outward directions for smallest ρ value, then repeat for increasing ρ values. Directions are ordered as in Fig. 2. <u>Do not enter unless IQB = 1.</u>																						
QT(2*MM,IT)	S(E)	2*IT*MM	Top boundary source (flux) in the in-down and out-down directions. Enter MM values for inward directions and MM values for outward directions for smallest ρ value, then repeat for increasing ρ values. Directions are ordered as in Fig. 2. <u>Do not enter unless IQT = 1.</u>																						
VEL(IGM)	S(E)	IGM	Group speeds.																						
Right Albedo			Number of entries depends on value of IBR. Enter all																						
RLBDO(IR)	S(E)		numbers for first group, then for second group, etc. <u>Do not enter if IBR < 3.</u>																						
			<table><tr><th>IBR</th><th>Number IR</th></tr><tr><td>3</td><td>1</td></tr><tr><td>4</td><td>JT</td></tr></table>	IBR	Number IR	3	1	4	JT																
IBR	Number IR																								
3	1																								
4	JT																								
Bottom Albedo			Number of entries depends on value of IBB. Enter all																						
BLBDO(IR)	S(E)		numbers for first group, then for second group, etc. <u>Do not enter if IBB < 3.</u>																						
			<table><tr><th>IBB</th><th>Number IR</th></tr><tr><td>3</td><td>1</td></tr><tr><td>4</td><td>IT</td></tr></table>	IBB	Number IR	3	1	4	IT																
IBB	Number IR																								
3	1																								
4	IT																								

Top Albedo

TLBDO(IR)

S(E)

Number of entries depends on value of IBT. Enter all numbers for first group, then for second group, etc. Do not enter if IBT < 3.

IBT	Number IR
3	1
4	IT

QCS(IGM)

S(E)

IGM

First collision source spectrum. Do not enter unless IQCOL = 1.

VI. COMPARISONS OF RESULTS WITH MONTE CARLO COMPUTATIONS

A. One Group Problem Without First Collision

Source

As a first test problem, we took a small, uniformly distributed, isotropically emitting source at the top ($0 < r < 0.1$, $1.99 < z < 2.0$) of a cylinder ($0 < r < 1.0$, $0 < z < 2.0$) uniformly composed of an isotropically scattering material with $\sigma_g/\sigma_t = 0.2$. We assumed that particles traveled with unit speed (1 cm/sec), and compared the total number of absorptions in the system in each 0.2 second time interval. We also compared the number of particles crossing the bottom boundary in each such interval. Physically, no particles could cross this boundary for $t < 1.99$.

The results of the calculations are plotted in Fig. 3. Three separate runs of 10^5 particles were run with the Monte Carlo program; these are plotted as horizontal bars. A smooth curve is drawn through the results obtained with TRANZIT. In order to obtain good resolution of the early time absorption rate, it was necessary to run TRANZIT with finer initial time intervals. These results are shown plotted with crosses. A similar time resolution would have been necessary to duplicate the Monte Carlo leakage rates near $t = 2.0$ when the most particles cross the bottom boundary. Note that the TRANZIT results show a characteristic early rise of the leakage rate; some particles are beginning to leak before $t = 1.99$. The TRANZIT computation used an S_8 approximation and 400 space intervals. It actually required more computational effort than the Monte Carlo calculation, but the only tallies made in the latter were for leakage and absorption, while TRANZIT produced angular fluxes at each space-time point.

B. One Group Problem with First Collision Source

In a minor modification of the preceding problem, we replaced the distributed source with a point source at $r = 0$, $z = 1.9$. In the TRANZIT calculation we reduced the S_N order to S_4 on the grounds that the collided flux is much more isotropic than the total flux. The comparison of results of these calculations is shown in Fig. 4. In the figure we draw a smooth curve through the TRANZIT results for the time dependence of the absorption and surface leakages. The Monte Carlo results (produced with the ANDYMG3 program⁶ in three separate runs using 120,000 starting particles in each run) are shown by a horizontal line, or when the results of the different runs showed a spread, by a vertical line from maximum to minimum value. These bars are omitted in places on the bottom leakage curve for clarity.

Inflections in the TRANZIT results curves are visible at $t = 1.9$ when the uncollided wave front reaches the bottom surface, at $t = 2.0$ when it reaches the right surface and at $t = 2.76$ when it leaves the cylinder. The Monte Carlo top, bottom, and right leakages are zero up to times $t = 0.1$, $t = 1.9$ and $t = 2.0$, respectively. The TRANZIT results are nonzero before these times but are all a factor of over 100 less in the time interval just preceding the wave arrival times than they are in the next time interval. At long times the TRANZIT results appear to decay exponentially with the same exponent; the uncertainty of the Monte Carlo results prohibits an estimate of the exponent.

In general, the agreement between the programs is excellent. Use of the uncollided flux option in TRANZIT reproduces the behavior of the leakages much more efficiently than when the option is not used. Each of the Monte Carlo runs required about four

Fig. 3. Comparison of TRANZIT and Monte Carlo. No first-collision source used in TRANZIT.

Fig. 4. Comparison of TRANZIT and Monte Carlo. First-collision source used in TRANZIT.

minutes (CDC 6600 CPU time); the TRANZIT run with 56 equal time steps, 0.0(0.1)5.6 required about nine minutes. When a 25 interval unequal time spacing [0.0, 0.1, 0.2, 0.4(0.4)1.6, 1.8(0.1)2.4 (0.2)4.0(0.4)5.6] was used, TRANZIT required about five minutes. With this cruder spacing TRANZIT values changed somewhat. For example, for $5.2 < t < 5.6$ the absorption changed from 2.2×10^{-5} (fine mesh) to 2.9×10^{-5} (coarse mesh).

The TRANZIT results for the right leakage show an irregular behavior for times just after the uncollided flux wave front leaves the system. We feel that this is an irregularity due to the implicit time differencing. It is also manifest in the point scalar fluxes, but is not observed in the problem run with larger time intervals. With larger intervals, the time difference equations are undoubtedly closer to the step function approximation which gives smoother results.

C. Program Output

Following is a portion of the TRANZIT output listing produced in executing the problem of Sec. B above. Most of the output is self-explanatory. The uncollided flux balance (just below the system picture for time step one) contains the entries:

G	group number
ITIM	time step number
TN	time normalization factor
TA	total absorption
RL	right leakage
TL	top leakage
BL	bottom leakage
TF	time flow to next time step
TFP	time flow from previous time step
TC	total collisions
TSS	total self scattering events

The item "zero source" indicates that we have not used the distributed source option; rather, we have used the uncollided flux option.

REFERENCES

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3. K. D. Lathrop, "Spatial Differencing of the Transport Equation: Positivity vs Accuracy," J. Comput. Phys. **4**, 475 (1969).
4. K. D. Lathrop and F. W. Brinkley, *op. cit.*, p. 11.
5. K. D. Lathrop, "Ray Effects in Discrete Ordinates Equations," Nucl. Sci. Eng. **32**, 357 (1968).
6. D. R. Harris, "ANDYMG3, The Basic Program of a Series of Monte Carlo Programs for Time-Dependent Transport of Particles and Photons," Los Alamos Scientific Laboratory Report LA-4539 (1970).

ACKNOWLEDGMENT

The authors are grateful to D. R. Harris for supplying Monte Carlo results and instructions in the use of his program.

THIS PROBLEM RUN WITH ROACH VERSION OF TRANZIT DATED 11-2-70 ON 12/09/70
 1 GROUP MONTE CARLO COMPARISON WITH EQUAL TIME STEPS, DELTA T=.1, ITM=56

ITM	NUMBER OF TIME STEPS	56
ISC	0/ISO/N, ANISO SCATTERING	0
ISM	ORDER OF SN APPROXIMATION	4
IGM	NUMBER OF GROUPS	1
IM	NUMBER OF R INTERVALS (COARSE MESH)	5
JM	NUMBER OF Z INTERVALS (COARSE MESH)	5
IBR	RIGHT, BOTTOM, TOP BOUNDARY CONDITION 0/1/2/3/4	0
IBB	VACUUM/REFLECTIVE/WHITE/CONSTANT ALBEDO/GROUP	0
IBT	DEPENDENT ALBEDO	0
ISTART	FLUX STARTING OPTIONS -) THRU +5 SEE WRITEUP	-1
IOOPT	SOURCE STARTING OPTION 0/1/2/3/4 SEE WRITEUP	0
IPLT	0/NO/N/PLOT FLUXES ON FILM AT NTH TIME STEP	0

MT	TOTAL NUMBER OF MATERIALS	1
MIN	NUMBER OF INPUT MATERIALS	1
MS	LENGTH OF MIXTURE TABLES	0
IMT	POSITION OF TOTAL CROSS SECTION	3
IMS	POSITION OF SCATTERING CROSS SECTION	4
IMM	CROSS SECTION TABLE LENGTH	4
IQCCL	0/NO/1/YES FIRST COLLISION SOURCE	1
IQAN	SOURCE ANISOTROPY	0
IQR	0/NO/1/YES RIGHT BOUNDARY SOURCE	0
IQB	0/NO/1/YES BOTTOM BOUNDARY SOURCE	0
IQT	0/NO/1/YES TOP BOUNDARY SOURCE	0
IITM	INNER ITERATION MAXIMUM	100

IPF	0/NO/N/PRINT FLUX AT NTH TIME STEP	1
IPBT	0/NO/N/PRINT COARSE MESH BALANCE TABLES AT NTH TIME STEP	0

EPSI	CONVERGENCE PRECISION	1.00000E-04
NORM	NORMALIZATION AMPLITUDE	1.00000E+00
SHGT	HEIGHT OF SOURCE (IQCCL, NE, 0 ONLY)	1.90000E+00
TIME LIM	TIME LIMIT DUMP (SECONDS)	0.

INPUT FINE R MESH	5			
1	4	5	5	5
INPUT FINE Z MESH	5			
5	5	5	4	1

CORE STORAGE REQUIREMENT 2776 ECS STORAGE REQUIREMENT 11085

THE FOLLOWING NUCLIDES ARE FROM CARDS
 MATL 1

INPUT CROSS SECT	1
GROUP	I
1	.800000E+00
2	0.
3	.100000E+01
4	.200000E+00

5 4 CONSTANTS

	MU	ETA	WEIGHT
1	.30163878E+00	.90444905E+00	.83333333E-01
2	.90444905E+00	.30163878E+00	.83333333E-01
3	.30163878E+00	.30163878E+00	.83333333E-01
P1 GENANO	1		
	1	2	3
1	.100000E+01	.100000E+01	.100000E+01
P2 GENANO	1		
	1	2	3
1	.100000E+01	.100000E+01	.100000E+01

```

P3  GENANG      1
      1      2      3
      1 .100000E+01 .100000E+01 .100000E+01
P4  GENANG      1
      1      2      3
      1 .100000E+01 .100000E+01 .100000E+01
INPUT S(1) VARIATN 56
1.0000E+00 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.
INPUT TIME POINTS 57
0. 1.0000E+01 2.0000E+01 3.0000E+01 4.0000E+01 5.0000E+01 6.0000E+01 7.0000E+01 8.0000E+01 9.0000E+01
1.0000E+00 1.1000E+00 1.2000E+00 1.3000E+00 1.4000E+00 1.5000E+00 1.6000E+00 1.7000E+00 1.8000E+00 1.9000E+00
2.0000E+00 2.1000E+00 2.2000E+00 2.3000E+00 2.4000E+00 2.5000E+00 2.6000E+00 2.7000E+00 2.8000E+00 2.9000E+00
3.0000E+00 3.1000E+00 3.2000E+00 3.3000E+00 3.4000E+00 3.5000E+00 3.6000E+00 3.7000E+00 3.8000E+00 3.9000E+00
4.0000E+00 4.1000E+00 4.2000E+00 4.3000E+00 4.4000E+00 4.5000E+00 4.6000E+00 4.7000E+00 4.8000E+00 4.9000E+00
5.0000E+00 5.1000E+00 5.2000E+00 5.3000E+00 5.4000E+00 5.5000E+00 5.6000E+00
INPUT COARSE RMESH 6
0. 5.0000E-02 5.0000E-01 1.0000E+00 1.5000E+00 2.0000E+00
INPUT COARSEZ MESH 6
0. 5.0000E-01 1.0000E+00 1.5000E+00 1.9000E+00 2.0000E+00
INPUT ZDENS.FACTOR 20
1.0000E+00 1.0000E+00 1.0000E+00 1.0000E+00 1.0000E+00 1.0000E+00 1.0000E+00 1.0000E+00 1.0000E+00 1.0000E+00
1.0000E+00 1.0000E+00 1.0000E+00 1.0000E+00 1.0000E+00 1.0000E+00 1.0000E+00 1.0000E+00 1.0000E+00 1.0000E+00
INPUT CROSS SEC ID 25
1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1
ZONE DELTA Z RECIPROCAL DELTA
1 1 1.00000E-01 1.00000E+01
2 1 1.00000E-01 1.00000E+01
3 1 1.00000E-01 1.00000E+01
4 1 1.00000E-01 1.00000E+01
5 1 1.00000E-01 1.00000E+01
6 2 1.00000E-01 1.00000E+01
7 2 1.00000E-01 1.00000E+01
8 2 1.00000E-01 1.00000E+01
9 2 1.00000E-01 1.00000E+01
10 2 1.00000E-01 1.00000E+01
11 3 1.00000E-01 1.00000E+01
12 3 1.00000E-01 1.00000E+01
13 3 1.00000E-01 1.00000E+01
14 3 1.00000E-01 1.00000E+01
15 3 1.00000E-01 1.00000E+01
16 4 1.00000E-01 1.00000E+01
17 4 1.00000E-01 1.00000E+01
18 4 1.00000E-01 1.00000E+01
19 4 1.00000E-01 1.00000E+01
20 5 1.00000E-01 1.00000E+01
ZONE A1 A1P AA AB
1 1 0. 4.00000E+01 0. 7.85398E+03
2 2 4.18301E+00 1.35948E+01 3.14159E-01 7.51037E+02
3 2 6.60317E+00 1.11746E+01 1.02102E+00 1.54625E+01
4 2 7.37945E+00 1.03983E+01 1.72788E+00 2.34147E+01
5 2 7.76213E+00 1.00156E+01 2.43473E+00 3.13668E+01
6 3 9.09091E+00 1.09091E+01 3.14159E+00 3.45575E+01
7 3 9.23077E+00 1.07692E+01 3.76991E+00 4.08407E+01
8 3 9.33333E+00 1.06667E+01 4.39823E+00 4.71239E+01
9 3 9.41176E+00 1.05882E+01 5.02655E+00 5.34071E+01
10 3 9.47368E+00 1.05263E+01 5.65487E+00 5.96963E+01
11 4 9.57381E+00 1.04762E+01 6.28319E+00 6.59734E+01
12 4 9.51522E+00 1.04348E+01 6.91150E+00 7.22566E+01
13 4 9.60100E+00 1.04000E+01 7.53982E+00 7.85398E+01
14 4 9.62963E+00 1.03704E+01 8.16814E+00 8.48236E+01
15 4 9.65517E+00 1.03448E+01 8.79646E+00 9.11062E+01
16 5 9.67742E+00 1.03226E+01 9.42478E+00 9.73894E+01
17 5 9.69697E+00 1.03030E+01 1.00531E+01 1.03673E+02
18 5 9.71429E+00 1.02857E+01 1.06814E+01 1.09956E+02
19 5 9.72973E+00 1.02703E+01 1.13097E+01 1.16239E+02
20 5 9.74359E+00 1.02564E+01 1.19381E+01 1.22522E+02
21 0 0. 0. 1.25664E+01 0.
DENSITY INTEGRAL
1=1.90000E+00
2=1.80000E+00
3=1.70000E+00
4=1.60000E+00

```


	SOURCE	DELTA PHI/DELTA T	IN SCATTER	SELF SCATTER	OUT SCATTER	NET LEAKAGE
1	1.0000000E+00	9.2493601E-01	0.	1.8515295E-02	1.3544721E-14	1.0028072E-03
2	1.0000000E+00	9.2493601E-01	0.	1.8515295E-02	1.3544721E-14	1.0028072E-03

	ABSORPTION	NEUTRON BALANCE	RIGHT LEAKAGE	LEFT LEAKAGE	TOP LEAKAGE	BOTTOM LEAKAGE
1	7.4061179E-02	2.4447502E-09	3.4499444E-20	0.	1.0028072E-03	1.0038524E-18
2	7.4061179E-02	2.4447502E-09	3.4499444E-20	0.	1.0028072E-03	1.0038524E-18

FLUX COMPONENTS FOR GROUP 1

COMPONENT NUMBER 1

	Z MESH 1	Z MESH 2	Z MESH 3	Z MESH 4	Z MESH 5	Z MESH 6	Z MESH 7	Z MESH 8
1	.560528E-16	.391049E-15	.272825E-14	.190117E-13	.132114E-12	.913792E-12	.627668E-11	.426917E-10
2	.335670E-16	.228510E-15	.154480E-14	.103520E-13	.684089E-13	.448557E-12	.288446E-11	.181935E-10
3	.251988E-16	.166983E-15	.109394E-14	.707308E-14	.450546E-13	.282329E-12	.173937E-11	.105469E-10
4	.186273E-16	.119672E-15	.758340E-15	.473660E-14	.291540E-13	.176963E-12	.106139E-11	.630942E-11
5	.131579E-16	.819682E-16	.503653E-15	.305360E-14	.182795E-13	.108116E-12	.631669E-12	.363452E-11
6	.105493E-16	.637280E-16	.379778E-15	.223205E-14	.129201E-13	.734234E-13	.407141E-12	.218090E-11
7	.805044E-17	.470740E-16	.270710E-15	.152688E-14	.840681E-14	.448696E-13	.230017E-12	.112173E-11
8	.571625E-17	.320881E-16	.175939E-15	.937509E-15	.482245E-14	.237632E-13	.111373E-12	.494861E-12
9	.371620E-17	.197956E-16	.102127E-15	.507288E-15	.241042E-14	.108924E-13	.466540E-13	.189796E-12
10	.217862E-17	.104953E-16	.523580E-16	.240433E-15	.104926E-14	.433279E-14	.168848E-13	.623786E-13
11	.114044E-17	.531159E-17	.236092E-16	.995987E-16	.394444E-15	.158131E-14	.519944E-14	.174891E-13
12	.530243E-18	.228456E-17	.932443E-17	.358069E-16	.128475E-15	.430526E-15	.138001E-14	.440383E-14
13	.218014E-18	.861941E-18	.319696E-17	.110397E-16	.347878E-16	.109171E-15	.347446E-15	.122088E-14
14	.787402E-19	.282590E-18	.941543E-18	.291442E-17	.866072E-17	.270594E-16	.963447E-16	.366538E-15
15	.247546E-19	.798187E-19	.238912E-18	.686084E-18	.212034E-17	.763554E-17	.299790E-16	.109187E-15
16	.673063E-20	.195601E-19	.549903E-19	.167116E-18	.607519E-18	.245048E-17	.929792E-17	.294730E-16
17	.159940E-20	.440132E-20	.132403E-19	.485201E-19	.200318E-18	.787534E-18	.266005E-17	.739325E-17
18	.353057E-21	.105403E-20	.388914E-20	.163786E-19	.664242E-19	.234392E-18	.690524E-18	.166949E-17
19	.842226E-22	.312790E-21	.133987E-20	.558400E-20	.204786E-19	.634945E-19	.163742E-18	.348494E-18
20	.252065E-22	.109618E-21	.467958E-21	.177599E-20	.576198E-20	.157345E-19	.358844E-19	.680476E-19

	Z MESH 9	Z MESH 10	Z MESH 11	Z MESH 12	Z MESH 13	Z MESH 14	Z MESH 15	Z MESH 16
1	.286482E-09	.188724E-08	.121252E-07	.754903E-07	.458855E-06	.422140E-05	.577745E-04	.833385E-03
2	.112250E-09	.677227E-09	.401965E-08	.240226E-07	.155780E-06	.170050E-05	.202696E-04	.228049E-03
3	.632069E-10	.377561E-09	.227598E-08	.140082E-07	.884798E-07	.519429E-06	.383871E-05	.446499E-04
4	.372715E-10	.218492E-09	.125620E-08	.686750E-08	.334477E-07	.158947E-06	.118906E-05	.119723E-04
5	.204225E-10	.110248E-09	.558167E-09	.260872E-08	.123124E-07	.718850E-07	.420574E-06	.115158E-05
6	.111323E-10	.534657E-10	.243023E-09	.111686E-08	.568975E-08	.270970E-07	.722076E-07	.186864E-06
7	.517270E-11	.227802E-10	.998077E-10	.454034E-09	.191464E-08	.553740E-08	.144814E-07	.180430E-07
8	.209851E-11	.868441E-11	.358756E-10	.139004E-09	.426682E-09	.118074E-08	.217078E-08	.204497E-08
9	.741098E-12	.282363E-11	.102825E-10	.329418E-10	.974761E-10	.219932E-09	.303539E-09	.204019E-09
10	.222098E-12	.771743E-12	.255263E-11	.805424E-11	.207747E-10	.365551E-10	.407370E-10	.296064E-10
11	.586049E-13	.198693E-12	.663961E-12	.189094E-11	.394252E-11	.559074E-11	.532147E-11	.359420E-11
12	.155391E-13	.545830E-13	.168177E-12	.397920E-12	.676241E-12	.806500E-12	.681779E-12	.433070E-12
13	.447668E-14	.147203E-13	.384678E-13	.752465E-13	.107499E-12	.111665E-12	.859568E-13	.516046E-13
14	.127343E-14	.360847E-14	.796190E-14	.130619E-13	.161540E-13	.149976E-13	.106817E-13	.607572E-14
15	.331096E-15	.795717E-15	.148307E-14	.212240E-14	.232630E-14	.196675E-14	.130946E-14	.707293E-15
16	.776417E-16	.160021E-15	.238965E-15	.327556E-15	.324037E-15	.252872E-15	.158535E-15	.815551E-16
17	.166003E-16	.298316E-16	.426825E-16	.485242E-16	.439371E-16	.319666E-16	.180721E-16	.933742E-17
18	.328375E-17	.522711E-17	.671329E-17	.695273E-17	.582544E-17	.398150E-17	.224742E-17	.106492E-17
19	.608824E-18	.870258E-18	.101595E-17	.968975E-18	.757736E-18	.489453E-18	.264019E-18	.121433E-18
20	.106898E-18	.138810E-18	.148835E-18	.131885E-18	.969249E-19	.594745E-19	.308149E-19	.139046E-19

	Z MESH 17	Z MESH 18	Z MESH 19	Z MESH 20
1	.120873E-01	.177440E+00	.225874E+01	.225874E+01
2	.270603E-02	.347721E-01	.280812E+00	.280116E+00
3	.549302E-03	.233463E-02	.297330E-02	.296687E-02
4	.423101E-04	.744399E-04	.176275E-04	.178267E-04
5	.286499E-05	.239208E-06	.875338E-06	.794739E-06
6	.756751E-07	.592000E-07	.349350E-07	.323154E-07
7	.913694E-08	.676113E-08	.330485E-08	.305522E-08
8	.114823E-08	.753267E-09	.328421E-09	.309794E-09
9	.141285E-09	.818606E-10	.337002E-10	.331367E-10
10	.169076E-10	.875052E-11	.356075E-11	.370335E-11
11	.197373E-11	.927764E-12	.387376E-12	.428408E-12
12	.225846E-12	.983165E-13	.434637E-13	.508822E-13
13	.254598E-13	.104935E-13	.502963E-14	.616978E-14
14	.284192E-14	.113703E-14	.601690E-15	.761351E-15
15	.315757E-15	.126091E-15	.743757E-16	.954887E-16
16	.351170E-16	.144191E-16	.948796E-17	.121712E-16
17	.393338E-17	.171026E-17	.124606E-17	.157736E-17
18	.446661E-18	.211024E-18	.167913E-18	.207939E-18
19	.517714E-19	.270731E-19	.231297E-19	.278859E-19
20	.616192E-20	.359794E-20	.324390E-20	.380201E-20

ALL DATA BELOW THIS LINE IS FOR TIME STEP NUMBER 2 FROM T= .1000E+00 TO T= .2000E+00

UNCOLLIDED FLUX BALANCE

G	ITIM	TN	TA	RL	TL	BL	TF	TFP	TC	TSS
1	2	1.0000E+00	5.8656E-02	0.	2.1854E-01	0.	6.1640E-01	9.0826E-01	7.3320E-02	1.4664E-02
TIME	1.77E-01	G	1	INNER ITER	6					

	SOURCE	DELTA PHI/DELTA T	IN SCATTER	SELF SCATTER	OUT SCATTER	NET LEAKAGE
1	0.	-2.8173070E-01	5.5511151E-17	1.5078011E-02	-2.3092639E-14	2.2141866E-01
2	0.	-2.8173070E-01	5.5511151E-17	1.5078011E-02	-2.3092639E-14	2.2141866E-01

	ABSORPTION	NEUTRON BALANCE	RIGHT LEAKAGE	LEFT LEAKAGE	TOP LEAKAGE	BOTTOM LEAKAGE
1	6.0312045E-02	5.2781246E-10	2.1939120E-18	0.	2.2141866E-01	4.5102348E-17
2	6.0312045E-02	5.2781246E-10	2.1939120E-18	0.	2.2141866E-01	4.5102348E-17

FLUX COMPONENTS FOR GROUP 1

COMPONENT NUMBER 1

	Z MESH 1	Z MESH 2	Z MESH 3	Z MESH 4	Z MESH 5	Z MESH 6	Z MESH 7	Z MESH 8
1	.152109E-14	.989580E-14	.642081E-13	.414687E-12	.265909E-11	.168763E-10	.105602E-09	.648301E-09
2	.106592E-14	.681551E-14	.431133E-13	.269151E-12	.165332E-11	.995974E-11	.586313E-10	.336159E-09
3	.906834E-15	.566487E-14	.348606E-13	.210930E-12	.125249E-11	.728846E-11	.415474E-10	.232278E-09
4	.740592E-15	.449862E-14	.288608E-13	.157898E-12	.911466E-12	.517157E-11	.288513E-10	.158198E-09