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**A User's Manual for FENAT: A Two-Dimensional
Multigroup Diffusion Theory Finite Element
Neutral Atom Transport Code**

by

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FENAT:
A Two-Dimensional Multigroup Diffusion Theory
Finite Element Neutral Atom Transport Code

ABSTRACT

1. Program name: FENAT
2. Computer for which program is designed: CRAY
3. Equation solved: FENAT solves the two-dimensional energy dependent diffusion equation in Cartesian (X-Y) and cylindrical/toroidal (R-Z) coordinates. The boundary conditions allowed are: vacuum, reflection, albedo and surface source.
4. Method of solution: The energy variable is treated by multigroup method. The resulting multigroup diffusion equation is solved by finite element Galerkin's method with triangular element discretization of the spatial domain. The algebraic matrix equation is solved by the direct method of Crout variation of Gauss' elimination.
5. Restrictions: Dynamic memory allocation has been used so that the maximum problem size is limited by the size of active core storage of the machine. When necessary, the global matrix is stored in a binary disk file. FENAT is particularly suitable for the transport of neutral atoms in fusion plasmas.
6. Running time: A fifteen group, 1886 nodal points (unknowns), 3640 triangular elements problem for neutral atom transport in the TEXTOR tokamak requires about two minutes of CRAY-1 time.
7. Other features of the program: Mesh plot in its entirety or in a specified number of windows, and various result plots such as 3-D total flux, total density, average energy plots and density contour plot are provided. Wall-material sputtering and erosion rates and wall power deposition due to the charge-exchange neutral atoms are calculated and plotted.
8. Materials available: An executable module of the code, test problems, results of executed test problems and this report.

I. INTRODUCTION

Neutral atom transport is an important part of plasma simulation and accounts for most of the compilation time. Independently, results of neutral atom transport are also used to compute neutral-wall interactions such as power deposition and material erosion rates. At present, because of computation time limitations, only one-dimensional neutral calculations are used by the fluid plasma codes. For example, the fluid plasma code WHIST [1] uses SPUDNIT [2], a one-dimensional slab geometry code, for neutral calculations. A one-dimensional approximation is most often severely inadequate. Multi-dimensional Monte Carlo codes for neutral atom transport are available, but they are very time consuming and hence are not used by plasma simulation codes.

A fast multi-dimensional neutral atom transport code is highly desirable. The code FENAT has been developed to meet this objective. It is based on the energy dependent diffusion theory which has been shown to provide very good accuracy for the transport of neutral atoms in fusion plasmas [3,4]. FENAT can be used to obtain solutions in X-Y Cartesian and R-Z cylindrical/toroidal geometries. The use of the finite element method allows solution in complicated plasma geometries such as D-shaped tokamak plasmas. FENAT has been verified for accuracy by comparing it with the two-dimensional transport theory code DOT-4.3 [5]. The code FENAT is quite accurate and is about two orders of magnitude faster than DOT-4.3 for medium sized problems [3,6]. FENAT has been used to obtain neutral atom distribution and calculate neutral-wall interactions in the TEXTOR and TFTR tokamaks [7]. Although the code FENAT has been developed to solve for neutral atom distribution in fusion plasmas, it can be used to obtain particle flux for problems which can be described by diffusion equation.

A brief theory for FENAT is provided in Sec. II. Necessary information for running the code is furnished in Sec. III. The output from FENAT is briefly described in Sec. IV. In Sec. V, brief descriptions of the five test problems are provided. The input data and outputs for these five test problems are provided in the Appendix.

II. THEORY

In this section, only the main equations solved by FENAT are presented. Details can be seen in Refs. [3,6]. The multigroup diffusion equation in toroidal coordinates (x, y, ψ) as shown in Fig. 1 can be written as:

$$-\frac{1}{(R+x)} \frac{\partial}{\partial x} (R+x) \frac{\partial \phi_g}{\partial x} - \frac{\partial}{\partial y} D_g \frac{\partial \phi_g}{\partial y} - \frac{1}{(R+x)^2} \frac{\partial}{\partial \psi} D_g \frac{\partial \phi_g}{\partial \psi} + \sigma_{t,g} \phi_g = \sum_{g'=1}^G \sigma_{g' \rightarrow g} \phi_{g'} + S_{v,g}$$

With toroidal symmetry (ψ -symmetry), the above equation becomes

$$-\frac{1}{(R+x)} \frac{\partial}{\partial x} (R+x) D_g \frac{\partial \phi_g}{\partial x} - \frac{\partial}{\partial y} D_g \frac{\partial \phi_g}{\partial x} + \sigma_{t,g} \phi_g = \sum_{g'=1}^G \sigma_{g' \rightarrow g} \phi_{g'} + S_{v,g} \quad (1)$$

$$g = 1, 2, \dots, G$$

where g denotes a particular energy group, ϕ_g is the total flux for group g , D is the diffusion coefficient, σ_t is the total (absorption or ionization plus scattering or charge-exchange) cross section, $\sigma_{g' \rightarrow g}$ is the group to group scattering or charge-exchange cross section and $S_{v,g}$ is the volumetric source of particles. With the factor $(R+x)$ replaced by 1, Eq. (1) becomes the multigroup diffusion equation in X-Y Cartesian coordinates, and when $(R+x)$ is replaced by R and y by Z , Eq. (1) becomes the multigroup diffusion equation in R-Z cylindrical coordinates.

The boundary conditions considered for Eq. (1) can be written as

$$-D_g \frac{\partial \phi_{s,g}}{\partial n} = -\left(\frac{1-\alpha_g}{1+\alpha_g}\right) \frac{\phi_{s,g}}{2} + \frac{2S_{o,g}}{(1+\alpha_g)} \quad (2)$$

$$g = 1, 2, \dots, G$$

where $\partial \phi_s / \partial n$ is the outward normal derivative of the flux at the surface, α is the reflection coefficient and S_o is the surface source. Particular cases included in Eq. (2) are

1. free surface boundary condition, $\alpha = 0$
2. reflection condition, $\alpha = 1$
3. albedo condition, $0 < \alpha < 1$

If there is no boundary source, $S_o = 0$.

The spatial domain is discretized into general triangular mesh as shown in Fig. 2. The domain is designated by Ω and its boundary by $\delta\Omega$. The element (i, j, k) is a boundary element with the side $j-k$ belonging to the boundary $\delta\Omega$. The choice of triangular elements is completely arbitrary except that the two adjacent triangles must have two common vertices. The group flux in

each element is approximated by a linear polynomial. This gives linear basis functions for each triangular element. The finite element equations corresponding to Eqs. (1) and (2) obtained by Galerkin's method can be written as

$$\underline{A}\{\phi_g\} = \{q_g\} \quad (3)$$

$$g = 1, 2, \dots, G.$$

where $\underline{A}$ is the global matrix, $\{\phi_g\}$ is the unknown vector of nodal fluxes for group g , and $\{q_g\}$ is the right hand side vector. Equation (3) is solved by the direct or elimination method of Crout variation of Gauss elimination [8].

The matrix $\underline{A}$ is symmetric, sparse, banded, diagonally dominant, and positive definite. The latter two properties guarantee stability and convergence of the solution. The use of linear basis functions gives a quadratic convergence such that reducing the element size by half will make the discretization error one-fourth. The convergence is checked after each iteration on the group fluxes at each node and on the total absorption (ionization) rate of the whole domain, that is, by

$$\frac{\phi_i^{n+1} - \phi_i^n}{\phi_i^n} < \epsilon_1$$

and

$$\frac{I^{n+1} - I^n}{I^n} < \epsilon_2,$$

where n is the iteration number, i is a node number and I is the total ionization or absorption rate. The user supplies the tolerance limits ϵ_1 and ϵ_2 . Iteration is terminated whenever any of the above two conditions is met. A simplified flow chart for FENAT is given in Fig. 3.

III. A GUIDE TO RUNNING FENAT

Necessary detailed information for preparing input data for running FENAT is provided in this section. All the input data is to be supplied in three files named DATAIN, XCTNIN and FLXGSS, which contain the integer/floating parameters for a problem, the multigroup cross sections and the flux guess, respectively. The contents, formats and orders of input in each of these files are described next.

3.A. File: DATAIN (Required)

1. Title Card (Format 10A8) (Required)
2. Integer Parameters (input as NAMELIST)

Number of entries = 57
(Required)

NEG: Number of energy groups

NDM: Number of spatial dimensions 1,2, or 3 (only NDM=2 at present)

IGEOM = 1, X-Y Cartesian

= 2, R-Z cylindrical (axisymmetric)

= 3, R-Z toroidal (axisymmetric)

= 4, 3-D toroidal (not available at present)

MTHT = 1, solution by isotropic diffusion theory

= 2, solution by flux-limited diffusion theory (not available at present)

- (5) NEL: Total number of elements

NNP: Total number of nodal points

NPFL: Number of nodes per element (use only 3 at present)

NMT: Number of materials used to approximate the plasma or the medium

NMTWL: Number of wall materials or type of albedos

- (10) MSHGN = 0, element data is supplied

= 1, automatic mesh generation (not available at present)

IENRGP = 0, energy group boundaries are supplied

= 1, calculate them using linear interpolation

= 2, calculate them using logarithmic interpolation

IVLS = 0, no volumetric source

= 1, volumetric source is supplied

ISS = 0, no surface source

= 1, surface source is supplied

NFC = 1, axisymmetric 2-D problem

= N, number of Fourier components for source in case of 3-D problems (not available at present)

- (15) NSRCTV: Number of types of volumetric source

NSRCTS: Number of types of surface source

NVSG: Number of energy groups with volumetric source

NSSG: Number of energy groups with surface source

NBENS: Number of boundary elements without source

- (20) NBESS: Number of boundary elements with surface source only

NBESVS: Number of boundary elements with surface and volumetric sources
 NBEVS: Number of boundary elements with volumetric source only
 NIEVS: Number of internal elements with volumetric source
 NIENS: Number of internal elements without source
 (25) IBC = 0, group albedos (reflection coefficients) are supplied
 = 1, calculate albedos for each wall material
 = 2, calculate effective albedos after each iteration (not available at present)

 IGSFLX = 0, flux guess is supplied
 = 1, start with flux from previous solution
 = 2, calculate flux guess
 IGXN = 0, group cross sections for each material are supplied
 = 1, generate cross sections (not available at present)
 LNKMAT = 0, elements are already linked to the materials in the input data
 = 1, link the elements to the material numbers
 LNKWX = 0, material numbers are proportional to radial distance
 = 1, they are proportional to x-distance
 (30) IPTD = 0, plasma temperature and density at NPTD points are supplied
 = 1, calculate plasma temperatures and density at NPTD supplied points (radial distance)
 = 2, calculate them at NPTD linear points

 NPTD: Number of points at which plasma temperature and density are needed
 ITRMX: Maximum number of iterations to be allowed
 ITRNS = 0, no effect
 = N, N final iterations on transport equation (not available at present)
 NORM = 0, no effect
 = 1, normalize flux to the desired value of the external source
 (35) ICHK = 0, only integer data printout
 = 1, only mesh data and cross sections printout
 = 2, mesh plot and all data printout
 = 3, mesh plot and data printout except the cross sections

 ISPUT = 0, no effect
 = 1, do neutral-wall interaction calculations
 IRSLT = 0, only results printout
 = 1, printout and plot results
 IXDIM: X-dimension of the array ZMAT (for 3-D plot)
 IYDIM: Y-dimension of the array ZMAT
 (40) ISCALE = 0, scales (step sizes) for the axes are supplied
 = 1, calculate them

 IXBLN: Number of X-values between lines in 3-D plots (must be between 1 and IXDIM)
 IYBLN: Number of Y-values between lines in 3-D plots (must be between 1 and IYDIM)

IADSS = 0, no effect
 = 1, a fraction of the particles not reflected directly desorb
 back into the medium in the lowest energy group
 MSHWND = 0, plot spatial mesh in one frame
 = 1, plot spatial mesh in the desired number of windows
 (45) NWNDS: Number of windows for mesh plot

 ICNTR = 0, no effect
 = 1, plot contour of total density
 IPPLT = 0, no effect
 = 1, plot poloidal variations of total density and average
 energy at the desired number of minor radii
 NPRAD: Number of minor radii at which poloidal plots are desired
 NSMBL = N, a symbol is drawn at every nth point for poloidal plots
 (50) ISCXRT = 0, do not store group charge-exchange rates (saves storage)
 = 1, store them

 IGPOUT = 0, do not print group fluxes
 = 1, print them
 IELFLX = 0, do not print average flux for each element
 = 1, print them
 IDUMP = 0, no effect
 = 1, create binary file FLXDMP to store flux for later use
 ITFLX = 0, no effect
 = N, printout and plot flux at N locations along the torus,
 for 3-D problem (not available at present)
 (55) ITORLC = 1, N toroidal locations are supplied
 = 2, calculate them with linear spacing
 (ITORLC is used only when IGEOM = 4.)

 MSLN = 0, element by element solution (NPEL=3 only) (not available)
 = 1, solve by forming global matrix
 (57) LTSGO = 0, only data check
 = 1, solve the problem

3. Floating Parameters: (Format: 6E12.4)

Number of entries = 15
 (Required)

RO: Major radius, cm
 AO: Minor radius, cm
 TOLF: Tolerance limit on nodal flux
 TOLN: Tolerance limit on total ionization rate
 (5) FNORM: Normalization factor; flux is normalized to this value of the
 external source

 VELF: Factor for converting eV to velocity (cm/sec)
 SIT: Angle of symmetry along the torus (2π for 2-D toroidal/
 cylindrical problems)
 EMAX: Maximum energy in the group structure
 EMIN: Minimum energy in the group structure
 (10) ANUTRL: Atomic weight of neutral particles

- ZNUTRL: Atomic number of neutral particles
 RCYCLF: Recycling coefficient for adsorbed neutral atoms
 PRCYCL: Plasma ion recycling coefficient
 PEFLXR: Total plasma ion efflux rate, number/sec
 (15) DUTYFC: Duty factor for the machine

4. Plotting Parameters: (Format 6E12.4)

Number of entries = 20
 (Required only if ICHK=2 and/or IRSLT=1)

- PAGEX: X-length of the plotting page
 PAGEY: Y-length of the plotting page
 XLNGTH: X-length of the plotting area
 YLNGTH: Y-length of the plotting area
 (5) X3AXIS: Relative length of the X-side of the 3-D box for 3-D plot

- Y3AXIS: Relative length of the Y-side of the 3-D box for 3-D plot
 Z3AXIS: Relative length of the Z-side of the 3-D box for 3-D plot
 PHI: Angle ϕ in X-Y plane defining the view-point
 THETA: Angle θ in X-Z plane defining the view-point
 (10) RADIUS: Radial distance from the center of the box

- XORIG: Actual value of x (in cm) at the origin
 XSTEP: Step size for x-axis (cm)
 XMAX: Maximum value of x (cm)
 YORIG: Similar to that for x
 (15) YSTEP: Similar to that for x
 YMAX: Similar to that for x
 ZORIG: Value at the origin ($\log_{10}$ of total flux, density or energy)
 ZSTEP: Step size for z-axis
 ZMAX: Maximum value for z-axis
 (20) CNTINC: Increment between contour lines

In the above data, X3AXIS = Y3AXIS = Z3AXIS = 1 would define a cube of unit size. PHI, THETA and RADIUS (ϕ , θ and r) defines the view-point for viewing the 3-D plots. These are shown in Fig. 4.

5. Window Parameters: (Format 6E12.4)

(Required only if MSHWND=1 and ICHK=2 or 3)

WNDVLS(I,J) ; I=1, NWNDS
 J=1,6

For each I (window number), six values for J = 1,6 are: X-LEFT, X-STEP, X-RIGHT, Y-BOTTOM, Y-STEP and Y-TOP. These are defined in Fig. 5.

All the elements whose centroids fall inside a window are plotted in that window.

6. Poloidal Plot Parameters: (Format: 6E12.4)

Number of entries = 18
(Required only if IPPLT=1)

- PDNMN: Value at the origin for total density
DNSTP: Step size for total density
PDNMX: Maximum value for total density
AEMIN: Average energy value at the origin
(5) AESTP: Step size for average energy

AEMAX: Maximum value of average energy
SPMIN: Sputtering yield value at the origin
SPSTP: Step size for sputtering yield
SPMAX: Maximum value of sputtering yield
(10) PDMIN: Value of power deposition at the origin

PDSTP: Step size for power deposition
PEMAX: Maximum value of power deposition
ERMIN: Erosion rate at the origin
ERSTP: Step size for erosion rate
(15) ERMAY: Maximum value of erosion rate

XPMIN: Poloidal angle (in degrees) at the origin
XPSTP: Step size for poloidal angle
(18) XPMAX: Maximum value of poloidal angle

The ordinates for total density, average energy, sputtering yield and power deposition are for $\log_{10}$ of these values.

7. Radii for Poloidal Plots: (Format: 6E12.4)

Number of entries = NPRAD + 1
(Required only if IPPLT = 1)

Enter NPRAD minor radii (in cm) for which poloidal plots are desired. The last entry to be entered is the half-width of the band about these radii. Only the nodal points which fall inside this band about each radius will be plotted in the poloidal plots for the radius. Larger half-width results in more nodal values being plotted for a radius but with lesser accuracy and vice versa. This is illustrated in Fig. 6.

8. Toroidal Locations: (Format: 6E12.4)

Number of entries = ITFLX
(Required only if IGEOM = 4 and ITORLC = 1)

Enter ITFLX number of locations in degrees at which flux and other results are desired.

9. X-Values of the Nodal Points:

Number of entries = NNP
(Required)

To facilitate entering the coordinate values of the nodal points, a special mode of entry is used. This is explained below. The X-values must be entered in the same order as the nodes are numbered, from 1 to NNP.

Mode of Entry:

First Card: N1 N2 (Format 12I5)

- N1= 1, N2 X-values are supplied
- = 2, repeat N2 times the value 'A'
- = 3, interpolate linearly between 'A' and 'B' to get N2 values of X (A and B included)
- = 4, repeat the sequence X(N1) to X(NL) N2 times to obtain the X-values for the next $N2*(NL-N1+1)$ nodal points.

Subsequent Card(s):

Enter N2 x-values with format 6E12.4 ; NI=1
Enter 'A' with format 6E12.4 ; NI=2
Enter 'A' and 'B' with format 6E12.4 ; NI=3
Enter NI and NL with format 12I5 ; NI=4

Repeat the above procedure until all of the NNP X-values are entered.

Note: In the first card one can enter useful information between columns 11 and 80, such as how many nodes are entered up to this point, etc. This will make data check easy.

10. Y-Values of the Nodal Points:

Number of entries = NNP
(Required)

Enter NNP number of Y-values of the nodal points exactly in the same manner as in 9.

11. Link Node Numbers with the Elements:

Number of entries = 3*NEL
(Required)

Enter the node numbers which are linked with each of the elements (i.e., which define each element). The node numbers (always read counterclockwise) for the elements must be entered in the following order.

- (a) for all the boundary elements without source, NBENS elements
- (b) for all the boundary elements with surface source, NBESS elements
- (c) for all the boundary elements with surface and volumetric source, NBESVS elements
- (d) for all the boundary elements with volumetric source, NBEVS elements
- (e) for all the internal elements with volumetric source, NIEVS elements
- (f) for all the internal elements without source, NIENS elements

$$NEL = NBENS + NBESS + NBESVS + NBEVS + NIEVS + NIENS$$

This means that the elements in a medium must be numbered in the above order. This is illustrated in Fig. 7. The medium is rectangular and is discretized into 54 triangular elements. Elements having surface and/or volumetric sources are marked by 'S' and/or 'V'. The elements are numbered by the above convention and the numbers are shown inside each element. There are 38 nodal points which are shown along the left and right boundary lines. One can see by inspection that:

- (a) there are 12 (1 to 12) boundary elements without source (NBENS = 12),
- (b) there are 4 (13 to 16) boundary elements with only surface source (NBESS = 4),
- (c) there are 2 (17 and 18) boundary elements with both surface source and volumetric source (NBESVS = 2),
- (d) there are 2 (19 and 20) boundary elements with only volumetric source (NBEVS = 2),
- (e) there are 14 (21 to 34) internal elements with volumetric source (NIEVS = 14), and
- (f) there are 20 (35 to 54) internal elements without source.

All the data connected to the elements must be supplied in the above order of the elements.

To facilitate entry, the following mode of entry is used. This greatly reduces the actual number of data entry if wisely used.

Mode of Entry:

First Card: N1 N2 (Format: 12I5)

- N1 = 1, node numbers for N2 elements are entered
- = 2, generate the node numbers for N2 elements contained in a band characterized by the values of M1, M2, M3, M4, M5 and M6
- = 3, same as for N1 = 2, but for either up-pointing or down-pointing elements only (useful for boundary elements)
- = 4, the procedure for N1 = 2 is repeated for N2 similar bands

Subsequent Card(s):

Enter 3*N2 node numbers, format: 4(2x,3I5) ; N1=1
 Enter M1, M2, M3, M4, M5, M6 (format: 12I5) ; N1=2,3, or 4

Conventions adopted in FENAT in defining triangular elements are explained with examples in Fig. 8. The values of M1, M2, M3, M4, M5 and M6 are explained with examples in Figs. 9a, 9b and 9c.

In Fig. 8, (a) shows that the vertices of an element are to be read counterclockwise. If vertex 1 corresponds to node #100, vertex 2 to 101 and vertex 3 to 240 in the first element of (a), then (100, 101, 240), (101, 240, 100) and (240, 100, 101) are all equivalent. Case (b) shows that the element on the left has a boundary side, 1-2 and the element on the right has two boundary sides, 1-2 and 2-3. In linking the node numbers to these elements, enter the node number for vertex 1, followed by that for vertex 2 and then for vertex 3. Formation of the elements is arbitrary except that two adjacent elements must have two vertices in common. This is shown in case (c).

Node connection with options N1 = 2, 3 and 4 is illustrated in Figs. 9a, 9b and 9c, respectively. M1-M2 is the base line for determining the up-pointing or down-pointing of an element. If a side of an element lies on the M1-M2 line, it is up-pointing and if only a vertex lies on the M1-M2 line, it is down-pointing. M6 could be either positive or negative. The node numbers M1 to M2 and M3 to M4 must form arithmetic series with common difference M6. Two adjacent elements in a band can't both be up-pointing or down-pointing. The value of M5 determines whether the first triangle is up-pointing (M5 = 1) or down-pointing (M5 = 2). The node numbers for the 14 elements shown in the example in Fig. 9a will be generated by FENAT from the values of M1 to M6 shown in the figure. Option N1 = 3 is particularly suitable for boundary elements since FENAT requires that the boundary elements be numbered first. This is illustrated in Fig. 9b. Option N1 = 4 is suitable for internal elements lying in a number of similar bands. The conditions that must be met for using this option are:

- (a) There must be the same number of elements in each band.
- (b) The nodes for the first and the last element in each band are already entered (as boundary elements).
- (c) M6 is the same for all the bands.
- (d) Up-pointing/down-pointing properties are mirror images for the adjacent bands.
- (e) The numbering of the nodes must be continuous (a simple arithmetic series).

This is illustrated in Fig. 9c. This assumes that there are elements below the band 1 and above the band 7. The left and the right lines are the boundary lines of the medium. There are 19 elements in each band. The node numbers form a continuous series with constant common difference (20 to 103, M6 = 1). FENAT will generate the node numbers for the 119 elements from the input values of M1 to M6 shown in the figure. For the option N1 = 4, M4 is the number of nodes on the base line (M1-M2) and M3 is the number of nodes on the upper line.

For the discretization in Fig. 7, as an example, use:

- (i) option N = 3 for the elements 1-4, 9-12, 42-44 and 52-54,
- (ii) option N = 1 for the elements 13-20,
- (iii) option N = 4 for the elements 21-34,
- (iv) option N = 2 for the elements 35-41 and 45-51.

Note: Useful information such as band numbers and the number of elements already entered up to this point, etc., can be entered in the first card between columns 11 and 80. This will help in data checking.

12. Link Material Numbers to the Elements:

Number of entries = NEL

(Required only if IGXK ≠ 1 and LNKMAT ≠ 1)

Material numbers range from 1 to NMT. Each element must be linked to a number in this range to indicate which material cross section set is to be used for that element. Material numbers must be entered in the same order as the elements are numbered.

Mode of Entry:

First Card: N1 N2 (Format: 2I5)

- N1 = 1, material numbers for N2 elements are supplied
- 2, repeat the material number M1 N2 times
- 3, interpolate linearly between M1 and M2 to get material numbers for N2 elements (M1 and M2 included)
- 4, repeat N2 times the sequence from N1 to NL to obtain material numbers for the next N2*(NL-N1+1) elements.

Subsequent Card(s): (Format 12I5)

Enter N2 material numbers; N1 = 1	
Enter M1	; N1 = 2
Enter M1 M2	; N1 = 3
Enter N1 NL	; N1 = 4

Repeat this procedure until the material numbers for all the elements are entered.

13. Link the Albedo Type Numbers to the Boundary Elements:

Number of entries = NBENS + NBESS + NBESVS + NBEVS = NBELT
= total number of boundary elements

(Required)

The range of albedo type number is from 1 to NMTWL. Follow the same procedure as in 12 except that the last option (N1 = 4) is not available.

14. Link the Number of Boundary Sides to the Boundary Elements:

Number of entries = NBELT
(Required)

Each boundary element is to be assigned a number from 1 to 3 to indicate how many sides of the element belong to the boundary. Enter the number of boundary side(s) following the same procedure as in 12 except that the option NI = 4 is not available. The numbering convention that must be followed is illustrated in Fig. 10. In Fig. 10, if the nodes for an element (I) are supplied in the order (i,j,k) then the side i-j is side number 1; side j-k, side number 2; and side k-i, side number 3. In case (b), the element (I) has only one side (i-j) as boundary element. The number to be linked to this boundary element is, therefore, 1. In case (c), the number to be linked is 2 and it is 3 in case (d). Case (d) is a single element medium.

15. Link the Volumetric Source Type Numbers:

Number of entries = NEVST = NBESVS + NBEVS + NIEVS
= total number of elements with volumetric source
(Required only if IVLS = 1)

The volumetric source type numbers range from 1 to NSRCTV. Follow the same procedure as in 12 except that the last option (NI = 4) is not available.

16. Link the Surface Source Type Numbers:

Number of entries = NESST = NBESS + NBESVS = total number of boundary elements with surface source
(Required only if ISS = 1)

The surface source type number ranges from 1 to NSRCTS. Follow the procedure in 12 except that the last option (NI = 4) is not available.

17. Link the Side Number with Surface Source:

Number of entries = NESST
(Required only if ISS = 1)

Only one boundary side of a boundary element can have surface source. This is illustrated in Fig. 11. Follow the same procedure as in 12 except that the last option (NI = 4) is not available.

In case (a) in Fig. 11, the boundary element (I) has only one boundary side (i-j) and this has a surface source. Therefore, link 1 to this element. The element (I) in case (b) has two boundary sides and the side (i-j) has boundary source. Hence, the number to be linked is again 1. In case (c), the element (I) has two boundary sides and the side (j-k) has surface source. Therefore, link '2' to this element.

18. Energy Group Boundaries: (Format: 6E12.4)

Number of entries = NEG + 1
(Required only if IENRGP = 0)

Enter the energy group boundaries starting with the highest energy, i.e., $E_{\max}$.

19. Volumetric Source: (Format 6E12.4)

Number of entries = NSRCTV*NVSG
(Required only if IVLS=1)

For each type of volumetric source, enter the source magnitudes (number/cm³-sec) for all the groups, NVSG. Start a new card for each type of source.

20. Group Numbers with Volumetric Source: (Format 12I5)

Number of entries = NVSG
(Required only if IVLS = 1)

Enter NVSG energy group numbers ranging from 1 to NEG which contain volumetric source.

21. Surface Source: (Format: 6E12.4)

Number of entries = NSRCTS*NSSG
(Required only if ISS = 1)

For each type of surface source, enter the source magnitudes (number/cm²-sec) for the NSSG number of energy groups. Start a new card for each type of surface source.

22. Group Numbers with Surface Source: (Format: 12I5)

Number of entries = NSSG
(Required only if ISS = 1)

Enter the NSSG energy group numbers ranging from 1 to NEG which contain the surface source.

23. Albedos or Reflection Coefficients: (Format: 6E12.4)

Number of entries = NMTWL*NEG
(Required only if IBC = 0)

For each wall material or albedo type, enter the reflection coefficients for all the energy groups starting with group 1. Start a new card for each type of albedos.

24. Wall Material Type: (Format: 12I5)

Number of entries = NMTWL
(Required only if IBC = 1 or 2)

Available wall material types are:

- 1, iron (Fe): range 10 eV to 10 keV
- 2, carbon/graphite (C): range 10 eV to 10 keV
- 3, silicon (Si): range 50 eV to 5 keV
- 4, tungsten (W): range 10 eV to 20 keV
- 5, stainless steel: range 2.5 keV to 15 keV

Enter the number(s) of wall material type from the above selection. For example, if there are two types of wall materials and the numbers 1 and 4 are entered, then FENAT will calculate the reflection coefficients for each energy group for iron and tungsten from the 5th degree least square polynomial fits to the data of Eckstein and Verbeck [9].

25. Wall Material Properties: (Format: 6E12.4)

Number of entries = NMTWL*4
(Required only if ISPUT = 1)

For each wall material, enter the four properties in the following order:

Atomic weight
Atomic number
Mass density (gm/cc)
Surface binding energy, eV.

These are used in neutral-wall interaction calculations. Start a new card for each wall material.

26. Material Radii:

Number of entries = NPTD = (NMT + 1)
(Required only if LNMAT = 1 or (IGNX = 1 and IPTD = 0 or 1))

Enter the material radii in a monotonic order. The region from the first entry to the second entry is for material #1 and so on. Follow the same procedure as in 9 except that N1 = 4 is not available. FENAT will assign a material number to each element by checking into which region the radial or x-distance of the centroid of that element falls.

27. Plasma Ion Temperature (eV):

Number of entries = NPTD
(Required only if IGNX = 1 and IPTD = 0)

Enter plasma ion temperatures (eV) at the NPTD points supplied in 26. Follow the same procedure as in 9 except that N1 = 4 is not available.

28. Plasma Electron Temperature (eV):

Number of entries = NPTD
(Required only if IGNX = 1 and IPTD = 0)

Enter plasma electron temperature at NPTD points as in 27.

29. Plasma Density (number/cm⁻³):

Number of entries = NPTD
(Required only if IGX = 1 and IPTD = 0)

Enter total plasma density (ion plus electron) at NPTD points as in 27.

FENAT will use these plasma properties to calculate the plasma-neutral interaction cross sections (multigroup).

30. Plasma Parameters: (Format: 6F12.4)

Number of entries = 11
(Required only if IGX = 1 and IPTD = 1 or 2)

TIMAX: Plasma ion temperature at the center, eV

TIMIN: Plasma ion temperature at the edge, eV

TEMAX: Plasma electron temperature at the center, eV

TEMIN: Plasma electron temperature at the edge, eV

(5) DNMAX: Plasma density (ions plus electrons) at the center, cm⁻³

DNMIN: Plasma density (ions plus electrons) at the edge, cm⁻³

EXPTI: Power index for ion temperature profile

EXPTI: Power index for electron temperature profile

EXPDI: Power index for plasma density profile

(10) ELNGTN: Plasma elongation

(11) TRIANG: Plasma triangularity

These values are used to calculate the plasma temperature and density at the NPTD flux radii. The profiles are defined as:

$$T_i(r) = TIMIN + (TIMAX - TIMIN) \left[1 - \left(\frac{r}{AO} \right)^{EXPTI} \right]$$

Profiles for electron temperature and density are similarly defined.

3.B. File: XCTNIN: (Required only if IGX = 0)

The medium is approximated by NMT number of materials in each of which material properties can be assumed constant. Multigroup cross sections are supplied in this file. The cross sections (σ) are to be entered in the following order.

$\sigma(I, J, K)$; I=1, NMT
J=1, NEG
K=1, NEG + 3

First exhaust K, then J, and then I. That is, for the first material, enter all the cross sections for group 1, then for group 2 and so on until all the groups are entered. Then enter the cross sections for the second material. Continue this process until all the materials are entered. Start a new card for each energy group. There is no title card in front of the materials. The cross sections for K = 1 to NEG + 3 for any group J must follow the following sequence. The format is (6F12.4).

Entry sequence for any group J:

```

K = 1       $\sigma_t$ , total ( $\sigma_a + \sigma_s$ ) cross section
  = 2       $\sigma_a$ , total absorption (ionization) cross section
  = 3       $\sigma_s$ , total scattering (charge-exchange) cross section
  = 4       $\sigma_{J+1}$ 
  = 5       $\sigma_{J+2}$ 
    .      upscattering
    .
    .
  = J + 2   $\sigma_{J+J-1}$       group to group
  = J + 3   $\sigma_{J+J}$  . self scattering      scattering
  = J + 4   $\sigma_{J+J+1}$       (charge-exchange)
    .      cross sections
    .      downscattering
    .
  = NEG + 3  $\sigma_{J+NEG}$ 

```

All the cross sections are macroscopic. Plasma-neutral group cross sections have total up and downscattering in the sense that a neutral atom in any energy group can "reappear" in any energy group upon a charge exchange event. The above ordering of the group cross sections will require the least number of storage locations. For this reason, ordering such as generally used in the transport codes such as ANISM [10], DOT [5] and TRIDENT [11] is not used in FENAT.

The code PLASMX [12] calculates multi-group plasma-neutral interaction cross sections. This code has been modified to create the file XCTNIN with the multigroup cross sections written in the above format usable by FENAT.

3.C. File: FLXGSS: (Required only if IGSFLX = 0)

Group flux guesses at the nodal points are to be entered in the following order.

```

 $\phi(I,J)$  ; I = 1, NEG
              J = 1, NNP

```

First exhaust J and then I. That is, for the first group, enter all the nodal fluxes starting with node #1, then for group #2 and so on until all the groups are supplied. For each group NNP nodal fluxes are entered by the same procedure as in 9 in 3.A for x_1 , but using the options N1 = 1 and N1 = 2 only.

Since it is rather difficult to obtain a good guess for the flux beforehand, it may be preferable to use the option IGSFLX = 2 in which case FENAT will set the flux guess to zero.

3.D. A few useful suggestions:

The following suggestions will help to increase accuracy, reduce computation time and facilitate input data check.

1. In discretizing a medium, try to achieve elements as close to equilateral as possible.
2. The element size, h , should be kept less than the mean free path ($\approx 1/\sigma_t$).
3. The numbering of the elements does not affect the final global matrix $\underline{A}$ and can be arbitrary, but the numbering of the nodal points is very important. The band size of the global matrix $\underline{A}$ depends upon the maximum difference between the node numbers linked to an element. The nodes should be numbered such that the difference, $d = |i-j|$, $|j-k|$ or $|k-i|$ for any element with nodes i, j, k as shown in Fig. 10, is as small as possible. The bandwidth is equal to $(2d + 1)$. In FENAT, the matrix $\underline{A}$ is stored by active column profile method. A few long columns will not greatly increase the storage requirement for $\underline{A}$. Still, it is helpful to keep 'd' as small as possible. This can be done by a good choice of node numbering such as numbering along the shorter side of a medium.
4. Discretization error can be made negligible by meeting the requirements (1) and (2) above. In CRAY computers, round-off errors can be neglected. The only error a user should guard against is possible error in the input data. For a medium or large problem, the amount of input data can be quite large. Most of the input data is from coordinates of the node points and element connection data. The user can check the input data for mesh by running FENAT with the option of mesh plot and LTSGO = 0 in 3.A.2. and then checking the resulting mesh plot and data printout.

IV. OUTPUT FILES

The output from FENAT is contained in the files named DATOUT, RESULT, MESSGE, F3MSH... and F3FDP.... The outputs are self explanatory. DATOUT contains the printout of the input data. RESULT contains the results in the following order: energy groups, group fluxes at the nodes, total flux, density and average energy at the nodes, group leakage rates for each boundary element, total leakage rates for each boundary element, particle and energy balance, and sputtering calculation results. The file MESSGE contains fatal error messages and other messages such as for errors in input data. Check of input data and issuance of error messages thereon are not extensive in FENAT at the present time. Extensive input data check in FENAT will be provided in the future. The plotting file F3MSH... contains the mesh plot in its entirety or in a number of windows and F3FDP... contains the 3-D plots of total flux, density and average energy, 2-D poloidal plots of total density and average energy at the specified number of minor radii, a contour plot of total density and plots of sputtering yield, power deposition and erosion rate as functions of poloidal angle. Use of the option IDUMP = 1 creates a binary file FLXDMP which contains the nodal group fluxes. This can be profitably used in subsequent runs of the same problem with only slight changes in source/boundary conditions.

V. TEST PROBLEMS

In this section, brief descriptions of five sample problems are provided. The five test problems are:

1. A one-group, one-element problem in Y-Y geometry with boundary source: since this is a single element medium, all three sides of the element belong to the boundary. Side #2 has boundary source. A particle reflection coefficient of 0.8 has been used at the boundary.
2. The same as test problem #1 but with volumetric source instead of surface source.
3. A two-group problem in R-Z toroidal geometry: group #2 has the boundary source. Albedo boundary conditions have been used with a reflection coefficient of 0.5 for all the groups and boundary elements (17 to 24) with surface source and 0.6 for all the groups and boundary elements (1 to 16) without source.
4. A five-group problem in square (20 cm x 20 cm) X-Y geometry: group #5 has the boundary source. The right surface is reflected ($\alpha = 1$), the left surface is vacuum ($\alpha = 0$) and the top and bottom surfaces are subject to albedo ($\alpha = 0.5$) boundary conditions for all the groups and boundary elements.
5. The same as test problem #4 but with both surface source and volumetric source.

Fictitious group cross sections have been used for the first three test problems. The medium is homogeneous in these three sample problems. Actual five-group plasma-neutral interaction cross sections calculated by the code PLASMX [12] have been used in the fourth and fifth test problems. Plasma density and temperature profiles have been assumed to be parabolic. They vary only along X-directions with the maximum values being at $X = 0$. Therefore, the medium is homogeneous along the Y-direction. Along the X-direction, it has been approximated by 20 materials.

Complete input for the third sample problem is provided in the appendix. Only input data, mesh plots and printed results are provided for test problems #1 and 2. Results of test problem #3 show the total plotting capability of FENAT. Only input data, mesh plot, first and last pages of the result print out and plotted results are provided for the fourth and fifth test problems. This has been done to save space (these test problems have 5 energy groups, 451 nodal points and 820 triangular elements). Almost all the options discussed in section III have been used in the file DATAIN for this problem. This has resulted in a great reduction in the actual amount of data input in DATAIN. The user should study the files DATAIN in conjunction with the mesh plots to familiarize himself with the available options in data input and the numbering of the nodes and elements in FENAT.

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$$\begin{aligned}
 X &= (R+x) \cos \psi & -\text{Cartesian } (X, Y, Z) \\
 Y &= (R+x) \sin \psi & -\text{Toroidal } (x, y, \psi) \\
 Z &= y
 \end{aligned}$$

FIGURE 1: TOROIDAL COORDINATES, (x, y, ψ) .

FIGURE 2: DISCRETIZATION OF A DOMAIN INTO TRIANGULAR ELEMENTS.

FIGURE 3: A SIMPLIFIED FLOW CHART FOR FENAT.

P IS THE VIEW POINT, C IS THE CENTER
OF THE BOX, VIEW ALONG PC

FIGURE 4: DEFINING VIEW POINT FOR 3-D PLOTS.

FIGURE 5: PARAMETERS FOR A WINDOW FOR MESH PLOT

FIGURE 6: BAND WIDTH FOR POLOIDAL PLOT AT r .

NBENS=12, NBESS=4, NBESVS=2

NBEVS=2, NIEVS=14, NIENS=20

FIGURE 7: CONVENTION FOR NUMBERING THE ELEMENTS.

INTERNAL ELEMENTS

BOUNDARY ELEMENTS: THE BOUNDARY SIDES MUST
BE NUMBERED FIRST.

ALLOWED

NOT ALLOWED

FIGURE 8: SPECIFICATION AND FORMATION OF ELEMENTS.

$N2=10$, $M5=2(10)$ ELEMENTS, 1ST ELEMENT IS DOWN-POINTING

$N2=9$, $M5=1(9)$ ELEMENTS, 1ST ELEMENT IS UP-POINTING

EXAMPLE:

$(M1=100, M2=107, M3=200, M4=207, M5=2, M6=1, N2=14)$

FIGURE 9a: LINKING NODES TO THE ELEMENTS WITH OPTION $N1=2$

N1=3

ONLY FOR THE 5 UP-POINTING ELEMENTS. N2=5, M5=1

ONLY FOR THE 5 DOWN-POINTING ELEMENTS. N2=5, M5=2

FIGURE 9b: LINKING NODES TO THE ELEMENTS WITH OPTION N1=3

ELEMENTS MARKED BY * ARE ALREADY ENTERED
AS BOUNDARY ELEMENTS.

NODES FOR THE 119 ELEMENTS(15 TO 133) IN THESE
7 BANDS CAN BE GENERATED BY THE INPUT:

(M1=20, M2=29, M3=11, M4=10, M5=1, M6=1, N2=7)

IF BAND 2 WERE THE STARTING BAND, USE:

(M1=31, M2=39, M3=10, M4=11, M5=2, M6=1)

FIGURE 9c: LINKING NODES TO THE ELEMENTS WITH OPTION N1=4

FIGURE 10: LINKING THE NUMBER OF BOUNDARY SIDES.

(a)

(b)

(c)

FIGURE 11: LINKING THE SIDE NUMBER WITH SOURCE

APPENDIX

Test problems and results.

1 1 GROUP, 1 ELEMENT DEBUG PROBLEM. WITH SURFACE SOURCE.
 2 NEG=1 NDM=2 IGEOM=1 MTHD=1 NEL=1 NNP=3
 3 MPFL=3 NMT=1 KMTWL=1 MSHGN=0 IENRGP=0 IVLS=0
 4 ISS=1 NFC=1 NSRCTV=0 NSRCTS=1 NVSG=0 NSSG=1
 5 NBENS=0 NBESS=1 NBESVS=0 NBEVS=0 NIEVS=0 NIENS=0
 6 JBC=0 JGSFLX=2 JGNX=0 LNKMAT=0 LNKWX=0 IPTD=0
 7 NPTD=0 ITRNMN=60 ITRNS=0 NORM=0 ICHCK=2 ISPUT=0
 8 IRSLT=0 IXDIM=0 IYDIM=0 ISCALE=0 IXBLN=0 IYBLN=0
 9 IADSS=0 MSHWMD=0 NWNDS=0 ICNTR=0 IPPLT=0 NPRAD=0
 10 NSMRL=10 ISCKRT=0 IGPOUY=0 IELFLX=1 IDUMP=0 ITFLX=0
 11 ITORLC=0 MSLN=1 LTSGO=1 \$
 12 4.0000E+01 1.0000E+01 1.0000E-05 1.0000E-07 1.0000E+00 1.3760E+06
 13 6.2832E+00 8.0000E+01 4.0000E+01 2.5000E+00 1.0000E+00 0.0000E+00
 14 9.0000E-01 6.0000E+16 1.0000E+00
 15 8.6000E+00 1.1000E+01 7.0000E-00 7.0000E+00 1.0000E+00 1.0000E+00
 16 1.0000E+00 1.3500E+02 4.5000E+01 1.0000E+01 -1.0000E-01 5.0000E-02
 17 1.0000E-01 -1.0000E-01 5.0000E-02 1.0000E-01 0.0000E+00 2.0000E+00
 18 1.0000E+01 0.0000E+00
 19 1 03. X-VALUES
 20 -1.0000E-01 5.0000E-02 5.0000E-02
 21 1 3 Y-VALUES
 22 0.0000E+00 -5.0000E-02 5.0000E-02
 23 1 01 NODE CONNECTION
 24 1 1 2 3
 25 1 1 MATERIAL CONNECTION
 26 1
 27 1 1 BOUNDARY CONDITIONS
 28 1
 29 1 1 # OF BOUNDARY SIDES
 30 3
 31 1 1 CONNECT SURFACE SOURCE TYPE
 32 1
 33 1 1 CONNECT SIDE # WITH SURFACE SOURCE
 34 2
 35 1.0000E+02 1.0000E+01
 36 1.0000E+00
 37 1
 38 0.0000E-01

"DATAIN"

Problem #1

1 2.5000E+00 4.0000E-01 1.6000E+00 1.6000E+00

"XCTNIN"

1 GROUP, 1 ELEMENT DEBUG PROBLEM. WITH SURFACE SOURCE.

THIS SOLUTION IS BY ISOTROPIC DIFFUSION THEORY.

"RESULT"

GEOMETRY IS X-Y CARTESIAN.

RESULT FOR FOURIER COMPONENT # 1

FLUX HAS CONVERGED IN 11 ITERATIONS.

TOLERANCE WAS MET ON FLUX.

GROUP ENERGY(EV) AND VELOCITY(CM/SEC)

GROUP #	LOWER BOUND	UPPER BOUND	GROUP ENERGY	GROUP VELOCITY
1	1.000000E+01	1.000000E+02	5.500000E+01	1.020469E+07

TOTAL FLUX, DENSITY(1/CM**3), AND AVERAGE ENERGY(EV).

NODE #	TOTAL FLUX	TOTAL DENSITY	AVE. ENERGY	NODE #	TOTAL FLUX	TOTAL DENSITY	AVE. ENERGY
1	3.425743E+00	3.357029E-07	5.500000E+01	2	4.068742E+00	3.987130E-07	5.500000E+01
3	4.068742E+00	3.987130E-07	5.500000E+01				

AVERAGE TOTAL FLUX FOR EACH ELEMENT.

EL. #	TOTAL AV FLX	EL. #	TOTAL AV FLX	EL. #	TOTAL AV FLX	EL. #	TOTAL AV FLX	EL. #	TOTAL AV FLX
1	3.85441E+00								

TOTAL PARTICLE LOSS FROM EACH SURFACE ELEMENT

EL. #	TOT PART LSS	EL. #	TOT PART LSS	EL. #	TOT PART LSS	EL. #	TOT PART LSS	EL. #	TOT PART LSS
1	8.84365E-02								

ABSORPTION(IONIZATION) AND DIFFUSION LOSS RATE

GROUP #	IONIZATION RATE	DIFFUSION RATE
1	1.156323E-02	8.843647E-02

PARTICLE BALANCE.

55
56
57
58
59
60
61
62
63
64
65
66
67
68
69
70
71
72
73
74
75
76
77
78
79
80
81
82
83
84
85
86
87
88

TOTAL ABSORPTION RATE= 1.156323E-02
TOTAL DIFFUSION LOSS RATE= 8.843647E-02
TOTAL EXTERNAL SOURCE= 1.000000E-01
ADDTL. SOURCE FROM DESORBED PARTICLES= 0.
LOSS TO SOURCE RATIO= 9.999970E-01

ENERGY BALANCE.

ENERGY GAIN FROM THE EXTERNAL SOURCE= 5.500000E+00EV
ENERGY GAIN FROM THE PLASMA= 0. EV
ENERGY LOSS BY IONIZATION= 6.359775E-01EV
ENERGY LOSS BY DIFFUSION= 4.864006E+00EV
GAIN TO LOSS RATIO= 1.000003E+00

COMPUTATION TIME REQUIRED FOR THIS JOB IS= 2.085000E-05 MINUTES.

TOTAL TIME REQUIRED FOR THIS JOB IS= 2.319995E-02 MINUTES.

1 1 GROUP, 1 ELEMENT DEBUG PROBLEM. WITH VOLUME SOURCE.
 2 NEG=1 NDM=2 IGEOM=1 MTHD=1 NEL=1 NNP=3
 3 NPFL=3 NMT=1 NMTWL=1 MSHGN=0 IENRGP=0 IVLS=1
 4 ISS=0 NFC=1 NSRCTV=1 NSRCTS=0 NVSG=1 NSSG=0
 5 NBENS=0 NBESS=0 NBESVS=0 NBEVS=1 NIEVS=0 NIENS=0
 6 IBC=0 IGSFLX=2 IGX=0 LNKMAT=0 LNKVX=0 IPTD=0
 7 NPFD=0 ITRNMX=0 ITRNS=0 NORM=0 ICHCK=2 ISPUT=0
 8 IASLT=0 IXDIM=0 IYDIM=0 ISCALE=0 IXBLN=0 IYBLN=0
 9 IADSS=0 MSHWMD=0 NWNDS=0 ICNTR=0 IPPLT=0 NPRAD=0
 10 NSMEL=1 ISXRT=0 IGPOUT=0 IELFLX=1 IDUMP=0 ITFLX=0
 11 ITORLC=0 MSLN=1 LTSGO=1 \$
 12 4.0000E+01 1.0000E+01 1.0000E-05 1.0000E-07 1.0000E+00 1.3760E+06
 13 6.2832E+00 0.0000E+01 4.0000E+01 2.5000E+00 1.0000E+00 0.0000E+00
 14 9.0000E+01 6.0000E+15 1.0000E+00
 15 8.5000E+00 1.1000E+01 7.0000E+00 7.0000E+00 1.0000E+00 1.0000E+00
 16 1.0000E+00 1.3500E+02 4.5000E+01 1.0000E+01 -1.0000E+01 5.0000E+02
 17 1.0000E+01 -1.0000E+01 5.0000E+02 1.0000E+01 0.0000E+00 2.0000E+00
 18 1.0000E+01 0.0000E+00
 19 1 03 X-VALUES
 20 -1.0000E+01 5.0000E+02 5.0000E+02
 21 1 3 Y-VALUES
 22 0.0000E+00 -5.0000E+02 5.0000E+02
 23 1 01 NODE CONNECTION
 24 1 1 2 3
 25 1 1 MATERIAL CONNECTION
 26 1
 27 1 1 BOUNDARY CONDITIONS
 28 1
 29 1 1 # OF BOUNDARY SIDES
 30 3
 31 1 1 CONNECT VOL. SOURCE TYPE
 32 1
 33 1.0000E+02 1.0000E+01
 34 1.0000E+00
 35 1
 36 8.0000E+01

"DATAIN"

Problem #2

plot of the spatial mesh

1 GROUP, 1 ELEMENT DEBUG PROBLEM. WITH VOLUME SOURCE.

THIS SOLUTION IS BY ISOTROPIC DIFFUSION THEORY.

GEOMETRY IS X-Y CARTESIAN.

"RESULT"

RESULT FOR FOURIER COMPONENT # 1

FLUX HAS CONVERGED IN 11 ITERATIONS.

TOLERANCE WAS MET ON FLUX.

GROUP ENERGY(EV) AND VELOCITY(CM/SEC)

GROUP #	LOWER BOUND	UPPER BOUND	GROUP ENERGY	GROUP VELOCITY
1	1.000000E+01	1.000000E+02	5.500000E+01	1.020469E+07

TOTAL FLUX, DENSITY (#/CM**3), AND AVERAGE ENERGY(EV).

NODE #	TOTAL FLUX	TOTAL DENSITY	AVE. ENERGY	NODE #	TOTAL FLUX	TOTAL DENSITY	AVE. ENERGY
1	2.837763E-01	2.780042E-08	5.500000E+01	2	2.890007E-01	2.832022E-08	5.500000E+01
3	2.890007E-01	2.832022E-08	5.500000E+01				

AVERAGE TOTAL FLUX FOR EACH ELEMENT.

EL.#	TOTAL AV FLX	EL.#	TOTAL AV FLX	EL.#	TOTAL AV FLX	EL.#	TOTAL AV FLX	EL.#	TOTAL AV FLX
1	2.87313E-01								

TOTAL PARTICLE LOSS FROM EACH SURFACE ELEMENT

EL.#	TOT PART LSS	EL.#	TOT PART LSS	EL.#	TOT PART LSS	EL.#	TOT PART LSS	EL.#	TOT PART LSS
1	6.63004E-03								

ABSORPTION(IONIZATION) AND DIFFUSION LOSS RATE

GROUP #	IONIZATION RATE	DIFFUSION RATE
1	8.619377E-04	6.630040E-03

PARTICLE BALANCE.

65
66
67
68
69
70
71
72
73
74
75
76
77
78
79
80
81
82
83
84
85
86
87
88

TOTAL ABSORPTION RATE= 8.619377E-04
TOTAL DIFFUSION LOSS RATE= 6.638040E-03
TOTAL EXTERNAL SOURCE= 7.500000E-03
ADDTL. SOURCE FROM DESORBED PARTICLES= 0.
LOSS TO SOURCE RATIO= 9.999970E-01

ENERGY BALANCE.

ENERGY GAIN FROM THE EXTERNAL SOURCE= 4.125000E-01EV
ENERGY GAIN FROM THE PLASMA= 0. EV
ENERGY LOSS BY IONIZATION= 4.740657E-02EV
ENERGY LOSS BY DIFFUSION= 3.650922E-01EV
GAIN TO LOSS RATIO= 1.000003E+00

COMPUTATION TIME REQUIRED FOR THIS JOB IS= 2.000333E-05 MINUTES.

TOTAL TIME REQUIRED FOR THIS JOB IS= 1.437360E-02 MINUTES.

```

1  2 GROUP TOROIDAL GEOMETRY TEST PROBLEM. WITH SURFACE SOURCE.
2  NEG=2  NDM=2  IGEOM=3  MTHD=1  NEL=112  NNP=69
3  NPFL=3  NMT=1  NMTVL=2  MSHGM=0  IENRGP=0  IVLS=0
4  ISS=1  NRC=1  NSRCTV=0  NSRCTS=2  NVSG=0  NSSG=1
5  MBENS=16  MBESS=0  MBESVS=0  MBEVS=0  MIEVS=0  MIENS=88
6  IBC=0  IGSFLX=2  IGHX=0  LNKMAT=0  LNKWX=0  IPTD=0
7  NPTD=0  ITRMMX=50  ITRANS=0  NORM=0  ICHCK=2  ISPUT=1
8  IRSLT=1  IXDIM=20  IYDIM=20  ISCALE=0  IXBLM=1  IYBLM=1
9  IADSS=0  MSHWHD=0  MWNDS=0  ICNTR=1  IPFLT=1  NPRAD=2
10  NSMBL=6  ISCRT=0  IGPOUT=1  IELFLX=0  IDUMP=0  ITFLX=0
11  ITOFLC=0  MSLN=1  LTSGO=1  $
12  4.0000E+00  1.0000E+00  1.0000E-04  1.0000E-06  1.0000E+00  1.3760E+06
13  6.2032E+00  2.0000E+02  1.0000E+01  2.5000E+00  1.0000E+00  1.0000E+00
14  9.0000E-01  6.0000E+20  1.0000E+00  1.0000E+00  1.0000E+00  1.0000E+00
15  0.5000E+00  1.1000E+01  7.0000E+00  7.0000E+00  1.0000E+00  1.0000E+00
16  1.0000E+00  -1.3500E+02  4.5000E+01  1.0000E+01  -1.2000E+00  4.0000E-01
17  1.2000E+00  -1.2000E+00  4.0000E-01  1.2000E+00  8.0000E+00  1.0000E+00
18  1.1000E+01  1.0000E-01  1.0000E+00  1.0000E+00  5.0000E-01  3.0000E+00
19  7.0000E+00  1.0000E+00  1.1000E+01  0.0000E+00  0.0000E-01  0.0000E+00
20  +1.4000E+01  1.0000E+00  2.0000E+01  -2.0000E+00  1.0000E+00  4.0000E+00
21  -1.0000E+00  1.0000E+00  4.0000E+00  0.0000E+00  4.5000E+01  3.6000E+02
22  1.0000E+00  5.0000E-01  1.2500E-01  1.0000E+00  1.0000E+00  1.0000E+00
23  1 5 X-VALUES
24  -8.5000E-01  -9.5000E-01  -1.0000E+00  -9.5000E-01  -8.5000E-01
25  2 6 -11
26  -7.5000E-01
27  2 9
28  -5.0000E-01
29  2 10 -30
30  -2.5000E-01
31  2 9
32  0.0000E+00
33  2 10
34  2.5000E-01
35  2 9 -58
36  5.0000E-01
37  2 6
38  7.5000E-01
39  1 5 -69
40  8.5000E-01  9.5000E-01  1.0000E+00  9.5000E-01  8.5000E-01
41  3 5 Y-VALUES
42  -5.0000E-01  5.0000E-01
43  1 1
44  -6.5000E-01
45  3 4 -10
46  -3.7500E-01  3.7500E-01
47  1 2
48  6.5000E-01  -8.5000E-01
49  3 7
50  -7.5000E-01  7.5000E-01
51  1 2
52  -0.6000E-01  -0.6000E-01
53  1 1 -30
54  9.5000E-01
55  3 9
56  -1.0000E+00  1.0000E+00
57  1 1 -40
58  -9.5000E-01
59  3 8
60  -8.7500E-01  8.7500E-01
61  1 2 -50
62  9.5000E-01  -8.5000E-01

```

"DATAIN"Problem #3


```

65      3      7
66 -7.5000E-01 7.5000E-01
67      1      2
68 8.5000E-01 -6.5000E-01
69      3      4
70 -3.7500E-01 3.7500E-01
71      1      1
72 6.5000E-01
73      3      5 =69
74 -5.0000E-01 5.0000E-01
75      1 24 NODE CONNECTION
76      30 20 29 39 30 29 49 39 48 58 49 48
77      64 60 57 69 64 63 68 69 63 67 68 62
78      66 67 61 65 66 68 59 65 60 58 59 51
79      40 50 41 31 40 41 21 31 22 12 21 22
80      6 12 13 1 6 7 2 1 7 3 2 6
81      4 3 9 5 4 10 11 5 10 20 11 19
82      3 3 =27
83      7 10 2 4 1 1
84      2 11
85      13 10 6 11 1 1
86      2 15 =63
87      22 29 12 20 2 1
88      2 16
89      31 39 22 29 1 1
90      2 15 =83
91      41 40 31 39 2 1
92      2 16
93      60 58 41 48 1 1
94      2 11
95      59 64 51 57 2 1
96      3 3 =112
97      66 68 60 63 2 1
98      2 112 MATERIAL CONNECTION
99      1
100      2 16 BOUNDARY CONDITIONS
101      1
102      2 8
103      2
104      2 024 # OF BOUNDARY SIDES
105      1
106      2 8 SURFACE SOURCE TYPES
107      2
108      2 08
109      1
110      2.0000E+02 1.0000E+02 1.0000E+01
111      0.0000E+00
112      1.0000E+00
113      2
114      6.0000E-01 6.0000E-01
115      5.0000E-01 5.0000E-01
116      5.6000E+01 2.6000E+01 7.8600E+00 4.3000E+00
117      1.2000E+01 6.0000E+00 1.5600E+00 2.5000E+00

```

1	1.0000E+00	2.0000E-01	3.0000E-01	4.0000E-01	4.0000E-01
2	2.0000E+00	4.0000E-01	1.6000E+00	8.0000E-01	8.0000E-01

"XCTNIN"

2 GROUP TOROIDAL GEOMETRY TEST PROBLEM. WITH SURFACE SOURCE.

THE INTEGER PARAMETERS.

```

NEG= 2      NDM= 2      IGEOM= 3      MTHD= 1      NEL= 112
NMP= 69     NFEL= 3     NMT= 1      NMTVL= 2      MSHGH= 0
IENRCP= 0   IVLS= 0     ISS= 1      IIFC= 1      NSRCTV= 0
NSRCTS= 2   NVSG= 0     NSSG= 1     NBESS= 8      NBESVS= 0
NBEVS= 0    NBEHS= 16   NIEVS= 0     NIENS= 88     IDC= 0
IGSFLX= 2   IGNX= 0     IPTD= 0     NPTD= 0      ITRNMX= 50
ITRNS= 0    NORM= 0     ICHCK= 2    IISLT= 1     ITFLX= 0
LTSO= 1     MSLN= 1     ITORLC= 0   LNKMAT= 0    ISCKRT= 0
ICPOT= 1    IXDIM= 20   IVDIM= 20   ISCALE= 0    IXBLN= 1
IYBLN= 1    IADSS= 0    MSHWND= 0   NWNDS= 0     ICNTR= 1
IELFLX= 0   LNKWX= 0    ISPUT= 1    IFPLT= 1     NPRAD= 2
IDUMP= 0    NSMBL= 5

```

"DATOUT"

THE FLOATING PARAMETERS.

```

THE MAJOR RADIUS= 4.000000E+00 CMS.
THE MINOR RADIUS= 1.000000E+00 CMS.
TOLERANCE ON FLUX= 1.000000E-04
TOLERANCE ON TOTAL ABSORPTION RATE= 1.000000E-06
NORMALIZATION FACTOR= 1.000000E+00
VELOCITY FACTOR= 1.376000E+06
MAXIMUM TOROIDAL ANGLE= 6.283200 RADIANS.
HIGHEST ENERGY IN THE GROUP STRUCTURE= 2.000000E+02 EV
LOWEST ENERGY IN THE GROUP STRUCTURE= 1.000000E+01 EV
NEUTRAL ATOMIC WEIGHT= 2.500000E+00
NEUTRAL ATOMIC NUMBER= 1.000000E+00
RECYCLING FACTOR= 1.000000E+00
PLASMA ION RECYCLING COEFF.= 9.000000E-01
TOTAL ION EFFLUX RATE(1/SEC)= 6.000000E+20
DUTY FACTOR(AS FRACTION)= 1.000000E+00

```

PARAMETERS FOR MESH AND/OR 3-D RESULT PLOT.

```

XLNGTH= 7.000  YLNGTH= 7.000  X3AXIS= 1.000  Y3AXIS= 1.000  Z3AXIS= 1.000
PHI=-135.000  THETA= 45.000  RADIUS= 10.000  XORIG= -1.200  XSTEP= 0.400
XMAX= 1.200  YORIG= -1.200  YSTEP= 0.400  YMAX= 1.200  YORIG= 0.000
ZSTEP= 1.000  ZMAX= 11.000  PAGEX= 8.500  PAGEY= 11.000  CNTINC= 0.100

```

POLOIDAL PLOTTING PARAMETERS.

```

PDMMN= 7.000  DNSTP= 1.000  PDNMN= 11.000  AEMIN= 0.000
AESTP= 0.500  AEMAX= 3.000  SPMIN= 14.000  SPSTP= 1.000
SPMAX= 20.000  XPMIN= 0.000  XPSTP= 45.000  XPMAX= 360.000
PDMIN= -2.000  PDSTP= 1.000  PDMAX= 4.000  ERMIN= -1.000
ERSTP= 1.000  ERMAX= 4.000

```

THE DESIRED RADIUS AND DELTA RADIUS.

1.0000E+00 5.0000E-01 1.2500E-01

WALL MATERIAL PROPERTIES.

WALL MAT #	ATOMIC WT.	ATOMIC NO.	DENSITY,G/CC	SUBL ENRG,EV
1	56.0000	26.0000	7.8600	4.3000
2	12.0000	6.0000	1.5600	2.5000

NODAL COORDINATES.

NODE#	X-COORDINATE	Y-COORDINATE	NODE#	X-COORDINATE	Y-COORDINATE	NODE#	X-COORDINATE	Y-COORDINATE
1	-8.50000E-01	-5.00000E-01	2	-9.50000E-01	-2.50000E-01	3	-1.00000E+00	0.
4	-9.50000E-01	-2.50000E-01	5	-8.50000E-01	0.00000E-01	6	-7.50000E-01	-6.50000E-01
7	-7.50000E-01	-3.75000E-01	8	-7.50000E-01	-1.25000E-01	9	-7.50000E-01	1.25000E-01
10	-7.50000E-01	3.75000E-01	11	-7.50000E-01	6.50000E-01	12	-5.00000E-01	-8.50000E-01
13	-5.00000E-01	-7.50000E-01	14	-5.00000E-01	-5.00000E-01	15	-5.00000E-01	-2.50000E-01
16	-5.00000E-01	-3.65271E-15	17	-5.00000E-01	2.50000E-01	18	-5.00000E-01	5.00000E-01
19	-5.00000E-01	7.50000E-01	20	-5.00000E-01	8.50000E-01	21	-2.50000E-01	-9.50000E-01
22	-2.50000E-01	-8.75000E-01	23	-2.50000E-01	-6.25000E-01	24	-2.50000E-01	-3.75000E-01
25	-2.50000E-01	-1.25000E-01	26	-2.50000E-01	1.25000E-01	27	-2.50000E-01	3.75000E-01
28	-2.50000E-01	6.25000E-01	29	-2.50000E-01	8.75000E-01	30	-2.50000E-01	9.50000E-01
31	0.	-1.00000E+00	32	0.	-7.50000E-01	33	0.	-5.00000E-01
34	0.	-2.50000E-01	35	0.	0.	36	0.	2.50000E-01
37	0.	5.00000E-01	38	0.	7.50000E-01	39	0.	1.00000E+00
40	2.50000E-01	-9.50000E-01	41	2.50000E-01	-8.75000E-01	42	2.50000E-01	-6.25000E-01
43	2.50000E-01	-3.75000E-01	44	2.50000E-01	-1.25000E-01	45	2.50000E-01	1.25000E-01
46	2.50000E-01	3.75000E-01	47	2.50000E-01	6.25000E-01	48	2.50000E-01	8.75000E-01
49	2.50000E-01	9.50000E-01	50	5.00000E-01	-8.50000E-01	51	5.00000E-01	-7.50000E-01
52	5.00000E-01	-5.00000E-01	53	5.00000E-01	-2.50000E-01	54	5.00000E-01	-3.55271E-15
55	5.00000E-01	2.50000E-01	56	5.00000E-01	5.00000E-01	57	5.00000E-01	7.50000E-01
58	5.00000E-01	8.50000E-01	59	7.50000E-01	-6.50000E-01	60	7.50000E-01	-3.75000E-01
61	7.50000E-01	-1.25000E-01	62	7.50000E-01	1.25000E-01	63	7.50000E-01	3.75000E-01
64	7.50000E-01	6.50000E-01	65	8.50000E-01	-5.00000E-01	66	9.50000E-01	-2.50000E-01
67	1.00000E+00	0.	68	9.50000E-01	2.50000E-01	69	6.50000E-01	5.00000E-01

ELEMENT CONNECTION DATA.

CONNECTED NODE NUMBERS:

EL.#	CONN. NODE NUMS	EL.#	CONN. NODE NUMS	EL.#	CONN. NODE NUMS	EL.#	CONN. NODE NUMS
1	30 20 29	2	39 30 29	3	49 39 48	4	58 49 48
5	64 58 57	6	69 64 63	7	68 69 63	8	67 50 62
9	66 67 64	10	55 66 60	11	59 65 60	12	50 59 51
13	40 50 41	14	31 40 41	15	21 31 22	16	12 21 22
17	6 12 13	18	1 6 7	19	2 1 7	20	3 2 8
21	4 3 9	22	5 4 10	23	11 5 10	24	20 11 19
26	7 8 2	26	8 9 3	27	9 10 4	28	13 14 6
29	7 6 14	30	14 15 7	31	8 7 15	32	15 16 8
33	9 8 16	34	16 17 9	35	10 9 17	36	17 10 10
37	11 10 18	38	10 19 11	39	13 12 22	40	22 23 13
41	14 13 23	42	23 24 14	43	15 14 24	44	24 25 15

129	45	16	15	25	46	25	26	16	47	17	16	26	48	26	27	17
130	49	18	17	27	50	27	28	18	51	19	18	28	52	28	29	19
131	53	20	19	29	54	31	32	22	55	23	22	32	56	32	33	23
132	57	24	23	33	58	33	34	24	59	25	24	34	60	34	35	25
133	61	26	25	35	62	35	36	26	63	27	26	36	64	36	37	27
134	65	28	27	37	66	37	38	28	67	29	28	38	68	38	39	29
135	69	32	31	41	70	41	42	32	71	33	32	42	72	42	43	33
136	73	34	33	43	74	43	44	34	75	35	34	44	76	44	45	35
137	77	36	35	45	78	45	46	36	79	37	36	46	80	46	47	37
138	81	38	37	47	82	47	48	38	83	39	38	48	84	48	49	39
139	85	42	41	51	86	51	52	42	87	43	42	52	88	52	53	43
140	89	44	43	53	90	53	54	44	91	45	44	54	92	54	55	45
141	93	46	45	55	94	55	56	46	95	47	46	56	96	56	57	47
142	97	48	47	57	98	57	58	48	99	52	51	59	100	59	60	52
143	101	53	52	60	102	60	61	53	103	54	53	61	104	61	62	54
144	105	55	54	62	106	62	63	55	107	56	55	63	108	63	64	56
145	109	57	56	64	110	61	60	66	111	62	61	67	112	63	62	68

CONNECTED MATERIAL NUMBERS: 112

1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

CONNECTED ALBEDO TYPE NUMBERS: 24

1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2	2
2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2

CONNECTED NUMBERS OF BOUNDARY SIDES: 24

1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

CONNECTED SURFACE SOURCE TYPE NUMBERS: 8

2	2	2	2	2	2	2	2	2
---	---	---	---	---	---	---	---	---

CONNECTED SOURCE SIDE NUMBERS: 8

1	1	1	1	1	1	1	1	1
---	---	---	---	---	---	---	---	---

SURFACE SOURCE.

SOURCE OF TYPE # 1

FOURIER COMPONENT # 1

GROUP # 2 SOURCE(#/CM**2/SEC) 0.

SOURCE OF TYPE # 2

```

193
194
195     FOURIER COMPONENT # 1
196
197     GROUP # 2      SOURCE(#/CM**2/SEC)      1.000000E+00
198
199
200 REFLECTION COEFFICIENT OR ALBEDO
201 -----
202
203     WALL MATERIAL OR ALBEDO TYPE # 1
204
205     GROUP # 1      ALBEDO=      6.000000E-01
206
207     GROUP # 2      ALBEDO=      6.000000E-01
208
209
210     WALL MATERIAL OR ALBEDO TYPE # 2
211
212     GROUP # 1      ALBEDO=      5.000000E-01
213
214     GROUP # 2      ALBEDO=      5.000000E-01
215
216
217 CROSS SECTION DATA.
218 -----
219
220
221     CROSS SECTIONS FOR ANY GROUP, I, ARE PRINTED AS:
222     TOTAL,ABS,TOTAL SCATT.,GR.1 TO GR.1,GR.1 TO GR.2,
223     .....GR.1 TO GR.NEG
224
225
226     MATERIAL #      1
227
228
229     1.000000E+00      2.000000E-01      8.000000E-01      4.000000E-01      4.000000E-01
230     2.000000E+00      4.000000E-01      1.600000E+00      8.000000E-01      8.000000E-01
231
232
233     FLUX GUESS WAS SET TO ZERO.
234     -----

```

2 GROUP TOROIDAL GEOMETRY TEST PROBLEM.

THIS SOLUTION IS BY ISOTROPIC DIFFUSION THEORY.

"RESULT"

GEOMETRY IS R-Z TOROIDAL.

RESULT FOR FOURIER COMPONENT # 1

FLUX HAS CONVERGED IN 28 ITERATIONS.

TOLERANCE WAS MET ON FLUX.

GROUP ENERGY(EV) AND VELOCITY(CM/SEC)

GROUP #	LOWER BOUND	UPPER BOUND	GROUP ENERGY	GROUP VELOCITY
1	1.000000E+02	2.000000E+02	1.500000E+02	1.685249E+07
2	1.000000E+01	1.000000E+02	5.500000E+01	1.020469E+07

GROUP FLUX:

NODE	X-VAL,CM	Y-VAL,CM	GROUP NO. 1	GROUP NO. 2	GROUP NO. 3	GROUP NO. 4	GROUP NO. 5
1	3.150	-0.500	5.919348E-01	1.845250E+00			
2	3.050	-0.250	6.308695E-01	1.870775E+00			
3	3.000	0.000	6.442163E-01	1.927866E+00			
4	3.050	0.250	6.308695E-01	1.870775E+00			
5	3.150	0.500	5.919348E-01	1.845250E+00			
6	3.250	-0.650	5.653925E-01	1.738205E+00			
7	3.250	-0.375	6.255062E-01	1.326479E+00			
8	3.250	-0.125	6.504786E-01	1.164778E+00			
9	3.250	0.125	6.504786E-01	1.164778E+00			
10	3.250	0.375	6.255062E-01	1.326479E+00			
11	3.250	0.650	5.653925E-01	1.738205E+00			
12	3.500	-0.850	4.727998E-01	1.052138E+00			
13	3.500	-0.750	5.028447E-01	9.844670E-01			
14	3.500	-0.500	5.548643E-01	8.265454E-01			
15	3.500	-0.250	5.770702E-01	7.230114E-01			
16	3.500	0.000	5.835089E-01	6.878146E-01			
17	3.500	0.250	5.770702E-01	7.230114E-01			
18	3.500	0.500	5.548643E-01	8.265454E-01			
19	3.500	0.750	5.028447E-01	9.844670E-01			
20	3.500	0.850	4.727998E-01	1.052138E+00			
21	3.750	-0.950	3.946327E-01	3.845388E-01			
22	3.750	-0.875	4.104394E-01	4.358955E-01			
23	3.750	-0.625	4.536173E-01	4.725003E-01			
24	3.750	-0.375	4.780475E-01	4.461345E-01			
25	3.750	-0.125	4.881287E-01	4.241712E-01			
26	3.750	0.125	4.881287E-01	4.241712E-01			
27	3.750	0.375	4.780475E-01	4.461345E-01			

65	28	3.75#	#.625	4.536173E-#1	4.725003E-#1
66	29	3.75#	#.875	4.184394E-#1	4.350955E-#1
67	30	3.75#	#.95#	3.946327E-#1	3.845388E-#1
68	31	4.0#	-1.0#	3.322337E-#1	2.231398E-#1
69	32	4.0#	-#7.5#	3.621912E-#1	2.612348E-#1
70	33	4.0#	-#5.0#	3.839460E-#1	2.722700E-#1
71	34	4.0#	-#2.5#	3.958650E-#1	2.692865E-#1
72	35	4.0#	#.0#	3.995282E-#1	2.668046E-#1
73	36	4.0#	#.25#	3.958650E-#1	2.692865E-#1
74	37	4.0#	#.5#	3.839460E-#1	2.722700E-#1
75	38	4.0#	#.75#	3.621912E-#1	2.612348E-#1
76	39	4.0#	1.0#	3.322337E-#1	2.231398E-#1
77	40	4.25#	-#9.5#	2.901120E-#1	1.564252E-#1
78	41	4.25#	-#8.75	2.949704E-#1	1.609049E-#1
79	42	4.25#	-#8.625	3.098643E-#1	1.726810E-#1
80	43	4.25#	-#8.375	3.198837E-#1	1.773591E-#1
81	44	4.25#	-#8.125	3.249614E-#1	1.781712E-#1
82	45	4.25#	#.125	3.249614E-#1	1.781712E-#1
83	46	4.25#	#.375	3.198837E-#1	1.773591E-#1
84	47	4.25#	#.625	3.098643E-#1	1.726810E-#1
85	48	4.25#	#.875	2.949704E-#1	1.609049E-#1
86	49	4.25#	#.95#	2.901120E-#1	1.564252E-#1
87	50	4.5#	-#8.5#	2.547328E-#1	1.171795E-#1
88	51	4.5#	-#7.5#	2.575999E-#1	1.196140E-#1
89	52	4.5#	-#6.5#	2.639643E-#1	1.241854E-#1
90	53	4.5#	-#5.5#	2.682908E-#1	1.264892E-#1
91	54	4.5#	#.0#	2.697152E-#1	1.270695E-#1
92	55	4.5#	#.25#	2.682908E-#1	1.264892E-#1
93	56	4.5#	#.5#	2.639643E-#1	1.241854E-#1
94	57	4.5#	#.75#	2.575999E-#1	1.196140E-#1
95	58	4.5#	#.85#	2.547328E-#1	1.171795E-#1
96	59	4.75#	-#6.5#	2.267032E-#1	9.337607E-#2
97	60	4.75#	-#3.75	2.294773E-#1	9.614143E-#2
98	61	4.75#	-#1.25	2.302894E-#1	9.688475E-#2
99	62	4.75#	#.125	2.302894E-#1	9.688475E-#2
100	63	4.75#	#.375	2.294773E-#1	9.614143E-#2
101	64	4.75#	#.65#	2.267032E-#1	9.337607E-#2
102	65	4.85#	-#0.5#	2.104068E-#1	8.734096E-#2
103	66	4.95#	-#0.25#	2.095346E-#1	8.145159E-#2
104	67	5.0#	#.0#	2.046262E-#1	7.818198E-#2
105	68	4.95#	#.25#	2.095346E-#1	8.145159E-#2
106	69	4.85#	#.5#	2.104068E-#1	8.734096E-#2

TOTAL FLUX,DENSITY(#/CM**3),AND AVERAGE ENERGY(EV).

113	NODE #	TOTAL FLUX	TOTAL DENSITY	AVE. ENERGY	NODE #	TOTAL FLUX	TOTAL DENSITY	AVE. ENERGY
114								
115	1	2.437185E+00	2.159482E-07	6.727301E+01	2	2.501645E+00	2.207598E-07	6.782256E+01
116	3	2.572082E+00	2.271464E-07	6.772066E+01	4	2.501645E+00	2.207598E-07	6.782256E+01
117	5	2.437185E+00	2.159482E-07	6.727301E+01	6	2.303598E+00	2.038835E-07	6.742367E+01
118	7	1.953986E+00	1.672998E-07	7.204687E+01	8	1.815256E+00	1.527398E-07	7.459929E+01
119	9	1.815256E+00	1.527398E-07	7.459929E+01	10	1.953986E+00	1.672998E-07	7.204687E+01
120	11	2.303598E+00	2.038835E-07	6.742367E+01	12	1.524937E+00	1.311505E-07	7.139603E+01
121	13	1.487311E+00	1.263100E-07	7.323041E+01	14	1.381410E+00	1.139214E-07	7.766003E+01
122	15	1.380082E+00	1.050933E-07	8.002655E+01	16	1.271315E+00	1.020250E-07	8.200673E+01
123	17	1.380082E+00	1.050933E-07	8.002655E+01	18	1.381410E+00	1.139214E-07	7.766003E+01
124	19	1.487311E+00	1.263100E-07	7.323041E+01	20	1.524937E+00	1.311505E-07	7.139603E+01
125	21	7.791714E-01	6.109943E-08	8.509241E+01	22	8.455350E-01	6.699165E-08	8.413659E+01
126	23	9.261176E-01	7.321921E-08	6.448780E+01	24	9.241820E-01	7.208616E-08	8.601333E+01
127	25	9.122999E-01	7.053109E-08	8.036438E+01	26	9.122999E-01	7.053109E-08	8.036438E+01
128	27	9.241820E-01	7.208616E-08	8.601333E+01	28	9.261176E-01	7.321921E-08	8.449700E+01

129	29	8.465368E-01	6.699165E-08	8.413669E+01	38	7.791714E-01	6.189943E-08	8.509241E+01
130	31	6.653727E-01	4.158854E-08	9.422192E+01	32	6.234260E-01	4.789134E-08	9.266507E+01
131	33	6.662160E-01	4.946362E-08	9.296762E+01	34	6.651511E-01	4.987851E-08	9.392417E+01
132	35	6.663327E-01	4.985266E-08	9.435684E+01	36	6.651516E-01	4.987851E-08	9.392417E+01
133	37	6.662160E-01	4.946362E-08	9.296762E+01	38	6.234260E-01	4.789134E-08	9.266507E+01
134	39	6.663727E-01	4.158854E-08	9.422192E+01	40	4.465388E-01	3.254359E-08	9.943724E+01
135	41	4.558754E-01	3.327882E-08	9.915813E+01	42	4.822451E-01	3.529886E-08	9.862281E+01
136	43	4.972427E-01	3.636154E-08	9.876788E+01	44	5.831325E-01	3.674243E-08	9.983581E+01
137	45	6.831325E-01	3.674243E-08	9.983581E+01	46	4.558754E-01	3.327882E-08	9.915813E+01
138	47	4.822451E-01	3.529886E-08	9.862281E+01	48	4.558754E-01	3.327882E-08	9.915813E+01
139	49	4.465388E-01	3.254359E-08	9.943724E+01	50	3.719122E-01	2.659834E-08	1.832687E+02
140	51	3.772139E-01	2.788785E-08	1.832687E+02	52	3.681457E-01	2.783267E-08	1.827193E+02
141	53	3.947888E-01	2.831515E-08	1.826681E+02	54	3.967847E-01	2.846654E-08	1.826864E+02
142	55	3.947888E-01	2.831515E-08	1.826681E+02	56	3.881497E-01	2.783267E-08	1.827193E+02
143	57	3.772139E-01	2.788785E-08	1.832687E+02	58	3.719122E-01	2.659834E-08	1.832687E+02
144	59	3.788792E-01	2.268252E-08	1.859167E+02	60	3.256187E-01	2.383812E-08	1.855886E+02
145	61	3.271742E-01	2.315915E-08	1.854886E+02	62	3.271742E-01	2.315915E-08	1.854886E+02
146	63	3.256187E-01	2.383812E-08	1.855886E+02	64	3.288792E-01	2.268252E-08	1.859167E+02
147	65	3.857477E-01	2.151882E-08	1.866235E+02	66	2.989862E-01	2.841523E-08	1.872999E+02
148	67	2.828882E-01	1.988357E-08	1.877118E+02	68	2.989862E-01	2.841523E-08	1.872999E+02
149	69	3.857477E-01	2.151882E-08	1.866235E+02				

PARTICLE LOSS BY GROUP AND SURFACE ELEMENT.

EL.#	X-VAL,CM	Y-VAL,CM	GROUP NO. 1	GROUP NO. 2	GROUP NO. 3	GROUP NO. 4	GROUP NO. 5
155							
156							
157	1	3.667	0.892	3.321418E-01	5.477356E-01		
158	2	3.833	0.942	2.817363E-01	2.358826E-01		
159	3	4.167	0.942	2.568484E-01	1.564786E-01		
160	4	4.333	0.892	2.518911E-01	1.263973E-01		
161	5	4.583	0.750	2.797984E-01	1.223891E-01		
162	6	4.783	0.508	1.512457E-01	6.148342E-02		
163	7	4.858	0.375	2.217071E-01	8.744354E-02		
164	8	4.988	0.125	2.862866E-01	7.958968E-02		
165	9	4.988	-0.125	2.862866E-01	7.958968E-02		
166	10	4.858	-0.375	2.217071E-01	8.744354E-02		
167	11	4.783	-0.508	1.512457E-01	6.148342E-02		
168	12	4.583	-0.750	2.797984E-01	1.223891E-01		
169	13	4.333	-0.892	2.518911E-01	1.263973E-01		
170	14	4.167	-0.942	2.568484E-01	1.564786E-01		
171	15	3.833	-0.942	2.817363E-01	2.358826E-01		
172	16	3.667	-0.892	3.321418E-01	5.477356E-01		
173	17	3.417	-0.750	5.867252E-01	1.573884E+00		
174	18	3.217	-0.508	3.495398E-01	1.624826E+00		
175	19	3.158	-0.375	5.343341E-01	1.624826E+00		
176	20	3.188	-0.125	5.148838E-01	1.533882E+00		
177	21	3.188	0.125	5.148838E-01	1.533882E+00		
178	22	3.158	0.375	5.343341E-01	1.624826E+00		
179	23	3.217	0.508	3.495398E-01	1.624826E+00		
180	24	3.417	0.750	5.867252E-01	1.573884E+00		

TOTAL PARTICLE LOSS FROM EACH SURFACE ELEMENT

185	EL.#	TOT PART LSS	EL.#	TOT PART LSS	EL.#	TOT PART LSS	EL.#	TOT PART LSS	EL.#	TOT PART LSS
186										
187	1	8.79877E-01	2	5.16819E-01	3	4.13327E-01	4	3.78288E-01	5	4.82187E-01
188	6	2.12649E-01	7	3.89151E-01	8	2.85796E-01	9	2.85796E-01	10	3.89151E-01
189	11	2.12649E-01	12	4.82187E-01	13	3.78288E-01	14	4.13327E-01	15	5.16819E-01
190	16	8.79877E-01	17	2.16061E+00	18	1.43178E+00	19	2.16061E+00	20	2.84877E+00
191	21	2.84877E+00	22	2.15836E+00	23	1.43178E+00	24	2.16061E+00		
192										

SPECIFIC(ATOM/ATOM) GROUP(GR.1 TO GR. NEG)
SPUTTERING YIELDS FOR EACH WALL MATERIAL.

FOR WALL MATERIAL # 1

1.1394E-02 1.0416E-03

FOR WALL MATERIAL # 2

4.6152E-02 2.2408E-02

TOTAL SPUTTRNG YIELD FOR EACH SURFACE ELEMENT

EL.#	TOT SPUT YLD	EL.#	TOT SPUT YLD	EL.#	TOT SPUT YLD	EL.#	TOT SPUT YLD	EL.#	TOT SPUT YLD
1	1.08871E-02	2	8.63724E-03	3	7.72364E-03	4	7.50410E-03	5	8.28838E-03
6	4.46804E-03	7	6.54290E-03	8	6.88388E-03	9	6.88388E-03	10	6.54290E-03
11	4.46804E-03	12	8.0838E-03	13	7.50410E-03	14	7.72364E-03	15	8.63724E-03
16	1.08871E-02	17	1.24692E-01	18	8.07658E-02	19	1.22104E-01	20	1.16268E-01
21	1.16268E-01	22	1.22104E-01	23	8.07658E-02	24	1.24692E-01		

LENGTH OF THE FIRST SIDE OF THE SURFACE ELMENT

EL.#	SIDE LENGTH.	EL.#	SIDE LENGTH.	EL.#	SIDE LENGTH.	EL.#	SIDE LENGTH.	EL.#	SIDE LENGTH.
1	2.69258E-01	2	2.54951E-01	3	2.54951E-01	4	2.69258E-01	5	3.20156E-01
6	1.80278E-01	7	2.69258E-01	8	2.54951E-01	9	2.54951E-01	10	2.69258E-01
11	1.80278E-01	12	3.20156E-01	13	2.69258E-01	14	2.54951E-01	15	2.54951E-01
16	2.69258E-01	17	3.20156E-01	18	1.80278E-01	19	2.69258E-01	20	2.54951E-01
21	2.54951E-01	22	2.69258E-01	23	1.80278E-01	24	3.20156E-01		

TOTAL POWER DEPOSITION(WATT) FOR EACH SUR. EL.

EL.#	POWER DEPSN.	EL.#	POWER DEPSN.	EL.#	POWER DEPSN.	EL.#	POWER DEPSN.	EL.#	POWER DEPSN.
1	1.28091E-17	2	8.84254E-18	3	7.95174E-18	4	7.16752E-18	5	7.80219E-18
6	4.17598E-18	7	6.09085E-18	8	5.65833E-18	9	5.65833E-18	10	6.09085E-18
11	4.17598E-18	12	7.80219E-18	13	7.16752E-18	14	7.95174E-18	15	8.84254E-18
16	1.28091E-17	17	2.79788E-17	18	1.79373E-17	19	2.71527E-17	20	2.58909E-17
21	2.58909E-17	22	2.71527E-17	23	1.79373E-17	24	2.79788E-17		

TOTAL EROSION RATE(CC/SEC) FOR EACH SUR. EL.

EL.#	EROSION RATE	EL.#	EROSION RATE	EL.#	EROSION RATE	EL.#	EROSION RATE	EL.#	EROSION RATE
1	1.28807E-25	2	1.02188E-25	3	9.13791E-26	4	8.87817E-26	5	9.80606E-26
6	5.28618E-26	7	7.74096E-26	8	7.19685E-26	9	7.19685E-26	10	7.74096E-26
11	5.28618E-26	12	9.80606E-26	13	8.87817E-26	14	9.13791E-26	15	1.02188E-25
16	1.28807E-25	17	1.59278E-24	18	1.03168E-24	19	1.55971E-24	20	1.40517E-24
21	1.40517E-24	22	1.55971E-24	23	1.03168E-24	24	1.59278E-24		

ABSORPTION(IONIZATION) AND DIFFUSION LOSS RATE

GROUP # IONIZATION RATE DIFFUSION RATE

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1      5.857621E+00      7.934273E+00
2      1.275413E+01      1.446079E+01

```

PARTICLE BALANCE.

```

-----
TOTAL ABSORPTION RATE= 1.861176E+01
TOTAL DIFFUSION LOSS RATE= 2.239507E+01
TOTAL EXTERNAL SOURCE= 4.100047E+01
ADDTL. SOURCE FROM DESORBED PARTICLES= 0.
LOSS TO SOURCE RATIO= 9.999597E-01

```

ENERGY BALANCE.

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-----
ENERGY GAIN FROM THE EXTERNAL SOURCE= 2.255466E+03EV
ENERGY GAIN FROM THE PLASMA= 1.310337E+03EV
ENERGY LOSS BY IONIZATION= 1.500120E+03EV
ENERGY LOSS BY DIFFUSION= 1.985405E+03EV
GAIN TO LOSS RATIO= 1.000055E+00

```

COMPUTATION TIME REQUIRED FOR THIS JOB IS= 3.374483E-03 MINUTES.

```

MAXIMUM TOTAL DENSITY= 2.271464E-07 #/CM**3
MINIMUM TOTAL DENSITY= 1.980357E-08 #/CM**3
ORDER OF DENSITY ATTENUATION= 1.0596

```

SUMMARY FOR POLOIDAL PLOTS.

FOR RADIUS= 1.0000 CMS, 32 TOTAL NODAL DENSITIES ARE PLOTTED.

FOR RADIUS= 0.5000 CMS, 12 TOTAL NODAL DENSITIES ARE PLOTTED.

FOR RADIUS= 1.0000 CMS, 32 NODAL AVERAGE ENERGIES ARE PLOTTED.

FOR RADIUS= 0.5000 CMS, 12 NODAL AVERAGE ENERGIES ARE PLOTTED.

TOTAL TIME REQUIRED FOR THIS JOB IS= 8.024575E-02 MINUTES.

3-d total flux plot

3-D AVERAGE ENERGY PROFILE

3-D TOTAL DENSITY PLOT

TOTAL DENSITY ALONG POL. DIR.

AVE. ENERGY ALONG POL. DIR.

WALL MATERIAL SPUTTERING RATE

POWER DEPOSITION ON THE WALL

WALL MATERIAL EROSION RATE

FR80

BOX K20 EXPENDSTD

TV80LIB.MFE.CRAY - VERSION 3 0

FR80 OUTPUT... 18:40:23 07/19/86D

0011 FRAMES PLOTTED

USER NUMBER = 014263

1 S GROUP, 22# ELEMENT, X-Y GEOMETRY SAMPLE PROBLEM. SURFACE SOURCE.
 2 NEG=5 NDM-2 IGEOM-1 NTHD-1 NEL=82# NMP=461
 3 MPFL-3 MMT-2# MNTVL-3 MSHGN=8 IENRGP=8 IVLS=8
 4 ISS=1 MFC-1 NSRCTV=8 NSRCTS=2 NVSG=8 MSSG=1
 5 MBENS=6# MBESS=2# MBESVS=8 MBEVS=8 NIEVS=8 MIENS=740
 6 IBC=8 ICSFLX=2 IGXN=8 LNKMAT=8 LNKWX=8 IPTD=8
 7 MPTD=8 ITRMMX=5# ITRMS=8 NORM=8 ICHCK=2 ISPUT=8
 8 IRSLT=1 IKD1M=2# IYD1M=2# ISCALE=8 IXBLN=1 IYBLN=1
 9 JADSS=8 MSHWMD=8 NWMD=8 ICMTR=1 IPPLT=8 MPRAD=8
 10 MSHBL=5 ISCMRT=8 IGPOUT=1 IELFLX=8 IDUMP=8 ITFLX=8
 11 ITORLC=8 MSLN=1 LTSCG=1 \$
 12 6.0000E+01 2.0000E+01 1.0000E+04 1.0000E+06 1.0000E+00 1.3760E+06
 13 0.0000E+00 3.0000E+03 1.0000E+00 2.5000E+00 1.0000E+00 0.0000E+00
 14 1.0000E+00
 15 0.5000E+00 1.1000E+01 7.0000E+00 7.0000E+00 1.0000E+00 1.0000E+00
 16 1.0000E+00 -1.3500E+02 4.5000E+01 2.0000E+01 0.0000E+00 5.0000E+00
 17 2.0000E+01 0.0000E+00 5.0000E+00 2.0000E+01 4.0000E+00 2.0000E+00
 18 1.0000E+01 5.0000E-01
 19 3 21 X-VALUES
 20 0.0000E+00 2.0000E+01
 21 1 1
 22 0.0000E+00
 23 3 20
 24 5.0000E-01 1.9500E+01
 25 1 1 +43
 26 2.0000E+01
 27 4 9 +43#-9X43+43
 28 1 43
 29 3 21 +451
 30 0.0000E+00 2.0000E+01
 31 2 21 Y-VALUES
 32 0.0000E+00
 33 2 22 -43
 34 1.0000E+00
 35 2 21
 36 2.0000E+00
 37 2 22
 38 3.0000E+00
 39 2 21
 40 4.0000E+00
 41 2 22 -129
 42 5.0000E+00
 43 2 21
 44 6.0000E+00
 45 2 22
 46 7.0000E+00
 47 2 21
 48 8.0000E+00
 49 2 22 -215
 50 9.0000E+00
 51 2 21
 52 1.0000E+01
 53 2 22
 54 1.1000E+01
 55 2 21
 56 1.2000E+01
 57 2 22 -301
 58 1.3000E+01
 59 2 21
 60 1.4000E+01
 61 2 22
 62 1.5000E+01
 63 2 21
 64 1.6000E+01

"DATAIN"

Problem #4


```

65      2 22 -387
66      1.7####E+01
67      2 21
68      1.8####E+01
69      2 22
70      1.9####E+01
71      2 21 -451
72      2.0####E+01
73      3 2# NODE CONNECTION
74      1 21 23 42 1 1
75      1 2#
76      22 1 23 44 22 23 65 44 66 87 65 66
77      100 87 109 13# 188 109 151 13# 152 173 151 152
78      194 173 195 216 194 195 237 216 238 259 237 238
79      28# 259 281 3#2 28# 281 323 3#2 324 345 323 324
80      366 345 367 388 366 367 489 388 41# 431 489 41#
81      3 2# -6#
82      41# 42# 431 451 2 1
83      1 2#
84      43# 451 429 4#8 43# 429 387 4#8 386 365 387 386
85      344 365 343 322 344 343 3#1 322 3#8 279 3#1 3#8
86      258 279 257 236 258 257 215 236 214 193 215 214
87      172 193 171 15# 172 171 129 15# 128 187 129 128
88      86 187 86 64 86 85 43 64 42 21 43 42
89      3 1# -99
90      2 2# 23 42 2 1
91      4 1# -8#1-18X39+99
92      23 42 21 22 2 1
93      3 1# -82#
94      41# 42# 432 45# 1 1
95      3 2# MATERIAL CONNECTION
96      1 2#
97      2 2#
98      1
99      3 2#
100      1 2# -6#
101      2 2#
102      2#
103      3 1# -99
104      1 1#
105      1 3# -138
106      1 1 2 2 3 3 4 4 5 5 6 6
107      7 7 8 8 9 9 1# 1# 11 11 12 12
108      13 13 14 14 15 15 16 16 17 17 18 18
109      19 19 2#
110      4 17 -8#1-17X39+138
111      1# 138
112      3 1# -82#
113      1 1#
114      2 2# BOUNDARY CONDITIONS
115      2
116      3 2#
117      2 2#
118      2
119      2
120      2 2# -8#
121      1
122      2 8# # OF BOUNDARY SIDES
123      1
124      2 6 SURFACE SOURCE TYPE CONNECTION
125      2
126      2 #8
127      1
128      2 6 -2#

```

129	2						
130	2	20	SIDE # WITH SURFACE SOURCE				
131	1						
132	3.0000E+03	1.0000E+03	5.0000E+02	2.0000E+02	0.0000E+02	1.0000E+00	
133	1.0000E+00						
134	0.0000E+00						
135	0						
136	1.0000E+00	1.0000E+00	1.0000E+00	1.0000E+00	1.0000E+00	1.0000E+00	
137	5.0000E-01	5.0000E-01	5.0000E-01	5.0000E-01	5.0000E-01	5.0000E-01	
138	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	

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GROUP # 4 ALBEDO= 0.

GROUP # 5 ALBEDO= 0.

CROSS SECTION DATA.

CROSS SECTIONS FOR ANY GROUP, I, ARE PRINTED AS:
TOTAL,ABS,TOTAL SCATT.,GR.I TO GR.I,GR.I TO GR.2
.....,GR.I TO GR.NEG

"DATOUT"

MATERIAL # 1

1.21711E-01	3.12311E-02	9.04800E-02	4.84500E-02	2.27370E-02	1.35407E-02
3.60245E-03	2.14911E-03				
1.76327E-01	4.82109E-02	1.28116E-01	7.16859E-02	3.12565E-02	1.77991E-02
4.63527E-03	2.73925E-03				
2.52175E-01	7.14310E-02	1.00744E-01	1.04556E-01	4.37040E-02	2.33690E-02
5.77906E-03	3.33606E-03				
3.70647E-01	1.06977E-01	2.63669E-01	1.55475E-01	6.38420E-02	3.27230E-02
7.51696E-03	4.11176E-03				
1.11599E-00	3.26714E-01	7.89277E-01	4.72153E-01	1.91599E-01	9.56029E-02
2.04737E-02	9.44942E-03				

MATERIAL # 2

1.21118E-01	3.10934E-02	9.00242E-02	4.80046E-02	2.26681E-02	1.35220E-02
3.60064E-03	2.14889E-03				
1.75440E-01	4.80002E-02	1.27440E-01	7.11412E-02	3.11603E-02	1.77745E-02
4.63293E-03	2.73897E-03				
2.50897E-01	7.11190E-02	1.79777E-01	1.03759E-01	4.35691E-02	2.33366E-02
5.77614E-03	3.33571E-03				
3.68740E-01	1.06512E-01	2.62236E-01	1.54290E-01	6.36447E-02	3.26773E-02
7.51315E-03	4.11132E-03				
1.11023E-00	3.25294E-01	7.84934E-01	4.68548E-01	1.91006E-01	9.54687E-02
2.04633E-02	9.44830E-03				

MATERIAL # 3

1.19931E-01	3.08178E-02	8.91127E-02	4.73546E-02	2.25280E-02	1.34846E-02
3.59705E-03	2.14849E-03				
1.73691E-01	4.75705E-02	1.26112E-01	7.00532E-02	3.09671E-02	1.77252E-02
4.62031E-03	2.73846E-03				
2.48340E-01	7.04971E-02	1.77843E-01	1.02160E-01	4.32900E-02	2.32714E-02
5.77036E-03	3.33508E-03				
3.64952E-01	1.05501E-01	2.59371E-01	1.51921E-01	6.32484E-02	3.25057E-02
7.50861E-03	4.11054E-03				
1.09870E-00	3.22453E-01	7.76250E-01	4.61347E-01	1.89814E-01	9.51996E-02
2.04425E-02	9.44624E-03				

MATERIAL # 4

1.18150E-01	3.04041E-02	8.77458E-02	4.62617E-02	2.23162E-02	1.34202E-02
3.59176E-03	2.14801E-03				
1.71055E-01	4.69455E-02	1.24109E-01	6.84242E-02	3.06751E-02	1.76509E-02
4.62150E-03	2.73784E-03				
2.44506E-01	6.95624E-02	1.74943E-01	9.97056E-02	4.28884E-02	2.31733E-02
5.76103E-03	3.33431E-03				

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833      4.34307E-02      1.40384E-02      2.94802E-02      4.02680E-03      0.62069E-03      1.01611E-02
834      3.06256E-03      2.72909E-03
835      6.01442E-02      2.00690E-02      3.92743E-02      5.02990E-03      1.20068E-02      1.32995E-02
836      4.01402E-03      3.32336E-03
837      8.63611E-02      3.13023E-02      5.50486E-02      0.64054E-03      1.75027E-02      1.05581E-02
838      6.26575E-03      4.09174E-03
839      2.54954E-01      9.66910E-02      1.59263E-01      2.62075E-02      5.25169E-02      5.41425E-02
840      1.70317E-02      9.36461E-03
841
842      MATERIAL #      19
843      -----
844
845      2.03063E-02      6.04193E-03      1.42644E-02      8.97117E-04      3.36345E-03      5.56059E-03
846      2.51442E-03      1.93878E-03
847      2.03071E-02      9.43444E-03      1.88727E-02      1.29596E-03      4.59509E-03      7.27776E-03
848      3.23300E-03      2.47006E-03
849      3.00461E-02      1.40346E-02      2.40116E-02      1.07216E-03      6.38926E-03      9.51220E-03
850      4.03041E-03      3.00754E-03
851      5.53226E-02      2.10559E-02      3.42666E-02      2.77260E-03      9.30570E-03      1.32531E-02
852      5.23403E-03      3.70117E-03
853      1.61920E-01      6.43793E-02      9.75409E-02      0.39749E-03      2.78023E-02      3.85893E-02
854      1.42202E-02      0.44363E-03
855
856      MATERIAL #      20
857      -----
858
859      9.04068E-03      2.71062E-03      6.32206E-03      1.14901E-04      9.26929E-04      2.49994E-03
860      1.47378E-03      1.30651E-03
861      1.28132E-02      4.25075E-03      0.26247E-03      1.65106E-04      1.26309E-03      3.27437E-03
862      1.89540E-03      1.66451E-03
863      1.69743E-02      6.32603E-03      1.06403E-02      2.30055E-04      1.75177E-03      4.26997E-03
864      2.36197E-03      2.02653E-03
865      2.30045E-02      9.49243E-03      1.43921E-02      3.52221E-04      2.54009E-03      5.93439E-03
866      3.06515E-03      2.49220E-03
867      6.89496E-02      2.90263E-02      3.99233E-02      1.06600E-03      7.62790E-03      1.72457E-02
868      0.32241E-03      5.66135E-03
869
870      FLUX GUESS WAS SET TO ZERO.
871      -----
872

```

plot of the spatial mesh

5 GROUP. 828 ELEMENT, X-Y GEOMETRY SAMPL. PROBLEM. SURFACE SOURCE.

THIS SOLUTION IS BY ISOTROPIC DIFFUSION THEORY.

GEOMETRY IS X-Y CARTESIAN.

"RESULT"

RESULT FOR FOURIER COMPONENT # 1

FLUX HAS CONVERGED IN 15 ITERATIONS.

TOLERANCE WAS MET ON FLUX.

GROUP ENERGY(EV) AND VELOCITY(CM/SEC)

GROUP #	LOWER BOUND	UPPER BOUND	GROUP ENERGY	GROUP VELOCITY
1	1.000000E+03	3.000000E+03	2.000000E+03	6.153659E+07
2	5.000000E+02	1.000000E+03	7.500000E+02	3.768331E+07
3	2.000000E+02	5.000000E+02	3.500000E+02	2.574260E+07
4	1.000000E+02	2.000000E+02	1.500000E+02	1.685249E+07
5	1.000000E+00	1.000000E+02	5.000000E+01	9.778317E+06

GROUP FLUX:

NODE	X-VAL,CM	Y-VAL,CM	GROUP NO. 1	GROUP NO. 2	GROUP NO. 3	GROUP NO. 4	GROUP NO. 5
1	0.000	0.000	2.390514E-02	7.346645E-03	2.058200E-03	2.524445E-04	3.782260E-05
2	1.000	0.000	2.856747E-02	9.502836E-03	2.904167E-03	3.092026E-04	7.251242E-05
3	2.000	0.000	3.371965E-02	1.202694E-02	3.071002E-03	5.223158E-04	9.095703E-05
4	3.000	0.000	3.935506E-02	1.502717E-02	5.057342E-03	6.739006E-04	1.113541E-04
5	4.000	0.000	4.551039E-02	1.864703E-02	6.569003E-03	8.635055E-04	1.360209E-04
6	5.000	0.000	5.217397E-02	2.301291E-02	8.539201E-03	1.114762E-03	1.664495E-04
7	6.000	0.000	5.931119E-02	2.826107E-02	1.112848E-02	1.460595E-03	2.044834E-04
8	7.000	0.000	6.685635E-02	3.452689E-02	1.453602E-02	1.940787E-03	2.526649E-04
9	8.000	0.000	7.471126E-02	4.192270E-02	1.899465E-02	2.640072E-03	3.149507E-04
10	9.000	0.000	8.274567E-02	5.052662E-02	2.475969E-02	3.653682E-03	3.994781E-04
11	10.000	0.000	9.080239E-02	6.035423E-02	3.200350E-02	5.009731E-03	5.302368E-04
12	11.000	0.000	9.891111E-02	7.141111E-02	4.111111E-02	6.777777E-03	7.217355E-04
13	12.000	0.000	1.062760E-01	8.326505E-02	5.211332E-02	9.046454E-03	1.172703E-03
14	13.000	0.000	1.133259E-01	9.581332E-02	6.400040E-02	1.134305E-02	1.430014E-03
15	14.000	0.000	1.196665E-01	1.084640E-01	7.802006E-02	1.386346E-02	1.751779E-03
16	15.000	0.000	1.251102E-01	1.204707E-01	9.337021E-02	1.666200E-02	2.137560E-03
17	16.000	0.000	1.295037E-01	1.310599E-01	1.072509E-01	2.030506E-02	2.637266E-03
18	17.000	0.000	1.329136E-01	1.397321E-01	1.194910E-01	2.341553E-02	3.025414E-03
19	18.000	0.000	1.354787E-01	1.457573E-01	1.283816E-01	2.736105E-02	3.396199E-03
20	19.000	0.000	1.371450E-01	1.492251E-01	1.334773E-01	3.196910E-02	3.825414E-03
21	20.000	0.000	1.376464E-01	1.501520E-01	1.347739E-01	3.402772E-02	4.195730E-03

833 56 6.08160E-02 57 7.96915E-02 58 9.17025E-02 59 1.02401E-01 60 1.08480E-01
 834 61 0. 62 0. 63 0. 64 0. 65 0.
 835 66 0. 67 0. 68 0. 69 0. 70 0.
 836 71 0. 72 0. 73 0. 74 0. 75 0.
 837 76 0. 77 0. 78 0. 79 0. 80 0.
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 839

ABSORPTION(IONIZATION) AND DIFFUSION LOSS RATE

GROUP #	IONIZATION RATE	DIFFUSION RATE
1	7.502889E-01	8.743998E-01
2	8.604726E-01	5.677813E-01
3	8.488756E-01	3.678195E-01
4	2.951946E-01	8.650375E-02
5	3.143194E+00	1.981862E-01

PARTICLE BALANCE.

TOTAL ABSORPTION RATE= 5.906025E+00
 TOTAL DIFFUSION LOSS RATE= 2.093090E+00
 TOTAL EXTERNAL SOURCE= 8.000000E+00
 ADDTL. SOURCE FROM DESORBED PARTICLES= 0.
 LOSS TO SOURCE RATIO= 9.999895E-01

ENERGY BALANCE.

ENERGY GAIN FROM THE EXTERNAL SOURCE= 4.040000E+02EV
 ENERGY GAIN FROM THE PLASMA= 4.504267E+03EV
 ENERGY LOSS BY IONIZATION= 2.662049E+03EV
 ENERGY LOSS BY DIFFUSION= 2.326076E+03EV
 GAIN TO LOSS RATIO= 1.000028E+00

COMPUTATION TIME REQUIRED FOR THIS JOB IS= 4.623923E-02 MINUTES.

MAXIMUM TOTAL DENSITY= 1.499392E-07 #/CM**3
 MINIMUM TOTAL DENSITY= 6.822316E-10 #/CM**3
 ORDER OF DENSITY ATTENUATION= 2.3420

TOTAL TIME REQUIRED FOR THIS JOB IS= 1.376142E-01 MINUTES.

3-D total flux plot

3-D AVERAGE ENERGY PROFILE

3-D TOTAL DENSITY PLOT

CONTOUR PLOT OF TOTAL DENSITY

```

1  $ GROUP, 82# ELEMENT, X-Y GEOMETRY SAMPLE PROBLEM. SUR+VOL SOURCE.
2  NEG=1 NDM=2 IGEOM=1 MTHD=1 NEL=82# NNP=451
3  NPFL=3 NMT=2# NHTWL=3 MSHGM=1 IENRGP=1 IVLS=1
4  ISS=1 NFC=1 NSRCTV=1 NSRCTS=2 NVSG=1 NSSG=1
5  NGENS=1# NDESS=1# NDESVS=2 NDEVS=2 NIEVS=7# NIENS=662
6  IBC=1 IGSFLX=2 ICMX=1 LNKHAT=1 LNKWX=1 IPTD=1
7  NPTD=1 ITRHMX=5# ITRANS=1 NORN=1 ICHCK=2 ISPUT=1
8  IRSLT=1 IXDIM=2# IYDIM=2# ISCALE=1 IXBLN=1 IYBLN=1
9  IADSS=1 MSHMND=1 MWINDS=1 ICHTR=1 IPFLT=1 NPRAD=1
1# MSHML=1 ISCKRT=1 IGPOUT=1 IELFLX=1 IDUMP=1 ITFLX=1
11 ITORLC=1 MSLN=1 LTSGO=1 $
12 6.0000E+01 2.0000E+01 1.0000E+04 1.0000E+06 1.0000E+08 1.3760E+06
13 0.0000E+00 3.0000E+03 1.0000E+08 2.5000E+06 1.0000E+08 0.0000E+00
14 1.0000E+00
15 0.0000E+00 1.1000E+01 7.0000E+00 7.0000E+00 1.0000E+00 1.0000E+00
16 1.0000E+00 -1.3500E+02 4.5000E+01 2.0000E+01 0.0000E+00 5.0000E+00
17 2.0000E+01 0.0000E+00 6.0000E+00 2.0000E+01 4.0000E+00 2.0000E+00
18 1.0000E+01 6.0000E+01
19 3 21 X-VALUES
20 0.0000E+00 2.0000E+01
21 1 1
22 0.0000E+00
23 3 2#
24 5.0000E+01 1.9500E+01
25 1 1 =43
26 2.0000E+01
27 4 9 =43#-9X43+43
28 1 43
29 3 21 =451
30 0.0000E+00 2.0000E+01
31 2 21 Y-VALUES
32 0.0000E+00
33 2 22 =43
34 1.0000E+00
35 2 21
36 2.0000E+00
37 2 22
38 3.0000E+00
39 2 21
40 4.0000E+00
41 2 22 =129
42 5.0000E+00
43 2 21
44 6.0000E+00
45 2 22
46 7.0000E+00
47 2 21
48 8.0000E+00
49 2 22 =215
50 9.0000E+00
51 2 21
52 1.0000E+01
53 2 22
54 1.1000E+01
55 2 21
56 1.2000E+01
57 2 22 =301
58 1.3000E+01
59 2 21
60 1.4000E+01
61 2 22
62 1.5000E+01
63 2 21
64 1.6000E+01

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"DATAIN"

Problem #5


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129      3
130      2  2#
131      2
132      2  1#
133      1
134      2  2
135      1
136      2  2  =3#
137      3
138      2  2#  # OF BOUNDARY SIDES
139      1
140      2  4#  VOL. SOURCE TYPE CONNECTION
141      1
142      2  6  SURFACE SOURCE TYPE CONNECTION
143      2
144      2  4#
145      1
146      2  6
147      2
148      2  2  =2#
149      1
150      2  2#  SIDE # WITH SURFACE SOURCE
151      1
152      3.####E+03  1.####E+03  5.####E+02  2.####E+02  1.####E+02  1.####E+00
153      5.####E-01
154      5
155      1.####E+00
156      5.####E+00
157      5
158      1.####E+00  1.####E+00  1.####E+00  1.####E+00  1.####E+00
159      5.####E-01  5.####E-01  5.####E-01  5.####E-01  5.####E-01
160      5.####E+00  5.####E+00  5.####E+00  5.####E+00  5.####E+00

```

plot of the spatial mesh

5 GROUP, #2# ELEMENT, X-Y GEOMETRY SAMPLE PROBLEM. SUR+VOL SOURCE.

THIS SOLUTION IS BY ISOTROPIC DIFFUSION THEORY.

GEOMETRY IS X-Y CARTESIAN.

"RESULT"

RESULT FOR FOURIER COMPONENT # 1

FLUX HAS CONVERGED IN 15 ITERATIONS.

TOLERANCE WAS MET ON FLUX.

GROUP ENERGY(EV) AND VELOCITY(CM/SEC)

GROUP #	LOWER BOUND	UPPER BOUND	GROUP ENERGY	GROUP VELOCITY
1	1.000000E+03	3.000000E+03	2.000000E+03	6.153659E+07
2	5.000000E+02	1.000000E+03	7.500000E+02	3.768331E+07
3	2.500000E+02	5.000000E+02	3.500000E+02	2.574266E+07
4	1.000000E+02	2.000000E+02	1.500000E+02	1.686249E+07
5	1.000000E+01	1.000000E+02	5.000000E+01	9.778317E+06

GROUP FLUX:

NODE	X-VAL,CM	Y-VAL,CM	GROUP NO. 1	GROUP NO. 2	GROUP NO. 3	GROUP NO. 4	GROUP NO. 5
1	0.0000	0.0000	1.459933E-01	3.941372E-02	1.156111E-02	1.519001E-03	2.239290E-04
2	1.0000	0.0000	1.733745E-01	5.038505E-02	1.611142E-02	2.342073E-03	4.620598E-04
3	2.0000	0.0000	1.992926E-01	6.104834E-02	2.030922E-02	3.022548E-03	5.652357E-04
4	3.0000	0.0000	2.252701E-01	7.227810E-02	2.492876E-02	3.706505E-03	6.734039E-04
5	4.0000	0.0000	2.508459E-01	8.406027E-02	2.983681E-02	4.427086E-03	7.796016E-04
6	5.0000	0.0000	2.764654E-01	9.683102E-02	3.547176E-02	5.274044E-03	9.134581E-04
7	6.0000	0.0000	3.014682E-01	1.104441E-01	4.189514E-02	6.263719E-03	1.049575E-03
8	7.0000	0.0000	3.265564E-01	1.264498E-01	4.959152E-02	7.525594E-03	1.231106E-03
9	8.0000	0.0000	3.508861E-01	1.415149E-01	5.867133E-02	9.093306E-03	1.425586E-03
10	9.0000	0.0000	3.753620E-01	1.592404E-01	6.943029E-02	1.116709E-02	1.707717E-03
11	10.0000	0.0000	3.988748E-01	1.779567E-01	8.199261E-02	1.378862E-02	2.078099E-03
12	11.0000	0.0000	4.224934E-01	1.982188E-01	9.684311E-02	1.722175E-02	2.796209E-03
13	12.0000	0.0000	4.447893E-01	2.188654E-01	1.133388E-01	2.142798E-02	4.275672E-03
14	13.0000	0.0000	4.669540E-01	2.403337E-01	1.318434E-01	2.663902E-02	7.923146E-03
15	14.0000	0.0000	4.874026E-01	2.610514E-01	1.510472E-01	3.256681E-02	1.616640E-02
16	15.0000	0.0000	5.072123E-01	2.811185E-01	1.706636E-01	3.913677E-02	3.353736E-02
17	16.0000	0.0000	5.242312E-01	2.980660E-01	1.880333E-01	4.538015E-02	6.306531E-02
18	17.0000	0.0000	5.400255E-01	3.129740E-01	2.035341E-01	5.126030E-02	1.006993E-01
19	18.0000	0.0000	5.518388E-01	3.232789E-01	2.142047E-01	5.543197E-02	1.506512E-01
20	19.0000	0.0000	5.602760E-01	3.302583E-01	2.210226E-01	5.806390E-02	2.000997E-01
21	20.0000	0.0000	5.620402E-01	3.316720E-01	2.223616E-01	5.857325E-02	2.107293E-01

833 56 2.00714E-51 57 2.22847E-51 58 2.30624E-51 59 #. 60 #.
 834 61 #. 62 #. 63 #. 64 #. 65 #.
 835 66 #. 67 #. 68 #. 69 #. 70 #.
 836 71 #. 72 #. 73 #. 74 #. 75 #.
 837 76 #. 77 #. 78 #. 79 3.03715E-51 80 3.91032E-51
 838
 839
 840
 841

ABSORPTION(IONIZATION) AND DIFFUSION LOSS RATE

GROUP #	IONIZATION RATE	DIFFUSION RATE
1	4.070497E+00	4.918436E+00
2	2.900512E+00	2.014241E+00
3	2.305397E+00	9.561078E-01
4	7.072794E-01	1.003211E-01
5	9.356577E+00	5.023300E-01

PARTICLE BALANCE.

TOTAL ABSORPTION RATE= 1.942026E+01
 TOTAL DIFFUSION LOSS RATE= 8.579444E+00
 TOTAL EXTERNAL SOURCE= 2.000000E+01
 ADDTL. SOURCE FROM DESORBED PARTICLES= 0.
 LOSS TO SOURCE RATIO= 9.999895E-01

ENERGY BALANCE.

ENERGY GAIN FROM THE EXTERNAL SOURCE= 1.414000E+03EV
 ENERGY GAIN FROM THE PLASMA= 2.200416E+04EV
 ENERGY LOSS BY IONIZATION= 1.176187E+04EV
 ENERGY LOSS BY DIFFUSION= 1.173581E+04EV
 GAIN TO LOSS RATIO= 1.000021E+00

COMPUTATION TIME REQUIRED FOR THIS JOB IS= 4.525736E-02 MINUTES.

MAXIMUM TOTAL DENSITY= 2.081505E-07 #/CM**3
 MINIMUM TOTAL DENSITY= 3.852581E-09 #/CM**3
 ORDER OF DENSITY ATTENUATION= 1.7326

TOTAL TIME REQUIRED FOR THIS JOB IS= 1.509574E-01 MINUTES.

3-D total flux plot

3-D AVERAGE ENERGY PROFILE

3-D TOTAL DENSITY PLOT

CONTOUR PLOT OF TOTAL DENSITY

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