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TWOTRAN SPHERE: A FORTRAN Program to Solve the Multigroup Transport Equation in Two-Dimensional Spherical Geometry

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by

K. D. Lathrop
F. W. Brinkley

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TWOTRAN SPHERE: A FORTRAN PROGRAM TO SOLVE THE MULTIGROUP TRANSPORT EQUATION IN TWO-DIMENSIONAL SPHERICAL GEOMETRY

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K. D. Lathrop
F. W. Brinkley

ABSTRACT

Finite difference techniques peculiar to the solution of the Boltzmann transport equation in two-dimensional spherical geometry are given. Programming information and input instructions are given for a FORTRAN program to solve the transport equation in this geometry.

I. INTRODUCTION

The TWOTRAN SPHERE program is a modification of the general-geometry TWOTRAN program[1] to solve the multigroup discrete ordinates approximation to the transport equation in two-dimensional (r,Θ) spherical geometry. In this geometry there are two angular derivatives in the transport divergence operator. Treatment of these derivatives has required development of techniques not anticipated in previous derivations of discrete ordinates difference equations,[2] and has made the programming of TWOTRAN SPHERE different enough from that of TWOTRAN to require this separate report.

An effort has been made to make TWOTRAN SPHERE compatible with the general geometry TWOTRAN program, and we describe here only the differences in the programs and the theory. We do not repeat explanations of common material such as cross section formats. For such details the reader is referred to LA-4432, (Ref. 1).

Two unexpected difficulties arose in developing TWOTRAN SPHERE. First, for systems larger than a hemisphere, our usual progression through the space-angle mesh became numerically unstable. Second, with our first representation of angle-to-angle streaming (two angular derivatives), we could not obtain constant in Θ solutions for homogeneous spheres. That is, we could not duplicate one-dimensional computations. Our solutions to these problems are described below.

II. THEORY

A. The Divergence Operator

In (r,Θ) spherical geometry we measure distance, r, from the origin and angle, Θ, from a pole through the origin. We choose this to be the south pole so that in our rectangular picture plots increasing Θ is drawn from the bottom to the top of the page. In this geometry, we write the transport divergence operator as[2]

$$\nabla\cdot\underline{\Omega}\psi = \frac{\mu}{r^2}\frac{\partial(r^2\psi)}{\partial r} + \frac{\eta}{r\sin\Theta}\frac{\partial(\sin\Theta\psi)}{\partial\Theta} + \frac{1}{r}\frac{\partial[(1-\mu^2)\psi]}{\partial\mu} - \frac{\cot\Theta}{r}\frac{\partial(\xi\psi)}{\partial\omega}. \tag{1}$$

In this equation, $\underline{\Omega}$ is a unit vector in the direction of particle motion and μ, η, and ξ are direction cosines such that

$$\mu = \hat{e}_r\cdot\underline{\Omega}\,,\quad \eta = \hat{e}_\Theta\cdot\underline{\Omega}\,,\quad \xi = (1-\mu^2-\eta^2)^{\frac{1}{2}}\,; \tag{2}$$

and ω is an azimuthal angle about the direction $\underline{\Omega}$ such that

$$\eta = (1 - \mu^2)^{\frac{1}{2}} \cos \omega \tag{3}$$

and

$$\xi = (1 - \mu^2)^{\frac{1}{2}} \sin \omega \;;$$

and ψ is the particle distribution function. By performing some of the derivatives, we can also write (1) as

$$\nabla \cdot \underline{\Omega} \psi = \mu \frac{\partial \psi}{\partial r} + \frac{\eta}{r} \frac{\partial \psi}{\partial \Theta} + \frac{1-\mu^2}{r} \frac{\partial \psi}{\partial \mu} - \frac{\xi \cot \Theta}{r} \frac{\partial \psi}{\partial \omega}. \tag{4}$$

B. Finite Difference Form of the Divergence Operator

Following the suggestion of Ref. 2, but using the consistent notation of Ref. 1, we approximate (1) by

$$\mu \frac{(A_{i+\frac{1}{2}}N_{i+\frac{1}{2}} - A_{i-\frac{1}{2}}N_{i-\frac{1}{2}})}{V} + \eta \frac{(B_{j+\frac{1}{2}}N_{j+\frac{1}{2}} - B_{j-\frac{1}{2}}N_{j-\frac{1}{2}})}{V}$$
$$+ \frac{A_{i+\frac{1}{2}} - A_{i-\frac{1}{2}}}{V} \frac{(\alpha_{m+\frac{1}{2}}N_{m+\frac{1}{2}} - \alpha_{m-\frac{1}{2}}N_{m-\frac{1}{2}})}{W}$$
$$+ \frac{B_{j+\frac{1}{2}} - B_{j-\frac{1}{2}}}{V} \frac{(\beta_{\ell+\frac{1}{2}}N_{\ell+\frac{1}{2}} - \beta_{\ell-\frac{1}{2}}N_{\ell-\frac{1}{2}})}{W}. \tag{5}$$

In this notation, V is the volume of a finite cell and A and B are surface areas. These are given by:

$$V_{ij} = 2\pi(r^3_{i+\frac{1}{2}} - r^3_{i-\frac{1}{2}})(\cos 2\pi\Theta_{j-\frac{1}{2}} - \cos 2\pi\Theta_{j+\frac{1}{2}}), \tag{6}$$

$$A_{i+\frac{1}{2},j} = 2\pi r^2_{i+\frac{1}{2}}(\cos 2\pi\Theta_{j-\frac{1}{2}} - \cos 2\pi\Theta_{j+\frac{1}{2}}), \tag{7}$$

and

$$B_{i,j+\frac{1}{2}} = \pi \sin 2\pi\Theta_{j+\frac{1}{2}}(r^2_{i+\frac{1}{2}} - r^2_{i-\frac{1}{2}}). \tag{8}$$

In these equations, as throughout the computer program, we measure Θ in units of revolutions, $0 < \Theta < \frac{1}{2}$.

In (5) the quadrature weight W plays the same role as the volume V and is also two dimensional. In the equation we use a subscripting convention in which centered subscripts are omitted, e.g., $W \equiv W_{m\ell}$, $\mu = \mu_m$, etc. The range of subscripts is

$$\begin{aligned} i &= 1, 2, \ldots, IT, \\ j &= 1, 2, \ldots, JT, \\ m &= 1, 2, \ldots, ISN, \end{aligned} \tag{9}$$

and

$$\ell = 1, 2, \ldots, ISN,$$

where there are IT r intervals, JT Θ intervals, and ISN*ISN angular intervals. ISN is the order of the angular approximation, ISN = 2, 4, ...

In the divergence free case when the particle distribution is a constant, we must have

$$-W_{m\ell}(\mu_m + \eta_{m\ell}) = \alpha_{m+\frac{1}{2}} - \alpha_{m-\frac{1}{2}} + \beta_{\ell+\frac{1}{2}} - \beta_{\ell-\frac{1}{2}}. \tag{10}$$

We satisfy this requirement in a nonunique fashion by assuming

$$\alpha_{m+\frac{1}{2}} - \alpha_{m-\frac{1}{2}} = -W_{m\ell}\mu_m \tag{11}$$

and

$$\beta_{\ell+\frac{1}{2}} - \beta_{\ell-\frac{1}{2}} = -W_{m\ell}\eta_{m\ell}. \tag{12}$$

We take $\alpha_{\frac{1}{2}} = \beta_{\frac{1}{2}} = 0$ and determine the rest of the α's and β's recursively using given values of W, μ, and η.

To solve (5), we use the standard diamond differencing, assuming that

$$2N = N_{i+\frac{1}{2}} + N_{i-\frac{1}{2}} = N_{j+\frac{1}{2}} + N_{j-\frac{1}{2}} = N_{m+\frac{1}{2}} + N_{m-\frac{1}{2}}$$
$$= N_{\ell+\frac{1}{2}} + N_{\ell-\frac{1}{2}}. \tag{13}$$

If negative fluxes arise from this assumption, we use the set-flux-to-zero-and-correct algorithm.

C. Progression Through the Angular Mesh

In our initial attempts to solve (5), we found that, when Θ was greater than one-quarter revolution (systems larger than a hemisphere), our normal recursion progression was unstable. The direct cause of this difficulty is the appearance of terms like $B_{j+\frac{1}{2}} - B_{j-\frac{1}{2}}$ in the numerator and denominator of our solution of (5) for N. For systems larger than a hemisphere, $B_{j+\frac{1}{2}} - B_{j-\frac{1}{2}}$ is negative, whereas all other coefficients in the recursion for N are always positive. The difficulty lay in our progression from most negative η to most positive η in analogy to our usual progression on μ from most negative to most positive values. This μ progression is based on the fact that a particle entering a sphere and streaming through the sphere has a constantly increasing μ cosine. To see this we write (4) in terms of $\eta = (1 - \mu^2)^{\frac{1}{2}}\kappa$, giving

$$\nabla \cdot \underline{\Omega} \psi = \mu \frac{\partial \psi}{\partial r} + \frac{1-\mu^2}{r} \frac{\partial \psi}{\partial \mu} + \frac{\eta \partial \psi}{r \partial \Theta} + \frac{(1-\mu^2)^{\frac{1}{2}} \cot \Theta (1-\kappa^2)}{r} \frac{\partial \psi}{\partial \kappa}. \tag{14}$$

Writing this operator as a total derivative with respect to the distance, s, in the direction $\underline{\Omega}$ gives

$$\frac{\partial r}{\partial s} = \mu, \frac{\partial \mu}{\partial s} = \frac{1-\mu^2}{r}, \frac{\partial \Theta}{\partial s} = \frac{\eta}{r}\frac{\partial \kappa}{\partial s} = \frac{(1-\mu^2)^{\frac{1}{2}}\cot\Theta(1-\kappa^2)}{r}, \tag{15}$$

from which

$$\frac{\partial r}{\partial \mu} = \frac{r\mu}{1-\mu^2} \tag{16}$$

and

$$\frac{\partial \Theta}{\partial \kappa} = \frac{\kappa}{\cot\Theta(1-\kappa^2)}. \tag{17}$$

From (16) we find

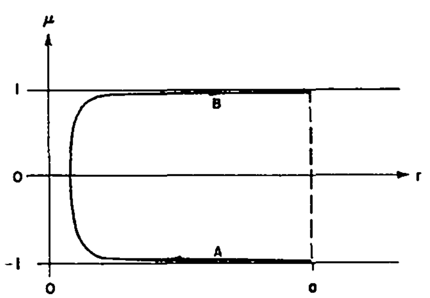
$$r(1 - \mu^2)^{\frac{1}{2}} = c_1 , \tag{18}$$

and from (17) we find

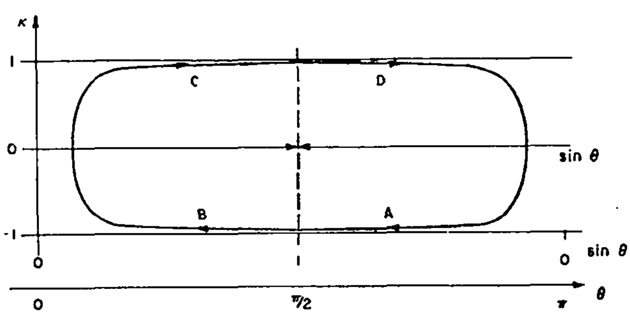
$$\sin \Theta(1 - \kappa^2)^{\frac{1}{2}} = c_2 \tag{19}$$

as the characteristic equations of particle motion. These characteristics are plotted in Fig. 1.

Our customary procedure for (r,μ) progression is to set the outer boundary condition at $r = a$ for negative (incoming) μ values. We then move to the center for increasingly more positive μ values. When we have treated all negative μ values, we move outward from the center for increasingly more positive values of μ. This procedure is numerically stable and follows paths like A-B in Fig. 1a.



1.a



1.b

Fig. 1. Characteristic particle paths in (a) the (r,μ) plane, and (b) the $(\kappa, \sin\Theta)$ plane.

The situation is more complicated for (κ,Θ) progression. If the system is smaller than a hemisphere ($\Theta < \pi/2$ in these variables), then we can use an analogous procedure, starting from the top boundary (Θ measured from the south pole), at values of Θ near $\pi/2$. We can then set the boundary condition for incoming η (negative κ) values and move to the bottom (Θ near zero). This is path B in Fig. 1b. Once the bottom is reached for all negative κ, we can set the bottom condition for all positive κ and move to the top. These are paths like C in Fig. 1b. We find this procedure stable when $\Theta < \pi/2$.

However, when $\Theta > \pi/2$, we find we must proceed on paths like D-A, moving so that values of κ decrease. This changes terms like $B_{j+\frac{1}{2}} - B_{j-\frac{1}{2}}$ (negative when $\Theta > \pi/2$) to terms like $B_{j-\frac{1}{2}} - B_{j+\frac{1}{2}}$ and our recursion is stable.

Our procedure, then, for systems with Θ greater than $\pi/2$ is to start at the top (Θ near π) for negative κ directions, move downward for decreasing κ values until $\Theta = \pi/2$, then continue downward for increasing κ values until Θ is near zero. These paths like A-B and we must complete all A paths before starting B paths. Once all negative κ values are computed to the bottom, we start upward first for all paths like C and then for all paths like D. This procedure is stable, and we obtain the same results for a homogeneous sphere if we represent it by $0 < \Theta < \pi/2$ or by $\pi/2 < \Theta < \pi$.

The above procedure is complicated, but because of the organization of TWOTRAN we were able to implement it by duplicating the sweep segments of subroutine INNER, using a trigger to tell us whether we are computing at Θ values greater or less than $\pi/2$. Details of the angular progression are given in the next section.

D. Treatment of Angular Streaming Terms

Moving through the angular mesh in a two dimensional sphere, we must treat terms in both $N_{m+\frac{1}{2}}$ and $N_{\ell+\frac{1}{2}}$. Even after selecting a stable progression through the mesh, we found that our first treatment of this angular streaming term was unsatisfactory. When we calculated homogeneous spheres, we found that our solution, which should have been independent of Θ, still showed Θ variation. This variation was the more rapid, the more rapid the r variation of the solution. The difficulty was traced to our treatment of angle-to-angle couplings. Because our present solution is not the most efficient, we describe both treatments.

1. Original (Incorrect) Procedure. In Fig. 2 we show the details of our original angular progression in the case of a standard S_6 quadrature

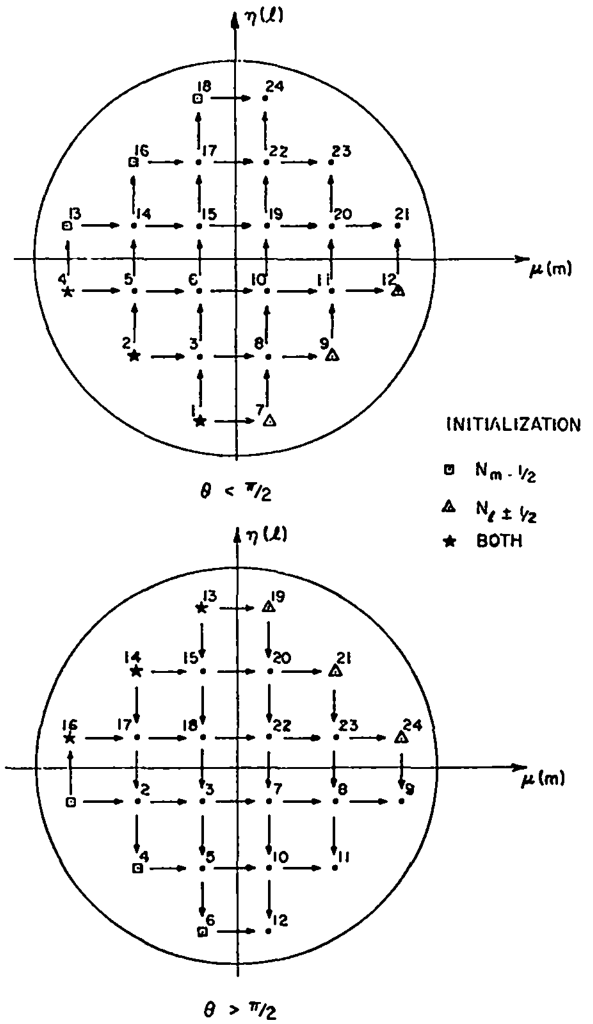


Fig. 2. Flux initialization and information flow for the first attempt (unsatisfactory).

point arrangement. Numbers by the points indicate the actual order of movement through the directions, and arrows between points indicate the direction of information flow. For example, point 10 for $\Theta < \pi/2$ corresponds to $\ell = 3$, $m = 4$. To calculate N_{ij43} we need $N_{\ell-\frac{1}{2}}$ and $N_{m-\frac{1}{2}}$ and these are gotten from the extrapolation performed after the calculation of N_{ij33} ($N_{m-\frac{1}{2}}$) at point 6 and the extrapolation after the calculation of N_{ij42} ($N_{\ell-\frac{1}{2}}$) at point 8. To start the calculation we must initialize $N_{m-\frac{1}{2}}$ and $N_{\ell-\frac{1}{2}}$. This we do by using the step scheme (Ref. 1), and the directions in which initialization is performed are shown in Fig. 2.

Note that when $\Theta > \pi/2$, our procedure is implicit. We start with negative η values and move downward, but we initialize for the most positive η values. The calculation of point 3, for example, depends on the calculation of point 18. Our other choice, to start at point 13, say, is also an implicit procedure because this positive value of η would imply that we should start computing at $\Theta = \pi/2$ moving upward, but then we require not yet computed flux information from locations of $\Theta < \pi/2$. We have noticed no increase of normal iteration time due to this implicitness,* but it does imply an iterative requirement even if we compute a pure absorber with vacuum boundary conditions.

The information flow in Fig. 2 is not the most general possible. For example, we could allow point 1 ($\Theta < \pi/2$) to feed point 2 as well as point 3. This, for symmetry, would require point 2 to feed point 1. In fact, we were able to show by hand computation for a simple system that the arrangement of Fig. 2 would not allow a flux independent of Θ without additional coupling. With the arrangement shown in Fig. 2, we found that the $\partial\psi/\partial\omega$ term in (4) did not vanish. Because the coefficient of this term involves Θ, our solution retained a Θ dependence.

2. Modified Procedure. Our hand computations convinced us that a more general coupling of the angular fluxes was needed. We accomplished this in a simple manner by using a different point arrangement on the unit sphere. Our angular integrals are given by

*Any full sphere computation will require an implicit top boundary condition ($\Theta = \pi$ reflective condition) which will require iteration anyway.

$$I = \frac{1}{2\pi}\int_{-1}^{1} d\mu \int_{0}^{\pi} d\omega = \frac{1}{2\pi}\int_{-1}^{1} d\mu \int_{-(1-\mu^2)^{\frac{1}{2}}}^{(1-\mu^2)^{\frac{1}{2}}} d\eta (1 - \mu^2 - \eta^2)^{-\frac{1}{2}}. \tag{20}$$

With the change of variable $\eta = (1 - \mu^2)^{\frac{1}{2}}\kappa$, we have

$$I = \frac{1}{2\pi}\int_{-1}^{1} d\mu \int_{-1}^{1} d\kappa (1 - \kappa^2)^{-\frac{1}{2}}, \tag{21}$$

which allows a separable quadrature using Gauss-Legendre for μ and Gauss-Chebyshev for κ. Such sets are built into TWOTRAN SPHERE. Our mesh progression and information flow is shown for the S_6 approximation (using these sets) in Fig. 3. While using more directions, this scheme is simpler to index and does allow Θ independent solutions when physically the solution should be Θ independent. In this scheme, the information transfer in each row (column) is the same. We believe that a point arrangement as in Fig. 2 could be used, provided more general coupling were allowed. Such a scheme would be cheaper in terms of points, but would be harder to program.

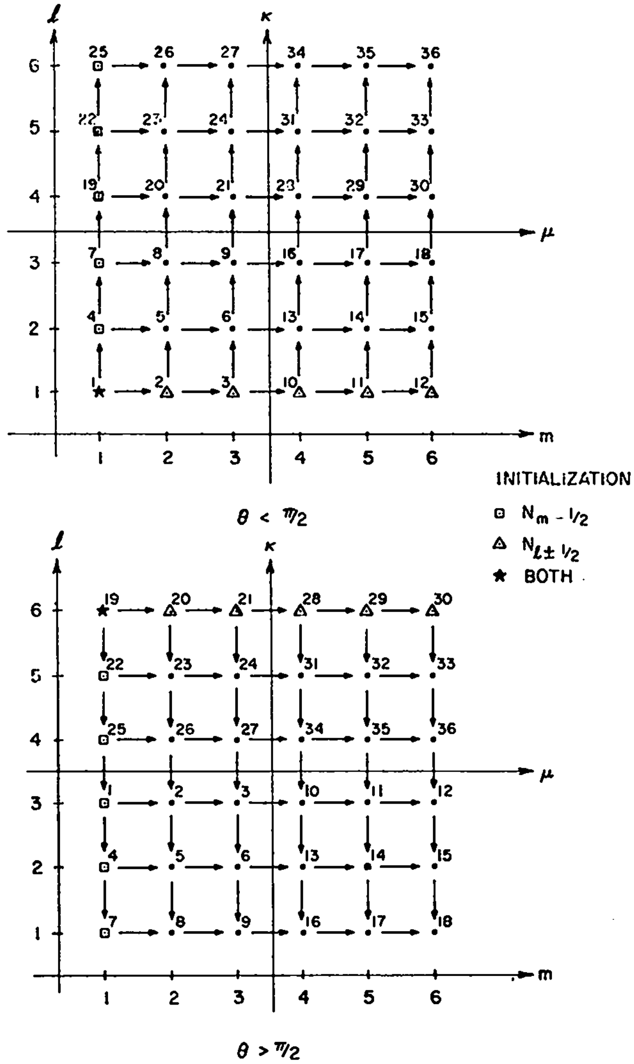


Fig. 3. Satisfactory flux initialization and information flow. The numbers on the points indicate the sequence of progress; the actual indexing in the program is done for one (μ, κ) quadrant at a time.

III. PROGRAM DESCRIPTION

The TWOTRAN SPHERE program operates just as does the general geometry TWOTRAN program. In this section we give tables of information similar to those given for the general geometry TWOTRAN routine of Ref. 1.

The major differences between the programs are

1. TWOTRAN SPHERE uses a separable Legendre-Chebyshev quadrature with MM = (ISN**2)/4 points per octant. Subroutine SNCON is completely revised to provide these points.
2. Geometric functions calculated in subroutine INITAL are different.
3. New angular coefficients $\beta_{\ell\pm\frac{1}{2}}$ and a new angular flux array $N_{\ell\pm\frac{1}{2}}$ are required in TWOTRAN SPHERE.
4. Area and volume elements are retained as two-dimensional arrays in TWOTRAN SPHERE.
5. Solution procedures in subroutine INNER are revised to allow for the computation of the extra angular flux and the special procedures necessary when $\Theta > \pi/2$.
6. A special edit (described below) is allowed in TWOTRAN SPHERE.

In TWOTRAN SPHERE, the normal edit of the general geometry TWOTRAN is augmented by a special edit, used only in adjoint calculations. The special edit uses two new input parameters, NSS and NBETA and four new input arrays. The edit allows the evaluation of an integral which depends parametrically on an angle β (there are NBETA such angles) and the further energy integration of the integral over several (NSS) source spectra. In the edit it is assumed that a full-sphere combination has been made.

The angle β is an incidence angle measured from the south pole. The other required input parameters are the J indices ($J = 1, \ldots, JT + 1$ for values of the Θ boundaries) of the angles $\Theta_1 = \pi/2 - \beta$ and $\Theta_2 = \pi/2 + \beta$. The inputs and arrays are

NSS	Number of input source spectra.
NBETA	Number of input incidence angles β.
SSP(IGM,NSS)	Input source spectra.
JBETA(NBETA)	J index of angle $\Theta_1 = \pi/2 - \beta$ where β and Θ_1 are measured from the south pole.
JBPI(NBETA)	J index of angle $\Theta_2 = \pi/2 + \beta$ where β and Θ_2 are measured from the south pole.
BETA(NBETA)	Angle of incidence β (measured in revolutions from the south pole).

The integral calculated for energy group g is

$$I_g(\beta) = 2\times 2\pi r_s \int_0^{\pi/2-\beta} \cos\Theta \sin\Theta d\Theta \psi_g^+(r_s,\Theta,\mu_o,\eta_o)$$

$$+ 2\pi r_s \int_{\pi/2-\beta}^{\pi/2+\beta} \cos\Theta \sin\Theta d\Theta \psi_g^+(r_s,\Theta,\mu_o,\eta_o) ,$$

where r_s is the outer radius of the system, and ψ_g^+ is the adjoint flux at the surface of the sphere at the angle Θ in the direction defined by μ_o and η_o. These cosines are given by

$$\mu_o = \cos(\beta - \Theta) \qquad \eta_o = \sin(\beta - \Theta) \qquad 0 \le \beta \le \pi/2.$$

In the edit, values of ψ_g^+ having values of μ and η closest to μ_o and η_o are used to evaluate the integral. In the case $\beta = 0$ when the system is independent of Θ (and hence η), the integral becomes

$$2\pi r_s \int_{-1}^{1} \mu_o d\mu_o \psi_g^+(r_s,\mu_o) ,$$

which is proportional to the adjoint leakage.

Restart options are essentially the same as in the TWOTRAN program. The special edit information is treated like the usual TWOTRAN edit information on a restart. At the time of restart, the quantities NSS and NBETA can be changed using the namelist option.

TABLE I

GEOMETRIC FUNCTIONS (θ IN REVOLUTIONS)

Array Name and Dimension: TWOTRAN	Array Name and Dimension: TWOTRAN SPHERE	Value: TWOTRAN SPHERE	Use: TWOTRAN SPHERE
XH(IM)	Y(IT,JT+1)	$\pi \sin(2\pi\theta_{j-\frac{1}{2}})(r^2_{i+\frac{1}{2}} - r^2_{i-\frac{1}{2}})$	θ direction area element ($B_{i,j-\frac{1}{2}}$)
YH(JM)	YH(0)	not used	---
A3(IT)	not used	---	---
A4(IT+1)	X(IT+1,JT)	$2\pi(\cos 2\pi\theta_{j-\frac{1}{2}} - \cos 2\pi\theta_{j+\frac{1}{2}})r^2_{i-\frac{1}{2}}$	r direction area element ($A_{i-\frac{1}{2},j}$)
A5(IT)	V(IT,JT)	$2\pi(\cos 2\pi\theta_{j-\frac{1}{2}} - \cos 2\pi\theta_{j+\frac{1}{2}})(r^3_{i+\frac{1}{2}} - r^3_{i-\frac{1}{2}})/3$	volume V_{ij}
A1(IT)	A1(JT)	$\pi r^2_{max}(\sin^2 2\pi\theta_{j+\frac{1}{2}} - \sin^2 2\pi\theta_{j-\frac{1}{2}})$	edit
A2(IT)	A2(JT)	$(\theta_{j+\frac{1}{2}} + \theta_{j-\frac{1}{2}})/2$	edit
B1(JT)	B1(JT)	0 for $\theta < 1/4$ 1 for $\theta > 1/4$	trigger for angular sweep

TABLE II

NEW ARRAYS IN TWOTRAN SPHERE

Array and Dimension	Use
BE1(MM)	Angular streaming coefficient $\beta_{\ell+\frac{1}{2}}$
BE2(MM)	Angular streaming coefficient $\beta_{\ell-\frac{1}{2}}$
BEFL(ISN,IT,JT)	Angular flux $N_{\ell\pm\frac{1}{2}}$

TABLE III

STRUCTURE OF THE TWOTRAN SPHERE PROGRAM

OVERLAY (0,0)	OVERLAY (1,0)	OVERLAY (2,0)	OVERLAY (3,0)	OVERLAY (4,0)
RTSECS	INPUT1	GRIND2	OUTPUT3	DUMP4*
1. MONITR*	1. READ*	1. INITAL	1. FINAL*	1. SPFDMP*
2. ERROR*	2. READI*	2. INITQ		2. MODDMP*
3. CLEAR*	3. LOAD*	3. FISCAL	OVERLAY (3,1)	3. INDXPT
4. WRITE*	4. REDUCE*	4. OUTER	OUTPT31	4. PRITNW*
5. ECLOAD*		5. INNER	1. EDCALL	
6. ECDUMP*	OVERLAY (1,1)	6. FIXUP	2. EDITOR	
7. SPREAD*	INPUT11	7. SETBC	3. EDMAP*	
8. UNITWR*		8. REBAL	4. SUMS	
9. JCDECS*	OVERLAY (1,2)	9. GSUMS		
10. MANAGR*	INPUT12	10. TESTS	OVERLAY (3,2)	
	1. CSPREP*	11. NEWPAR*	OUTPT32	
	2. READQF*		1. PLOTS*	
	3. SNCON		2. PLOTP*	
	4. PNGEN*		3. PLOTC*	
	5. LAXS*		4. CONTRB*	
	OVERLAY (1,3)			
	INPUT13			
	1. MAPPER*			

*indicates that routine is taken intact from the general geometry TWOTRAN program.

TABLE IV

CONTENTS OF BLANK COMMON BLOCK IA

Position	Name	Pointer for Array	Remarks
1	ITH		Theory
2	ISCT		Scattering order
3	ISN		Order of S_n
4	IGM		Number of groups
5	IM		Number of radial coarse-mesh intervals
6	JM		Number of axial coarse-mesh intervals
7	IBL		Left boundary specification
8	IBR		Right boundary specification
9	IBB		Bottom boundary specification
10	IBT		Top boundary specification
11	IEVT		Eigenvalue type specification
12	ISTART		Flux input option
13	MT		Total number of materials
14	MIN		Total number of input nuclides from both library and cards
15	MS		Number of mixture instructions
16	IHT		Position in table of total cross section
17	IHS		Position in table of self-scatter cross section
18	IHM		Cross section table length
19	IQOPT		Source input options
20	IQAN		Distributed source anisotropy order
21	IQB		Bottom boundary source indicator
22			Not used
23	IPVT		Parametric eigenvalue indicator
24	IANG		Must be zero (not presently used)
25			Not used
26	IITL		Maximum number of inner iterations
27			Not used
28	IRBM		Maximum number of rebalance iterations which is set in INPUT11
29	IXM		Radial-mesh modification indicator
30	IYM		Axial-mesh modification indicator
31	IEDOPT		Edit options
32	IGEOM		Geometry type indicator is set to three for compatibility
33	IQR		Right boundary source indicator
34	IQT		Top boundary source indicator
35	ISDF		Density factor input indicator (0/1 = no/yes)
36			Not used
37	EV		Eigenvalue guess
38	EVM		Eigenvalue modifier
39	PVM		Parametric value of k_{eff}
40	XLAL		Search lambda lower limit
41	XLAH		Search lambda upper limit
42	XLAX		Fine-mesh search precision
43	EPS(EPSO)		Convergence precision and outer convergence precision

Table IV (cont)

Position	Name	Pointer for Array	Remarks
44	EPSI		Inner convergence precision = EPSO
45	EPSR		Within-group rebalance convergence precision = EPSO/2
46	EPSX		Whole-system rebalance convergence precision = EPSO
47			Not used
48	NORM		Normalization amplitude
49	POD		New parameter modifier
50	BHGT		Must be zero
51	IUP		IHS-IHT-1 (up-scatter indicator)
52	IHF		IHT-1 (position of $\nu\sigma_f$ - in cross section table)
53	IHA		IHT-2 (position of σ_a - in cross section table)
54	IHTR		IHT-3 (position of σ_{tr} - transport cross section - in cross section table if present)
55	IHNN		IHT-4 (position of $\sigma_{n,2n}$ - cross section in cross section table if present)
56	IMJM		Product IM*JM
57	MM		Number of directions = ISN**2/4
58	NM		((ISCT+1)*(ISCT+2))/2, number of anisotropic components of flux
59	NMQ		((IQAN+1)*(IQAN+2))/2, number of anisotropic source components
60	IP		Sum IM+1
61	JP		Sum JM+1
62	IGP		Sum IGM+1
63	IJMM		Product IM*JM*MM
64	IT		Total number of radial fine-mesh intervals
65	JT		Total number of axial fine-mesh intervals
66	ITJT		Product IT*JT
67	ITMM		Product IT*MM
68	JTMM		Product JT*MM
69	NMIJ		Product NM*IT*JT
70	NMM		Product NM*MM
71	ISPANC		Last word address of cross section and Q-source block
72	IHMT		Product IHM*MT
73	ISPANF		Last word address of flux block
74	ISCP		Sum ISCT+1
75	IMJP		Product IM*JP
76	IPJM		Product IP*JM
77	ITP		Sum IT+1
78	JTP		Sum JT+1
79	ICLIM		Length of cross section portion of cross section and Q-source block
80	LIHX	IHX(IM)	Number of radial fine-mesh intervals per coarse interval
81	LIHY	IHY(JM)	Number of axial fine-mesh intervals per coarse interval
82	LC	C(IHM,MT)	Cross sections for a group
83	LA1	A1(JT)	Geometric function used in edit
84	LA2	A2(JT)	Geometric function used in edit

Table IV (cont)

Position	Name	Pointer for Array	Remarks
85			Not used
86	LA4	X(ITP,JT)	Area element in radial direction
87	LA5	V(IT,JT)	Volume element
88	LQ	Q(NM,IT,JT)	Distributed source
89	LQR1	QR1(JT,MM)	Input right boundary source for in-down directions (conditional on IQR.EQ.1)
90	LQR2	QR2(JT,MM)	Input right boundary source for in-up directions (conditional on IQR.EQ.1)
91	LQT1	QT1(IT,MM)	Input top boundary source for in-down directions (conditional on IQT.EQ.1)
92	LQT2	QT2(IT,MM)	Input top boundary source for out-down directions (conditional on IQT.EQ.1)
93	LBR1	BR1(JT,MM)	Right boundary flux (in-down and out-down)
94	LBR2	BR2(JT,MM)	Right boundary flux (in-up and out-up)
95	LBT1	BT1(IT,MM)	Top boundary flux (in-down and in-up)
96	LBT2	BT2(IT,MM)	Top boundary flux (out-down and out-up)
97	LXDF	XDF(IT)	Radial fine-mesh cross section density factor (conditional input on ISDF.EQ.1)
98	LYDF	YDF(JT)	Axial fine-mesh cross section density factor (conditional input on ISDF.EQ.1)
99			Not used
100			Not used
101			Not used
102			Not used
103			Not used
104			Not used
105	LFL	FLUX(NM,IT,JT)	Flux components
106	LFLA	FLUXA(IT,JT)	Scalar flux from previous inner iteration
107			Not used
108	LFIS	FISS(IT,JT)	Same origin as FISSA
109	LFISA	FISSA(IT,JT)	Fission source
110			Not used
111	LDC	IDCS(IM,JM)	Cross section zone identification integers
112	LXR	XRAD(IP)	Input radial coarse-mesh boundaries
113	LYR	YRAD(JP)	Input axial coarse-mesh boundaries
114	LDX	IDX(IT)	Radial direction indicators showing which radial coarse-mesh interval a fine radial mesh interval belongs to
115	LDY	IDY(JT)	Axial direction zone index multiples
116	LDYA	IDYA(JT)	Axial direction indicators showing which axial coarse-mesh interval a fine axial mesh interval belongs to
117	LXH	Y(IT,JTP)	Area element in axial direction
118	LYH		Not used
119	LW	WGT(MM)	Direction weights
120	LCM	COSMU(MM)	Radial direction cosines

Table IV (cont)

Position	Name	Pointer for Array	Remarks
121	LCE	COSETA(MM)	Axial direction cosines
122	LWM	WMU(MM)	Product WGT*COSMU
123	LWE	WETA(MM)	Product WGT*COSETA
124	LP1	P1(NM,MM)	Spherical harmonic functions for in-down sweep
125	LP2	P2(NM,MM)	Spherical harmonic functions for out-down sweep
126	LP3	P3(NM,MM)	Spherical harmonic functions for in-up sweep
127	LP4	P4(NM,MM)	Spherical harmonic functions for out-up sweep
128	LMN	MIXNUM(MS)	Input mixture numbers (conditional on MS.GT.0)
129	LMC	MIXCOM(MS)	Input mixture instructions (conditional on MS.GT.0)
130	LMD	MIXDEN(MS)	Input mixture densities (conditional on MS.GT.0)
131	LF	F(IM,JM)	Coarse-mesh rebalance factors
132	LFU	FU(IM,JP)	Coarse-mesh upward partial current
133	LFD	FD(IM,JP)	Coarse-mesh downward partial current
134	LFR	FR(IP,JM)	Coarse-mesh rightward partial current
135	LFLL	FL(IP,JM)	Coarse-mesh leftward partial current
136	LAB	AB(IM,JM)	Coarse-mesh absorption removal rate
137	LQQ	QQ(IM,JM)	Coarse-mesh source
138	LQQG	QQG(IM,JM)	Coarse-mesh source over all groups (conditional on IEVT.EQ.0)
139	LFUT	FUT(IM,JP)	Sum of FU over all groups (same origin as FU)
140	LFDT	FDT(IM,JP)	Sum of FD over all groups (same origin as FD)
141	LFRT	FRT(IP,JM)	Sum of FR over all groups (same origin as FR)
142	LFLT	FLT(IP,JM)	Sum of FL over all groups (same origin as FL)
143	LABT	ABT(IM,JM)	Sum of absorption rate over all groups
144	LHA	HA(IM)	Used in subroutine REBAL for inversion
145	LGA	GA(IM)	Used in subroutine REBAL for inversion
146	LQG	QG(IGP)	Space integral of Q
147	LFG	FG(IGP)	Space integral of FISSA
148	LSIN	SIN(IGP)	Space integral of group inscatter source
149	LSS	SS(IGP)	Space integral of group self-scatter source
150	LSOUT	SOUT(IGP)	Space integral of group outscatter source
151	LHL	HL(IGP)	Group horizontal leakage
152	LVL	VL(IGP)	Group vertical leakage
153	LTL	TL(IGP)	Group total leakage
154	LNL	NL(IGP)	Group net leakage
155	LRL	RL(IGP)	Group right leakage
156	LABG	ABG(IGP)	Space integral of group absorption rate
157	LBAL	BAL(IGP)	Group neutron balance
158	LCHI	CHI(IGP)	Input fission spectrum
159	LCHIA	CHIA(IGP)	Fission spectrum used in the calculation
160	LVEL	VEL(IGP)	Group velocities
161	LYM	YM(JM)	Input axial direction modifiers (conditional on IEVT.EQ.4 and IYM.EQ.1)
162	LXM	XM(IM)	Input radial direction modifiers (conditional on IEVT.EQ.4 and IXM.EQ.1)

Table IV (cont)

Position	Name	Pointer for Array	Remarks
163	LXRA	XRADA(IP)	Modified coarse-mesh radial boundaries
164	LYRA	YRADA(JP)	Modified coarse-mesh axial boundaries
165	LSOU	SOURCE(NM,IT,JT)	Total source in a group (same origin as Q)
166	LANF		
167	LAA	AAJ(MT)	Adjoint absorption (conditional on ITH.EQ.1)
168	LB1	B1(JT)	Trigger for systems larger than a hemisphere
169	LAL1	AL1(MM)	α coefficient (MM+1/2)/WGT
170	LAL2	AL2(MM)	α coefficient (MM-1/2)/WGT
171	LALF	ALFL(NN,IT)	α flux due to curvature streaming
172	LQB1	QB1(IT,MM)	Input bottom boundary source for in-up directions (conditional on IQB.EQ.1)
173	LQB2	QB2(IT,MM)	Input bottom boundary source for out-up directions (conditional on IQB.EQ.1)
174	LCTOT	CTOT(IT,JT)	Effective total cross section
175	JCONV		Final convergence indicator
176	TN2N		N,2N reaction term used in balance equations
177	XLAPP		Value of lambda from sequence of outer iterations previous to that of XLAP
178	XLAP		Value of lambda from previous sequence of outer iterations
179	ICNT		Iteration trigger used in NEWPAR
180	E2		Temporary storage
181	E1		Temporary storage
182	EVPP		Eigenvalue from cycle of outer iteration previous to that of EVP
183	EVP		Eigenvalue from previous sequence of outer iterations
184	E4		Temporary storage
185	NGO		Return indicator set in NEWPAR
186	ALAR		Value of lambda from previous iteration
187			Not used
188	IITNO		Inner iteration number
189	TS		Total integrated source to a group
190	G		Number of current group (Integer)
191	ICONV		Secondary convergence indicator
192	NGOTO		Return indicator set in TESTS
193	E3		Temporary storage
194	EVS		Slope used in eigenvalue search
195	IITOT		Total number of inner iterations
196	ALA		Parameter lambda
197	TIN		Time
198	FTP		Previous fission total
199	IFN		Fission calculation indicator set in INITAL
200	OITNO		Outer iteration number
201	ZZ		Radial geometric function used in FIXUP
202	BB		Axial geometric function used in FIXUP

Table IV (cont)

Position	Name	Pointer for Array	Remarks
203	CC		Angular function used in FIXUP
204	DD		Angular function used in FIXUP
205	T		Cell-centered flux used in FIXUP
206	S		Source used in FIXUP
207	CT		Total cross section used in FIXUP
208	SUMMU		$\sum_{m=1}^{MM}$ COSMU(M)*WGT(M)
209	SUMETA		$\sum_{m=1}^{MM}$ COSETA(M)*WGT(M)
210	NN		ISN/2
211	AA		Radial geometric function used in FIXUP
212	TI		Temporary i-flux used in FIXUP
213	TJ		Temporary j-flux used in FIXUP
214	TM		Temporary m-flux used in FIXUP
215			Not used
216	ERR		Scalar flux error from comparison with previous flux
217			Not used
218			Not used
219			Not used
220	LBT3	BT3(IT,MM)	Top boundary flux (conditional on IBT.EQ.3)
221			Not used
222			Not used
223	LBT4	BT4(IT,MM)	Top boundary flux (conditional on IBT.EQ.3)
224			Not used
225	NLIMIT		Used in INNER to determine setting of IFLAG
226	IFLAG		Whole-system rebalance indicator
227	LBE1	BE1(MM)	β coefficient (L + 1/2)/WGT
228	LBE2	BE2(MM)	β coefficient (L - 1/2)/WGT
229	LBEF	BEFL(ISN,IT,JT)	β flux due to η curvature streaming
230	NNP		Sum NN + 1
231	YY		Used in FIXUP
232	XX		Used in FIXUP
233	WW		Used in FIXUP
234			Not used
235			Not used
236	LSSP	SSP(IGM,NSS)	Edit source spectrum (conditional input on NSS > 0)
237	LJB	JBETA(NBETA)	Edit j level of $\pi/2 - \beta$ (conditional input on NSS > 0)
238	LJBP	JBPI(NBETA)	Edit j level of $\pi/2 + \beta$ (conditional input on NSS > 0)
239	LMUB	UB(NN+1)	Edit μ boundary pairs
240	LBETA	BETA(NBETA)	Edit angle β (conditional input on NSS > 0)
241	NBETA		Edit number of incident angles
242	NSS		Edit number of source spectra
243 through 248			Not used

Table IV (cont)

Position	Name	Pointer for Array	Remarks
249	NOSGUP		Sigma up included in cross sections indicator
250	IOLYCS		Overlay indicator as a two-digit octal number with the eight's digit indicating the primary level and unit's digit indicating the secondary level

TABLE V

CONTENTS OF NAMED COMMON BLOCK FWBGN1

The named common block FWBGN1 contains the information required to continue the processing of the current problem if it is restarted.

Name	Contents and Remarks
IDUSE	Last title card. This is a vector 12 words in length used for the title of the plot routines. The words are A6 in format.
ECPTFX	ECS pointer for the flux block for the first group. The flux block contains the three-dimensional flux array as well as boundary arrays stored consecutively.
ECLTFX	Length of the flux block for a group.
ECLXFX	Length of the three-dimensional flux array.
ECPTCQ	ECS pointer for the cross section and Q-source block for the first group. The cross section and Q-source block contains the cross section array, the adjoint absorption vector (when problem is adjoint), the spatial total cross section matrix, and the various Q sources.
ECLTCQ	Length of the cross section and Q-source block for a group.
ECLCCQ	Combined length of the cross section array and the adjoint absorption vector for a group.
ECLBCQ	Combined length of the cross section array, the adjoint absorption vector and the total cross section array, CTOT(IT,JT), for a group.
ECLACQ	Length of the cross section matrix for a group (excluding the adjoint cross sections, and the CTOT array).
ECLQCQ	Length of the Q-source block.
ECMACQ	Used to locate the total cross section array, CTOT, in the ECS cross section and source block.
ECMQCQ	Used to locate the Q-source block in the ECS cross section and source block.
ECPTFL	ECS pointer for the flow block for the first group. The flow block contains the coarse-mesh partial-currents matrices for the upward, downward, rightward, and leftward directions.
ECLTFL	Length of the flow block for a group.
ECPTSO	ECS pointer for the source to the group block. This is the source to the group calculated by OUTER and used in INNER.
ECLTSO	Length of the source to the group block.
ECLAST	ECS pointer for the next block to be assigned.
NOFILM	Plot type and plot storage indicator. -1/0/1 = no plot/plot/plot storage error. An error indication is given if temporary storage required for plot exceeds the core available.
LPTFMX	Core pointer of fine radial mesh for plot.
LPTFMY	Core pointer of fine axial mesh for plot.
LPTFMA	Core pointer of first temporary block for plot. The length of this block is the maximum of the total number of fine radial mesh intervals, the total number of fine axial mesh intervals, or 21.

Table V (cont)

Name	Contents and Remarks
LPTFMB	Core pointer of second temporary block for plot. The length of this block is the same as that of the first temporary plot block.
LPTFMC	Core pointer of third temporary block for plot. The length of this block is the same as that of the first temporary plot block.
LPTFMD	Core pointer of the fourth temporary block for plot. The length of the block is the same as that of the first temporary block.
LPTFLX	Core pointer of scalar-flux block for plot.
TIMACC	Accumulated problem running time.
IGCDMP	Group number of restart dump.
LENDBA	Length of A data block. Used to return the A vector to core in a restart.

TABLE VI
CONTENTS OF NAMED COMMON BLOCK FWBGN2

The named common block FWBGN2 consists primarily of those indicators used by the program but not vital to restart. Parameters that define options are set in program RTSECS.

Name	Contents and Remarks
IFNOVY	Overlay file name. File name is given in a hollerith form and is not entered into the file name table of the program card. This name must be the same as that of the overlay specification card.
IRCOVY	Recall overlay indicator. When the overlay is in core, it will be recalled from the overlay file only if the indicator is set properly (0/6 HRECALL = no/yes).
IDUMDM	Unused. This is a vector of four words which is unused.
LENCCA	Length of the current-adjusted main data block. Used in core adjustment.
IFLCDC	Current-adjusted field length of the problem. Used in core adjustment.
LENXCA	Maximum length of the main data block. Used in core adjustment. Length of the common block called A.
IFLCDX	Maximum field length of core. Used in core adjustment.
INRCOR	Core adjustment indicator. (0/1 = no/yes). Must be zero in overlay version of TWOTRAN SPHERE.
LENCIA	Length of the common parameter block IA.
LENXEC	Number of ECS blocks requested for the problem. Each block is equal to 512 words. This is initially set in program RTSECS to the number of blocks requested on the job card.
INRECS	Reduce ECS storage indicator. (0/1 = no/yes). If more than one case is to be run and the indicator is on, the cases must be in order of decreasing ECS size.
LENMCB	Length of the named common block called FWBGN1.
LETMCB	Length of the named common block called FWBGN2.
LENERB	Length of the named common block called LOCAL.
LENTAP	Length of the permanent file common block. This block is the first of the blank common blocks (NINP, ..., NSCRAT).
NCARDX	Retained for compatibility only.
NCARDL	Retained for compatibility only.
NCARDT	Retained for compatibility only.
INTAPE	Retained for compatibility only.

Table VI (cont)

Name	Contents and Remarks
IOTAPE	Retained for compatibility only.
ILTNOP	Retained for compatibility only.
ILTPOP	Retained for compatibility only.
ILTSOP	Retained for compatibility only.
ILCSOP	Retained for compatibility only.
IECSPI	Initial ECS pointer for block assignment. The first ECS block of a problem will be given this pointer and the other blocks will be assigned consecutive locations. This number is usually one.
IFILM	File unit number for SC-4020 plot film output.
IWFILM	Flux storage indicator. (0/1 = ECS/NFLUX).
TIMBDP	Minimum time between periodic dumps. (0/F = no periodic dumps/second).
TIMSLD	Elapsed time since last dump.
TIMOFF	Floating-point form of the input fixed-point parameter ITLIM.
IPRLCD	Print data block input cards as read indicator. (0/1 = no/yes). When the indicator is on, each card of a data block is printed as it is read. Usually zero.
IPRLOT	Print loaded data block vectors in full indicator. (0/1 = yes/no). When the indicator is on, the entire contents of the block will be printed. When the indicator is off, only the title of the block will be printed. Usually zero.
IPRXCD	Print cross section card input indicator. (0/1 = no/yes). When the indicator is on, each cross section card is printed as it is read. Usually zero.
LENMAP	Length of the storage map vector.
ISDMAP	Storage map request indicator. (0/1 = no/yes). This section of the program is not operational.
INDPLT	SC-4020 film output indicator. (0/1/2/3 = none/contour/projection/both contour and projection).
NOCLNS	Number of contour lines desired in the plot. This must be less than 51.
IMODER	Mode error information. This is the mode error by-pass vector of two words. The first word contains the transfer address to be taken in the event of a mode error. The second word at the time of a mode error will be filled with the error information.

TABLE VII

CONTENTS OF NAMED COMMON BLOCK LOCAL

The named common block LOCAL contains information that is passed from overlay to overlay for a problem but is not needed in restart.

Name	Contents and Remarks
NERROR	Parameter input-error indicator.
ITLIM	Fixed-point time problem removal value. (0/N = no/seconds).
LENCLR	Length of the partial block to be cleared during input.
ISNT	S_n library request indicator.
LIMIT	Storage length required by the cross section phase of input.
LAST	Storage length required by the problem. This is a temporary value.
MCR	Number of nuclides requested from cards.
MTP	Number of nuclides requested from library.
LMTP	The core pointer for the library ID request table.
IERRST	Storage-error indicator.

Table VII (cont)

Name	Contents and Remarks
IERRRT	Restart-error indicator.
MAXLEN	Total storage length to be cleared. This is a temporary storage.
NEDIT	File unit number upon which to place edit input information.
IEDIT	Edit information. This is a vector of two words that contains the edit values of NZ and NORMZ.
NEXTER	Fetch next case indicator. If nonzero after all input is successfully read, next problem is fetched.
ICPLOG	SC-4020 contour flux log plot indicator. (0/1 = plot of flux/plot of log flux).
NEXTRA	File unit number of a scratch file.

TABLE VIII

ECS STORAGE

ECS First Word Address	Total Length	Contents
ECPTCQ	(ISPANC+1-LC)*IGM	Cross section and Q-source blocks by group.
ECPTFX	(ISPANF+1-LFL)*IGM	Flux blocks by group.
ECPTFL	(IPJM+IMJP)*2*IGM	Flow blocks by group.
ECPTSO	NM*ITJT	Source to the group not including within group scatter.

TABLE IX

FILE NAMES AND UNIT REQUIREMENTS

Name	Logical Unit	Contents	Remarks
NINP	10	Problem decimal input unit	Generally this unit is equivalenced to the system input unit. In case both code and problems are contained on a tape, this cannot be done.
NOUT	9	System output decimal unit	
IFILM	12	System SC-4020 plot output unit	
NCAQ	6	Cross section library unit	The name of the library disk file must be equivalenced to this unit number in the file definition section of the program card.
NFLUX	7	First unit for restart dumps	Serves as an initial unit for flux guesses from tape as well as a dump unit.
NSCRAT	5	Second unit for restart dumps	Restart dumps are taken alternately upon NFLUX and this unit during the execution of a problem.
NEDIT	17	Storage for edit information	
NEXTRA	18	Used as a scratch file	This is used by the edit program to accumulate certain sums.
IFNOVY	-	Overlay file name	This file name is given in a hollerith form and must match that of the overlay control cards. The name is never entered into the file-definition section of the program card.

IV. INPUT SPECIFICATIONS

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

A. Job Title Cards

The user begins by indicating on a card in an I6 format the number of title or job description cards he wants to use. He then enters the descriptive material on these cards which are read with a 12A6 format.

B. Input of Control Numbers

On cards 1 through 3, the user enters the following control integers which are read in a 12I6 format.

Number of Word on Card	Name of Variable	Comments
CONTROL INTEGERS		CARD 1
1	ITH	0/1 (direct/adjoint) type of calculation to be performed.
2	ISCT	0/N (isotropic/Nth-order anisotropic) order of scattering calculation. There are NM = (ISCT + 1)(ISCT + 2)/2 spherical harmonics flux components. These are not used to compute a scattering source unless some zone material identification number is negative. See IDCS below.
3	ISN	S_n Order. Even integer only. If negative, user must supply his own quadrature coefficients. Otherwise (for ISN = 2 through 16) built-in constants are used.
4	IGM	Number of groups.
5	IM	Number of coarse-mesh intervals in the i-direction.
6	JM	Number of coarse-mesh intervals in the j-direction.
7	IBL	Left boundary condition: 0/1 vacuum/reflective.
8	IBR	Right boundary condition: 0/1/2 vacuum/reflective/white.
9	IBB	Bottom boundary condition: 0/1/2/3 vacuum/reflective/white/periodic.
10	IBT	Top boundary condition: 0/1/2/3 vacuum/reflective/white/periodic.
11	IEVT	Eigenvalue type - 0/1/2/3/4 - inhomogeneous source (Q)/k_{eff} calculation/time absorption (alpha) search/nuclide concentration (C) search/zone thickness (delta) search.
12	ISTART	Input flux guess and starting options -7/-6/-5/-4/-3/-2/-1/0/1/2/3/4/5/6/7. See Ref. 1.
CONTROL INTEGERS		CARD 2
1	MT	Total number of materials (cross section blocks including anisotropic cross sections) in the problem.
2,3	MIN	Number of input materials. This number is divided into 2I3 words, MTP and MCR, where MTP is the number of materials from the LIBRARY disk and MCR is the number of materials from the card reader.
4	MS	Number of mixture instructions. See Ref. 1 and items MIXNUM, MIXCOM, and MIXDEN below.
5	IHT	Row of total cross section in the cross section format. If IHT < 0, code assumes that there is no σ^{up} in cross section table.

6	IHS	Row of within-group scattering cross section in the cross section format.
7	IHM	Total number of rows in the cross section format.
8	IQOPT	0/1/2/3/4 Options for input of inhomogeneous source. See Ref. 1.
9	IQAN	Order of anisotropy of inhomogeneous distributed source.
10,11,12	IQR/IQB/ IQT	Right/bottom/top boundary sources to be specified as input. 0/1 - (no/yes). This word is split into a 3I2 format. See items QR1, QR2, QB1, QB2, QT1, and QT2 below. These sources are the value of the incoming flux on the boundary.
13	IPVT	0/1 (no/yes) Is a parametric eigenvalue being entered? See item PV below.
14	IITL	Maximum number of inner iterations allowed per group.
15	IXM	0/1 (no/yes) Are the i-direction zone thicknesses to be modified? See item XM below.

CONTROL INTEGERS--CARD 3

1	IYM	0/1 (no/yes) Are the j-direction zone thicknesses to be modified? See item YM below.
2	ITLIM	0/seconds If an integer number of seconds is entered, a restart dump is taken after this number of seconds and the problem is terminated.
3	NBETA	Number of incident angles.
4	IEDOPT	0/1/2/3/4 (none/option) Edit options. Option 1 is a macroscopic edit, Option 2 is a macroscopic plus microscopic edit. Options 3 and 4 give the information of options 1 and 2 (respectively) plus a zone relative power density edit.
5	ISDF	Density factor input indicator (0/1 = no/yes).
6	NSS	Number of source spectra.

Cards 4 and 5 consist of control floating-point numbers read in a E12.6 format.

CONTROL FLOATING-POINT DATA---CARD 4

1	EV	Eigenvalue guess. It is satisfactory to enter 1.0 for IEVT = 3 and 0.0 for all other problems.
2	EVM	Eigenvalue modifier used only if IEVT > 1. See Ref. 1.
3	PV	Parametric value of k_{eff} for subcritical or supercritical systems.
4	XLAL	Lambda lower limit for eigenvalue searches. See Ref. 1.
5	XLAH	Search lambda upper limit.
6	XLAX	Search lambda convergence precision for second and subsequent values of the eigenvalue.

CONTROL FLOATING-POINT DATA---CARD 5

1	EPS	Convergence precision.
2	NORM	Normalization factor. Total number of particles in system normalized to this number if it is nonzero. No normalization if NORM is zero.
3	POD	Parameter oscillation damper used in eigenvalue searches. See Ref. 1.

C. Input of Remaining Data

With the exception of the cross sections, most of the following data are read by the special formats discussed in Ref. 1. We denote these formats by S(I) for integers and S(E) for floating-point numbers.

Block Name and Dimension	Format	Number of Entries	Comments
IHX(IM)	S(I)	IM	Integers defining the number of fine-mesh i-intervals in each coarse-mesh k-interval.
IHY(JM)	S(I)	JM	Integers defining the number of fine-mesh j-intervals in each coarse-mesh ℓ-interval.
IDLIB(MTP)	S(I)	MTP	Identification numbers designating nuclides to be read from the library. Nuclides read from the library are assigned identification numbers MCR + 1, MCR + 2, etc., in the order read.
C(IHM,IGM,MIN)	(6E12.5)		MCR blocks of IHM*IGM numbers. Cross section blocks from cards. Each block is preceded by a header (identification) card read with a 12A6 format. MCR blocks are read in this fashion, and MIN = MCR + MTP.
Input FLUX Guess FLUX(NM,IT,JT)	S(E)		Number of entries depends on option. See Ref. 1. Option — Number -4 — IGM+IT+JT -3 — IGM+IT*JT -2 — IGM blocks of IT*JT -1 — IGM 0 — None 1 — NM sets of IGM 2 — IGM groups of NM sets of IT*JT 3 — NM sets of IGM+IT*JT 4 — NM sets of IGM+IT+JT
Input Source Q(NMQ,IT,JT)	S(E)		Number of entries depends on option. See Ref. 1. Option — Number 0 — None 1 — NMQ sets of IGM 2 — IGM groups of NMQ blocks of IT*JT 3 — NMQ sets of IGM+IT*JT 4 — NMQ sets of IGM+IT+JT
QR1(JT,MM)	S(E)	JT*MM	Right boundary source (flux) in the in-down directions. Do not enter unless IQR = 1.
QR2(JT,MM)	S(E)	JT*MM	Right boundary source (flux) in the in-up directions. Do not enter unless IQR = 1.
QB1(IT,MM)	S(E)	IT*MM	Bottom boundary source (flux) in the in-up directions. Do not enter unless IQB = 1.
QB2(IT,MM)	S(E)	IT*MM	Bottom boundary source (flux) in the out-up directions. Do not enter unless IQB = 1.
QT1(IT,MM)	S(E)	IT*MM	Top boundary source (flux) in the in-down directions. Do not enter unless IQT = 1.
QT2(IT,MM)	S(E)	IT*MM	Top boundary source (flux) in the out-down directions. Do not enter unless IQT = 1.
WGT(MM)	S(E)	MM	Quadrature weights. Do not enter unless ISN < 0.
COSMU(MM)	S(E)	MM	Quadrature μ cosines. Do not enter unless ISN < 0.

Block Name and Dimension	Format	Number of Entries	Comments
COSETA(MM)	S(E)	MM	Quadrature η cosines. Do not enter unless ISN < 0.
XRAD(IP)	S(E)	IM+1	Coarse k-mesh boundaries (cm). Must form increasing sequence.
YRAD(JP)	S(E)	JM+1	Coarse ℓ-mesh boundaries (revolutions). Must form increasing sequence and maximum be less than or equal one half.
IDCS(IM,JM)	S(I)	IM*JM	Cross sections zone identification numbers. These numbers assign a cross section block to each zone defined by the coarse-mesh boundaries. If these numbers are negative, an anisotropic scattering source is calculated in the zone. Do not use negative numbers here if ISCT = 0. These numbers need not be negative, however, if ISCT > 0.
CHI(IGP)	S(E)	IGM	Fission fractions. Fraction of fission yield emerging in each group.
VEL(IGP)	S(E)	IGM	Group speeds. Used only in time absorption calculations.
MIXNUM(MS)	S(I)	MS	Numbers identifying cross section block being mixed. See Ref. 1. Do not enter if MS = 0.
MIXCOM(MS)	S(I)	MS	Numbers controlling cross section mixture process. See Ref. 1. Do not enter if MS = 0.
MIXDEN(MS)	S(E)	MS	Mixture densities. See Ref. 1. Do not enter if MS = 0.
XM(IM)	S(E)	IM	i-mesh modification factors. See Ref. 1. Do not enter unless IEVT = 4 and IXM > 0.
YM(JM)	S(E)	JM	j-mesh modification factors. See Ref. 1. Do not enter unless IEVT = 4 and IYM > 0.
XDF(IT)	S(E)	IT	Radial fine-mesh cross section density factors. Do not enter unless ISDF = 1.
YDF(JT)	S(E)	JT	Axial fine-mesh cross section density factors. Do not enter unless ISDF = 1.
NEDS	I6	1	Integer defining number of edits to be performed IEDOPT > 0 only.
MN	I6	1	Integer defining number of microscopic activities to be computed. IEDOPT = 2 and 4 only. See Ref. 1.
MICID(MN)	S(I)	MN	Integers defining material blocks for which microscopic edit is to be made. IEDOPT = 2 and 4 only. See Ref. 1.
NZ,NORMZ	2I6	2	The integer NZ is the number of edit zones. The integer NORMZ is the zone to which the power density is normalized (NORMZ is not used unless IEDOPT = 3 or 4). See Ref. 1.
NEDZ(IM,JM)	S(I)	IM*JM	Integers defining which edit zone each coarse-mesh zone is in. See Ref. 1.
SSP(IGM,NSS)	S(E)	IGM*NSS	Edit source spectra. Do not enter unless NSS > 0.
JBETA(NBETA)	S(I)	NBETA	Edit j-level of $\pi/2 - \beta$. Do not enter unless NSS > 0.
JBPI(NBETA)	S(I)	NBETA	Edit j-level of $\pi/2 + \beta$. Do not enter unless NSS > 0.
BETA(NBETA)	S(E)	NBETA	Edit angle β. Do not enter unless NSS > 0.

References

1. K. D. Lathrop and F. W. Brinkley, "Theory and Use of the General-Geometry TWOTRAN Program," Los Alamos Scientific Laboratory Report LA-4432 (May 1970).

2. B. G. Carlson and K. D. Lathrop, "Transport Theory - Method of Discrete Ordinates," Chapter III of Computing Methods in Reactor Physics, (Gordon and Breach, New York, 1968).

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