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# TIMEX: A Time-Dependent Explicit Discrete Ordinates Program for the Solution of Multigroup Transport Equations



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by

Wm. H. Reed

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# TIMEX: A TIME-DEPENDENT EXPLICIT DISCRETE ORDINATES PROGRAM FOR THE SOLUTION OF MULTIGROUP TRANSPORT EQUATIONS

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ABSTRACT

A finite difference technique is given for solving the one-dimensional (slab, cylindrical, spherical), time-dependent, multigroup transport equations with anisotropic scattering. This technique is unconditionally stable so that arbitrarily large time steps can be taken. Because no iteration is performed the method is exceptionally fast in terms of computing time per time step. Two acceleration methods designed to improve the accuracy of the finite difference technique are presented. Both acceleration methods are available in the TIMEX code, which uses the finite difference technique to solve the time-dependent transport equation in one space dimension. Detailed input and usage instructions for TIMEX are given. A sample problem is presented.

## I. INTRODUCTION

The TIMEX program was designed to solve the time-dependent, multigroup transport equations in one-dimensional geometries. Slab, cylindrical, and spherical geometries are available. All of the features commonly available in one-dimensional, steady-state transport codes were incorporated into TIMEX, with the exception of the various eigenvalue searches that are meaningless in a time-dependent context.

The code produces meaningful results in both wave and diffusion situations. Wave situations are characterized by spatial discontinuities in the neutron flux that propagate with the velocity of the neutrons and are important over short time intervals. A diffusion situation occurs when scattering is important and when the neutron flux is smooth and varies slowly. A typical time-dependent transport problem can involve a progression through a wavelike regime in the beginning to a diffusion situation after all of the wavefronts have left the system of interest.

An instantaneous point source of neutrons in a sphere represents the ultimate in wavefront behavior. Here the solution is a series of shells of neutrons propagating outward with velocities characteristic of each energy group. Inside the outermost shell lies a continuum of neutrons that have suffered one or more collisions. To treat such a difficult problem, a first-collision source option was included in the TIMEX code. Under this option an analytic representation of the uncollided flux is used to generate a source to the collided flux, which is calculated numerically by the code. This approach improves the accuracy of the code in the above situation. A first-collision source is also used to treat instantaneous plane sources in slabs and line sources in cylinders.

Other special features and capabilities of the TIMEX code include:

(1) Direct or adjoint calculations
(2) General order scattering anisotropy
(3) Vacuum, specular reflection, isotropic return, periodic and albedo boundary conditions allowed
(4) Built-in $S_n$ constants
(5) Coarse-mesh problem description
(6) Input of cross sections from cards or disk file

(7) Core dump and restart available at selected time steps

(8) Flexible input for initial condition and inhomogeneous source

(9) Input of isotropic or anisotropic inhomogeneous distributed sources and boundary sources

(10) Detailed editing capability

(11) Input of space-dependent material density

(12) Ability to load new cross sections, sources, radii, velocities, densities, etc., at selected times

(13) Time step sizes may differ for each energy group

(14) Use of either or both of two devices to improve accuracy

(15) Extensive use of extended core storage to minimize fast core storage requirements.

## II. THEORY

The multigroup neutron transport equations can be written in the form

$$\mathbf{V}^{-1} \frac{\partial \Psi}{\partial t} = -\mathbf{B}\,\Psi + q \quad , \tag{1}$$

subject to the initial condition $\Psi(0) = \Psi_o$. The vector $\Psi$ contains the unknown angular fluxes in each energy group as a function of time t, position r, and direction $\Omega$. The diagonal matrix **V** contains the neutron velocities, the vector q contains inhomogeneous sources, and the linear operator **B** takes the standard form

$$\mathbf{B}\Psi = (\mathbf{L} - \mathbf{S})\Psi \tag{2a}$$

$$(\mathbf{L}\,\Psi)_g = \Omega \cdot \nabla\Psi_g + \sigma(r)\Psi_g \tag{2b}$$

$$(\mathbf{S}\,\Psi)_g = \sum_{g'} \int d\Omega' \; K(r;\, g',\Omega' \rightarrow g,\Omega)\Psi_{g'}(r,\Omega') . \tag{2c}$$

The subscript g appearing above denotes the g'th component of subscripted vectors. In what follows we will always order the unknowns $\Psi_g$, g = 1, 2, ..., G, so that $\Psi_1$ contains the neutrons of highest energy. Appropriate homogeneous boundary conditions for Eq. (1) are assumed to be incorporated into the domain of the operator **B**. Inhomogeneous boundary conditions must be accounted for in the source term q. (See Sec. II.F. for boundary conditions available in TIMEX.)

In Eqs. (2) the operator **L** represents the loss mechanisms of the transport equation, and the term $\Omega \cdot \nabla\Psi_g$, which could well be written $\nabla \cdot \Omega\Psi_g$, represents loss due to neutron streaming. The loss due to scattering and absorption is given by $\sigma(r)\Psi_g$, where the total cross section $\sigma$ is the sum of the scattering and absorption cross sections. The operator **S** represents all homogeneous source mechanisms, therefore the kernel K should be considered to represent both the scattering and fission processes. Details about the assumed form of the kernel K are given in Sec. II.B.

### A. One-Dimensional Geometries

The TIMEX code handles the three standard one-dimensional geometries. The operator $\nabla \cdot \Omega$ is expressed in each of these geometries in Table I. (See also Ref. 1.)

### B. Spherical Harmonic Expansion of Source Kernel

The kernel K of the operator S shown in Eqs. (2) can be represented as the sum of a fission and a scattering contribution, that is,

$$K = K_F + K_S \quad . \tag{3}$$

The fission kernel is particularly simple and is given by

$$K_F = \frac{1}{4\pi}\, \chi_{gg'}(r)\nu\sigma^f_{g'}(r) \quad . \tag{4}$$

In Eq. (4), $\sigma^f_g$, is the fission cross section in group g', $\nu$ is the average number of neutrons

TABLE I

ANALYTIC FORMS OF $\nabla \cdot \Omega\Psi$ IN COMMON ONE-DIMENSIONAL GEOMETRIES

| Geometry | Variables | $\nabla \cdot \Omega\Psi$ |
|---|---|---|
| Slab | x,μ | $\mu \frac{\partial \Psi}{\partial x}$ |
| Cylindrical[a] | r,μ,ξ | $\frac{\mu}{r}\frac{\partial(r\Psi)}{\partial r} + \frac{\eta}{r}\frac{\partial(\eta\Psi)}{\partial \mu}$ |
| Spherical | r,μ | $\frac{\mu}{r^2}\frac{\partial(r^2\Psi)}{\partial r} + \frac{1}{r}\frac{\partial[(1-\mu^2)\Psi]}{d\mu}$ |

[a] $\eta = \sqrt{1 - \mu^2 - \xi^2}$

released per fission, and $\chi_{gg'}$ is the fraction of fission neutrons born in group g due to a fission caused by a neutron in group g'. The function $\chi$ is normalized so that $\sum_g \chi_{gg'}(r) = 1$ for all r and g'. If $\chi$ is independent of g' and r, it is referred to as the fission spectrum. The TIMEX code allows the input of a simple fission spectrum or the complete fission matrix. Each of these may in turn be entered by coarse mesh zone, or a single spectrum or matrix may be entered for the entire system.

The scattering kernel is usually more complicated. It is assumed that this kernel can be expanded in spherical harmonics (Legendre polynomials $P_\ell$) as follows

$$K_S = \sum_{\ell=0}^{ISCT} \frac{2\ell+1}{4\pi} \sigma_\ell^s (r,g' \rightarrow g) P_\ell(\Omega' \cdot \Omega) \quad . \tag{5}$$

The scattering cross sections $\sigma_\ell^s$ must be read in to the code for $\ell = 0, 1, \ldots,$ ISCT. The scattering source is then given by (see Eq. (2c))

$$(S\Psi)_g = \sum_{g'} \sum_{\ell=0}^{ISCT} \frac{2\ell+1}{2} \sigma_\ell^s(r,g' \rightarrow g) P_\ell(\mu) \times \int_{-1}^{1} P_\ell(\mu')\Psi_{g'}(r,\mu')d\mu' \tag{6}$$

in slab and spherical geometry and by a more complicated expression in cylindrical geometry.[2]

## C. Difference Equations

We assume that the phase space under consideration has been divided into a set of mesh cells. Parameters with half-integral subscripts are taken as lying on the boundaries of the mesh cells, and parameters with integer subscripts represent quantities integrated over a mesh cell or "cell-centered" quantities. The spatial grid is then defined by a set of points $r_{i+\frac{1}{2}}$ specifying the cell boundaries, and the angular grid becomes a set of quadrature points $\mu_m$ and quadrature weights $w_m$. We may think of the quadrature weights as being related to some interval $(\mu_{m-\frac{1}{2}}, \mu_{m+\frac{1}{2}})$, but in practice it is unnecessary to specify the boundaries $\mu_{m+\frac{1}{2}}$ of the directional cells. In cylindrical geometry the extra angular variable $\xi$ must be contended with, and the quadrature becomes two dimensional, represented by a set of points $(\mu_m, \xi_m)$ on the unit sphere and a set of weights $w_m$.

The unknowns in the finite-dimensional case are the angular fluxes in all energy groups at the mesh cell centers, $\Psi_{g,m,i}$, and the mesh cell boundaries, $\Psi_{g,m,i+\frac{1}{2}}$, $\Psi_{g,m+\frac{1}{2},i}$, etc. Here we assume that $\Psi_{g,m,i} \approx \Psi_g(\mu_m, r_i)$.

The source integrals described in Sec. I.B. are computed using the assumed numerical quadrature. The moments of the angular flux are computed as

$$\phi_{g,i}^\ell = \sum_{m=1}^{MM} w_m P_\ell(\mu_m) \Psi_{g,m,i} \quad ,$$

where we assume a total of MM directions. The scattering source is then given by

$$S_{g,m,i}^s = \sum_{g'} \sum_{\ell=0}^{ISCT} \frac{2\ell+1}{2} \sigma_\ell^s(r_i,g' \rightarrow g) P_\ell(\mu_m) \phi_{g',i}^\ell \tag{7}$$

in slab and spherical geometries, and by a more complicated expression in cylindrical geometry. The fission source is given by

$$S_{g,m,i}^f = \sum_{g'} \frac{1}{2} \chi_{gg'}(r_i) \nu\sigma_{g'}^f(r_i) \phi_{g',i}^0 \quad , \tag{8}$$

and the total source $S_{g,m,i}$ is obtained by adding the scattering and fission sources

$$S_{g,m,i} = S_{g,m,i}^s + S_{g,m,i}^f \quad . \tag{9}$$

The following difference approximation to the g'th member of the set of Eq. (1) is used by the TIMEX code

$$\frac{1}{v}\left(\frac{\psi^{j+1}-\psi^j}{\Delta t}\right) + \mu_m\left(\frac{A_{i+\frac{1}{2}}\psi^{j+1}_{i+\frac{1}{2}} - A_{i-\frac{1}{2}}\psi^{j+1}_{i-\frac{1}{2}}}{V_i}\right)$$

$$+\left(\frac{\alpha_{m+\frac{1}{2}}\psi^{j+1}_{m+\frac{1}{2}} - \alpha_{m-\frac{1}{2}}\psi^{j+1}_{m-\frac{1}{2}}}{w_m V_i}\right)$$

$$+ \sigma_i\psi^{j+1} = S^j_{m,i} + q_{m,i} \quad , \qquad (10)$$

where group and some cell-centered subscripts have been deleted. The notations used above are:

- $v$ = group velocity
- $\Delta t$ = time step size
- $\mu_m$ = quadrature points
- $A_{i+\frac{1}{2}}$ = area of cell face
- $V_i$ = cell volume
- $w_m$ = quadrature weights
- $\alpha_{m+\frac{1}{2}}$ = curvature coefficients
- $\sigma_i$ = total cross section
- $S^j_{m,i}$ = scattering and fission sources computed from fluxes at j'th time level
- $q_{m,i}$ = inhomogeneous sources.

The geometric coefficients for the three geometries under consideration are listed in Table II.

The area elements for a sphere are not $4\pi r^2_{i+\frac{1}{2}}$ as would be expected but are defined recursively as indicated in Table II in order to improve the accuracy of the flux near the center of the sphere. The curvature coefficients are also defined in a recursive manner by

$$\alpha_{m+\frac{1}{2}} - \alpha_{m-\frac{1}{2}} = \mu_m w_m\left(A_{i+\frac{1}{2}} - A_{i-\frac{1}{2}}\right) \qquad (11)$$

and the starting conditions

$$\alpha_{\frac{1}{2}} = \alpha_{MM+\frac{1}{2}} = 0 \quad . \qquad (12)$$

To solve Eq. (10) for $\psi^{j+1}$ given $\psi^j$, it is necessary to make an assumption concerning the shape of the flux over a mesh cell. The "diamond" relations are used in TIMEX; these relations are given by

$$\psi^{j+1} = \frac{\psi^{j+1}_{i+\frac{1}{2}} + \psi^{j+1}_{i-\frac{1}{2}}}{2} \qquad (13a)$$

$$\psi^{j+1} = \frac{\psi^{j+1}_{m+\frac{1}{2}} + \psi^{j+1}_{m-\frac{1}{2}}}{2} \quad . \qquad (13b)$$

TABLE II

GEOMETRIC FUNCTIONS FOR ONE-DIMENSIONAL GEOMETRIES

| Geometry | Variable | $A_{i+\frac{1}{2}}$ | $V_i$ |
|---|---|---|---|
| Slab | $x_{i+\frac{1}{2}}$ | 1 | $x_{i+\frac{1}{2}} - x_{i-\frac{1}{2}}$ |
| Cylindrical | $r_{i+\frac{1}{2}}$ | $2\pi r_{i+\frac{1}{2}}$ | $\pi\left(r^2_{i+\frac{1}{2}} - r^2_{i-\frac{1}{2}}\right)$ |
| Spherical | $r_{i+\frac{1}{2}}$ | $\frac{2V_i}{r_{i+\frac{1}{2}} - r_{i-\frac{1}{2}}} - A^a_{i-\frac{1}{2}}$ | $\frac{4\pi}{3}\left(r^3_{i+\frac{1}{2}} - r^3_{i-\frac{1}{2}}\right)$ |

[a] Defined recursively with $A_{\frac{1}{2}} = 0$

If the above relations are used to eliminate $\Psi^{j+1}_{i+\frac{1}{2}}$ and $\Psi^{j+1}_{m+\frac{1}{2}}$ in Eq. (10), we obtain the following equation

$$\left(\frac{V_i}{v\Delta t} + 2\mu_m A_{i+\frac{1}{2}} + \frac{2\alpha_{m+\frac{1}{2}}}{w_m} + \sigma_i V_i\right)\Psi^{j+1}$$

$$= \mu_m\left(A_{i+\frac{1}{2}} + A_{i-\frac{1}{2}}\right)\Psi^{j+1}_{i-\frac{1}{2}}$$

$$+ \left(\frac{\alpha_{m+\frac{1}{2}} + \alpha_{m-\frac{1}{2}}}{w_m}\right)\Psi^{j+1}_{m-\frac{1}{2}}$$

$$+ \left(\frac{V_i}{v\Delta t}\right)\Psi^j + S^j_{m,i}V_i + q_{m,i}V_i \quad . \qquad (14)$$

We use the recursion relation of Eq. (11), which is used to define the $\alpha$ coefficients, to rewrite Eq. (14) as follows,

$$\left[\frac{V_i}{v\Delta t} + \mu_m\left(A_{i+\frac{1}{2}} + A_{i-\frac{1}{2}}\right) + \left(\frac{\alpha_{m+\frac{1}{2}} + \alpha_{m-\frac{1}{2}}}{w_m}\right) + \sigma_i V_i\right]\Psi^{j+1}$$

$$= \mu_m\left(A_{i+\frac{1}{2}} + A_{i-\frac{1}{2}}\right)\Psi^{j+1}_{i-\frac{1}{2}} + \left(\frac{\alpha_{m+\frac{1}{2}} + \alpha_{m-\frac{1}{2}}}{w_m}\right)\Psi^{j+1}_{m-\frac{1}{2}}$$

$$+ \left(\frac{V_i}{v\Delta t}\right)\Psi^j + S^j_{m,i}V_i + q_{m,i}V_i \quad . \qquad (15)$$

Equation (15) is used to determine $\Psi^{j+1}$ from $\Psi^{j+1}_{i-\frac{1}{2}}$, $\Psi^{j+1}_{m-\frac{1}{2}}$, and $\Psi^j$ for directions so that $\mu_m > 0$. When $\mu_m < 0$ a similar equation is used to determine $\Psi^{j+1}$ from $\Psi^{j+1}_{i+\frac{1}{2}}$, $\Psi^{j+1}_{m-\frac{1}{2}}$, and $\Psi^j$. The diamond difference relations in Eq. (13) are then used to obtain the cell edge fluxes $\Psi^{j+1}_{m+\frac{1}{2}}$ and $\Psi^{j+1}_{i+\frac{1}{2}}$ for $\mu_m > 0$, and $\Psi^{j+1}_{m+\frac{1}{2}}$ and $\Psi^{j+1}_{i-\frac{1}{2}}$ for $\mu_m < 0$.

Use of a diamond relation such as

$$\Psi_{i+\frac{1}{2}} = 2\Psi_i - \Psi_{i-\frac{1}{2}}$$

may give rise to negative fluxes. This is likely to occur whenever $\left(\sigma_i + \frac{1}{v\Delta t}\right)V_i$ is large. To prevent negative fluxes, a set to zero fixup is used. The cell edge fluxes $\Psi^{j+1}_{i+\frac{1}{2}}$($\Psi^{j+1}_{i-\frac{1}{2}}$ for $\mu_m < 0$) are tested immediately after computation and are set to zero if negative. The cell centered flux $\Psi^{j+1}$ is then recomputed from Eqs. (10) and (13b) with $\Psi^{j+1}_{i+\frac{1}{2}} = 0$ $\left(\Psi^{j+1}_{i-\frac{1}{2}} = 0 \text{ for } \mu_m < 0\right)$ to preserve neutron balance. The cell edge flux $\Psi^{j+1}_{m+\frac{1}{2}}$ is not tested for positivity because in practice it is rarely negative.

Occasionally the cell centered flux is negative following a set to zero fixup. This is due to the presence of negative sources. Here the fixup attempt is aborted and the originally calculated fluxes are taken as correct.

D. Acceleration Methods

The two acceleration devices available in the TIMEX code are known as rebalance and extrapolation. The purpose of these devices is to improve the accuracy of the numerical solution. Each method is designed to work properly in most situations, although there are occasions in which the use of one or the other of these devices is specifically recommended. Both methods are usually stable, but there are certain circumstances under which the use of the rebalance method can lead to an unstable algorithm. These circumstances are discussed later in this section.

1. Exponential Extrapolation. The extrapolation method[3] is derived in the following manner. We assume the equation to be solved is written as

$$v^{-1}\frac{d\Psi}{dt} = B\Psi + q \quad , \qquad (16)$$

where B is a matrix and $\Psi$ and q are vectors containing the flux and source at all mesh points. The matrix B is a finite difference approximation of the operator **B** shown in Eq. (1). We assume that the flux can be written as

$$\Psi(t) = e^{\omega t}\phi(t) \quad , \qquad (17)$$

where $\omega$ is a diagonal matrix and the function $\phi$ represents a small modulation of the assumed exponential behavior. The function $\phi$ obeys the following equation

$$V^{-1} \frac{d\phi}{dt} = e^{-\omega t}(B - V^{-1}\omega)e^{\omega t}\phi + e^{-\omega t}q \quad . \tag{18}$$

Equation (18) is easier to solve than Eq. (16), if $\phi$ is slowly varying with time. This occurs if the frequencies $\omega$ are chosen properly. This point is discussed later in this section.

Let us assume that we have a method available for solving Eq. (16). The method of Sec. II.C. is such a method and can be described as follows. The matrix B is split

$$B = -L + S \quad ,$$

where L is a matrix representing loss mechanisms and is an approximation of the operator **L** introduced in Sec. II.A. Similarly, S is a matrix representing the source mechanisms. The method of Sec. II.C. is then formally given by

$$V^{-1}\left(\frac{\Psi^{j+1} - \Psi^{j}}{\Delta t}\right) = -L\,\Psi^{j+1} + S\,\Psi^{j} + q \tag{19a}$$

or

$$\left(\frac{V^{-1}}{\Delta t} + L\right)\Psi^{j+1} = \left(\frac{V^{-1}}{\Delta t} + S\right)\Psi^{j} + q \quad . \tag{19b}$$

The same method is applied to Eq. (18)

$$V^{-1}\,\frac{\phi^{j+1} - \phi^{j}}{\Delta t} = e^{-\omega\Delta t}(-L - V^{-1}\omega_+)e^{\omega\Delta t}\phi^{j+1} + e^{-\omega\Delta t}(S - V^{-1}\omega_-)e^{\omega\Delta t}\phi^{j} + e^{-\omega\Delta t}q \ , \tag{20}$$

where the factors $e^{\omega t}$ have been approximated by their values at the end of the time step.

The matrix $\omega$ has been split into the components $\omega_+$ and $\omega_-$, where $\omega_+$ contains all of the positive elements of $\omega$, $\omega_-$ contains all of the negative elements of $\omega$, and $\omega = \omega_+ + \omega_-$. The frequencies are split in this manner so that they will always appear as positive quantities in the relevant equations.

Assuming that $t = 0$ at the beginning of the step so that $\phi^j = \Psi^j$, we rewrite Eq. (20) as

$$e^{-\omega\Delta t}\left[\frac{V^{-1}}{\Delta t} + L + V^{-1}\omega_+\right]e^{\omega\Delta t}\phi^{j+1} = e^{-\omega\Delta t}\left[\frac{V^{-1}}{\Delta t} + S - V^{-1}\omega_-\right]e^{\omega\Delta t}\phi^{j} + e^{-\omega\Delta t}q \quad .$$

Because $\Psi^{j+1} = e^{\omega\Delta t}\phi^{j+1}$, we have

$$\left[\frac{V^{-1}}{\Delta t} + L + V^{-1}\omega_+\right]\Psi^{j+1} = \left[\frac{V^{-1}}{\Delta t} + S - V^{-1}\omega_-\right]e^{\omega\Delta t}\Psi^{j} + q \quad . \tag{21}$$

Equation (21) is similar to Eq. (19b). In Eq. (21) the flux at the beginning of the time step is scaled by the factor $e^{\omega\Delta t}$ and the terms $V^{-1}\omega_+$ and $V^{-1}\omega_-$ are added to the matrices L and S. Because $V^{-1}\omega_+$ is diagonal, it suffices to add this term to the total cross section, which appears on the diagonal of L. Thus, the algorithm for solving Eq. (19b) for $\Psi^{j+1}$ can be used with minor modification to solve Eq. (21).

The frequencies $\omega$ are altered after each time step to obtain the best accuracy. A good, practical choice for these frequencies seems to be given by

$$\omega_j = \frac{1}{\Delta t}\ln\left(\frac{\Psi^j}{\Psi^{j-1}}\right) \quad , \tag{22}$$

where the division is performed componentwise. The frequencies $\omega_j$ are then used in Eq. (21) to obtain the flux $\Psi^{j+1}$. If in Eq. (22) the flux is zero at some points, the frequencies are set to zero at those points.

It is unnecessary to allow the frequencies to depend on angle, energy, and space to obtain a significant increase in the accuracy of the code. In practice, the TIMEX code allows energy and space-dependent frequencies only.

The extrapolation method is a special kind of predictor-corrector method and is especially appropriate in situations where the time variation of the flux is smooth and nearly exponential. This condition is always true at long times following some initial transient if the cross sections and sources remain constant with time. It has been experimentally observed that, for long times following some perturbation in a system, the above frequencies converge to a single number that is an approximation to the inverse of the asymptotic period of the system.

2. Rebalance. The second acceleration method available in the TIMEX code is more appropriate to situations in which the flux changes rapidly than is the extrapolation method. Let us assume that we are solving Eq. (16) using the method of Eq. (19a). This method, as it stands, is inaccurate. The lack of accuracy is due to the splitting of the matrix B, so that the loss mechanisms are taken as proportional to the flux at the new time and the sources are proportional to the fluxes at the old time. The resulting inbalance between sources and losses prevents the computed flux from following transients as rapidly as it should.

A more accurate scheme is the first-order accurate fully implicit method

$$V^{-1}\;\frac{\Psi^{j+1}-\Psi^{j}}{\Delta t}=B\,\Psi^{j+1}+q\quad, \tag{23}$$

or the second-order accurate Crank-Nicholson method

$$V^{-1}\,\frac{\Psi^{j+1}-\Psi^{j}}{\Delta t}=B\left(\frac{\Psi^{j+1}+\Psi^{j}}{2}\right)+q\quad. \tag{24}$$

The Crank-Nicholson method is equivalent to a diamond difference assumption in the time variable. These two schemes are unconditionally stable, so that large time steps can be taken. Unfortunately, to advance the solution by one time step the full matrix B must be inverted. This is equivalent to the solution of a steady-state transport problem, and iterative procedures must be used. These iterative processes can be slowly convergent so that a large amount of computation is expended in the coarse of a single time step. Modern convergence acceleration devices such as coarse-mesh rebalance[4] can reduce this computation significantly.

It is our purpose to describe how this acceleration device can be applied in a different manner to improve the accuracy of the difference scheme of Eq. (19). In what follows we will deal exclusively with a one-group problem, and the matrices L and S must be considered as representing a single group of neutrons. In TIMEX the coarse-mesh acceleration device is applied to each group individually, with sources from other groups treated as constants. Given the flux at time level j, we calculate a first approximation $\tilde{\Psi}^{j+1}$ to the flux $\Psi^{j+1}$ at time level j+1 from Eq. (19) in the following manner:

$$\left(\frac{V^{-1}}{\Delta t}+L\right)\tilde{\Psi}^{j+1}=\left(\frac{V^{-1}}{\Delta t}+S\right)\Psi^{j}+q\quad. \tag{25}$$

The flux $\Psi^{j+1}$ is then assumed to be represented as

$$\Psi^{j+1}=\sum_{i}f_i\,\tilde{\Psi}_i^{j+1}\quad, \tag{26}$$

where the vectors $\tilde{\Psi}_i^{j+1}$ contain the elements of $\tilde{\Psi}^{j+1}$ corresponding to the i'th spatial mesh cell and are zero elsewhere. Fluxes on the boundary between mesh cells i and i+1 are included with $\tilde{\Psi}_i^{j+1}$ for directions so that $\mu_m > 0$, and with $\tilde{\Psi}_{i+1}^{j+1}$ for directions so that $\mu_m < 0$. The parameters $f_i$ are called rebalance factors. To determine these factors, and therefore the desired flux $\Psi^{j+1}$, we insert the expression on the right-hand side of Eq. (26) into Eq. (23) and integrate over all directions (that is, multiply by $w_m$ and sum over all m). The integrals can be performed because the $\mu$ dependence of $\Psi^{j+1}$ is specified by Eq. (26). The result of this integration is a set of equations for the rebalance factors $f_i$. This set of equations is written as

$$\left(-FL_{i+\frac{1}{2}}^{j+1}\right)f_{i+1}+\left(AB_i^{j+1}+FL_{i-\frac{1}{2}}^{j+1}+FR_{i+\frac{1}{2}}^{j+1}\right)f_i+\left(-FR_{i-\frac{1}{2}}^{j+1}\right)f_{i-1}=Q+\frac{\phi^{j}V_i}{v\Delta t}\quad. \tag{27}$$

In Eq. (27) the quantities $FL^{j+1}_{i+\frac{1}{2}}$ and $FR^{j+1}_{i+\frac{1}{2}}$ are the left and right flows across the cell face at $i+\frac{1}{2}$ computed from $\tilde{\Psi}^{j+1}$ as

$$FL^{j+1}_{i+\frac{1}{2}} = \sum_m |\mu_m| \tilde{\Psi}^{j+1}_m w_m , \quad \mu_m < 0$$

$$FR^{j+1}_{i+\frac{1}{2}} = \sum_m |\mu_m| \tilde{\Psi}^{j+1}_m w_m , \quad \mu_m > 0 \quad .$$

The quantity $AB^{j+1}_i$ is the total absorption in the i'th cell augmented by the term $\frac{\tilde{\phi}^{j+1} V_i}{v \Delta t}$, where $\tilde{\phi}^{j+1}$ is the scalar flux given by $\tilde{\phi}^{j+1} = \int \tilde{\Psi}^{j+1} d\mu$. The above equations for the rebalance factors are tridiagonal and are easily solved. Having solved for these factors, we obtain the flux at the time level j+1 from Eq. (26).

It is possible to insert Eq. (26) into Eq. (24) and integrate over all directions to obtain a set of equations for the rebalance factors. These equations are again tridiagonal in form, but they also involve flows and absorptions at the previous time level. The resulting method gives answers that are more accurate than if the rebalance factors were obtained from Eq. (27). However, there is an increased danger of instability when the rebalance factors are obtained from the Crank-Nicholson method. Therefore, the rebalance factors are calculated from Eq. (27) in the TIMEX code.

## E. First-Collision Source

In some transport problems the exact flux at an instant of time involves Dirac delta functions. For example, such functions are obtained for an instantaneous point burst of neutrons at time zero. The accurate prediction of such irregular functions is quite difficult with standard finite difference methods, so that exceedingly fine meshes are required. To circumvent this difficulty, a first-collision source option is provided in the TIMEX code. This option is selected by setting INSTART equal one and is restricted to the treatment of instantaneous sources located at the origin of the coordinate system, that is, point sources in slab geometry, line sources in cylindrical geometry, and plane sources in slab geometry. The angular dependence of the source neutrons is assumed to be given by $\delta(\mu - 1)$ in all three geometries, so that in each case the neutrons are assumed to stream directly away from the origin.

If the first-collision source option is specified, the neutron flux is considered as the sum of two terms, the flux due to neutrons that have suffered no collisions (the uncollided flux) and the flux due to neutrons that have suffered one or more collisions (the collided flux). We define the two functions $\Psi_u$ and $\Psi_c$ to be the uncollided and collided fluxes, respectively, so that the total flux $\Psi$ is given by $\Psi = \Psi_u + \Psi_c$. These two functions are assumed to obey the two equations

$$\frac{1}{v}\frac{\partial \Psi_u}{\partial t} + L\,\Psi_u = q \tag{28a}$$

and

$$\frac{1}{v}\frac{\partial \Psi_c}{\partial t} + L\,\Psi_c = S(\Psi_u + \Psi_c) \quad . \tag{28b}$$

Equation (28a) is easy to solve analytically for $\Psi_u$ because there are no scattering sources. When $\Psi_u$ has been obtained, Eq. (28b) can be solved with difference methods derived earlier. We note that the sum of Eqs. (28a) and (28b) gives

$$\frac{1}{v}\frac{\partial}{\partial t}(\Psi_u + \Psi_c) + L(\Psi_u + \Psi_c) = S(\Psi_u + \Psi_c) + q$$

or

$$\frac{1}{v}\frac{\partial \Psi}{\partial t} + L\,\Psi = S\,\Psi + q \quad , \tag{29}$$

which is the full transport equation for the complete angular flux $\Psi$.

The rationale for splitting the angular flux into collided and uncollided components is that the function $\Psi_c$ is smoother than $\Psi_u$. Because we are solving Eq. (28a) by analytic methods, a nonsmooth solution does not cause concern. All errors in the calculation are introduced in the solution of Eq. (28b) for the collided flux. Because $\Psi_c$ is smooth, these errors will be smaller than those involved in the direct solution of Eq. (29) by difference methods.

The analytic uncollided fluxes due to the sources mentioned above are presented in Table III for a single group of neutrons with velocity v. In the following we deal exclusively with a single energy group; all groups are treated in the same manner.

The quantities $N_o$ shown in Table III for slab, cylinders and spheres are the total number of source neutrons emitted per unit area, the total number of neutrons per unit length, and the total number of neutrons, respectively.

To calculate the source in Eq. (28b) due to the uncollided flux, we need the spherical harmonic moments of the uncollided flux. In slab and spherical geometry these moments are given by

$$\phi_\ell(r,t) = \int_{-1}^{+1} d\mu P_\ell(\mu)\Psi_u(\mu) \quad .$$

Because $\Psi_u$ involves the delta function $\delta(1 - \mu)$, and because $P_\ell(1) = 1.0$ for all the Legendre polynomials, all of the above moments are identical. In cylindrical geometry the spherical harmonics $Y_\ell^\beta(\mu,\eta)$ are used instead of the Legendre polynomials. We have

$$Y_\ell^\beta\Big|_{\mu=1} = \begin{cases} 1.0 & \beta = 0 \\ 0.0 & \beta \neq 0 \end{cases} ,$$

so that only the $Y_\ell^o$ moments of the uncollided flux are nonzero. As above, all the $Y_\ell^o$ moments are identical. For this reason we need only to calculate the zeroth moment of the flux in all three geometries. These moments can always be obtained from the uncollided flux in Table III by omitting the factor $\delta(1 - \mu)$.

We next define an appropriate average $\phi_i^j$ of the zeroth moment of the uncollided flux over a time step $\Delta t_j$ and over a cell volume $V_i$. In spherical geometry we have

TABLE III

ANALYTIC UNCOLLIDED FLUX

| Geometry | Source | Uncollided Flux |
|---|---|---|
| Slab | $N_o\delta(x)\delta(1 - \mu)\delta(t)$ | $N_o e^{-\int_o^x \sigma(x')dx'} \delta(t - \frac{x}{v})\delta(1 - \mu)$ |
| Cylindrical | $\frac{N_o\delta(r)\delta(1 - \mu)\delta(t)}{2\pi r}$ | $\frac{N_o e^{-\int_o^r \sigma(r')dr'} \delta(t - \frac{r}{v})\delta(1 - \mu)}{2\pi r}$ |
| Spherical | $\frac{N_o\delta(r)\delta(t)}{4\pi r^2}$ | $\frac{N_o e^{-\int_o^r \sigma(r')dr'} \delta(t - \frac{r}{v})\delta(1 - \mu)}{4\pi r^2}$ |

($\sigma$ = total cross section)

$$\phi_i^j = \frac{1}{V_i\Delta t}\int_{r_{i-\frac{1}{2}}}^{r_{i+\frac{1}{2}}} 4\pi r^2 dr \int_t^{t+\Delta t} dt\ \phi_o(r,t)$$

$$= \frac{1}{V_i\Delta t}\int_{r_{i-\frac{1}{2}}}^{r_{i+\frac{1}{2}}} 4\pi r^2 dr \int_t^{t+\Delta t} dt$$

$$\times\ \frac{N_o e^{-\int_o^r \sigma(r')dr''}\ \delta(t - \frac{r}{v})}{4\pi r^2}$$

$$= \frac{N_o}{V_i\Delta t}\int_{r_{i-\frac{1}{2}}}^{r_{i+\frac{1}{2}}} dr \int_t^{t+\Delta t} dt\ e^{-\int_o^r \sigma(r')dr'}\ \delta(t - \frac{r}{v})$$

$$\phi_i^j = \frac{N_o}{V_i\Delta t}\int_{r_{i-\frac{1}{2}}}^{r_{i+\frac{1}{2}}} dr\ e^{-\int_o^r \sigma(r')dr'}$$

$$\times\ [U(r - vt) - U(r - vt - v\Delta t)] \quad ,$$

where $U(x)$ is the step function defined by

$$U(x) = \begin{Bmatrix} 0, & x < 0 \\ 1, & x \geq 0 \end{Bmatrix} \quad .$$

We then have, for appropriate limits $a_j$ and $b_j$, depending on $j$,

$$\phi_i^j = \frac{N_o}{V_i\Delta t}\int_{a_j}^{b_j} dr\ e^{-\int_o^r \sigma(r')dr'}$$

$$= \frac{N_o}{V_i\Delta t}\ \frac{e^{-\int_o^{a_j} \sigma(r')dr'} - e^{-\int_o^{b_j} \sigma(r')dr'}}{\sigma(r_i)}$$

$$\phi_i^j = \frac{N_o e^{-\int_o^{a_j} \sigma(r')dr'}\left[1 - e^{-\sigma(r_i)(b_j - a_j)}\right]}{V_i\Delta t\sigma(r_i)} \quad . \quad (30)$$

The integration limits $a_j$ and $b_j$ shown above are given by the following expressions,

$$a_j = \max\ (r_{i-\frac{1}{2}}, vt)$$

$$b_j = \min\ (r_{i+\frac{1}{2}}, vt + v\Delta t) \quad ,$$

provided the intervals $(vt, vt + v\Delta t)$ and $(r_{i-\frac{1}{2}}, r_{i+\frac{1}{2}})$ are not disjoint. If these intervals are disjoint, then the uncollided flux is zero in the i'th mesh cell during the time step $t$ to $t + \Delta t$, so $\phi_i^j = 0$.

The above expression for $\phi_i^j$ was derived for spherical geometry. However, the same expression is valid in slab and cylindrical geometries, with an appropriate cell volume $V_i$.

In TIMEX, the average of the uncollided flux at each mesh cell over each time step is evaluated as specified by Eq. (30). This is done separately for each neutron group; the groups are not coupled because there are no scattering terms in the equations for the uncollided flux. These averaged uncollided fluxes are then added to all moments of the collided flux in slab and spherical geometries and to the $Y_\ell^o$ moments in cylindrical geometry. This total flux is used in the algorithms that generate the scattering and fission sources.

F. Boundary Conditions

Five different types of boundary conditions are allowed by the TIMEX code: vacuum, reflective, periodic, white, and albedo. Let $\Psi_l(\mu)$ and $\Psi_r(\mu)$ be the left and right boundary fluxes, respectively. We will discuss each of these conditions for the right boundary; the left boundary is treated in a similar fashion.

1. Vacuum. The incoming flux is set to zero on the boundary, thus $\Psi_r(\mu) = 0$, $\mu < 0$.

2. Reflection. The incoming flux is set equal to the outgoing flux in the conjugate direction, that is, $\Psi_r(\mu) = \Psi_r(-\mu)$, $\mu < 0$.

3. Periodic. The incoming flux is set equal to the outgoing flux on the opposite boundary,

therefore, $\Psi_r(\mu) = \Psi_1(\mu)$, $\mu < 0$.

4. White. The incoming flux is constant in angle and is chosen so that there is no net flow across the boundary. This is accomplished by setting

$$\Psi_r(\mu) = \frac{\int_0^1 \mu\ \Psi_r(\mu)d\mu}{\int_0^1 \mu\ d\mu} \quad , \mu < 0 \quad .$$

5. Albedo. The incoming flux is set equal to the albedo times the outgoing flux in the conjugate direction, therefore,

$$\Psi_r(\mu) = \alpha\ \Psi_r(-\mu),\ \mu < 0 \quad ,$$

where $\alpha$ = albedo.

## G. Moving Boundaries

The TIMEX code allows the user to enter new cross sections, sources, coarse-mesh boundaries, velocities, etc., at the beginning of each time zone. Most of these options present no special difficulty for the code. If, however, the user wishes to move the coarse-mesh boundaries with time, then some effort must be expended by the code to interpolate the old fluxes onto the new mesh. There are various ways to accomplish this interpolation; TIMEX uses the simplest method that guarantees conservation of neutrons.

We insist that the outer or right-hand boundary remain fixed during the computation (the left-hand boundary is always fixed at 0.0). This condition is necessary to eliminate the possibility of an extrapolation at the outer boundary. It may be circumvented in some problems by including a large fictitious vacuous cell adjacent to this boundary. With this restriction, the new flux $\Psi_{i,m}^{new}$ at the i'th mesh cell in the m'th direction is computed from

$$\Psi_{i,m}^{new} = \frac{\int_{r^{new}_{i+\frac{1}{2}}}^{r^{new}_{i+\frac{1}{2}}} \Psi^{old}(r,\mu)dV}{V_i^{new}} \quad . \tag{31}$$

The integral appearing in Eq. (31) is a volume integral. The old flux appearing under the integral sign must be construed as a series of step functions in each of the old mesh cells because only cell-centered fluxes are stored by the code.

# III. PROGRAM DESCRIPTION

The TIMEX code is written in FORTRAN-IV and is divided structurally into a main program and a number of subroutines with fairly restricted tasks. Because the code is relatively short, it is not necessary to use an overlay structure. Because the subroutines fall naturally into several classes, input and initialization, execution and edit, and service, such an overlay structure would be easy to incorporate into the code.

Variable dimensioning is used exclusively throughout TIMEX. The bulk of the data, such as cross sections, sources, fluxes, and frequencies, resides in extended or large core memory. Only the data pertinent to a single energy group are contained in fast core at a given instant. Therefore, large problems can be run with TIMEX.

## A. Subroutines

A list of TIMEX subroutines with a brief description of the primary functions of each is presented in Table IV. The subroutines are listed in the order of their appearance in TIMEX.

In addition, a number of system routines, listed in Table V, are necessary for the satisfactory execution of the TIMEX code.

TABLE IV

TIMEX SUBROUTINES

| | |
|---|---|
| TIMEX | is the main program. The input routines INPUT1 and INPUT2 are called first. Certain initializations are performed by a call to INITAL; the initial condition is printed by FINAL. Time steps are accomplished by successive calls to OUTER; the subroutine SCALE is called if the extrapolation option is selected. TIMEX reads the time zone cards that specify the number of time steps to be taken and the time step size. |
| INPUT1 | is called by TIMEX. This subroutine reads the control integers and certain floating point constants. Some input checking is performed here. |
| INPUT2 | is called by TIMEX. Calculation of most of the integers in the common block IA is |

performed by INPUT2. This subroutine also reads the remaining problem input, often by calls to specialized routines. New values of time-varying parameters are also read by INPUT2 on successive time steps.

CSPREP is called by INPUT2. Cross sections are read by a call to LAXS, checked, rearranged for an adjoint problem, and stored in Extended Core Storage (ECS).

READF is called by INPUT2. The initial flux shape is read by this routine and stored in ECS. Various options are permitted here.

READQ is called by INPUT2. The distributed and boundary sources are read here and stored in ECS.

SNCON is called by INPUT2. This routine reads or generates the $S_N$ quadrature set and other special arrays and indices for the treatment of the angular variable.

INITAL is called by TIMEX. This routine initializes many arrays through calls to several subroutines.

REBOUND is called by INITAL after the first time zone if new coarse-mesh boundaries are read. Its purpose is to interpolate the old flux to the new mesh points in a manner that will conserve particles.

GEOFUN is called by INITAL. All geometric functions such as mesh spacings, area elements, and cell volumes are generated here.

INITQ is called by INITAL. The volume and group integrals of the source are performed by this routine, as well as source normalization, if requested. The source is also multiplied here by one-half the mesh spacing for convenience in later calculations.

INITF is called by INITAL. The fission matrix is computed, transposed for adjoint problems, and stored in ECS. Integrals and normalizations are performed.

OUTER is called by TIMEX. A single call to OUTER advances the solution by a single time step. The uncollided flux is computed if that option is specified. A sweep through the energy groups is performed next, with successive calls to SOURCE and TINNER.

UNCOLL is called by OUTER. This subroutine computes the uncollided flux and stores it in ECS. It is called only if the uncollided flux option is specified.

SOURCE is called by OUTER. The source to a particular group from all other groups is generated by this routine. The total source for the rebalance acceleration method is also computed.

TINNER is called by OUTER and is the heart of the code. This routine adds the within group scattering and fission sources to the source generated by SOURCE. With this total source, the flux in a single group is advanced by one time step, or by several partial steps if the time step size depends upon the group. Group rebalance factors are calculated and applied to the flux. Frequencies are computed, and the fluxes are stored in ECS.

FINAL is called by TIMEX and contains all editing and printing logic. Various options are allowed.

SCALE is called by TIMEX. This routine multiplies the flux by the factor $e^{\omega\Delta t}$ if the extrapolation option has been selected.

REBAL is called by TIMEX. This routine solves a tridiagonal algebraic system for the rebalance factors.

SETBC is called by TIMEX. Boundary conditions are set by this routine.

MAPPER is called by INPUT2 and draws a diagram of the geometry of the problem.

DUMPER is called by TIMEX and records on a tape the necessary information for a problem restart at selected time steps. This routine also reads the dump tape when a restart is requested.

LAXS is called by CSPREP and reads cross sections.

READ is called by several routines. Its function is to read data in the special Los Alamos Scientific Laboratory (LASL) format.

WRITE is called by several routines and is capable of writing arrays in several formats.

ERROR writes error messages.

CLEAR clears a block of core.

ECRITE transfers a block of core into ECS.

ECREAD transfers a block of ECS into core.

REDUCE checks core storage requirements and adjusts core size to size of problem.

PRINTP is called by INPUT2 and prints the control integers.

TABLE V

NECESSARY SYSTEM ROUTINES

| Subroutine | Description |
|---|---|
| SECOND(I) | Returns clock time in seconds. |
| DATE1(I) | Returns current date in A8 format. |
| ECWR(CM,EC,LEN,IERR) | Transmits LEN words of fast core beginning with CM into large core beginning with EC. IERR = error parameter. |
| ECRD(CM,EC,LEN,IERR) | Transmits LEN words of large core beginning with EC into fast core beginning with CM. IERR = error parameter. |

| Function | Description |
|---|---|
| SQRT(X) | $\sqrt{x}$ |
| ATAN(X) | Actan (x) |
| COS(X) | cos (x) |
| EXP(X) | $e^x$ |
| ALOG(X) | $\log_e(x)$ |

B. Data Storage

Most of the group-dependent data are stored in extended or large core, with space provided in small or fast core only for the data pertinent to a single energy group. All single fixed and floating point parameters are stored in the IA array of blank common. All arrays are stored in the A array of blank common, which immediately follows the IA array. The location of a particular subarray, such as the flux, within block A is specified by a pointer contained in block IA. The computation of all these pointers is performed by the subroutine INPUT2 in such a manner that data are stored compactly in the A block.

A list of these pointers is given in Table VI. This list gives the position in the IA block of each of these pointers and the name and length of the array specified by the pointer. Some of the positions in the IA block are reserved for control integers and floating point constants. These parameters are also listed in Table VI with the meaningless array name blank. A brief description of these parameters is also included in Table VI.

A good many positions in the IA block are not used at present. Sometimes these unused positions have been named. This is because TIMEX was developed from the steady-state code ONETRAN, which had a need for parameters and arrays that are meaningless in a time-dependent context.

TABLE VI

CONTENTS OF BLANK COMMON BLOCK IA

| Position | Name | Pointer for Array | Remarks |
|---|---|---|---|
| 1 | ITH,ITC | | Indicator for direct or adjoint problem |
| 2 | ISCT | | Scattering order |
| 3 | ISN | | Order of $S_N$ approximation |
| 4 | IGM | | Number of groups |
| 5 | IM | | Number of coarse-mesh intervals |
| 6 | IBL | | Left-boundary condition indicator |

| Position | Name | Pointer for Array | Remarks |
|---|---|---|---|
| 7 | IBR | | Right-boundary condition indicator |
| 8 | IEVT | | Not used |
| 9 | ISTART | | Indicator for input of initial condition |
| 10 | IQOPT | | Indicator for input of sources |
| 11 | IGEOM | | Geometry indicator |
| 12 | IQUAD | | Quadrature indicator |
| 13 | MT | | Number of materials |
| 14 | MTP | | Materials from tape library |
| 15 | MCR | | Materials from cards |
| 16 | MS | | Number of mixture instructions |
| 17 | IHT | | Position of total cross section in table |
| 18 | IHS | | Position of self-scatter cross section in table |
| 19 | IHM | | Cross-section table length |
| 20 | IDEN | | Indicator for fine-mesh density factors |
| 21 | IQAN | | Order of source anisotropy |
| 22 | IQL | | Indicator for left-boundary source |
| 23 | IQR | | Indicator for right-boundary source |
| 24 | IACC | | Indicator for rebalance acceleration |

| Position | Name | Pointer for Array | Remarks |
|---|---|---|---|
| 25 | OITM | | Not used |
| 26 | IITL | | Not used |
| 27 | IITM | | Not used |
| 28 | IFISS | | Indicator for fission spectrum or matrix |
| 29 | IEDOPT | | Edit option indicator |
| 30 | ITN | | Initial time step number |
| 31 | IDO | | Not used |
| 32 | IPVT | | Not used |
| 33 | ICON | | Not used |
| 34 | IMU | | Type of quadrature cosines |
| 35 | IPLOT | | Flux plot indicator |
| 36 | IACT | | Activity indicator |
| 37 | ITXS | | Indicator for time-dependent cross sections |
| 38 | ITQ | | Indicator for time-dependent sources |
| 39 | ITB | | Indicator for time-dependent coarse-mesh boundaries |
| 40 | ITIDXS | | Indicator for time-dependent cross-section identifications |
| 41 | ITFISS | | Indicator for time-dependent fission spectrum |
| 42 | ITVEL | | Indicator for time-dependent velocities |

| Position | Name | Pointer for Array | Remarks | Position | Name | Pointer for Array | Remarks |
|---|---|---|---|---|---|---|---|
| 43 | IIMIX | | Indicator for time-dependent mixture instructions | 68 | EPSI | | Not used |
| | | | | 69 | EPSX | | Not used |
| | | | | 70 | EPST | | Not used |
| 44 | ITDEN | | Indicator for time-dependent density factors | 71 | POD | | Not used |
| | | | | 72 | NORM | | Normalization factor |
| 45 | ITLBDO | | Indicator for time-dependent left albedo | 73 | BHGT | | Buckling height |
| | | | | 74 | BWTH | | Buckling width |
| 46 | ITRBDO | | Indicator for time-dependent right albedo | 75 | TIMOFF | | Dump time |
| | | | | 76 | | | Not used |
| | | | | 77 | | | Not used |
| 47 | ITSTEP | | Not used | 78 | | | Not used |
| 48 | INDTS | | Group-dependent time step indicator | 79 | | | Not used |
| | | | | 80 | RTIME | | Real time |
| 49 | IFCS | | Indicator for first-collision source | 81 | TIME | | Computation time |
| | | | | 82 | TOUT | | Not used |
| | | | | 83 | IDUMP | | Not used |
| 50 | | | Not used | 84 | EPSR | | Not used |
| 51 | | | Not used | 85 | | | Not used |
| 52 | | | Not used | 86 | | | Not used |
| 53 | | | Not used | 87 | | | Not used |
| 54 | | | Not used | 88 | | | Not used |
| 55 | | | Not used | 89 | | | Not used |
| 56 | | | Not used | 90 | | | Not used |
| 57 | | | Not used | 91 | | | Not used |
| 58 | | | Not used | 92 | | | Not used |
| 59 | | | Not used | 93 | | | Not used |
| 60 | | | Not used | 94 | | | Not used |
| 61 | EV | | Not used | 95 | | | Not used |
| 62 | EVM | | Not used | 96 | TACC | | Not used |
| 63 | PV | | Not used | 97 | IGCDMP | | Not used |
| 64 | XLAL | | Not used | 98 | TIN | | Not used |
| 65 | XLAH | | Not used | 99 | TSLDMP | | Not used |
| 66 | XLAX | | Not used | 100 | TIMBDP | | Not used |
| 67 | EPSO | | Not used | 101 | MIN | | MCR+MTP |

| Position | Name | Pointer for Array | Remarks |
|---|---|---|---|
| 102 | IUP | | IHS-IHT-1 |
| 103 | IHF | | IHT-1 |
| 104 | IHA | | IHT-2 |
| 105 | MM | | Total number of directions |
| 106 | NM | | Total number of flux components |
| 107 | NMQ | | Number of source components |
| 108 | M2 | | MM/2 |
| 109 | NN | | ISN/2 |
| 110 | IP | | IM+1 |
| 111 | IGP | | IGM+1 |
| 112 | IHMT | | MT*IHM |
| 113 | ISCP | | ISCT+1 |
| 114 | M2P | | Not used |
| 115 | ITMM | | IT*MM |
| 116 | ITP | | IT+1 |
| 117 | ITPM | | ITP*MM |
| 118 | IMGP | | IM*IGM |
| 119 | IT | | Number of fine-mesh intervals |
| 120 | IHNN | | IHT-3 |
| 121 | IPGP | | IP*IGM |
| 122 | IFISP | | Zone fission spectrum indicator |
| 123 | LFLM | | LQA-1 |
| 124 | EVR | | Not used |
| 125 | KM | | Not used |
| 126 | IAFT | | 3*ITMM+ITPM |
| 127 | KEND | | Length of ECS needed |
| 128 | LAST | | Length of block A of blank common |
| 129 | | | Not used |
| 130 | | | Not used |

| Position | Name | Pointer for Array | Remarks |
|---|---|---|---|
| 131 | LIHR | IHR(JM) | Number of fine-mesh intervals per coarse-mesh zone |
| 132 | LW | WGT(MM) | Quadrature weights |
| 133 | LU | U(MM) | Direction cosines |
| 134 | LWM | WMU(MM) | Product WGT*UB |
| 135 | LBP | BP(MM) | Curvature coefficient $B(M+\frac{1}{2})$ |
| 136 | LBM | BM(MM) | Curvature coefficient $B(M-\frac{1}{2})$ |
| 137 | LDM | BS(MM) | Sum BP+BM |
| 138 | LSE | SE(MM) | Not used |
| 139 | LSC | SC(MM) | Not used |
| 140 | LUB | UB(ISN) | Full range quadrature cosines |
| 141 | LWB | WB(ISN) | Level weights |
| 142 | LCM | MC(MM) | Not used |
| 143 | LME | ME(MM) | Not used |
| 144 | LPN | PN(NM*MM) | Spherical harmonic function |
| 145 | LLI | LI(MM) | Level indices |
| 146 | LFT | | Not used |
| 147 | | | Not used |
| 148 | | | Not used |
| 149 | | | Not used |
| 150 | LC | C(IHM,MT) | Cross-section array |
| 151 | | | Not used |
| 152 | LCT | CT(IT) | Total cross section |
| 153 | LCS | CS(IT) | Scattering cross section |
| 154 | LCA | CA(IT) | Absorption cross section |
| 155 | LCF | CF(IT) | $\nu\sigma_f$ cross section |

| Position | Name | Pointer for Array | Remarks |
|---|---|---|---|
| 156 | LDC | IDC(IP) | Cross-section identifiers |
| 157 | LMN | MIXNUM(MS) | Mixture numbers |
| 158 | LMC | MIXCOM(MS) | Mixture commands |
| 159 | LMD | MIXDEN(MS) | Mixture densities |
| 160 | LMT | MTT(2*MTP) | Identifiers for materials from tape library |
| 161 | LDEN | DEN(IT) | Density factors |
| 162 | LNMA | NMAC(IACT) | Activity material numbers |
| 163 | LNPA | NPAC(IACT) | Activity cross-section positions |
| 164 | LACT | ACT(IACT,IT) | Activities |
| 165 | | | Not used |
| 166 | LQ | Q(NM,IT) | Distributed source |
| 167 | LQR | QR(M2) | Right-boundary source |
| 168 | LQL | QL(M2) | Left-boundary source |
| 169 | LFL | FLUX(NM,IT) | Flux components |
| 170 | LUF | UF(IT) | Uncollided flux |
| 171 | LFLB | FLUXB(IT) | Scalar flux |
| 172 | LFLT | FLT | Not used |
| 173 | LCUR | CUR | Not used |
| 174 | LIN | FIN | Not used |
| 175 | LBL | BL(M2) | Left-boundary flux |
| 176 | LBR | BR(M2) | Right-boundary flux |
| 177 | LAFE | AFE(MM,ITP) | Angular flux on cell boundary |
| 178 | LAFC | AFC(MM,IT) | Angular flux on μ boundaries |
| 179 | LQA | QA(MM,IT) | Angular source |
| 180 | LTA | TA(MM,IT) | Angular flux at cell centers |
| 181 | LP | P(IT) | Effective total cross section |
| 182 | | | Not used |
| 183 | | | Not used |
| 184 | | | Not used |
| 185 | | | Not used |
| 186 | | | Not used |
| 187 | | | Not used |
| 188 | LRAD | RAD(IP) | Coarse-mesh radii |
| 189 | LIDR | IDR(IT) | Coarse-mesh zone identifiers |
| 190 | LH | H(IM) | Mesh spacings |
| 191 | LAI | AI(ITP) | Fine-mesh areas |
| 192 | LV | V(ITP) | Fine-mesh volumes |
| 193 | LAP | AP(ITP) | AI(I+1)/AS(I) |
| 194 | LAM | AM(ITP) | AI(I)/AS(I) |
| 195 | LAS | AS(ITP) | AI(I+1)/AI(I) |
| 196 | LAD | AD(ITP) | AP-AM |
| 197 | LR | R(ITP) | Fine-mesh radii |
| 198 | LRAV | RAV(ITP) | Fine-mesh average radii |
| 199 | LRM | | Not used |
| 200 | LRDA | RADA(ITP) | Fine-mesh radii from previous time zone |
| 201 | LDEL | DEL(IP) | Distance between coarse-mesh boundaries |
| 202 | LIED | | Not used |
| 203 | LDH | DH(ITP) | 0.5*DEN*H |
| 204 | | | Not used |
| 205 | LUFS | UFS | Uncollided flux spectrum |
| 206 | LIUF | IUF(IGM) | Mesh position of uncollided flux |

| Position | Name | Pointer for Array | Remarks |
|---|---|---|---|
| 207 | LIGT | IGTSF(IGM) | Number of time steps per group |
| 208 | LQG | QG(IGP) | Total inhomogeneous sources |
| 209 | LFG | FG(IGP) | Total fission sources |
| 210 | LSIN | SIN(IGP) | Inscattering |
| 211 | LSS | SS(IGP) | Self-scattering |
| 212 | LSOU | SOUT(IGP) | Outscattering |
| 213 | LRL | RL(IGP) | Right leakage |
| 214 | LNL | NL(IGP) | Net leakage |
| 215 | LABG | ABG(IGP) | Absorption |
| 216 | LBAL | BAL(IGP) | Balance |
| 217 | LCHI | CHI(IGM) | Fission spectrum (also CHI(IM,IGM)) |
| 218 | LVEL | VEL(IGP) | Velocities |
| 219 | LAF | | Not used |
| 220 | LLB | LBDO(IGP) | Left albedo |
| 221 | LRB | RBDO(IGP) | Right albedo |
| 222 | | | Not used |
| 223 | | | Not used |
| 224 | | | Not used |
| 225 | | | Not used |
| 226 | | | Not used |
| 227 | LF | F(IT) | Rebalance factors |
| 228 | LFR | FR(ITP) | Right flows |
| 229 | LFLL | FL(ITP) | Left flows |
| 230 | LAB | AB(IT) | Absorption |
| 231 | LQQ | QQ(IT) | Rebalance source |
| 232 | LQQG | | Not used |
| 233 | LCR | | Not used |
| 234 | LHA | HA(IT) | Temporary array used in REBAL |
| 235 | LGA | GA(IT) | Temporary array used in REBAL |
| 236 | LFGG | | Not used |
| 237 | LSGG | | Not used |
| 238 | LTD | | Not used |
| 239 | | | Not used |
| 240 | | | Not used |
| 241 | | | Not used |
| 242 | | | Not used |
| 243 | LOMG | FREQ(IT) | Frequencies |
| 244 | LENC | | ECS length of cross-section array |
| 245 | LENQ | | ECS length of source array |
| 246 | LENF | | ECS length of flux arrays |
| 247 | LENS | | ECS length of source to group |
| 248 | LNAF | | ECS length of angular flux array |
| 249 | LNFS | | ECS length of fission spectrum array |
| 250 | LENP | | Not used |
| 251 | LNFG | | Not used |
| 252 | LNSG | | Not used |
| 253 | LNUF | | ECS length of uncollided flux array |
| 254 | | | Not used |
| 255 | KOM | | ECS position of frequency array |
| 256 | KC | | ECS position of cross-section array |
| 257 | KQ | | ECS position of source array |
| 258 | KF | | ECS position of flux array |

| Position | Name | Pointer for Array | Remarks |
| --- | --- | --- | --- |
| 259 | KS | | ECS position of source to group array |
| 260 | KAF | | ECS position of angular flux array |
| 261 | KFS | | ECS position of fission spectrum |
| 262 | KP | | Not used |
| 263 | KFG | | Not used |
| 264 | KSG | | Not used |
| 265 | KF2 | | ECS position of scalar flux from previous time step |
| 266 | KUF | | ECS position of uncollided flux |
| 267 | | | Not used |
| 268 | | | Not used |
| 269 | ALR | | Not used |
| 270 | ALL | | Not used |
| 271 | SUMMUL | | Not used |
| 272 | SUMMUR | | Not used |
| 273 | OITNO | | Not used |
| 274 | IITOT | | Not used |
| 275 | E1 | | Not used |
| 276 | E2 | | Not used |
| 277 | E3 | | Not used |
| 278 | E4 | | Not used |
| 279 | EVP | | Not used |
| 280 | EVPP | | Not used |
| 281 | ALA | | Not used |
| 282 | ALAR | | Not used |
| 283 | XLAP | | Not used |
| 284 | XLAPP | | Not used |
| 285 | EVS | | Not used |
| 286 | ICNT | | Not used |
| 287 | IUPTOT | | Not used |
| 288 | JCONV | | Not used |
| 289 | TS | | Not used |
| 290 | IITNO | | Not used |
| 291 | G | | Group index |
| 292 | TF | | Not used |
| 293 | AFA,AF | | Not used |
| 294 | NGO | | Not used |
| 295 | NGOTO | | Not used |
| 296 | ICONV | | Not used |
| 297 | | | Not used |
| 298 | DELTAT | | Time step size |
| 299 | KSTEP | | Time step counter |
| 300 | IFREQ | | Frequency indicator |

C. Problem Restart

If the problem being run requires a considerable amount of computer time, it is advisable to dump core occasionally onto a tape in such a way that the problem can be restarted at selected time steps. This option is incorporated in the TIMEX code. In each time zone the user can cause such a dump to be taken as often as is desired. The problem can then be restarted at any of the time steps at which a dump was taken. This is accomplished by setting ISTART = 5 and ITN equal to the selected time step number. After such a restart, further tape dumps will be written in succession on the same tape from which the restart data were taken, starting immediately following the restart data at the selected restart time step number. Old data following this time step will be obliterated by the new data. If it felt that the restart tape is approaching capacity, then setting ISTART = -5 will cause this tape to be rewound before new dumps are taken so that all of the old data is obliterated.

Several parameters may be changed at a restart. These parameters are ISTART, IACC, IEDOPT, ITN, IPLOT, and ITXS through ITRBDO. All other parameters must be left unchanged. TIMEX reads only cards 1 through 7 and card 31 (see Sec. V), if the restart option is selected. All other input data are obtained from the dump tape and must not be entered on cards.

Each restart dump results in the writing of IGM + 2 records on tape. The first record contains the parameters KSTEP, IGM, NM, IT, L, and LENIA, where L = LAST + LENIA. The parameter LENIA is the length of the IA block (currently 300 words) and L is the total length of the IA and A blocks. The second record contains all of fast core, and the succeeding IGM records contain all the extended core data.

D. Input/Output Files

The input/output (I/O) file designators are stored in a common block labeled UNITS. The assignment of file designators is given in Table VII.

## IV. DETAILED INPUT SPECIFICATION

Most of the input data, with the exception of cross sections and control integers, are read in a special format that provides for automatic repetition and interpolation. This format is referred to as the LASL format in the remainder of this report. When the LASL format is specified for a block of integer or floating-point data, then these data are entered, six numbers to a card, in the formats [6(I1,I2,I9)] or [6(I1,I2,E9.4)], respectively. Two integers must proceed each data word in this format. The first integer specifies the desired option according to Table VIII; the second integer controls the execution of the particular option selected by the first integer.

Five examples of the use of the special LASL formats are given in Table IX. These examples result in the input of the following blocks of data:

(1) A block of 47 zeros is read.
(2) A block of 470 zeros is read.
(3) Four interpolants are inserted between 0.0 and 5.0, giving a block of six numbers: 0.0, 1.0, 2.0, 3.0, 4.0, and 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. A total of 18 numbers are entered in the data block.
(5) The data block consists of the three integers: 0, 4, and 7.

TABLE VII

ASSIGNMENT OF I/O FILE DESIGNATORS

| File Name | Logical Unit | Remarks |
|---|---|---|
| NINP | 10 | System input unit |
| NOUT | 9 | System output unit |
| NFILM | 12 | System film unit |
| NLAXS | 6 | Cross-section library |
| NAFLX | 8 | Angular flux tape |
| NDUMP1 | 7 | Restart dump tape |
| NDUMP2 | 5 | Not used |

TABLE VIII

OPTIONS FOR LASL FORMATS

| Value of I1 | Option |
|---|---|
| 0 or blank | Single data word entered in block. |
| 1 | Repeat following data word number of times indicated in I2 field. |
| 2 | Place number of linear interpolants indicated in I2 field between this data word and next data word. Total entries in block equals number in I2 field plus 2. |
| 3 | Terminates reading of data block. Every block must be terminated with a 3 in the I1 position. |
| 4 | Fill remainder of block with following data word. Remember to terminate with a 3. |
| 5 | Repeat following data word 10 times the number in the I2 field. |
| 9 | Skip to next data card. |

TABLE IX

EXAMPLES OF THE USE OF LASL FORMATS

| Example | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 | 36 | 37 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 4 | 7 | | 0 | . | 0 | | | | | | 3 | | | | | | | | | | | | | | | | | | | | | | | | |
| 2 | 5 | 4 | 7 | | 0 | . | 0 | | | | | | 3 | | | | | | | | | | | | | | | | | | | | | | | | |
| 3 | 2 | | 4 | | 0 | . | 0 | | | | | | | | | | 5 | . | 0 | | | | | | 3 | | | | | | | | | | | | |
| 4 | 2 | | 4 | | 0 | . | 0 | | | | | | 2 | | 2 | | 5 | . | 0 | | | | | | 1 | 1 | 0 | | 7 | . | 0 | | | | | | 3 |
| 5 | | | | | | | | | | | | 0 | | | | | | | | | | | | 4 | 9 | | | | | | | | | | | | |
| 5 | | | | | | | | | | | | 7 | 3 | | | | | | | | | | | | | | | | | | | | | | | | |
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 | 36 | 37 |

The input data are listed in the order in which they must be read in to the code. These data are divided into three categories, title information, control parameters, and input arrays. The title information and control parameters must be entered in full for all problems, including restart problems, but many of the input arrays are optional. None of the input arrays are entered for a restart problem because they are obtained from the dump tape.

A. Title Information

The first card in the problem deck must contain an integer in I6 format, which specifies the number of title cards to be read. The appropriate number of title cards must then be entered. These cards should contain descriptive information about the problem and are read in a 12A6 format.

B. Control Parameters

A total of five cards must be entered. The first four cards contain integer data in a 12I6 format and the next card contains floating-point data in a 6E12.6 format. These data are adequately described in Sec. V.

C. Input Arrays

1. Fine Mesh. This is the mesh on which the difference approximations are taken. Each fine-mesh interval is contained in a coarse-mesh zone. Each coarse-mesh zone may contain one or more fine-mesh intervals. All material properties are assumed constant within a single-coarse mesh zone with the exception of the material density, which may depend upon the fine mesh (see paragraph 12 below). The fine mesh is specified by giving the number of fine-mesh intervals in each coarse-mesh zone.

2. Quadrature Weights and Points. The $P_N$ (Gaussian) quadrature sets are built into the code for N = 2, 4, 6, 8, 12, 16, 20, 24, 32, and 48. The $DP_N$ quadrature is also available for N = 4, 8, 12, 16, 24, 32, 40, 48, 64, and 96. These quadratures are obtained by setting IQUAD = 1 or 2, respectively. If IQUAD = 3, then both weights and cosines must be read in to the code. An array of MM weights and an array of MM cosines are required where MM = ISN in slab or spherical geometry, and MM = ISN*(ISN+2)/4 in cylindrical geometry. The weights are read in first.

3. Library Cross Sections. If cross-section data are to be obtained from a library, an array containing the identification numbers of the desired library materials must be entered. The first and subsequent entries in this array will be assigned the TIMEX identification numbers 1, 2, ..., MTP for the purpose of assigning these materials to a particular coarse-mesh zone (see paragraph 8).

4. Cross Sections. The standard LASL cross-section format is used by the TIMEX code. In this format a single block of IHM X IGM numbers is required for each nuclide (assuming scattering is isotropic). IHM and IGM are input parameters and are the "table length" and the number of energy groups,

respectively. We consider this single block to consist of a set of IGM subblocks or "tables" of length IHM. Each table contains the cross sections indicated in Table X. The positions of the total and self-scatter cross sections within the table are given by the input parameters IHT and IHS, respectively.

In this format, downscattering through M groups and upscattering through N groups is allowed (recall the group g+1 is of lower energy than group g). In the notation of Table X, $\sigma_a$ = absorption cross section, $\nu\sigma_f$ = product of the mean number of neutrons per fission times the fission cross section, $\sigma_t$ = total cross section, and $\sigma_{g'\to g}$ = cross section for scattering from group g' to g. Additional cross sections may be entered preceding IHT-2 in the table

TABLE X

STRUCTURE OF CROSS-SECTION BLOCK

| Position | Cross Section |
|---|---|
| . | . |
| . | . |
| . | . |
| IHT-2 | $\sigma_a$ |
| IHT-1 | $\nu\sigma_f$ |
| IHT | $\sigma_t$ |
| IHT+1 | $\sigma_{g+N\to g}$ |
| . | . |
| . | . |
| . | . |
| IHS-2 | $\sigma_{g+2\to g}$ |
| IHS-1 | $\sigma_{g+1\to g}$ |
| IHS | $\sigma_{g\to g}$ |
| IHS+1 | $\sigma_{g-1\to g}$ |
| IHS+2 | $\sigma_{g-2\to g}$ |
| . | . |
| . | . |
| . | . |
| IHS+M | $\sigma_{s,g-M\to g}$ |

for editing purposes (activation, etc.), although such cross sections are not used in the calculation. If no upscattering is to be allowed, IHS = IHT+1. Also, all cross-section blocks, including those from the library, must be in the same format with the same values of IHM, IHT, and IHS.

Each cross-section block must be preceded by a title card, which is read in the format (12A6). After the title card a single block of cross sections is read in a (6E12.5 format). The entries must be ordered within subblocks as indicated in Table X, and these subblocks must be ordered according to group index, with the cross sections for group 1 first.

Each nuclide read from cards is assigned a TIMEX identification number in the order of input, starting with MTP+1.

If the computation of an anisotropic scattering source is desired, additional cross sections are necessary. These cross sections are the Legendre components of the expansion of the scattering kernel (see Eq. (5)), $\sigma_\ell^s(r,g' \to g)$. These anisotropic scattering cross sections must be entered as additional cross-section blocks, one for each term in the expansion, immediately following the primary cross sections for that nuclide. These additional blocks are entered in the same manner as the primary cross sections, each block being preceded by a title card. The entries in these blocks corresponding to $\sigma_a$, $\nu\sigma_f$, and $\sigma_t$ are meaningless and are not used in the calculations. These anisotropic blocks are treated by the code in exactly the same manner as a nuclide and are assigned identification numbers in sequence. If desired, these blocks can be mixed (see paragraph 11).

In an adjoint calculation, cross sections are entered in exactly the same way as for a direct calculation. The code then performs the necessary transpositions to form the adjoint operators.

<u>5. Initial Flux</u>. In a time-dependent problem the complete angular flux at the initial time is needed to begin the calculation. Because this is an enormous array, various options that simplify its input are provided in the TIMEX code. These options are selected by the ISTART parameter, which may assume the values given in Table XI.

If the right (or outer) boundary is other than vacuum, the angular flux on the boundary is also

TABLE XI

ISTART OPTIONS

| ISTART | Entries |
|---|---|
| 0 | Initial flux set to zero. No entries required. |
| 1 | First-collision source option. Enter energy shape for uncollided flux, IGM numbers. |
| 2 | Isotropic initial flux. If IBR = 0 enter IGM blocks of IT fluxes. Otherwise, enter a block of IT fluxes and a block of MM/2 right-boundary fluxes for each energy group. |
| 3 | Complete angular flux. If IBR = 0 enter IGM blocks of IT*MM fluxes (all angular fluxes at a space point must be grouped). Otherwise, enter a block of IT*MM fluxes and MM/2 right-boundary fluxes for each energy group. |
| 4 | Obtain angular flux from tape. No entries required. |
| 5 | Restart problem; angular flux obtained from restart tape at selected time step. No entries required. |

TABLE XII

SOURCE INPUT OPTIONS

| IQOPT | Entries |
|---|---|
| 0 | All sources set to zero. No entries required. |
| 1 | Energy spectrum on all sources. Enter IGM distributed sources. If IQL $\neq$ 0 enter IGM left-boundary sources and if IQR $\neq$ 0 enter IGM right-boundary sources. |
| 2 | Complete distributed source, spectrum on boundary sources. Enter NMQ blocks of IT distributed sources for each group. If IQL $\neq$ 0, enter IGM left-boundary sources after group one distributed sources. If IQR $\neq$ 0, enter IGM right-boundary sources following left-boundary sources. |
| 3 | Zero distributed source, spectrum on boundary sources. If IQL $\neq$ 0 enter IGM left-boundary sources, and if IQR $\neq$ 0 enter IGM right-boundary sources. |
| 4 | Energy spectrum on distributed source, complete boundary sources. Enter IGM distributed sources. For each group enter MM/2 left-boundary sources if IQL $\neq$ 0, and MM/2 right-boundary sources if IQR $\neq$ 0. |
| 5 | Complete sources of all types. For each group enter NMQ*IT distributed sources, MM/2 left-boundary sources if IQL $\neq$ 0, and MM/2 right-boundary sources if IQR $\neq$ 0. |

needed to begin the calculation. If ISTART = 0, these boundary fluxes are set to zero. Only a vacuum right boundary is allowed if ISTART = 1. Otherwise, these boundary fluxes must be read in as specified in Table XI.

6. Sources. Both boundary and distributed sources can be read in to the code. Distributed sources may be isotropic or anisotropic, in which case NMQ spherical harmonic moments of the source are entered. In slab or spherical geometry NMQ = IQAN+1, but in cylindrical geometry NMQ = $(\text{IQAN}+2)^2/4$. Various input options are allowed for the sources; these options are discussed in Table XII.

7. Coarse-Mesh Radii. The radii (or x-coordinates) of the coarse mesh must be entered. The left-hand radius must be zero in all cases, including slab geometry. This zero must be entered so that a total of IM+1 radii are required.

8. Cross-section Identification. An integer must be assigned to each coarse-mesh interval. These integers must be valid cross-section identifiers specifying the particular material contained within a coarse-mesh zone. If the computation of an anisotropic scattering source is desired within a coarse-mesh zone, then the material ID number for that zone must be tagged with a minus sign, otherwise isotropic scattering is assumed. A total of IM cross-section identifiers must be entered.

9. Fission Spectrum. Either a fission spectrum or a fission matrix can be specified; either

of these may depend on the coarse-mesh zone. Selection of these options is accomplished by means of the IFISS parameter, which can be assigned the values given in Table XIII.

10. Velocities. A total of IGM group velocities must be entered.

11. Mixture Tables. Cross-section tables read from cards or a tape library may be manipulated or mixed to form new materials or alter old ones. This is accomplished by entering a set of mixture instructions. The number of such instructions is given by the input parameter MS. A mixture instruction consists of a single entry in each of the integer arrays MIXNUM and MIXCOM and in the real array MIXDEN. The mixture instructions are executed sequentially. The execution of a single mixture instruction results in the addition to cross-section block MIXNUM of MIXDEN times the contents of cross-section block MIXCOM. If MIXCOM = 0, then the cross-section block MIXNUM is multiplied by MIXDEN. Let us consider a few simple examples. Suppose five materials have been read in and MS = 4. The mixture instructions in Table XIV will produce the following results. First, the cross sections of material 1 are all multiplied by 0.5. Next, cross-section block six is cleared. Then material 6 is formed by adding 0.01 times the contents of block 2 to 10.1 times the contents of block 4. It is important when forming a new material, like 6 above, to clear the block initially, otherwise, garbage cross sections may result.

The three arrays, each consisting of a block of MS entries, are entered in the order: MIXNUM, MIXCOM, and MIXDEN.

TABLE XIII
IFISS OPTIONS

| IFISS | Entries |
|---|---|
| 1 | Fission spectrum. Enter IGM numbers. |
| 2 | Zone-dependent fission spectrum. Enter IM*IGM numbers. |
| 3 | Fission matrix. Enter IGM blocks of IGM numbers. |
| 4 | Zone fission matrix. Enter IGM blocks of IM*IGM numbers. |

TABLE XIV
SAMPLE MIXTURE INSTRUCTIONS

| MIXNUM | MIXCOM | MIXDEN |
|---|---|---|
| 1 | 0 | 0.5 |
| 6 | 0 | 0.0 |
| 6 | 2 | 0.01 |
| 6 | 4 | 10.1 |

12. Density Factors. Although only a single material is permitted within each coarse-mesh zone, the densities of that material can vary on the fine mesh. This is accomplished by the input of an array of IT densities. This array is read only if IDEN $\neq$ 0, otherwise the densities are set to 1.0. The cross sections at any mesh interval are then found by multiplying the cross sections for the appropriate coarse-mesh zone by the density factor for this interval.

13. Albedos. If IBL = 4, a total of IGM left albedos must be entered. If IBR = 4, a total of IGM right albedos must be entered.

14. Activities. If IACT $\neq$ 0, the TIMEX code will calculate activities for selected cross sections. An activity A, depending on position x, is defined as

$$A(x) = \sum_g \sigma_g \phi_g(x) \quad ,$$

where $\sigma_g$ is any desired cross section in the g'th energy group. The selection of the cross sections for which activities are desired is accomplished by entering two arrays, NMAC and NPAC, each of which contains IACT entries. The array NMAC specifies the table in which the cross section is located; NPAC specifies the position of the cross section within the table.

15. Time Step Control. TIMEX assumes that the time axis has been divided into a series of time zones. Each time zone is further divided into one or more time steps of equal size. Within a time zone all physical parameters are assumed to be constant. These time zones are delineated by

entering a set of cards, one for each time zone, that give vital information such as the number of time steps in the zone and the time step size. As many of these cards as desired may be entered. These cards are read in the format 6I6, E12.5 and contain the information given in Table XV.

If INDTS = 1, then group dependent time step sizes are indicated. The size of the time step within a particular group is specified by entering an array of time step scale factors, which are integers. The time step in a group is then given by the time step size entered on the time zone control card divided by the time step scale factor for that group. The scale factor array (IGM entries) should be entered only if INDTS = 1 and must immediately follow the zone control card.

TABLE XV

TIME ZONE CONTROL CARD

| Input Parameter | Remarks |
|---|---|
| NTS | Number of time steps in this zone. If NTS = -1, the input arrays indicated by nonzero parameters ITXS through ITRBDO must be entered. Set NTS = 0 to terminate problem. |
| NSPP | Number of steps per printout. |
| NSPD | Number of steps per restart dump. |
| IFREQ | Set IFREQ = 1 if the exponential extrapolation acceleration method is to be used over this zone. Otherwise set IFREQ = 0. |
| INDTS | Set INDTS = 1 for group dependent time step sizes; otherwise set INDTS. If INDTS = 1, enter time step scale factors on following card. |
| IEDOPT | Output edit options 0/1/2/3/4/5, Nothing/Activities/Activities + Flux Components/Activities + Flux + Frequencies/Activities + Flux + Angular Flux/Activities + Flux + Angular Flux + Frequencies. |
| DELTAT | Step size in this time zone. |

## V. QUICK REFERENCE INPUT INSTRUCTIONS

| | |
|---|---|
| CARD TYPE 1 | FORMAT (I6) |
| Number of title cards | |
| CARD TYPE 2 | FORMAT (12A6) Repeat ITC times |
| Title | |
| CARD TYPE 3 | FORMAT (12I6) |
| ITH | 0/1 Direct/Adjoint |
| ISCT | 0/N Isotropic/N'th Order Anisotropic |
| ISN | SN Order |
| IGM | Number of Groups |
| IM | Number of Coarse-Mesh Intervals |
| IBL | Left-right Boundary Condition-0/1/2/3/4 |
| IBR | Vacuum/Reflective/Periodic/White/Albedo |
| ISTART | 0 Through 5 Starting Options |
| IQOPT | 0 Through 5 Source Input Options |
| IGEOM | 1/2/3 Plane/Cylinder/Sphere |
| IQUAD | 1-PN W and MU, 2-DPN W and MU, 3-Read W and MU |
| MT | Total Number of Materials |
| CARD TYPE 4 | FORMAT (12I6) |
| MTP | Number of Materials from Library |
| MCR | Number of Materials from Cards |
| MS | Number of Mixture Instructions |
| IHT | Row of Total Cross Section |
| IHS | Row of Self Scatter Cross Section |
| IHM | Last Row of Cross-Section Table |
| IDEN | 0/1 No/Yes Space-Dependent Material Density |
| IQAN | 0/N Isotropic/N'th Order Anisotropic Source |
| IQL | 0/1 No/Yes Left-Boundary Source |
| IQR | 0/1 No/Yes Right-Boundary Source |
| IACC | 0-Nothing, 1-Coarse-Mesh Rebalance |
| IFISS | 1/2/3/4 Fission Fractions/Zone Fission Fractions/Fission Matrix/Zone Fission Matrix |
| CARD TYPE 5 | FORMAT (12I6) |
| IEDOPT | Output Edit Option |
| ITN | Restart Time Step Number |
| IPLOT | 0/1 No/Yes Plot Final Flux |
| IACT | Number of Activities |

CARD TYPE 6 FORMAT (12I6)

One or more of the following arrays may be loaded at each time zone.

| | |
|---|---|
| ITXS | 0,NO/1, Cross Sections |
| ITQ | 0,NO/1, Sources |
| ITB | 0,NO/1, Coarse-Mesh Boundaries |
| ITIDXS | 0,NO/1, Cross-Section Identification |
| ITFISS | 0,NO/1, Fission Spectrum |
| ITVEL | 0,NO/1, Velocities |
| ITMIX | 0,NO/1, Mixture Instructions |
| ITDEN | 0,NO/1, Density Function |
| ITLBDO | 0,NO/1, Left Albedo Factors |
| ITRBDO | 0,NO/1, Right Albedo Factors |

CARD TYPE 7 FORMAT (6E12.6)

| | |
|---|---|
| NORM | Normalization Amplitude |
| BHGT | Buckling Height in CM |
| BWTH | Buckling Width in CM |
| TIMOFF | Time (Seconds) After Which Dump Taken |

CARD TYPE 8 FORMAT (LASL)

Number of fine-mesh intervals in each coarse-mesh zone, IM entries.

CARD TYPE 9 FORMAT (LASL) Skip if IQUAD = 1, 2

Quadrature weights, MM entries

If IGEOM = 1, 3 MM = ISN

If IGEOM = 2 $NN = \frac{ISN*(ISN+2)}{4}$

CARD TYPE 10 FORMAT (LASL) Skip if IQUAD = 1, 2

Quadrature cosines, MM entries.

CARD TYPE 11 FORMAT (LASL) Skip if MTP = 0

Library cross section ID, MTP entries.

Repeat card types 12 and 14 MCRC times.

CARD TYPE 12 FORMAT (12A6)

Cross-section title card

CARD TYPE 13 FORMAT (6E12.5) Repeat as needed

All cross sections for a single material, IGM*IHM entries.

ISTART OPTIONS

0 Zero initial flux; skip cards 14 and 15.

1 Energy shape for uncollided flux; enter card 14, skip card 15.

2 Isotropic initial flux; if IBR = 0 enter card 14 IGM times, if IBR > 0 enter cards 14 and 15 IGM times.

3 Complete angular flux; if IBR = 0 enter card 14 IGM times, if IBR > 0 enter cards 14 and 15 IGM times.

4 Angular flux obtained from tape; no entries required.

5 Restart problem; no entries required.

CARD TYPE 14 FORMAT (LASL) Repeat as needed

Initial flux. Enter numbers according to following table.

| ISTART | Entries |
|---|---|
| 0 | 0 |
| 1 | IGM |
| 2 | IT |
| 3 | IT*MM |
| 4 | 0 |
| 5 | 0 |

CARD TYPE 15 FORMAT (LASL) Skip if IBR = 0

Boundary flux. Enter numbers according to following table.

| ISTART | Entries |
|---|---|
| 0 | 0 |
| 1 | 0 |
| 2 | MM/2 |
| 3 | MM/2 |
| 4 | 0 |
| 5 | 0 |

IQOPT OPTIONS

0 Zero sources. Skip cards 16, 17, and 18.

1 Energy spectrum on all sources.

2 Complete distributed source, spectrum on boundary sources. Enter cards 16, 17, and 18, repeat cards 16 IGM-1 times.

3 Zero distributed source, spectrum on boundary sources. Skip card type 16, enter card types 17 and 18.

4 Energy spectrum on distributed source, complete boundary sources. Enter cards 16, 17, and 18, repeat card types 17 and 18 IGM-1 times.

5. Complete sources of all types. Enter card types 16, 17, and 18 IGM times.

CARD TYPE 16 FORMAT (LASL) Repeat as needed

Distributed source. Enter numbers according to following table.

| IQOPT | Entries |
|---|---|
| 0 | 0 |
| 1 | IGM |
| 2 | NMQ* blocks of IT |
| 3 | 0 |
| 4 | IGM |
| 5 | NMQ[a] blocks of IT |

[a] $NMQ = \begin{cases} IQAN+1, & IGEOM=1,3 \\ \frac{(IQAN+2)^2}{4}, & IGEOM=2 \end{cases}$

CARD TYPE 17 FORMAT (LASL) Skip if IQL = 0

Left-boundary source. Enter numbers according to following table.

| IQOPT | Entries |
|---|---|
| 0 | 0 |
| 1 | IGM |
| 2 | IGM |
| 3 | MM/2 |
| 4 | MM/2 |
| 5 | MM/2 |

CARD TYPE 18 FORMAT (LASL) Skip if IQR = 0

Right-boundary source. Enter as for left-boundary source above.

CARD TYPE 19 FORMAT (LASL)

Coarse-mesh radii, IM+1 entries.

CARD TYPE 20 FORMAT (LASL)

Cross section ID, IM entries.

CARD TYPE 21 FORMAT (LASL)

Fission spectrum or matrix. Entries according to table below.

| IFISS | Entries |
|---|---|
| 1 | IGM |
| 2 | IM*IGM |
| 3 | IGM blocks of IGM |
| 4 | IGM blocks of IM*IGM |

CARD TYPE 22 FORMAT (LASL)

Velocities, IGM entries.

CARD TYPE 23 FORMAT (LASL) Skip if MS = 0

Mixture numbers, MS entries.

CARD TYPE 24 FORMAT (LASL) Skip if MS = 0

Mixture commands, MS entries.

CARD TYPE 25 FORMAT (LASL) Skip if MS = 0

Mixture densities, MS entries.

CARD TYPE 26 FORMAT (LASL) Skip if IDEN = 0

Density factors, IT entries.

CARD TYPE 27 FORMAT (LASL) Skip if IBL < 4

Left albedos, IGM entries.

CARD TYPE 28 FORMAT (LASL) Skip if IBR < 4

Right albedos, IGM entries.

CARD TYPE 29 FORMAT (LASL) Skip if IACT = 0

Activity material numbers, IACT entries.

CARD TYPE 30 FORMAT (LASL) Skip if IACT = 0

Activity cross-section positions, IACT entries.

Repeat card types 31 and 32 for each time zone.

CARD TYPE 31 FORMAT (6I6, E12.6)

| | |
|---|---|
| NTS | Number of time steps. If NTS = -1 input arrays specified in card type 6. Set NTS = 0 to terminate problem. |
| NSPP | Number of time steps per printout. |
| NSPD | Number of time steps per restart dump. |
| IFREQ | 0,NO/1, frequency extrapolation. |
| INDTS | 0,NO/1, group-dependent time step sizes. |
| IEDOPT | Edit options 0/1/2/3/4/5, Nothing/ Activities/Activities + Flux/ Activities + Flux + Frequencies/ Activities + Flux + Angular Flux/ Activities + Flux + Angular Flux + Frequencies. |
| DELTAT | Time step size. |

CARD TYPE 32 FORMAT (LASL) Skip if INDTS = 0

Time step scale factors, IGM entries.

## VI. SAMPLE PROBLEM

The following sample problem illustrates most of the input options, features, and output formats of the TIMEX code. The problem is an instantaneous point burst of neutrons at the center of a sphere. The uncollided flux option is exercised. There are two neutron groups and three coarse-mesh intervals, each containing 10 fine-mesh intervals. An $S_8$ approximation is used. Three cross-section sets are used in the calculation. Two are read from cards and the third is mixed. Space-dependent material densities are used; these densities are allowed to vary with time during the course of the calculation.

The left boundary is reflecting (necessary at the center of a sphere) and the right boundary is vacuum. Zone dependent fission matrices are entered.

The input cards necessary for this sample problem are listed in Table XVI. Card 1 indicates that two title cards are to be read, which follow as cards 2 and 3. Cards 4 through 6 contain the control integers. Card 7 indicates that new material densities may be read in at each time zone, if desired. Card 8 contains certain floating point control parameters. Card 9 is the first card in LASL format and results in the input of an array of three integers, each of which equals 10. These integers specify the number of fine-mesh intervals in each of the three coarse-mesh zones. Cross sections are entered on cards 10 through 15. Card 16 contains the uncollided flux spectrum. Card 17 results in the input of four numbers, 0.0, 10.0, 20.0, and 30.0, which are the coarse-mesh radii. Three integers specifying the material contained in each coarse-mesh zone are entered on card 18.

TABLE XVI

INPUT CARDS FOR SAMPLE PROBLEM

```
         11111111112222222222333333333344444444445555555555666666666677777777778
12345678901234567890123456789012345678901234567890123456789012345678 9C12345678 9C

     2                                                                   CARD  1
 SAMPLE PROBLEM                                                          CARD  2
 INSTANTANEOUS POINT BURST IN SPHERE                                     CARD  3
     0     0     8     2     3     1     0     1     0     3     1     3 CARD  4
     0     2     3     3     5     6     1     0     0     0     C     4 CARD  5
     2     0     0     1                                                 CARD  6
     0     0     0     0     0     0     0     1     0     0             CARD  7
         0.0         0.0         0.0         0.0                         CARD  8
103       103                                                            CARD  9
 MATERIAL ONE (PURE ABSORBER)                                            CARD 1C
         1.0         0.0         1.0         0.0         0.0         C.0 CARD 11
        10.0         0.0        10.0         0.0         0.0         C.0 CARD 12
  MATERIAL TWO                                                           CARD 13
         0.1         0.2         1.0         1.0         0.5         C.0 CARD 14
         5.0        10.0        10.0         0.0         4.0         C.4 CARD 15
        10.0         1.03                                                CARD 16
2 2      0.0        30.03                                                CARD 17
           2           3           13                                    CARD 18
         1.0         0.0         0.8         0.2         1.0         C.0 CARD 19
3                                                                        CARD 2C
         0.6         0.4         0.7         0.3         1.0         C.0 CARD 21
3                                                                        CARD 22
      1000.0         1.03                                                CARD 23
           3           3           33                                    CARD 24
           0           1           23                                    CARD 25
         0.0         0.5         0.53                                    CARD 26
         1.0         .95         .85          .6          .3          .2 CARD 27
         .15         .14         .13         .12         .114         .1 CARD 28
3                                                                        CARD 29
           13                                                            CARD 3C
           13                                                            CARD 31
    30    10    3C     0     0     2  0.001                              CARD 32
    -1                                                                   CARD 33
4        0.13                                                            CARD 34
    30    30    3C     0     0     2  1.0                                CARD 35
    30    10    3C     1     0     3  1.0                                CARD 36
                                                                         CARD 37

         11111111112222222222333333333344444444445555555555666666666677777777778
12345678901234567890123456789012345678901234567890123456789012345678 9C12345678 9C
```

Cards 19 and 20 contain the fission fractions for fissions caused by neutrons of group one for each coarse-mesh interval. Cards 21 and 22 contain the same information for fissions caused by neutrons of group two. Group velocities are entered on card 23. Cards 24 through 26 contain the mixture numbers, mixture commands, and mixture densities, respectively. Cards 27 through 29 contain the space-dependent material densities. Cards 30 and 31 contain the activity material numbers and the activity cross-section positions. Card 32 contains the information necessary to define the first time zone. This card specifies that 30 time steps be taken, printing every tenth step and dumping after 30 steps. Frequency extrapolation and group-dependent time step sizes are not used. The activities and the flux moments are to be printed and the time step size is 0.001. Card 33 indicates that new material densities are to be read. These densities are on card 34. Cards 35 and 36 define two successive time zones. Note that the frequency extrapolation option is selected in the final time zone. The problem input is terminated with a blank card. Further problems may be entered at this point.

All of the code output for this sample problem is shown in the appendix. The first page of the output contains the heading, title information, and a list of the control integers and floating point parameters. All the input arrays are listed on output pp. (1), (2), (3), and (4). Output p. (5) shows a schematic map of the system that indicates the material in each coarse-mesh zone, radii, number of fine intervals in each coarse zone, and boundary conditions. The boundary conditions are indicated by the numbers forming the left and right boundaries of the diagram.

Following the system map is a list of the mixture tables and the mixed cross sections. The coarse-mesh and fine-mesh geometries are then described, followed by a fission fractions listing. The initial condition is printed on output p. (7). This print is controlled by the value of the integer IEDOPT, which is equal to 2 in this problem. This integer is also entered on the time zone cards so that the output edit may be changed if desired. For this sample problem, the collided flux is initially zero so that the total flux equals the uncollided flux. The uncollided flux is the average of the uncollided flux over the mesh cell indicated. The first time zone card is printed on output p. (8). The results of the execution of the time zone card are printed on output pp. (9), (10), and (11) in the same format as the initial condition. On output p. (11) a message is printed indicating that the requested restart dump was made successfully.

Since the next time zone card contains a negative number in the first position (see card 33 of Table XVI), the code attempts to read the new arrays selected on card 7 of Table XVI. Because ITDEN is the only nonzero parameter on this card the material density is the only new array read by the code. The new densities are printed on output p. (12); another new time zone card is read and printed on output p. (13), with the resultant output printed on output p. (14). The final time zone card is printed on output p. (15). Note that the frequency extrapolation option is selected and that the output indicator IEDOPT is changed so that the frequencies are printed. These frequencies appear on output pp. (16), (17), and (18). It is interesting to note that the frequencies appear to converge to a single number for late times.

ACKNOWLEDGMENT

The TIMEX code is based largely on the steady-state program ONETRAN that was written by K. D. Lathrop.

REFERENCES

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2. K. D. Lathrop, "DTF-IV - A FORTRAN-IV Program for Solving the Multigroup Transport Equation with Anisotropic Scattering," LA-3373, Los Alamos Scientific Laboratory (1965).

3. Wm. H. Reed and K. F. Hansen, "Alternating Direction Methods for the Reactor Kinetics Equations," Nucl. Sci. Eng. 41, 431 (1970).

4. W. H. Reed, "The Effectiveness of Acceleration Techniques for Iterative Methods in Transport Theory," Nucl. Sci. Eng. 45, 245 (1971).

## APPENDIX A

## SAMPLE PROBLEM

```
THIS TIMEX PROBLEM RUN CN  03/23/72 WITH VERSION      10/7/71
SAMPLE PROBLEM
INSTANTANEOUS POINT BURST IN SPHERE

       0  ITH      0/1  DIRECT/ADJCINT
       0  ISCT     0/N  ISOTROPIC/NTH CRDER ANISOTROPIC
       8  ISN      SN ORDER
       2  IGM      NUMBER CF GROUPS
       3  IM       NUMBER CF COARSE MESH INTERVALS
       1  IBL      LEFT/RIGHT BOUNDARY CONDITION-0/1/2/3/4
       0  IBR       VACUUM/REFLECTIVE/PERICCIC/WHITE/ALBEDO
       1  ISTART   0 THRU 5 STARTING OPTICNS (SEE MANUAL)
       0  IQOPT    0 THRU 5 SOURCE INPUT CPTIONS (SEE MANUAL)
       3  IGEOM    1/2/3 PLANE/CYLINDER/SPHERE
       1  IQUAD    1-PN W AND MU,2-DPN W ANC MU,3-READ W AND MU
       3  MT       TOTAL NUMBER OF MATERIALS

       0  MTP      NUMBER OF MATERIALS FRCM LIBRARY
       2  MCR      NUMBER OF MATERIALS FRCM CARDS
       3  MS       NUMBER OF MIXTURE INSTRUCTIONS
       3  IHT      ROW OF TOTAL CRCSS SECTICN
       5  IHS      ROW OF SELF SCATTER CRCSS SECTICN
       6  IHM      LAST ROW OF CRCSS SECTICN TABLE
       1  IDEN     0/1 NO/YES SPACE DEPENDENT MATERIAL CENSITY
       0  IQAN     0/N ISOTROPIC/NTH CRCER ANISOTRCPIC SOURCE
       0  IQL      0/1 NO/YES LEFT BCUNCARY SOURCE
       0  IQR      0/1 NO/YES RIGHT BCUNDARY SOURCE
       0  IACC     0-NOTHING,1-COARSE MESH REBALANCE
       4  IFISS    1/2/3/4 FISSION FRACTICNS/ZONE FISSICN FRACTIONS/FISSION MATRIX/ZONE FISSION MATRIX

       2  IEDOPT   OUTPUT EDIT OPTICN
       0  ITN      RESTART TIME STEP NUMBER
       0  IPLOT    0/1 NO/YES PLOT FINAL FLUX
       1  IACT     NUMBER OF ACTIVITIES

            ***** ONE OR MORE OF THE FCLLOWING CONCITICNAL ARRAYS MAY BE LOADED AT EACH TIME ZONE.*****
       0  ITXS     0,NO/1,CROSS SECTIONS
       0  ITQ      0,NO/1,SOURCES
       0  ITB      0,NO/1,COARSE MESH BCUNDARIES
       0  ITIDXS   0,NO/1,CROSS SECTICN IDENTIFICATION
       0  ITFISS   0,NO/1,FISSION SPECTRUM
       0  ITVEL    0,NO/1,VELOCITIES
       0  ITMIX    0,NO/1,MIXTURE INSTRUCTICNS
       1  ITDEN    0,NO/1,DENSITY FUNCTION
       0  ITLBDO   0,NO/1,LEFT ALBEDC FACTCRS
       0  ITRBDO   0,NO/1,RIGHT ALBEDO FACTCRS


  0.           NORM    NORMALIZATION AMPLITUDE
  0.           BHGT    BUCKLING HEIGHT IN CM.
  0.           BWTH     BUCKLING WIDTH  IN CM.
  0.           TIMOFF   TIME (SECCNDS) AFTER WHICH DUMP TAKEN



INPUT FINE R MESH      3
          10          10           10
```

(1)

1904 WORDS OF CORE REQUIRED ( 27000 ALLOWED)
1131 WORDS OF EXTENDED CORE REQUIRED (EQUAL TO 000003 OCTAL THOUSAND, WITH 00C30C OCTAL THOUSAND ALLOWED)

ANGULAR COEFFICIENTS

| M | POINT WEIGHT | LEVEL WEIGHT | MU COSINE | MUBAR COSINE | WGT*MU | BETA PLUS | BETA MINUS |
|---|---|---|---|---|---|---|---|
| 1 | 5.061427E-02 | 5.061427E-02 | -9.602899E-01 | -9.602899E-01 | -4.860437E-02 | 9.6C2899E-C1 | 0. |
| 2 | 1.111905E-01 | 1.111905E-01 | -7.966665E-01 | -7.966665E-01 | -8.858176E-C2 | 1.233793E+CC | 4.371269E-01 |
| 3 | 1.568533E-01 | 1.568533E-01 | -5.255324E-01 | -5.255324E-01 | -8.24315CE-C2 | 1.4CC146E+CC | 8.746141E-01 |
| 4 | 1.813419E-01 | 1.813419E-01 | -1.834346E-01 | -1.834346E-01 | -3.326439E-02 | 1.3945C4E+CC | 1.211C69E+00 |
| 5 | 1.813419E-01 | 1.813419E-01 | 1.834346E-01 | 1.834346E-01 | 3.326439E-02 | 1.211C69E+CC | 1.394504E+00 |
| 6 | 1.568533E-01 | 1.568533E-01 | 5.255324E-01 | 5.255324E-01 | 8.24315CE-02 | 8.746141E-C1 | 1.4C0146E+00 |
| 7 | 1.111905E-01 | 1.111905E-01 | 7.966665E-01 | 7.966665E-01 | 8.858176E-02 | 4.371269E-C1 | 1.233793E+00 |
| 8 | 5.061427E-02 | 5.061427E-02 | 9.602899E-01 | 9.602899E-01 | 4.860437E-02 | C. | 9.602899E-01 |

SPHERICAL HARMONIC FUNCTIONS

| | ISOTROPIC |
|---|---|
| 1 | .100000E+01 |
| 2 | .100000E+01 |
| 3 | .10C000E+01 |
| 4 | .100000E+01 |
| 5 | .100000E+01 |
| 6 | .100000E+01 |
| 7 | .100000E+01 |
| 8 | .100000E+01 |

(2)

(3)

```
                                       * * * * * INPUT CROSS SECTIONS * * * * *

MAT NO                                       CARD CROSS SECTION INPUT SECTION
    1                   LOADED FRCM CARDS     MATERIAL ONE (PURE ABSORBER)
    2                   LOADED FROM CARDS      MATERIAL TWO

 INPUT CROSS SECT      1

        GROUP    1    GROUP    2

   1   .100000E+01   .100000E+02
   2  0.            0.
   3   .100000E+01   .100000E+02
   4  0.            0.
   5  0.            0.
   6  0.            0.

 INPUT CROSS SECT      2

        GROUP    1    GROUP    2

   1   .100C00E+00   .5C00C0E+01
   2   .200000E+00   .1C00C0E+02
   3   .100000E+01   .100000E+02
   4   .100C00E+01  0.
   5   .500000E+00   .400000E+01
   6  0.             .400000E+00


 INITIAL CONDITION


 UNCOLLIDED FLUX

 INPUT ENERGY SHAPE     2
   1.0000E+01  1.0000E+00


 INPUT SOURCE FOR GROUP   1


 ISOTROPIC COMPONENT
 SOURCE ZERO EVERYWHERE


 INPUT SOURCE FOR GROUP   2


 ISOTROPIC COMPONENT
 SOURCE ZERO EVERYWHERE

 INPUT COARSE MESH      4
   0.          1.0000E+01  2.0000E+01  3.0000E+01

 INPUT CROSS SEC ID     3
           2            3           1

 INPUT FISSN G SPEC     6
```

```
INPUT VELOCITIES        2
  1.0000E+03  1.0000E+00

INPUT MIX NUMBERS       3
          3           3           3

INPUT MIX COMMANDS      3
          0           1           2

INPUT MIX DENSITY       3
  0.          5.0000E-01  5.0000E-01

INPUT R DENSITY        30
  1.0000E+00  9.5000E-01  8.5000E-01  6.0000E-01  3.0000E-01  2.0000E-01  1.5000E-01  1.4000E-01  1.3000E-01  1.2000E-01
  1.1000E-01  1.0000E-01  1.0000E-01  1.0000E-01  1.0000E-01  1.0000E-01  1.0000E-01  1.0000E-01  1.0000E-01  1.0000E-01
  1.0000E-01  1.0000E-01  1.0000E-01  1.0000E-01  1.0000E-01  1.0000E-01  1.0000E-01  1.0000E-01  1.0000E-01  1.0000E-01

INPUT ACT MAT NO.S      1
          1

INPUT ACT XS POS        1
          1
```

M IS NUMBER OF FINE INTERVALS IN EACH COARSE INTERVAL

```
          1111111111111111111
          1     *     *     0
          1   2 *   3 *   1 0
          1     *     *     0
          1111111111111111111
    R     0.    10.   20.   30.
           0     0     0     0

    M        10    10    10
  COLUMN      1     2     3
```

| MIXTURE NUMBER | MIXTURE COMMAND | MATERIAL ATOMIC DENSITY | |
|---|---|---|---|
| 3 | 0 | 0. | 1 |
| 3 | 1 | 5.0000000E-01 | 2 |
| 3 | 2 | 5.0000000E-01 | 3 |

GROUP NUMBER 1

MIXED X-SECT

| | MATERL 3 |
|---|---|
| 1 | .550000E+00 |
| 2 | .100000E+00 |
| 3 | .100000E+01 |
| 4 | .500000E+00 |
| 5 | .250000E+00 |
| 6 | 0. |

(5)

GROUP NUMBER 2

MIXED X-SECT

| | MATERL 3 |
|---|---|
| 1 | .750000E+01 |
| 2 | .500000E+01 |
| 3 | .100000E+02 |
| 4 | 0. |
| 5 | .200000E+01 |
| 6 | .200000E+00 |

COARSE MESH GEOMETRY

| | NO. OF INTERVALS | WIDTH | FINE MESH SIZE | LEFT BOUNDARY |
|---|---|---|---|---|
| 1 | 10 | .10000000E+02 | .10000000E+01 | 0. |
| 2 | 10 | .10000000E+02 | .10000000E+01 | .10000000E+02 |
| 3 | 10 | .10000000E+02 | .10000000E+01 | .20000000E+02 |
| 4 | 0 | C. | 0. | .30000000E+02 |

FINE MESH GEOMETRY

| | COARSE MESH | LEFT BOUNDARY | AVERAGE RADIUS | VOLUME | LEFT AREA |
|---|---|---|---|---|---|
| 1 | 1 | 0. | .50000000E+00 | .41887902E+01 | 0. |
| 2 | 1 | .10000000E+01 | .15000000E+01 | .29321531E+02 | .83775804E+01 |
| 3 | 1 | .20000000E+01 | .25000000E+01 | .79587014E+02 | .50265482E+02 |
| 4 | 1 | .30000000E+01 | .35000000E+01 | .15498524E+03 | .10890855E+03 |
| 5 | 1 | .40000000E+01 | .45000000E+01 | .25551620E+03 | .20106193E+03 |
| 6 | 1 | .50000000E+01 | .55000000E+01 | .38117991E+03 | .30997048E+03 |
| 7 | 1 | .60000000E+01 | .65000000E+01 | .53197636E+03 | .45238934E+03 |
| 8 | 1 | .70000000E+01 | .75000000E+01 | .70790554E+03 | .61156337E+03 |
| 9 | 1 | .80000000E+01 | .85000000E+01 | .90896747E+03 | .80424772E+03 |
| 10 | 1 | .90000000E+01 | .95000000E+01 | .11351621E+04 | .10136872E+04 |
| 11 | 2 | .10000000E+02 | .10500000E+02 | .13864896E+04 | .12566371E+04 |
| 12 | 2 | .11000000E+02 | .11500000E+02 | .16629497E+04 | .15163421E+04 |
| 13 | 2 | .12000000E+02 | .12500000E+02 | .19645426E+04 | .18095574E+04 |
| 14 | 2 | .13000000E+02 | .13500000E+02 | .22912682E+04 | .21195278E+04 |
| 15 | 2 | .14000000E+02 | .14500000E+02 | .26431266E+04 | .24630086E+04 |
| 16 | 2 | .15000000E+02 | .15500000E+02 | .30201177E+04 | .28232446E+04 |
| 17 | 2 | .16000000E+02 | .16500000E+02 | .34222416E+04 | .32169909E+04 |
| 18 | 2 | .17000000E+02 | .17500000E+02 | .38494982E+04 | .36274923E+04 |
| 19 | 2 | .18000000E+02 | .18500000E+02 | .43018875E+04 | .40715041E+04 |
| 20 | 2 | .19000000E+02 | .19500000E+02 | .47794096E+04 | .45322710E+04 |
| 21 | 3 | .20000000E+02 | .20500000E+02 | .52820644E+04 | .50265482E+04 |
| 22 | 3 | .21000000E+02 | .21500000E+02 | .58098520E+04 | .55375807E+04 |
| 23 | 3 | .22000000E+02 | .22500000E+02 | .63627723E+04 | .60821234E+04 |
| 24 | 3 | .23000000E+02 | .23500000E+02 | .69408254E+04 | .66434213E+04 |
| 25 | 3 | .24000000E+02 | .24500000E+02 | .75440112E+04 | .72382295E+04 |
| 26 | 3 | .25000000E+02 | .25500000E+02 | .81723297E+04 | .78497928E+04 |
| 27 | 3 | .26000000E+02 | .26500000E+02 | .88257810E+04 | .84948665E+04 |
| 28 | 3 | .27000000E+02 | .27500000E+02 | .95043650E+04 | .91566954E+04 |
| 29 | 3 | .28000000E+02 | .28500000E+02 | .10208082E+05 | .98520346E+04 |
| 30 | 3 | .29000000E+02 | .29500000E+02 | .10936931E+05 | .10564129E+05 |
| 31 | 0 | .30000000E+02 | 0. | 0. | .11309734E+05 |

UNALTERED FISSION FRACTIONS FOR GROUP 1

GROUPS BY ROWS 1

| | ZONE 1 | ZONE 2 | ZONE 3 |
|---|---|---|---|
| 1 | .100000E+01 | .800000E+00 | .100000E+01 |
| 2 | 0. | .200000E+00 | 0. |

UNALTERED FISSION FRACTIONS FOR GROUP 2

GROUPS BY ROWS 1

| | ZONE 1 | ZONE 2 | ZONE 3 |
|---|---|---|---|
| 1 | .600000E+00 | .700000E+00 | .100000E+01 |
| 2 | .400000E+00 | .300000E+00 | 0. |

```
TIME STEP NUMBER =     0           REAL TIME =   0.                    TIME STEP SIZE =   0.

FLUXES FOR GROUP      1
UNCOLLIDED FLUX IS     .238732E+04   AT MESH INTERVAL     1
COMPONENT NO.    1
  1  .238732E+04    2 0.            3 0.            4 0.            5 0.            6 0.            7 0.
  8 0.              9 0.           10 0.           11 0.           12 0.           13 0.           14 0.
 15 0.             16 0.           17 0.           18 0.           19 0.           20 0.           21 0.
 22 0.             23 0.           24 0.           25 0.           26 0.           27 0.           28 0.
 29 0.             30 0.
FLUXES FOR GROUP      2
UNCOLLIDED FLUX IS     .238732E+00   AT MESH INTERVAL     1
COMPONENT NO.    1
  1  .238732E+00    2 0.            3 0.            4 0.            5 0.            6 0.            7 0.
  8 0.              9 0.           10 0.           11 0.           12 0.           13 0.           14 0.
 15 0.             16 0.           17 0.           18 0.           19 0.           20 0.           21 0.
 22 0.             23 0.           24 0.           25 0.           26 0.           27 0.           28 0.
 29 0.             30 0.
ACTIVITIES
  1  1    .23897E+04   1  2   0.        1  3   0.        1  4   0.        1  5   0.        1  6   0.
  1  7   0.            1  8   0.        1  9   0.        1 10   0.        1 11   0.        1 12   0.
  1 13   0.            1 14   0.        1 15   0.        1 16   0.        1 17   0.        1 18   0.
  1 19   0.            1 20   0.        1 21   0.        1 22   0.        1 23   0.        1 24   0.
  1 25   0.            1 26   0.        1 27   0.        1 28   0.        1 29   0.        1 30   0.
```

(7)

TIME ZONE PARAMETERS

```
NUMBER OF TIME STEPS =   30
NUMBER OF STEPS PER PRINT =   10
NUMBER OF STEPS PER DUMP =   30
FREQUENCY INDICATOR =    0
VARIABLE TIME STEP INDICATOR =    0
OUTPUT INDICATOR =    2
TIME STEP SIZE =      .100000E-02
```

(8)

```
TIME STEP NUMBER =   10          REAL TIME =    .100000E-01          TIME STEP SIZE =    .1C0000E-02

FLUXES FOR GROUP     1
UNCOLLIDED FLUX IS    .850777E-01   AT MESH INTERVAL   11
COMPONENT NO.    1
   1  .141738E+02    2  .850987E+01    3  .345835E+01    4  .144101E+01    5  .594947E+C0    6  .330314E+00    7  .185076E+00
   8  .109320E+00    9  .615357E-01   10  .353009E-01   11  .101724E+00   12 0.             13 0.             14 0.
  15 0.             16 0.             17 0.             18 0.             19 0.             20 0.             21 0.
  22 0.             23 0.             24 0.             25 0.             26 0.             27 0.             28 0.
  29 0.             30 0.
FLUXES FOR GROUP     2
UNCOLLIDED FLUX IS    .216014E+00   AT MESH INTERVAL    1
COMPONENT NO.    1
   1  .159792E+01    2  .169399E+00    3  .237585E-01    4  .464571E-02    5  .73012CE-C3    6  .219563E-03    7  .798522E-04
   8  .399452E-04    9  .199802E-04   10  .104695E-04   11  .493636E-06   12 0.             13 0.             14 0.
  15 0.             16 0.             17 0.             18 0.             19 0.             20 C.             21 0.
  22 0.             23 0.             24 0.             25 0.             26 0.             27 0.             28 0.
  29 0.             30 0.
ACTIVITIES
  1  1   .30153E+02   1  2   .10204E+02   1  3   .36959E+01   1  4   .14875E+01   1  5   .6C225E+00   1  6   .33251E+00
  1  7   .18587E+00   1  8   .10972E+00   1  9   .61735E-01   1 10   .35406E-01   1 11   .1C173E+C0   1 12  0.
  1 13  0.            1 14  0.            1 15  0.            1 16  0.            1 17  0.            1 18  0.
  1 19  0.            1 20  0.            1 21  0.            1 22  0.            1 23  0.            1 24  0.
  1 25  0.            1 26  0.            1 27  0.            1 28  0.            1 29  0.            1 30  0.
```

(9)

```
TIME STEP NUMBER =   20          REAL TIME =    .200000E-01          TIME STEP SIZE =    .100000E-02

FLUXES FOR GROUP     1
UNCOLLIDED FLUX IS    .813376E-02   AT MESH INTERVAL   21
COMPONENT NO.    1
   1  .268435E+01    2  .128720E+01    3  .465693E+00    4  .298148E+00    5  .173388E+00    6  .133938E+00    7  .100119E+00
   8  .813797E-01    9  .639398E-01   10  .498847E-01   11  .377476E-01   12  .289929E-01   13  .226407E-01   14  .174733E-01
  15  .132523E-01   16  .986869E-02   17  .720682E-02   18  .516276E-02   19  .366631E-02   20  .254281E-02   21  .970594E-02
  22 0.             23 0.             24 0.             25 0.             26 0.             27 0.             28 0.
  29 0.             30 0.
FLUXES FOR GROUP     2
UNCOLLIDED FLUX IS    .195458E+00   AT MESH INTERVAL    1
COMPONENT NO.    1
   1  .159286E+01    2  .181165E+00    3  .289437E-01    4  .683177E-02    5  .126042E-02    6  .463202E-03    7  .198335E-03
   8  .121495E-03    9  .721436E-04   10  .445513E-04   11  .136586E-04   12  .836398E-05   13  .567930E-05   14  .390947E-05
  15  .265627E-05   16  .181891E-05   17  .122804E-05   18  .832836E-06   19  .559187E-06   20  .375706E-06   21 0.
  22 0.             23 0.             24 0.             25 0.             26 0.             27 0.             28 0.
  29 0.             30 0.
ACTIVITIES
  1  1    .18613E+02    1  2    .30988E+01    1  3    .75513E+00    1  4    .36647E+00    1  5    .18599E+00    1  6    .13857E+00
  1  7    .10210E+00    1  8    .82595E-01    1  9    .64661E-01    1 10    .50330E-01    1 11    .37884E-01    1 12    .29077E-01
  1 13    .22698E-01    1 14    .17512E-01    1 15    .13279E-01    1 16    .98869E-02    1 17    .72191E-02    1 18    .51711E-02
  1 19    .36719E-02    1 20    .25466E-02    1 21    .97059E-02    1 22   0.             1 23   0.             1 24   0.
  1 25   0.             1 26   0.             1 27   0.             1 28   0.             1 29   0.             1 30   0.
```

(10)

```
TIME STEP NUMBER =   30          REAL TIME =    .300000E-01          TIME STEP SIZE =    .100000E-02

FLUXES FOR GROUP     1
COMPONENT NO.    1
   1  .201522E+01    2  .744201E+00    3  .161138E+00    4  .841110E-01    5  .464335E-01    6  .371252E-01    7  .296622E-01
   8  .257193E-01    9  .217266E-01   10  .182443E-01   11  .149658E-01   12  .126451E-01   13  .110089E-01   14  .963684E-02
  15  .844687E-02   16  .739540E-02   17  .644297E-02   18  .557091E-02   19  .475988E-02   20  .396998E-02   21  .321391E-02
  22  .259969E-02   23  .210252E-02   24  .168027E-02   25  .132299E-02   26  .102488E-02   27  .779897E-03   28  .582562E-03
  29  .426358E-03   30  .305140E-03
FLUXES FOR GROUP     2
UNCOLLIDED FLUX IS    .176857E+00   AT MESH INTERVAL     1
COMPONENT NO.    1
   1  .157203E+01    2  .182413E+00    3  .292951E-01    4  .728713E-02    5  .137748E-02    6  .537921E-03    7  .238739E-03
   8  .155362E-03    9  .970190E-04   10  .638858E-04   11  .206831E-04   12  .137361E-04   13  .100639E-04   14  .764517E-05
  15  .571486E-05   16  .437977E-05   17  .329747E-05   18  .251804E-05   19  .188956E-05   20  .141032E-05   21 0.
  22 0.             23 0.             24 0.             25 0.             26 0.             27 0.             28 0.
  29 0.             30 0.
ACTIVITIES
  1  1   .17736E+02   1  2   .25683E+01   1  3   .45409E+00   1  4   .15698E+00   1  5   .60208E-01   1  6   .42504E-01
  1  7   .32050E-01   1  8   .27273E-01   1  9   .22697E-01   1 10   .18883E-01   1 11   .15173E-01   1 12   .12782E-01
  1 13   .11110E-01   1 14   .97133E-02   1 15   .85040E-02   1 16   .74392E-02   1 17   .64759E-02   1 18   .55961E-02
  1 19   .47788E-02   1 20   .39841E-02   1 21   .32139E-02   1 22   .25997E-02   1 23   .21025E-02   1 24   .16803E-02
  1 25   .13230E-02   1 26   .10249E-02   1 27   .77990E-03   1 28   .58256E-03   1 29   .42636E-03   1 30   .30514E-03


********* DUMP WRITTEN ON UNIT  7 AT TIME STEP NUMBER   30 *********
```

(11)

THE FOLLOWING INPUT WAS READ AT THE END CF TIME STEP 30

INPUT R DENSITY 30

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 1.0000E-01 | 1.0000E-01 | 1.0000E-01 | 1.0000E-01 | 1.0000E-01 | 1.0000E-01 | 1.00CCE-C1 | 1.00CCE-01 | 1.CC00E-01 | 1.0000E-01 |
| 1.0000E-01 | 1.0000E-01 | 1.0000E-01 | 1.0000E-01 | 1.0000E-01 | 1.0000E-01 | 1.00CCE-C1 | 1.0CCCE-01 | 1.CC00E-01 | 1.0000E-01 |
| 1.0000E-01 | 1.0000E-01 | 1.0000E-01 | 1.0000E-01 | 1.0000E-01 | 1.0000E-01 | 1.000CE-C1 | 1.0CCCE-01 | 1.CC00E-01 | 1.0000E-01 |

(12)

```
TIME ZONE PARAMETERS

NUMBER OF TIME STEPS =   30
NUMBER OF STEPS PER PRINT =   30
NUMBER OF STEPS PER DUMP =   30
FREQUENCY INDICATOR =    0
VARIABLE TIME STEP INDICATOR =    0
OUTPUT INDICATOR =    2
TIME STEP SIZE =      .100000E+01
```

```
TIME STEP NUMBER =   60          REAL TIME =    .300300E+02          TIME STEP SIZE =    .1C0000E+01

FLUXES FOR GROUP     1
COMPONENT NO.     1
   1  .134133E-02    2  .121555E-02    3  .106581E-02    4  .917929E-03    5  .759291E-C3    6  .616585E-03    7  .488318E-03
   8  .382674E-03    9  .293654E-03   10  .219614E-03   11  .158894E-03   12  .116567E-C3   13  .885211E-04   14  .687372E-04
  15  .541444E-04   16  .431344E-04   17  .345762E-04   18  .278160E-04   19  .2234C5E-C4   20  .176726E-04   21  .137127E-04
  22  .107780E-04   23  .867711E-05   24  .704816E-05   25  .576279E-05   26  .473942E-C5   27  .391612E-05   28  .324998E-05
  29  .270692E-05   30  .226242E-05
FLUXES FOR GROUP     2
COMPONENT NO.     1
   1  .228534E-02    2  .201740E-02    3  .165962E-02    4  .129341E-02    5  .944142E-C3    6  .661163E-03    7  .44647[illegible]E-03
   8  .295469E-03    9  .187874E-03   10  .102186E-03   11  .357822E-04   12  .116C1CE-C4   13  .654254E-05   14  .394734E-05
  15  .301339E-05   16  .223017E-05   17  .180785E-05   18  .139699E-05   19  .110548E-C5   20  .683246E-06   21  .182094E-06
  22  .293331E-07   23  .762303E-08   24  .212286E-08   25  .616063E-09   26  .184965E-C9   27  .569C66E-10   28  .178769E-10
  29  .570938E-11   30  .185507E-11
ACTIVITIES
  1  1   .24195E-01   1  2   .21390E-01   1  3   .17662E-01   1  4   .13852E-01   1  5   .1C2C1E-01   1  6   .72282E-02
  1  7   .49531E-02   1  8   .33374E-02   1  9   .21724E-02   1 10   .12415E-02   1 11   .51672E-C3   1 12   .23258E-03
  1 13   .15395E-03   1 14   .10821E-03   1 15   .84278E-04   1 16   .65436E-04   1 17   .52655E-C4   1 18   .41786E-04
  1 19   .33395E-04   1 20   .24505E-04   1 21   .15534E-04   1 22   .11071E-04   1 23   .87533E-C5   1 24   .70694E-05
  1 25   .57690E-05   1 26   .47413E-05   1 27   .39167E-05   1 28   .32502E-05   1 29   .27070E-C5   1 30   .22624E-05


********* DUMP WRITTEN ON UNIT  7 AT TIME STEP NUMBER   60 *********
```

```
TIME ZONE PARAMETERS

NUMBER OF TIME STEPS =   30
NUMBER OF STEPS PER PRINT =   10
NUMBER OF STEPS PER DUMP =   30
FREQUENCY INDICATOR =    1
VARIABLE TIME STEP INDICATOR =    0
OUTPUT INDICATOR =    3
TIME STEP SIZE =       .100000E+01
```

(15)

```
TIME STEP NUMBER =   70          REAL TIME =    .400300E+02          TIME STEP SIZE =    .100000E+01

FLUXES FOR GROUP     1
COMPONENT NO.     1
   1  .163402E-03    2  .153741E-03    3  .142514E-03    4  .130727E-03    5  .116398E-03    6  .101168E-03    7  .852424E-04
   8  .697945E-04    9  .550881E-04   10  .416654E-04   11  .301878E-04   12  .219636E-04   13  .164834E-04   14  .126866E-04
  15  .991938E-05   16  .785806E-05   17  .627143E-05   18  .502896E-05   19  .403002E-05   20  .318641E-05   21  .247589E-05
  22  .194849E-05   23  .156904E-05   24  .127461E-05   25  .104219E-05   26  .857117E-06   27  .708212E-06   28  .587729E-06
  29  .489511E-06   30  .409120E-06
FREQUENCIES FOR GROUP     1
   1 -.205191E+00    2 -.203160E+00    3 -.200201E+00    4 -.196764E+00    5 -.192511E+00    6 -.188211E+00    7 -.183955E+00
   8 -.180474E+00    9 -.177858E+00   10 -.176462E+00   11 -.175981E+00   12 -.176311E+00   13 -.176903E+00   14 -.177346E+00
  15 -.177745E+00   16 -.178064E+00   17 -.178322E+00   18 -.178515E+00   19 -.178665E+00   20 -.178762E+00   21 -.178803E+00
  22 -.178832E+00   23 -.178876E+00   24 -.178915E+00   25 -.178950E+00   26 -.178981E+00   27 -.179009E+00   28 -.179034E+00
  29 -.179056E+00   30 -.179076E+00
FLUXES FOR GROUP     2
COMPONENT NO.     1
   1  .247473E-03    2  .232925E-03    3  .212311E-03    4  .187634E-03    5  .159293E-03    6  .130081E-03    7  .101650E-03
   8  .752786E-04    9  .516636E-04   10  .292127E-04   11  .106646E-04   12  .348641E-05   13  .177123E-05   14  .954566E-06
  15  .674756E-06   16  .472984E-06   17  .375077E-06   18  .285086E-06   19  .223047E-06   20  .137559E-06   21  .392500E-07
  22  .788557E-08   23  .223436E-08   24  .711183E-09   25  .232935E-09   26  .759259E-10   27  .241005E-10   28  .759425E-11
  29  .241567E-11   30  .770338E-12
FREQUENCIES FOR GROUP     2
   1 -.225500E+00    2 -.221414E+00    3 -.215170E+00    4 -.207409E+00    5 -.197798E+00    6 -.187550E+00    7 -.177107E+00
   8 -.167849E+00    9 -.160149E+00   10 -.155131E+00   11 -.151391E+00   12 -.149292E+00   13 -.152390E+00   14 -.157570E+00
  15 -.163138E+00   16 -.168345E+00   17 -.171089E+00   18 -.172684E+00   19 -.173301E+00   20 -.173770E+00   21 -.173216E+00
  22 -.172307E+00   23 -.175889E+00   24 -.175539E+00   25 -.155848E+00   26 -.118326E+00   27 -.906997E-01   28 -.868217E-01
  29 -.849127E-01   30 -.820413E-01
ACTIVITIES
  1  1   .26381E-02   1  2   .24830E-02   1  3   .22657E-02   1  4   .20071E-02   1  5   .17093E-02   1  6   .14020E-02
  1  7   .11017E-02   1  8   .82258E-03   1  9   .57172E-03   1 10   .33379E-03   1 11   .13683E-03   1 12   .56828E-04
  1 13   .34196E-04   1 14   .22232E-04   1 15   .16667E-04   1 16   .12588E-04   1 17   .10022E-04   1 18   .78798E-05
  1 19   .62605E-05   1 20   .45620E-05   1 21   .28684E-05   1 22   .20273E-05   1 23   .15914E-05   1 24   .12817E-05
  1 25   .10445E-05   1 26   .85788E-06   1 27   .70845E-06   1 28   .58781E-06   1 29   .48953E-06   1 30   .40913E-06
```

```
TIME STEP NUMBER =   80          REAL TIME =    .500300E+02          TIME STEP SIZE =    .100000E+01

FLUXES FOR GROUP     1
COMPONENT NO.    1
   1  .229093E-04    2  .217632E-04    3  .204693E-04    4  .190730E-04    5  .173356E-04    6  .153950E-04    7  .132588E-04
   8  .110608E-04    9  .885948E-05   10  .675854E-05   11  .491502E-05   12  .357352E-05   13  .267553E-05   14  .205527E-05
  15  .160408E-05   16  .126895E-05   17  .101156E-05   18  .810398E-06   19  .648915E-06   20  .512740E-06   21  .398182E-06
  22  .313220E-06   23  .252128E-06   24  .204750E-06   25  .167370E-06   26  .137615E-06   27  .113683E-06   28  .943256E-07
  29  .785494E-07   30  .656398E-07
FREQUENCIES FOR GROUP     1
   1 -.192444E+00    2 -.191985E+00    3 -.191328E+00    4 -.190548E+00    5 -.189567E+00    6 -.188539E+00    7 -.187493E+00
   8 -.186593E+00    9 -.185876E+00   10 -.185439E+00   11 -.185225E+00   12 -.185221E+00   13 -.185306E+00   14 -.185382E+00
  15 -.185459E+00   16 -.185524E+00   17 -.185579E+00   18 -.185624E+00   19 -.185663E+00   20 -.185699E+00   21 -.185733E+00
  22 -.185761E+00   23 -.185783E+00   24 -.185800E+00   25 -.185815E+00   26 -.185828E+00   27 -.185840E+00   28 -.185850E+00
  29 -.185858E+00   30 -.185866E+00
FLUXES FOR GROUP     2
COMPONENT NO.    1
   1  .310468E-04    2  .298022E-04    3  .279822E-04    4  .256661E-04    5  .228260E-04    6  .196149E-04    7  .161686E-04
   8  .125770E-04    9  .900348E-05   10  .524240E-05   11  .196223E-05   12  .654423E-06   13  .329252E-06   14  .173018E-06
  15  .118779E-06   16  .810849E-07   17  .632300E-07   18  .474922E-07   19  .368855E-07   20  .226645E-07   21  .652032E-08
  22  .134427E-08   23  .384854E-09   24  .123142E-09   25  .406963E-10   26  .138115E-10   27  .477743E-11   28  .167816E-11
  29  .595830E-12   30  .213758E-12
FREQUENCIES FOR GROUP     2
   1 -.198175E+00    2 -.197207E+00    3 -.195759E+00    4 -.193934E+00    5 -.191672E+00    6 -.189203E+00    7 -.186648E+00
   8 -.184308E+00    9 -.182294E+00   10 -.180848E+00   11 -.179486E+00   12 -.178159E+00   13 -.178123E+00   14 -.178951E+00
  15 -.180357E+00   16 -.181698E+00   17 -.182723E+00   18 -.183417E+00   19 -.183903E+00   20 -.184111E+00   21 -.183504E+00
  22 -.181588E+00   23 -.180250E+00   24 -.179019E+00   25 -.177663E+00   26 -.176240E+00   27 -.174553E+00   28 -.173038E+00
  29 -.172714E+00   30 -.173488E+00
ACTIVITIES
  1  1    .33338E-03   1  2    .31979E-03   1  3    .30029E-03   1  4    .2[illegible]573E-03   1  5    .24560E-03   1  6    .21154E-03
  1  7    .17494E-03   1  8    .13683E-03   1  9    .98894E-04   1 10    .59183E-04   1 11    .24537E-04   1 12    .10118E-04
  1 13    .59680E-05   1 14    .37854E-05   1 15    .27919E-05   1 16    .20798E-05   1 17    .16439E-05   1 18    .12853E-05
  1 19    .10178E-05   1 20    .73938E-06   1 21    .46339E-06   1 22    .32666E-06   1 23    .25598E-06   1 24    .20598E-06
  1 25    .16778E-06   1 26    .13775E-06   1 27    .11373E-06   1 28    .94342E-07   1 29    .78555E-07   1 30    .65642E-07
```

```
TIME STEP NUMBER =   90          REAL TIME =    .600300E+02          TIME STEP SIZE =    .100000E+01

FLUXES FOR GROUP     1
COMPONENT NO.    1
   1  .340677E-05    2  .324382E-05    3  .306107E-05    4  .286327E-05    5  .261505E-05    6  .233399E-05    7  .202033E-05
   8  .169271E-05    9  .136047E-05   10  .104001E-05   11  .757102E-06   12  .550475E-06   13  .411988E-06   14  .316369E-06
  15  .246831E-06   16  .195205E-06   17  .155570E-06   18  .124606E-06   19  .997580E-07   20  .788097E-07   21  .611914E-07
  22  .481278E-07   23  .387367E-07   24  .314550E-07   25  .257104E-07   26  .211383E-07   27  .174613E-07   28  .144874E-07
  29  .120638E-07   30  .100808E-07
FREQUENCIES FOR GROUP     1
   1 -.189622E+00    2 -.189510E+00    3 -.189352E+00    4 -.189166E+00    5 -.188935E+00    6 -.188697E+00    7 -.188459E+00
   8 -.188256E+00    9 -.188097E+00   10 -.188001E+00   11 -.187953E+00   12 -.187952E+00   13 -.187970E+00   14 -.187986E+00
  15 -.188002E+00   16 -.188015E+00   17 -.188027E+00   18 -.188036E+00   19 -.188045E+00   20 -.188053E+00   21 -.188062E+00
  22 -.188068E+00   23 -.188073E+00   24 -.188077E+00   25 -.188081E+00   26 -.188084E+00   27 -.188086E+00   28 -.188089E+00
  29 -.188091E+00   30 -.188092E+00
FLUXES FOR GROUP     2
COMPONENT NO.    1
   1  .448389E-05    2  .432591E-05    3  .409223E-05    4  .378859E-05    5  .340780E-05    6  .296423E-05    7  .247381E-05
   8  .194582E-05    9  .140618E-05   10  .824286E-06   11  .310504E-06   12  .104213E-06   13  .524644E-07   14  .274811E-07
  15  .187501E-07   16  .127238E-07   17  .987324E-08   18  .739018E-08   19  .572477E-08   20  .351368E-08   21  .101425E-08
  22  .211341E-09   23  .610147E-10   24  .196796E-10   25  .656992E-11   26  .225355E-11   27  .788368E-12   28  .280339E-12
  29  .100806E-12   30  .365901E-13
FREQUENCIES FOR GROUP     2
   1 -.191061E+00    2 -.190808E+00    3 -.190436E+00    4 -.189979E+00    5 -.189429E+00    6 -.188848E+00    7 -.188265E+00
   8 -.187749E+00    9 -.187315E+00   10 -.187010E+00   11 -.186723E+00   12 -.186442E+00   13 -.186410E+00   14 -.186545E+00
  15 -.186813E+00   16 -.187070E+00   17 -.187289E+00   18 -.187444E+00   19 -.187566E+00   20 -.187618E+00   21 -.187442E+00
  22 -.186886E+00   23 -.186424E+00   24 -.185947E+00   25 -.185359E+00   26 -.184674E+00   27 -.183889E+00   28 -.183004E+00
  29 -.182009E+00   30 -.180916E+00
ACTIVITIES
  1  1   .48246E-04   1  2   .46503E-04   1  3   .43983E-04   1  4   .40749E-04   1  5   .36693E-04   1  6   .31976E-04
  1  7   .26758E-04   1  8   .21151E-04   1  9   .15422E-04   1 10   .92829E-05   1 11   .38621E-05   1 12   .15926E-05
  1 13   .93663E-06   1 14   .59118E-06   1 15   .43433E-06   1 16   .32244E-06   1 17   .25430E-06   1 18   .19851E-06
  1 19   .15701E-06   1 20   .11395E-06   1 21   .71334E-07   1 22   .50241E-07   1 23   .39347E-07   1 24   .31652E-07
  1 25   .25776E-07   1 26   .21161E-07   1 27   .17469E-07   1 28   .14490E-07   1 29   .12065E-07   1 30   .10081E-07


********* DUMP WRITTEN ON UNIT  7 AT TIME STEP NUMBER   90 *********
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EE/rr:403(150)

THIS TIMEX PROBLEM RUN ON 03/23/72 WITH VERSION 10/7/71

END OF FILE ON INPUT UNIT. NO MORE PRCBLEMS

(19)