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**HYBRID-II, A TWO-DIMENSIONAL MULTISPECIES
FOKKER-PLANCK COMPUTER CODE**

Arthur A. Mirin

February 3, 1975

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HYBRID-II, A TWO-DIMENSIONAL MULTISPECIES FOKKER-PLANCK COMPUTER CODE

Abstract

The computer program Hybrid-II solves the time-dependent two-dimensional Fokker-Planck equation for an arbitrary number of ion species plus electrons. The two velocity dimensions are velocity magnitude and pitch angle, and it is assumed that the electron distribution is a function of velocity magnitude only.

The program may be applied to problems in the areas of both mirror confinement and toroidal confinement. In the former case, a self-consistent ambipolar potential is computed to assure charge neutrality. In the latter case, we include terms representing finite particle and energy confinement times along with major radius compression.

The ion distribution functions are integrated in time using either a split semi-implicit algorithm or an alternating-direction-implicit (A.D.I.) difference scheme. The electron distribution function is advanced using either a semi-implicit or fully-implicit difference algorithm. In addition, since the electrons are usually on a faster time scale than the ions, a multiple number of smaller electron time steps per large ion time step may be employed to increase the accuracy of the electron integration.

The ion velocity and angular finite-difference meshes usually consist of 45 and 14 points, respectively. The electron velocity mesh, which is an extension of the ion velocity mesh, usually consists of 201 points. The field length for a four species calculation on the above mesh is approximately 75,000 (decimal), and the running time is approximately 80 time steps per minute. No tapes or disc files are necessary for code input or for the operation of the code. Both plots and printed data (including microfiche) comprise the output.

Introduction

This report summarizes the basic equations of the Hybrid-II code and the methods used to solve them numerically. A detailed description of the program along with a commented listing is included.

1. Basic Equations

We let $f_a(v, \theta)$ be the distribution function for ion species "a" and $f_e(v)$ be the electron distribution function. Here, v is velocity magnitude and θ is the angle between

$\vec{v}$ and the magnetic axis. We may or may not assume symmetry of $f_a(v, \theta)$ about $\theta = \pi/2$. The normalized velocity x is defined by

$$v = \tilde{v} x, \quad (1.1)$$

where $\tilde{v}$ is an input constant, and the normalized distribution functions are given by

$$F_a = \frac{\tilde{v}^3}{K_a} \cdot f_a, \quad (1.2)$$

where $K_a = n_a(0)$ is the initial density of species "a".

The equation for species "a" is then

$$\frac{\partial F_a}{\partial t} = \left(\frac{\partial F_a}{\partial t} \right)_c + S_a + C_a + M_a + T_a + R_a + B_a + A_a, \quad (1.3)$$

where $(\partial F_a / \partial t)_c$ is the Fokker-Planck collision term, S_a is the source term, C_a is the charge-exchange loss term, M_a is the mirror loss term, T_a is the toroidal term representing finite particle and energy confinement times, R_a is the toroidal major radius compression term, B_a is the time-dependent magnetic field derivative term, and A_a is the alpha particle heating term.

2. The Fokker-Planck Collision Term

The Fokker-Planck collision operator for ion species "a" is given by

$$\left(\frac{\partial F_a}{\partial t} \right)_c = \frac{K_a \Gamma_a}{\tilde{v}^3} \left(\frac{1}{x^2} \frac{\partial \bar{G}_a}{\partial x} + \frac{1}{x^2 \sin \theta} \frac{\partial \bar{H}_a}{\partial \theta} \right), \quad (2.1)$$

where

$$\bar{G}_a = \bar{A}_a F_a + \bar{B}_a \frac{\partial F_a}{\partial x} + \bar{C}_a \frac{\partial F_a}{\partial \theta}, \quad (2.2)$$

$$\bar{H}_a = \bar{D}_a F_a + \bar{E}_a \frac{\partial F_a}{\partial x} + \bar{F}_a \frac{\partial F_a}{\partial \theta}. \quad (2.3)$$

The coefficients $\bar{A}_a$, $\bar{B}_a$, $\bar{C}_a$, $\bar{D}_a$, $\bar{E}_a$, and $\bar{F}_a$ satisfy

$$\begin{aligned} \bar{A}_a = & \frac{x^2}{2} \frac{\partial^3 G_a}{\partial x^3} + x \frac{\partial^2 G_a}{\partial x^2} - \frac{\partial G_a}{\partial x} - \frac{1}{x} \frac{\partial^2 G_a}{\partial \theta^2} + \frac{1}{2} \frac{\partial^3 G_a}{\partial x \partial \theta^2} - \frac{\cot \theta}{x} \frac{\partial G_a}{\partial \theta} \\ & + \frac{\cot \theta}{2} \frac{\partial^2 G_a}{\partial x \partial \theta} - x^2 \frac{\partial H_a}{\partial x}, \end{aligned} \quad (2.4)$$

$$\overline{B}_a = \frac{x^2}{2} \frac{\partial^2 G_a}{\partial x^2}, \quad (2.5)$$

$$\overline{C}_a = -\frac{1}{2x} \frac{\partial G_a}{\partial \theta} + \frac{1}{2} \frac{\partial^2 G_a}{\partial x \partial \theta}, \quad (2.6)$$

$$\begin{aligned} \overline{D}_a = & \frac{\sin \theta}{2x^2} \frac{\partial^3 G_a}{\partial \theta^3} + \frac{\sin \theta}{2} \frac{\partial^3 G_a}{\partial x^2 \partial \theta} + \frac{\sin \theta}{x} \frac{\partial^2 G_a}{\partial x \partial \theta} \\ & - \frac{1}{2x^2 \sin \theta} \frac{\partial G_a}{\partial \theta} + \frac{\cos \theta}{2x^2} \frac{\partial^2 G_a}{\partial \theta^2} - \sin \theta \frac{\partial H_a}{\partial \theta}, \end{aligned} \quad (2.7)$$

$$\overline{E}_a = \sin \theta \overline{C}_a, \quad (2.8)$$

$$\overline{F}_a = \frac{\sin \theta}{2x^2} \frac{\partial^2 G_a}{\partial \theta^2} + \frac{\sin \theta}{2x} \frac{\partial G_a}{\partial x}. \quad (2.9)$$

The Rosenbluth potentials G_a and H_a are given by

$$G_a = \sum_b \ln \Lambda_{ab} \frac{Z_b^2}{Z_a^2} \frac{K_b}{K_a} g_b, \quad (2.10)$$

$$H_a = \sum_b \ln \Lambda_{ab} \frac{Z_b^2}{Z_a^2} \frac{K_b}{K_a} \left(1 + \frac{m_a}{m_b} \right) h_b, \quad (2.11)$$

and

$$\nabla^4 g_b = -b\pi F_b, \quad (2.12)$$

$$\nabla^2 h_b = -4\pi F_b. \quad (2.13)$$

Here, Z_a is the atomic number for species "a", m_a is the mass, and

$$\Gamma_a = 4\pi Z_a^4 e^4 / m_a^2. \quad (2.14)$$

The Coulomb logarithm is defined by

$$\ln \Lambda_{ab} = \ln \left[\left(\frac{m_a m_b}{m_a + m_b} \right) \frac{2 \alpha \lambda_D}{r_e m_e c} \sup_{k=a,b} \sqrt{\frac{2 E_k}{m_k}} \right] - \frac{1}{2}, \quad (2.15)$$

where

$$\alpha = 1/137, \quad (2.16)$$

$$\lambda_D = \sqrt{E_e / 6 \pi n_e e^2}, \quad (2.17)$$

with E_k the energy of species k , and r_e the classical electron radius.

To solve Eqs. (2.12) and (2.13), we expand in Legendre polynomials

$$F_b(x, \theta) = \sum_{j=0}^M V_j(x) P_j(\cos \theta), \quad (2.18)$$

$$g_b(x, \theta) = \sum_{j=0}^M \hat{G}_j(x) P_j(\cos \theta), \quad (2.19)$$

$$h_b(x, \theta) = \sum_{j=0}^M \hat{H}_j(x) P_j(\cos \theta). \quad (2.20)$$

Here, the P_j satisfy

$$j P_j(\mu) - (2j - 1) \mu P_{j-1}(\mu) + (j - 1) P_{j-2}(\mu) = 0, \quad (2.21)$$

$$P_0(\mu) = 1, \quad (2.22)$$

$$P_1(\mu) = \mu. \quad (2.23)$$

We define the functionals

$$M_j(f)(x) = \int_x^\infty f(y) y^{1-j} dy, \quad (2.24)$$

$$N_j(f)(x) = \int_0^x f(y) y^{2+j} dy, \quad (2.25)$$

$$R_j(f)(x) = \int_x^\infty f(y) y^{3-j} dy, \quad (2.26)$$

$$E_j(f)(x) = \int_0^x f(y) y^{4+j} dy. \quad (2.27)$$

Then,

$$\hat{H}_j = \frac{4\pi}{(2j+1)} \left[x^{-j-1} N_j(V_j) + x^j M_j(V_j) \right], \quad (2.28)$$

$$\frac{\partial \hat{H}_j}{\partial x} = \frac{4\pi}{(2j+1)} \left[j x^{j-1} M_j(V_j) - (j+1) x^{-j-2} N_j(V_j) \right], \quad (2.29)$$

$$\begin{aligned} \hat{G}_j = \frac{4\pi}{(2j+1)} \left\{ \frac{1}{(2j+3)} \left[x^{-j-1} E_j(V_j) + x^{j+2} M_j(V_j) \right] \right. \\ \left. - \frac{1}{(2j-1)} \left[x^{1-j} N_j(V_j) + x^j R_j(V_j) \right] \right\}, \end{aligned} \quad (2.30)$$

$$\begin{aligned} \frac{\partial \hat{G}_j}{\partial x} = \frac{4\pi}{(2j+1)} \left\{ \frac{1}{(2j+3)} \left[(j+2) x^{j+1} M_j(V_j) - (j+1) x^{-j-2} E_j(V_j) \right] \right. \\ \left. - \frac{1}{(2j-1)} \left[j x^{j-1} R_j(V_j) - (j-1) x^{-j} N_j(V_j) \right] \right\}, \end{aligned} \quad (2.31)$$

$$\begin{aligned} \frac{\partial^2 \hat{G}_j}{\partial x^2} = \frac{4\pi}{(2j+1)} \left\{ \frac{(j+1)(j+2)}{(2j+3)} \left[x^{-j-3} E_j(V_j) + x^j M_j(V_j) \right] \right. \\ \left. - \frac{j(j-1)}{(2j-1)} \left[x^{-j-1} N_j(V_j) + x^{j-2} R_j(V_j) \right] \right\}, \end{aligned} \quad (2.32)$$

$$\begin{aligned} \frac{\partial^3 \hat{G}_j}{\partial x^3} = \frac{4\pi}{(2j+1)} \left\{ \frac{1}{(2j+3)} \left[j(j+1)(j+2) x^{j-1} M_j(V_j) - (j+1)(j+2)(j+3) x^{-j-4} E_j(V_j) \right] \right. \\ \left. - \frac{1}{(2j-1)} \left[j(j-1)(j-2) x^{-j-3} R_j(V_j) - (j+1)(j)(j-1) x^{-j-2} N_j(V_j) \right] \right\}. \end{aligned} \quad (2.33)$$

The electron collision operator is defined in a similar fashion. All angular derivatives in Eqs. (2.1) through (2.9) are set to 0, and the anisotropic components of the Rosenbluth potentials ($M > 0$) are ignored.

3. Source Term and Charge-Exchange Loss Term

The source term can be represented as a linear combination of Gaussians, i.e.,

$$S_a(x, \theta) = \sum_{\ell} \frac{1}{K_a} J_a^{\ell} \tilde{S}_a^{\ell}(x, \theta), \quad (3.1)$$

where $\tilde{S}_a^{\ell}$ is a shape function of density 1 satisfying

$$\tilde{S}_a^{\ell}(x, \theta) = a' e^{-b'(x-c')^2} e^{-d'(\cos\theta - e')^2}, \quad (3.2)$$

and J_a^{ℓ} is a current of the form

$$J_a^{\ell} = \sum_b \left(J_{ab}^{\ell 1} + J_{ab}^{\ell 2} \sqrt{n_b} + J_{ab}^{\ell 3} n_b \right) \delta_s^{a\ell}. \quad (3.3)$$

Here, the constants b' , c' , d' , e' , $J_{ab}^{\ell k}$ are input parameters. The quantity c' is input in energy units, and if it is 0, b' is input in energy units. The term $\delta_s^{a\ell}$ is 1 if $\tau_{on}^{a\ell} \leq t \leq \tau_{off}^{a\ell}$, otherwise it is 0. Here, $\tau_{on}^{a\ell}$ and $\tau_{off}^{a\ell}$ are the on and off times for source " ℓ " of species " a ", and are input parameters. Clearly d' is 0 for the electron source terms.

The charge-exchange loss term is defined as

$$C_a(x, \theta) = - \left[\sum_{b, \ell} c_{ab}^{\ell} \delta_s^{b\ell} \right] F_a, \quad (3.4)$$

where the constants c_{ab}^{ℓ} are input parameters. The presence of the factors $\delta_s^{b\ell}$ allows the whole charge-exchange process to be implemented as a unit; i.e., the appropriate source term is on only while the corresponding loss term is on, and vice versa.

4. Mirror Loss Term

Letting R_m denote the mirror ratio and ϕ_m the ambipolar potential at the mirror relative to the center ($\phi_m \geq 0$), we let

$$\gamma_{ca}^2 = (e\phi_m) / \frac{1}{2} m_a \tilde{v}^2 \quad (4.1)$$

and

$$\theta_L = \sin^{-1} \sqrt{1/R_m}. \quad (4.2)$$

For each ion species we define a function $\theta_{La}(x)$ by

$$\sin^2 \theta_{La} = 1 \quad \text{if } x^2 \geq \frac{x_{ca}^2 Z_a}{R_m - 1}; \quad (4.3)$$

otherwise,

$$\sin^2 \theta_{La} = \frac{1 + \frac{x_{ca}^2 Z_a}{x^2}}{\frac{x^2}{R_m}}. \quad (4.4)$$

The ion mirror loss term is

$$M_a = \frac{-\tilde{v}x \cos \theta}{L} F_a \quad (4.5)$$

if

$$|\theta - \pi/2| \geq |\theta_{La} - \pi/2|,$$

where L is the half-length of the mirror machine. We may also assume that the ions get lost instantly, in which case we set $M_a = 0$ and $F_a = 0$ if $|\theta - \pi/2| \geq |\theta_{La} - \pi/2|$.

The electron mirror loss term is

$$M_e = \frac{-K_e \Gamma_e}{\tilde{v}^3} \cdot \frac{\bar{F}_e \lambda \Gamma_e}{x^2}, \quad (4.6)$$

where

$$\lambda = 1.4 \log_{10} R_{\text{eff}}. \quad (4.7)$$

Here,

$$R_{\text{eff}} = R_m / (1 - \tilde{x}_{ce}^2 / x^2), \quad (4.8)$$

if $x \geq \tilde{x}_{ce}$; otherwise $R_{\text{eff}} = \infty$.

The quantity $\tilde{x}_{ce}$ is given by

$$\frac{\tilde{x}_{ce}^2}{x^2} = \phi_{\text{wall}} / \phi_m = \phi_r, \quad (4.9)$$

where ϕ_r is an input parameter. The term $\bar{F}_e$ is the same as that in Eq. (2.9), with $\sin \theta = 1$, i.e.,

$$\bar{F}_e = \frac{1}{2x} \frac{\partial G_e}{\partial x} \quad (4.10)$$

5. Toroidal Finite Confinement Term

The toroidal finite confinement term is defined as

$$T_a = \frac{-F_a}{\tau_{pa}} + \frac{1}{x^2} \frac{\partial}{\partial x} \left(\frac{1}{\tau_{ea}} \frac{x^3 F_a}{2} \right) \quad (5.1)$$

where

$$\tau_{pa} = \tau_{pa}^0 + (\tau_{pa}^1 - \tau_{pa}^0) (x/x_{\tau a})^{\tau_{pa}} \quad (5.2)$$

Here, the quantities τ_{ea} , τ_{pa}^0 , τ_{pa}^1 , $p_{\tau a}$, and $x_{\tau a}$ are input parameters, the last term being input in energy units. The number τ_{pa} is the particle confinement time for species "a", and τ_{ea} is the energy confinement time for species "a".

To preserve charge neutrality, we may use an option to calculate τ_{pe} instead of using the data card value. In this case we let $\tau_{pe}^1 = \tau_{pe}^0$, $x_{\tau e} = \infty$, $p_{\tau e} = 1$, and compute $\tau_{pe} = \tau_{pe}^0$ via

$$\sum_{a=\text{ions}} K_a Z_a 2\pi \int_0^\pi \int_0^\infty \frac{F_a}{\tau_{pa}} x^2 \sin \theta \, dx \, d\theta = 4\pi \int_0^\infty \frac{K_e F_e}{\tau_{pe}} x^2 \, dx \quad (5.3)$$

For programming convenience, there is a one time-step lag when computing τ_{pe} by this method.

6. Toroidal Major Radius Compression Term

We let R represent the "major radius," or average radial position of the particles, and define the logarithmic derivative of R as a step function in time:

$$\dot{R}/R = A_k / [1 - B_k \exp(t/\tau_k)] \quad (6.1)$$

if $\hat{\tau}_k \leq t < \hat{\tau}_{k+1}$. Here, k ranges from 1 to 5 ($\hat{\tau}_6 = \infty$), and the quantities A_k , B_k , τ_k , and $\hat{\tau}_k$ are input parameters.

The toroidal major radius compression term (for ions) is then

$$R_a = \frac{1}{x^2} \frac{\partial}{\partial x} (\tilde{A}_a F_a) + \frac{1}{x^2 \sin \theta} \frac{\partial}{\partial \theta} (\tilde{D}_a F_a) - 2 \dot{R}/R F_a, \quad (6.2)$$

where

$$\tilde{A}_a = x^3 \dot{R}/R \{ (\gamma - 1) - (\gamma - 1.5) \sin^2 \theta \}, \quad (6.3)$$

$$\tilde{D}_a = -x^2 \dot{R}/R (\gamma - 3/2) \sin^2 \theta \cos \theta, \quad (6.4)$$

and

$$\gamma = 2. \quad (6.5)$$

The corresponding term for electrons becomes

$$R_e = \frac{1}{x^2} \frac{\partial}{\partial x} (\tilde{A}_e F_e) - 2 \dot{R}/R F_e, \quad (6.6)$$

where

$$\tilde{A}_e = \frac{\gamma x^3}{3} F_e. \quad (6.7)$$

7. Time-Dependent Magnetic Field Derivative Term

This term is very similar to the toroidal major radius compression term, and may be applied to both mirror and toroidal problems. It is (for ions)

$$B_a = \frac{1}{x^2} \frac{\partial}{\partial x} (\hat{A}_a F_a) + \frac{1}{x^2 \sin \theta} \frac{\partial}{\partial \theta} (\hat{D}_a F_a) + \dot{B}/B F_a, \quad (7.1)$$

where

$$\hat{A}_a = \frac{-x^3}{2} \sin^2 \theta \dot{B}/B, \quad (7.2)$$

$$\hat{D}_a = \frac{-x^2}{2} \sin^2 \theta \cos \theta \dot{B}/B, \quad (7.3)$$

and B is the magnetic field.

The corresponding term for electrons has

$$\hat{A}_e = \frac{-x^3}{3} \dot{B}/B, \quad (7.4)$$

$$\hat{D}_e = 0. \quad (7.5)$$

8. Alpha Particle Heating Term

Here we assume that species one through three are deuterium, tritium and alpha particles, respectively, and we identify these three species with subscripts D, T, and α . Then,

$$A_D = -n_T F_D x \bar{v} \sigma_{DT} \left(\frac{5}{6} m_D \bar{v}^2 x^2 \right) \delta_s^{\alpha 1}, \quad (8.1)$$

$$A_T = -n_D F_T (\bar{\sigma v})_{DT} \delta_s^{\alpha 1}, \quad (8.2)$$

$$A_\alpha = \frac{1}{K_\alpha} \left[n_D n_T (\bar{\sigma v})_{DT} \right] \cdot \bar{S}_\alpha^1(x, \theta) \delta_s^{\alpha 1}. \quad (8.3)$$

Here, n_D and n_T are the deuterium and tritium densities, σ_{DT} is the D-T reaction cross section (discussed later), $(\bar{\sigma v})_{DT}$ is the one-dimensional integral approximation to the $(\bar{\sigma v})$ for the D-T reaction (also discussed later), and A_α is really part of the alpha particle source number one. We see that Eqs. (8.1) through (8.3) are controlled by the on and off times for source number one of the alpha particles.

9. Initial Distributions

We specify initial distributions of the form

$$F_a(x, \theta) = a' e^{-b'(x-c')^2} e^{-d'(\cos\theta - e')^2}, \quad (9.1)$$

where the constants b' , c' , d' , and e' are input parameters. The quantity c' is input in energy units and, if it is 0, b' is input in energy units. Clearly $d' = 0$ for the electrons.

The density of species "a" is given by

$$n_a = 2\pi K_a \int_0^\pi \int_0^\infty x^2 \sin \theta F_a(x, \theta) dx d\theta, \quad (9.2)$$

and the quantity a' in Eq. (9.1) is computed from the initial density, which is also an input parameter. The mean energy of species "a" is given by

$$E_a = \frac{1}{2} m_a \bar{v}_a^2 \langle x^2 \rangle_a, \quad (9.3)$$

where

$$\langle x^2 \rangle_a = \frac{\int_0^\pi \int_0^\infty x^4 \sin \theta F_a(x, \theta) dx d\theta}{\int_0^\pi \int_0^\infty x^2 \sin \theta F_a(x, \theta) dx d\theta}. \quad (9.4)$$

10. Computation of a Self-Consistent Ambipolar Potential

For mirror systems, a self-consistent ambipolar potential at the mirror, ϕ_m , is computed at each time step by requiring charge neutrality. We let

$$n_+(t) = \sum_{\text{ions}} n_a(t) Z_a. \quad (10.1)$$

$$n_-(t) = n_e(t), \quad (10.2)$$

$$d_\pm(t) = n_\pm(t + \Delta t) - n_\pm(t). \quad (10.3)$$

If $n_+(t) > n_-(t)$ and $d_+(t) \geq d_-(t)$, we raise ϕ_m by an amount $\phi_m \Delta\phi_m$ and readvance the distributions from t to $t + \Delta t$. If $n_+(t) < n_-(t)$ and $d_+(t) \leq d_-(t)$, we lower ϕ_m by an amount $\phi_m \Delta\phi_m$ and readvance the distributions from t to $t + \Delta t$. This procedure is repeated until neither of the above conditions hold. If the neutrality requirements are not met after a certain number of tries, the calculation is terminated.

11. Potential as a Function of Magnetic Field

For a mirror system, we compute $\phi(\psi)$, where $1 < \psi \leq R_m$, $\phi(1) = 0$, and $\phi(R_m) = \phi_m$. We let

$$n_i(\psi, \phi) = \sum_{\text{ions}} Z_a n_a(\psi, \phi), \quad (11.1)$$

$$n_a(\psi, \phi) = 4\pi K_a \int_0^\infty x \sqrt{x^2 + x_{ca}^2} dx \int \frac{\min\left\{1, \frac{x}{\sqrt{x^2 + x_{ca}^2}} \sqrt{\psi}\right\}}{\sqrt{x^2 + x_{ca}^2}} \sqrt{\frac{\psi}{R_m}} \frac{s ds}{\sqrt{1 - s^2}} F_a(x, \theta), \quad (11.2)$$

where

$$x_{ca}^2 = Z_a e \phi / \frac{1}{2} m_a \tilde{v}^2, \quad (11.3)$$

$$\mu^2 = \cos^2 \theta = 1 - \frac{s^2(x^2 + x_{ca}^2)}{\psi x^2}. \quad (11.4)$$

Also,

$$n_e(\psi, \phi) = 4\pi K_e \left[\int_{x_{ce}}^{\bar{x}_{ce}} x^2 dx F_e(x) \sqrt{1 - x_{ce}^2/x^2} + \int_{\bar{x}_{ce}}^{\infty} x^2 dx F_e(x) \sqrt{1 - \frac{x_{ce}^2}{x^2} + \frac{\psi}{R} \left(\frac{\bar{x}_{ce}^2}{x^2} - 1 \right)} \right], \quad (11.5)$$

where

$$x_{ce}^2 = e \phi / \frac{1}{2} m_e \tilde{v}^2 \quad (11.6)$$

and

$$\bar{x}_{ce}^2 = e \bar{\phi}_m / \frac{1}{2} m_e \tilde{v}^2 \quad (11.7)$$

For computational convenience, we multiply the right hand side of Eq. (11.5) by $n_+(t)/n_e(1,0)$, where $n_+(t)$ is defined in Eq. (10.1) and $n_e(1,0)$ is the right hand side of Eq. (11.5) at $\psi = 1, \phi = 0$; i.e., $n_e(\psi, \phi)$ is scaled uniformly so that $n_e(1,0) = n_+(t)$.

Given ψ , we compute ϕ satisfying

$$n_1(\psi, \phi) = n_e(\psi, \phi), \quad (11.8)$$

and set $\phi = \phi^*(\psi)$ and $n(\psi) = n_1(\psi, \phi^*(\psi))$.

Pressure terms are defined similarly. We let

$$P_{1,\parallel}(\psi) = \sum_{\alpha} P_{1,\parallel}^{\alpha}(\psi). \quad (11.9)$$

Here, $P_{\perp}^a(\psi)$ is defined like $n_a(\psi, \phi^*(\psi))$, but a factor $\frac{1}{2} m_a \tilde{v}^2 x^2 (1 - \mu^2) \psi$ is inserted into the integrand for the perpendicular case, and a factor $m_a \tilde{v}^2 [x^2 (1 - \psi(1 - \mu^2)) + e \phi^* Z_a / \frac{1}{2} m_a \tilde{v}^2]$ for the parallel case. The electron term $P_{\perp, \parallel}^e(\psi)$ drops the second term in Eq. (11.5) and a factor $\frac{1}{3} m_e \tilde{v}^2 (x^2 - e \phi^* / \frac{1}{2} m_e \tilde{v}^2)$ is inserted into the integrand in the first term.

A few other diagnostic quantities are computed, such as

$$K_m = \inf \left[\frac{-\frac{\partial}{\partial \psi}(\psi^2)}{\frac{\partial}{\partial \psi}(P_{\perp}(\psi))} \right]_{P_{\perp}(\psi) \leq 0}, \quad (11.10)$$

$$L_m = \inf \left[\frac{\frac{\partial}{\partial \psi}(\psi^2)}{\frac{\partial}{\partial \psi}(P_{\parallel}(\psi))} \right]_{P_{\parallel}(\psi) \geq 0}, \quad (11.11)$$

$$\psi_{\text{vac}}(\psi) = \sqrt{\psi^2 + K_m P_{\perp}(\psi)}, \quad (11.12)$$

$$R_{\text{vac}} = R/\psi_{\text{vac}}(1), \quad (11.13)$$

$$(kT)_{\perp} = P_{\perp}(1)/n(1), \quad (11.14)$$

and

$$\beta_{\text{max}} = K_m P_{\perp}(1) / (1 + K_m P_{\perp}(1)). \quad (11.15)$$

12. Reaction Cross Section

The reaction cross section between two species is defined as

$$(\bar{\sigma v})_{ab} = \frac{\int_0^{\infty} ds \int_0^s u^2 du \int_0^u l_1(s, t) \sigma_{ab}(E) dt}{\int_0^{\infty} ds \int_0^s u du \int_0^u l_1(s, t) dt}, \quad (12.1)$$

where

$$I_1(s, t) = (s^2 - t^2) \left[f_a \left(\frac{s+t}{2} \right) f_b \left(\frac{s-t}{2} \right) + f_a \left(\frac{s-t}{2} \right) f_b \left(\frac{s+t}{2} \right) \right], \quad (12.2)$$

$$E = \frac{\frac{1}{2} m_a t^2}{1.602 \times 10^{-9}}. \quad (12.3)$$

An approximation to Eq. (12.1), where a = deuterium (D) and b = tritium (T), is

$$(\overline{\sigma v})_{DT} = \sqrt{1 + m_D E_T / m_T E_D} \frac{\int_0^\infty v^3 \sigma_{DT}(E) f_D(v) dv}{\int_0^\infty v^2 f_D(v) dv}, \quad (12.4)$$

where

$$E = \frac{1}{2} m_D v^2 (1 + m_D E_T / m_T E_D) / 1.602 \times 10^{-9}. \quad (12.5)$$

The quantity $\sigma_{DT}(E)$ is given by

$$10^{24} \times \sigma = 2.25 \times 10^4 \exp(-44.4/\sqrt{E})/E \text{ if } E < 20, \quad (12.6)$$

$$10^{24} \times \sigma = 4.62 \times 10^{-4} E^2 - 0.137 \text{ if } 20 \leq E < 30, \quad (12.7)$$

$$10^{24} \times \sigma = 6.7 \times 10^{-4} E^2 - 0.32 \text{ if } 30 \leq E < 50, \quad (12.8)$$

$$10^{24} \times \sigma = 8.55 \times 10^{-2} E - 2.93 \text{ if } 50 \leq E < 87, \quad (12.9)$$

$$10^{24} \times \sigma = \frac{1.98 \times 10^4}{(E - 107)^2 + 4000} \text{ if } 87 \leq E < 107, \quad (12.10)$$

$$10^{24} \times \sigma = \frac{3.56 \times 10^4}{(E - 107)^2 + 7200} \text{ if } 107 \leq E < 137, \quad (12.11)$$

$$10^{24} \times \sigma = 8.7 - 0.0314 E \text{ if } 137 \leq E < 185, \quad (12.12)$$

$$10^{24} \times \sigma = 7.05 \times 10^3 / E^{3/2} \text{ if } 185 \leq E < 400, \quad (12.13)$$

$$10^{24} \times \sigma = 255 / (E - 110) \text{ if } 400 \leq E. \quad (12.14)$$

The quantities $f_a(v)$ appearing in Eqs. (12.2) and (12.4) are defined as

$$f_a(v) = \frac{1}{2} \int_0^\pi f_a(v, \theta) \sin \theta d\theta. \quad (12.15)$$

Values of $(\bar{\sigma v})_{DT}$ are computed periodically for D-T calculations. Either the three-fold integral or the one-dimensional approximation may be used. (In the event Eq. (12.4) is used, one may set $E_T = 0$ to compare with calculations performed elsewhere.)

At the termination of D-T mirror runs, Eq. (12.1) is always implemented. In addition, we compute

$$Q_{DT} = \frac{n_D n_T (\bar{\sigma v})_{DT} \cdot 22,400}{\sum_{a=D, T} \sum_{\ell} J_a^\ell \hat{E}_a^\ell}, \quad (12.16)$$

where $\hat{E}_a^\ell$ is the mean energy of the ℓ th source of species "a".

For D-T toroidal runs, we compute the fusion energy according to the formula

$$F.E. = \int_0^t V(\tilde{t}) n_D n_T (\bar{\sigma v})_{DT} \cdot 17,600 d\tilde{t}, \quad (12.17)$$

where

$$V(t) = V_0/c(t)^2, \quad (12.18)$$

$$V_0 = 1, \quad (12.19)$$

and

$$c(t) = \exp\left(-\int_0^t \dot{R}/R d\tilde{t}\right). \quad (12.20)$$

We also compute the bulk plasma loss energy

$$B.P.L.E. = \int_0^t V(\tilde{t}) \cdot \sum_a n_a E_a / \tau_{ea} d\tilde{t}. \quad (12.21)$$

13. Construction of Finite Difference Mesh

The velocity mesh is represented as $\{x_j\}_{j=1}^J$, where $x_1 = 0$, $x_J = x_{\max}$, and $x_{J+1} = x_{\max}^i$, the ion x -maximum. We let $h_1 = x_{\max}/(J+1)$ and $f_2 = f_1 h_1$, where f_1 is an input parameter, and then compute r_1 satisfying

$$x_{j+1} - x_j = r_1(x_j - x_{j-1}) \quad (13.1)$$

for $2 \leq j \leq J' - 1$. We then define

$$x_{J'+1} = 2x_{J'} - x_{J'-1} \quad (13.2)$$

the compute r_2 satisfying Eq. (13.1) for $J' + 1 \leq j \leq J - 1$. Thus we see that the electron velocity mesh is an extension of the ion velocity mesh, and the double geometricity enables us to represent low energy ions and high energy electrons on the same mesh.

The ion angular mesh is represented as $\{\theta_i\}_{i=1}^I$, where $\theta_1 = 0$ or θ_L , depending on whether or not we are considering a mirror problem in which ions get lost instantly. The quantity θ_1 is either $\pi - \theta_1$ or $\pi/2$. In the latter case, we assume symmetry about $\theta = \pi/2$ and add an extra point θ_{I+1} for reflection purposes. We define the integer I' as that index corresponding to $\pi/2$, i.e., $\theta_{I'} = \pi/2$, and let $h_2 = (\theta_{I'} - \theta_1)/(I' - 1)$. A geometric theta mesh may be constructed in either of two ways. In one case, we let $\theta_2 = \theta_1 + f_2 h_2$, where f_2 is an input parameter, and then compute r_3 satisfying

$$\theta_{i+1} - \theta_i = r_3(\theta_i - \theta_{i-1}) \quad (13.3)$$

for $2 \leq i \leq I' - 1$. Alternatively, we let $\theta_{I'-1} = \theta_{I'} - f_2 h_2$ and compute r_3 satisfying

$$\theta_{i-1} - \theta_i = r_3(\theta_i - \theta_{i+1}) \quad (13.4)$$

for $2 \leq i \leq I' - 1$. In effect, we may specify the angular mesh thickness in the neighborhood of either $\theta = \theta_1$ or $\theta = \pi/2$. The remaining angular mesh points are defined via reflection about $\pi/2$.

The time step Δt is an input parameter, but it may be changed several times throughout the course of a calculation. The various new time steps along with the cycle numbers at which Δt takes on these new values are also input parameters.

14. Boundary Conditions

For a toroidal configuration or for a mirror problem in which the inverse loss time for the ions is finite, the analytic boundary conditions for the ions are

$$F_a(\infty, \theta) = 0, \quad (14.1)$$

$$\frac{\partial F_a}{\partial x}(0, \theta) = 0, \quad (14.2)$$

$$\frac{\partial F_a}{\partial \theta}(x, 0) = \frac{\partial F_a}{\partial \theta}(x, \pi) = 0, \quad (14.3)$$

$$\frac{\partial F_a}{\partial \theta}(x, \pi/2) = 0 \text{ (if } \pi/2 \text{ - symmetry).} \quad (14.4)$$

In an attempt to impose density conservation on the ions, conditions (14.2) through (14.4) are replaced by conservation conditions (dropping subscript "a")

$$(\bar{A}_{i,1} F_{i,1} + \bar{A}_{i,2} F_{i,2}) + \frac{(\bar{B}_{i,1} + \bar{B}_{i,2})}{(x_2 - x_1)} (F_{i,2} - F_{i,1}) = 0, \quad (14.5)$$

and

$$(\bar{D}_{k,j} F_{k,j} + \bar{D}_{k+1,j} F_{k+1,j}) + \frac{(\bar{F}_{k,j} + \bar{F}_{k+1,j})}{(\theta_{k+1} - \theta_k)} (F_{k+1,j} - F_{k,j}) = 0, \quad (14.6)$$

where $k = 1, l' - 1$, $l - 1$. Conditions (14.5) and (14.6) do not assure precise density conservation because of the mixed second derivative terms present in the collision operator.

For a mirror configuration where the ions are lost instantly, the boundary conditions (14.2) through (14.4) are replaced by those given in Sec. 4.

The boundary conditions for the electrons are analogous to Eqs. (14.1) and (14.5), only the theta dependence is obviously dropped. For a mirror problem, we may opt to set $F_e(x) = 0$ if $x \geq \tilde{x}_{ce}$ (see Sec. 4.).

15. Finite Differencing

Let

$$\tilde{t}_a = \tilde{v}^3 / K_a \Gamma_a \quad (15.1)$$

and

$$\tau_a = t / \tilde{t}_a. \quad (15.2)$$

Then Eq. (2.1) may be written as

$$\left(\frac{\partial F_a}{\partial t} \right)_c = \frac{1}{x^2} \frac{\partial \bar{G}_a}{\partial x} + \frac{1}{x^2 \sin \theta} \frac{\partial \bar{H}_a}{\partial \theta}. \quad (15.3)$$

The term $\partial \bar{G}_a / \partial x$ is differenced in space (dropping the subscript "a") as

$$\begin{aligned}
\frac{\partial \bar{G}_a}{\partial x} = & \frac{\bar{A}_{i,j+1} F_{i,j+1} - \bar{A}_{i,j-1} F_{i,j-1}}{2\Delta x_j} \\
& + \left[\frac{\bar{B}_{i,j+1/2} (F_{i,j+1} - F_{i,j})}{\Delta x_{j+1/2}} - \frac{\bar{B}_{i,j-1/2} (F_{i,j} - F_{i,j-1})}{\Delta x_{j-1/2}} \right] \frac{1}{\Delta x_j} \\
& + \frac{1}{2\Delta x_j} \left[\bar{C}_{i,j+1} \frac{(F_{i+1,j+1} - F_{i-1,j+1})}{2\Delta \theta_i} - \bar{C}_{i,j-1} \frac{(F_{i+1,j-1} - F_{i-1,j-1})}{2\Delta \theta_i} \right], \quad (15.4)
\end{aligned}$$

where

$$\bar{B}_{i,j\pm 1/2} = \frac{1}{2} (B_{i,j} + B_{i,j\pm 1}), \quad (15.5)$$

$$\Delta x_{j\pm 1/2} = \pm (x_{j\pm 1} - x_j), \quad (15.6)$$

$$\Delta x_j = \frac{1}{2} (\Delta x_{j-1/2} + \Delta x_{j+1/2}). \quad (15.7)$$

The $\partial H_a / \partial \theta$ term, $\Delta \theta_i$, and $\Delta \theta_{i\pm 1/2}$ are defined analogously.

In advancing the ions from cycle n to cycle $n+1$, splitting is used. We consider the equations

$$\frac{\partial F_a}{\partial t} = \left(\frac{\partial F_a}{\partial t} \right)_c + S_a + C_a + M_a + A_a, \quad (15.8)$$

$$\frac{\partial F_a}{\partial t} = R_a + T_a + B_a, \quad (15.9)$$

and integrate them sequentially. Splitting is also used when integrating each of the individual Eqs. (15.8) and (15.9). Letting superscript "0" denote data at cycle n and "4" denote data at $n+1$, we solve

$$\frac{F_a^1 - F_a^0}{\Delta \tau_a} = \frac{1}{x^2} \frac{\partial}{\partial x} \left[\bar{A}_a^0 F_a^1 + \bar{B}_a^0 \frac{\partial F_a^1}{\partial x} + \bar{C}_a^0 \frac{\partial F_a^0}{\partial \theta} \right] + \frac{\tilde{t}_a}{2} [S_a^0 + C_a^1 + M_a^1 + A_a^{0-1}], \quad (15.10)$$

$$\frac{F_a^2 - F_a^1}{\Delta \tau_a} = \frac{1}{x^2 \sin \theta} \frac{\partial}{\partial \theta} \left[\bar{D}_a^0 F_a^2 + \bar{E}_a^0 \frac{\partial F_a^1}{\partial x} + \bar{F}_a^0 \frac{\partial F_a^2}{\partial x} \right] + \frac{\tilde{t}_a}{2} [S_a^0 + C_a^2 + M_a^2 + A_a^{0-2}], \quad (15.11)$$

$$\frac{F_a^3 - F_a^2}{\Delta t} = x R_a^3 + T_a^3 + x B_a^3, \quad (15.12)$$

$$\frac{F_a^4 - F_a^3}{\Delta t} = \theta R_a^4 + \theta B_a^4. \quad (15.13)$$

Here,

$$x_{R_a} = \frac{1}{x^2} \frac{\partial}{\partial x} (\tilde{A}_a F_a) - \dot{R}/R F_a, \quad (15.14)$$

$$\theta_{R_a} = \frac{1}{x^2 \sin \theta} \frac{\partial}{\partial \theta} (\tilde{D}_a F_a) - \dot{R}/R F_a, \quad (15.15)$$

$$x_{B_a} = \frac{1}{x^2} \frac{\partial}{\partial x} (\hat{A}_a F_a) + \frac{1}{2} \dot{B}/B F_a, \quad (15.16)$$

$$\theta_{B_a} = \frac{1}{x^2 \sin \theta} \frac{\partial}{\partial \theta} (\hat{D}_a F_a) + \frac{1}{2} \dot{B}/B F_a, \quad (15.17)$$

and the A_a^{0-K} term ($K = 1, 2$) uses implicit distribution functions and explicit coefficients in its evaluation.

The solution of Eqs. (15.10) through (15.13) involves sweeping the finite-difference mesh along $x = \text{constant}$ and $\theta = \text{constant}$ lines. The procedure for solving these tridiagonal systems is adequately described in an LLL report.¹ One may substitute an alternating direction implicit (A.D.I.) technique for the splitting technique when advancing Eqs. (15.10) and (15.11).

The integration of the electron distribution function is analogous to that of the ions. The analogue of Eq. (15.10) is advanced using implicit or semi-implicit differencing, whereas fully-implicit differencing is used for the analogue of Eq. (15.12). In addition, when integrating Eq. (15.10), one may divide the time step into several smaller time steps and recompute the relevant Fokker-Planck coefficients each smaller time step. This greatly increases the accuracy of the electron integration (the electrons are on a faster time scale), while causing only a minimal increase in computer time.

16. Input-Output

The code input consists solely of data cards, with the exception of the initial distribution functions that (if desired) may be read from binary disc files. All data-card input statements originate from the MAIN program and from subroutine INITIAL.

Both printed data and plotted data comprise the output. Printed output quantities include densities, energies, pressures and distribution functions. Plotted quantities include three-dimensional $v - \theta$ plots of the ions, a $v_{\perp} - v_{\parallel}$ deuterium contour plot, and plots of the various densities and energies as functions of time.

1. J. Killeen and K. D. Marx, The Solution of the Fokker-Planck Equation for a Mirror Confined Plasma, Lawrence Livermore Laboratory, Rept. UCRL-71662 (1969).

17. Program Listing

The following is a listing of Hybrid-II.

```

PROGRAM DUMFG(TAPE2,TAPE6,TAPE3=TAPE6,PRINT)
CLICHE COMM
CMNT  IY IS THE NUMBER OF THETA MESH POINTS
CMNT  JX IS THE NUMBER OF X MESH POINTS FOR ELECTRONS
C
      PARAMETER(IY=14,JX=201)
C
CMNT  JXI IS THE NUMBER OF X MESH POINTS FOR IONS
C
      PARAMETER(JXI=45)
C
CMNT  NEQ IS THE MAXIMUM NUMBER OF ION SPECIES
CMNT  IF DEUTERIUM IS PRESENT, SPECIES 1 SHOULD BE DEUTERIUM
CMNT      IF TRITIUM IS ALSO PRESENT, SPECIES 2 SHOULD BE TRITIUM
CMNT      IF ALPHA PARTICLES ARE ALSO PRESENT, SPECIES 3 SHOULD BE ALPHAS
C
      PARAMETER(NEQ=3)
C
      PARAMETER(KSYDM=IY-2*(IY/2))
CMNT  IF IY IS EVEN, KSYDM IS 0 AND THERE IS SYMMETRY ABOUT PI/2
CMNT      IF IY IS ODD KSYDM IS 1 AND THERE IS NO SUCH SYMMETRY
CMNT  MMX IS THE NUMBER OF LEGENDRE POLYNOMIALS IN THE ROSENBLUTH POTENTIAL
CMNT      EXPANSIONS
C
      PARAMETER(MMX=8)
C
      DIF (KSYDM) NOSYM,YESYM,NOSYM
YESYM  CONTINUE
      PARAMETER(IYDM=IY+1,MXDM=2)
NOSYM  CONTINUE
      DIF (KSYDM) NOSYN,YESYN,NOSYN
NOSYN  CONTINUE
      PARAMETER(IYDM=IY,MXDM=1)
YESYN  CONTINUE
      PARAMETER(IYP1JX=IYDM*JXI,MX=MMX/MXDM,IYH=IY-KSYDM*(IY/2))
      PARAMETER(IYHM1=IYH-1,IYHP1=IYH+1)
      PARAMETER(MXP3M=-MMX-3,MXP4=MMX+4)
CMNT  KMACH = 1 FOR THE CCC 7600, 0 FOR THE CDC 6600
C
      PARAMETER(KMACH=1)
C
CMNT  NONCH IS THE NUMBER OF POINTS THAT MAY BE STORED SIMULTANEOUSLY FOR THE
CMNT      TIME DEPENDENT PLOTS
C
      PARAMETER(NONCH=100)
C
      PARAMETER(IYP1=IY+1,IYP2=IY+2,JXP1=JX+1)
      PARAMETER(IYJX=IY*JX)
CMNT  LZ IS THE NUMBER OF B-POINTS FOR THE PHI(B) CALCULATION (MIRRORS ONLY)
C
      PARAMETER(LZ=25,NB=25,NPTS=200)
C
CMNT  NSOR IS THE MAXIMUM NUMBER OF GAUSSIAN SOURCES PER SPECIES
C
      PARAMETER(NSOR=2)
C
CMNT  NSTEP IS THE MAXIMUM ALLOWABLE NUMBER OF TIME STEP CHANGES
C
      PARAMETER(NSTEP=15)
C

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COMMON/MLZU/PPOT(LZ),BMAG(LZ),FS1(LZ),PS2(LZ),ONGIE(LZ),
C PPERP(LZ),PPAR(LZ),PSVAC(LZ),DNS1(NB),DNSF(NB),DDIFF(NB),PH1(NB),
C VINT(JX1),VINTPE(JX1),VINTPA(JX1),VENT(JX),UMMU(IY),COSYN(NPTS),
COMMON/MCON1/P1,TWOP1,FOURP1,PIO2,CHARGE,TIME,DTR,DTN(NSTEP),
C NSETN(NSTEP),NSTEPU,N,NPRINT,NPLOT,NSTO?,NRSTRT,NCH,NCHEC,
C IYMI,IYH2,IYH3,JXM1,JXM2,JXM3,JXIM,JXIM2,JXIM3,ERGTEKEV,
C POTENT,DPOT,XMAX,XMAX1,EXT(3,4),KBOUND,KGETGFK,KAMBI,
C KGNANDE,MIMAX,BRATIO,BRATIO1,PLTANG,KSINGUL,VNORM,EFUSION,
C KNPROBS,NSL,BETA0,FGMESH,SBPL,SFE0,CT,VFO0,RDOR,SIGVH,
C NSPLIT,RH00,NEL10,ELENGTH,NSLE,NSLE2,NDTAL,RFDJGE,BDOB,
C RDORA(5),RDORB(5),RDORT(5),RDTCHG(5),SFSE,KBUFIN,KBUFOU,
C NAMEBIN,NAMEBOUT,KBUFU(10,NEQ),NCSIG,TAUEK(10,NEQ),
C TAUEN(10,NEQ),TAUPK(10,NEQ),TAUPK(10,NEQ),
C TAUPPR(10,NEQ),KCHNUT,FGTMESH,IGTMESH,KTPNUT,SIGVHAL,
C NCUTFE,POTRAT,NSIGM(3),NPOTZ,FGBMESH
COMMON/MCON2/JO(IY,NEQ),IO(JX,NEQ),JM1N(NEQ),IM1N(NEQ),
C TNORM(10,NEQ),RAT10M(10,NEQ),EMASS(10,NEQ),
C ANUMB(10,NEQ),ANORMK(10,NEQ),DENS(10,NEQ),REGEN(10,NEQ),
C ENERGY(10,NEQ),ENGY(10,NEQ),DENSTOR(10,NEQ),
C ESOR(NSOR,10,NEQ),XSOR(NSOR,10,NEQ),YSOR(NSOR,10,NEQ),
C USOR(NSOR,10,NEQ),ENIT(10,NEQ),XNIT(10,NEQ),
C YNIT(10,NEQ),VNIT(10,NEQ),GAM2(10,NEQ),10,NEQ),
C GAMMA(10,NEQ),10,NEQ),RATK(10,NEQ),10,NEQ),EIONS(10,NEQ),
C TSON(NSOR,10,NEQ),TSOFF(NSOR,10,NEQ),
C ABJ1(NSOR,10,NEQ),10,NEQ),ABJ2(NSOR,10,NEQ),10,NEQ),
C ABJ3(NSOR,10,NEQ),10,NEQ),CCEX(NSOR,10,NEQ),10,NEQ),
C RATIO22(10,NEQ),10,NEQ),PERPB(10,NEQ),ENSOR(NSOR,10,NEQ),
C EJSOR(NSOR,10,NEQ),ENSAVG(10,NEQ),EJSTOT(10,NEQ)
COMMON/MCON3/CYNT(IY),CINT(JX),FT(IYDM,JX1),X1(JX),TEMPG(JX),
C X1(JX),X2(JX),X3(JX),XSQ(JX),DXMS(JXP1),DX(JX),Y(IYP1),DX1(JX),
C DYM5(IYP2),DY(IY),DY1(IY),COSS(IY),SINN(IY),
C EP(IYJX),FP(IYJX),YMINN(JX1),SDTAL(JX1),CYNT2(IY),CINT2(JX)
DIMENSION DXP5(JX),DYP5(IYP1)
EQUIVALENCE(DXP5(1),DXMS(2))
EQUIVALENCE(DYP5(1),DYM5(2))
COMMON/MCON4/XM(JX),(MXP3M,MXP41),COG(10,MX1,15),PLEG(10,MMX1,IY),
C DPLEG(10,MMX),IY),DDPLEG(10,MMX),IY),DDDPLEG(10,MMX),IY),
C EQF(JX,10,MX),EQF(JX,10,MX),EQF(JX,10,MX),EQF(JX,10,MX),
COMMON/MTEMP/FN(IYDM,JX1),SO(IYDM,JX1),
C CA(IYDM,JX1),CB(IYDM,JX1),CC(IYDM,JX1),CD(IYDM,JX1),
C CE(IYDM,JX1),CF(IYDM,JX1)
COMMON/MPL0T/PTIME(NONCH),PDENS(NONCH,10,NEQ),
C PENGY(NONCH,10,NEQ),PPOTENT(NONCH),POTSE(NONCH),
C PQBPLE(NONCH),PQFEO(NONCH)
COMMON/MILEC/FE(JX),FE1(JX),SORE(JX),AEL(JX),BEL(JX),CCEL(JX),
C AELL(JX),BELL(JX),CELL(JX),TETAU(JX)
DIF(KMACH) LAB3,LAB3,LAB4
LAB4 CONTINUE
LCM (MLCMC)
LAB3 CONTINUE
COMMON/MLCMC/F(IYDM,JX1,NEQ),F1(IYDM,JX1,NEQ),
C SOURCE(IYDM,JX1,NEQ),CAL(IYDM,JX1,NEQ),CBL(IYDM,JX1,NEQ),
C CCL(IYDM,JX1,NEQ),CDL(IYDM,JX1,NEQ),CEL(IYDM,JX1,NEQ),
C CFL(IYDM,JX1,NEQ),AELT(JX),BELT(JX),CELT(JX),
C AELST(JX),BELST(JX),CELST(JX)
ENDCLICHE
USE COMM
CALL ASSIGN(2,0,7,PRINTIONS,0)
CMNT KNS1 IS THE NUMBER OF PROBLEMS TO BE RUN
C

```

```

      READ (2,2) KNSET
C
      2 FORMAT(15)
      DIMENSION ND(5) $ ND(1)=0 $ ND(3)=6 $ ND(4)=0
CMNT ND(2) SPECIFIES THE PRINT OUTPUT MEDIUM--F,H, OR P
CMNT IPLOT SPECIFIES THE PLOT OUTPUT MEDIUM - F FOR FR80 ONLY,
CMNT      0 FOR DD80 ONLY, K FOR DD80 TO BE KEPT ON DISC, AND
CMNT      B FOR BOTH DD80 AND FR80
C
CMNT ***IMPORTANT*** - THE FR80 OPTION IS NOT AVAILABLE ON
CMNT THE CDC 6600 - FOR MICROFICHE PLOTS USE
CMNT FROG
C
C
      READ (2,46) ND(2),IPLOT
C
      46 FORMAT(2A10)
      ND(5)=1 $ CALL HSP(ND)
      IF (IPLOT .NE. 1HF .OR. KMACH .EQ. 0) CALL DD80ID(2HAM,1)
      IF (IPLOT .EQ. 1HK) CALL KEEP80(1)
      DIF (KMACH) LAB1,LAB1,LAB2
LAB2 CONTINUE
      IF (IPLOT .NE. 1HD .AND. IPLOT .NE. 1HK) CALL FR80ID(2HAM,1)
      CALL DDERS(0)
LAB1 CONTINUE
      CALL FRAME
      DO 1 KNPROBS=1,KNSET
      KGNANDE=0 $ KBOUND=0 $ KGETGFK=0 $ KAMBI=0
      KSINGUL=0
C
      WRITE (3,3) KNPROBS
C
      3 FORMAT(1H1,27HBEGINNING OF PROBLEM NUMBER,15,/)
CMNT INITIALIZE VARIOUS PARAMETERS
      CALL INITIAL
CMNT EXIT IF MESH RATIO CANT BE COMPUTED
      IF (KSINGUL .EQ. 1) GO TO 1
CMNT PRINT OUT DATA
      CALL EEPRINT
CMNT PLOT OUT DATA
      CALL EEPLT
      IF (KBOUND .EQ. 1) GO TO 1
CMNT EXIT IF FAILURE IN COMPUTING LOSS-CONE BOUNDARY
      IF (KGNANDE .EQ. 1) GO TO 1
CMNT EXIT IF ZERO DENSITY
      IF (NSTOP .EQ. 0) GO TO 1
      11 N=N+1
CMNT CHECK TO RESET TIME STEP AND CHECK FOR SENSE SWITCH 1
      CALL TLOOP
CMNT COMPUTE COULOMB LOGARITHM
      CALL GAMMAIN
CMNT CHECK FOR ALPHA-PARTICLE HEATING
      CALL DTALINIT
CMNT COMPUTE SOURCE TERMS
      CALL SOURCEE
CMNT COMPUTE COEFFICIENTS
      CALL COEF
CMNT ADVANCE DIFFERENCE EQUATIONS
      CALL AMBI
CMNT CHECK FOR BOUNDARY FAILURE, ZERO DENSITY, OR UNSAT'S. AMBI. POT.

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      IF (KGNANDE .EQ. 1 .OR. KAMBI .EQ. 1 .OR. KBOUND .EQ. 1) GO TO 19
CMNT  STORE FOR TIME DEPENDENT PLOTS
      CALL TDSTORE
      IF (N .GT. NPRINT*(N/NPRINT)) GO TO 12
CMNT  PRINT OUT DATA
      CALL EEPRINT
      12 IF (N .GT. NPLT*(N/NPLT)) GO TO 13
CMNT  PLOT OUT DATA
      CALL EEPLT
      13 IF (N .LT. NSTOP) GO TO 11
CMNT  PLOT OUT DATA
      CALL EEPLT
      19 CONTINUE
CMNT  PRINT OUT DATA
      CALL EEPRINT
CMNT  COMPUTE PHI(B) AND ASSOCIATED FUNCTIONS (MIRRORS ONLY)
      CALL POTSHAPE
      CALL DENSNPT
CMNT  COMPUTE Q (MIRRORS ONLY)
      CALL QCALC
      1 CONTINUE
CMNT  WRITE OUT DISTRIBUTION FUNCTIONS ONTO DISC FILE (IF DESIRED)
      CALL FBUFOUT
      CALL QUIT(1)
      END

C
C
C      SUBROUTINE RWLCM
C
      USE COMM
      DIM (KMACH) LAB1,LAB1,LAB2
      LAB1 CONTINUE
      ENTRY READLCM(AX,BX,NX)
      DIMENSION AX(NX),BX(NX)
      DO 1 I=1,NX
      1 AX(I)=BX(I)
      RETURN
      ENTRY WRITELCM(AX,BX,NX)
      DO 2 I=1,NX
      2 BX(I)=AX(I)
      RETURN
      LAB2 CONTINUE
      RETURN
      END

C
C
C      SUBROUTINE INITIAL
C
      USE COMM
      N=0
      NCH=0
      TIME=0.
CMNT  XMAX IS THE ELECTRON X-MAXIMUM (IN UNITS OF VNORM)
CMNT  XMAXI IS THE ION X-MAXIMUM (IN UNITS OF VNORM)
CMNT  FGMESH IS THE INITIAL VELOCITY MESH SPACING DIVIDED BY THE UNIFORM
CMNT  VELOCITY MESH SPACING
CMNT  FGTMesh IS THE INITIAL THETA MESH SPACING DIVIDED BY THE UNIFORM
CMNT  THETA MESH SPACING
C
      READ (2,1) XMAX,XMAXI,FGMESH,FGTMESH

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C
  1 FORMAT(5E16.6)
  2 FORMAT(16I5)
CMNT NSTOP IS THE NUMBER OF TIME STEPS
CMNT NPRINT IS THE NUMBER OF CYCLES BETWEEN PRINTS
CMNT NPLT IS THE NUMBER OF CYCLES BETWEEN PLOTS
CMNT NRSTRT IS 1 + THE NUMBER OF CYCLES TO BE RUN BEFORE RESTARTING
C
  READ (2,2) NSTOP,NPRINT,NPLT,NRSTRT
C
CMNT NCHEC IS THE NUMBER OF CYCLES IN BETWEEN TIME DEPENDENT DATA SAMPLING
CMNT NCSIG DETERMINES THE METHOD OF OBTAINING (SIGMA-V) FOR D-T PROBLEM
CMNT      0 FOR 1-D INTEGRAL AND 0 TRITIUM ENERGY
CMNT      1 FOR 1-D INTEGRAL AND ARBITRARY TRITIUM ENERGY
CMNT      2 FOR 3-D INTEGRAL
CMNT KCHNUT IS 1 FOR RENORMALIZING ELECTRON DENSITY EACH TIME STEP TO FORCE
CMNT      CHARGE NEUTRALITY - 0 OTHERWISE
CMNT IGTSMESH IS 0 FOR UNIFORM THETA MESH, 1 FOR NON-UNIFORM THETA MESH
CMNT      SPECIFIED NEAR 0., 2 FOR NON-UNIFORM THETA MESH SPECIFIED NEAR P1/2
C
  READ (2,2) NCHEC,NCSIG,KCHNUT,IGTSMESH
C
CMNT NSL IS 1 FOR LOSS-CONE POTENTIAL BOUNDARY CONDITIONS, 0 OTHERWISE
CMNT NSLE IS 1 FOR FINITE MIRROR LOSS TERM, 0 OTHERWISE
CMNT NSLE2 IS 1 FOR MIRROR ELECTRON LOSS TERM, 0 OTHERWISE
C
  READ (2,2) NSL,NSLE,NSLE2
C
CMNT DTR IS THE INITIAL TIME STEP (SECONDS)
CMNT VNORM IS THE VELOCITY NORMALIZATION FACTOR
C
  READ (2,1) DTR,VNORM
C
CMNT NSTEPU IS THE NUMBER OF TIME STEP CHANGES
C
  READ (2,2) NSTEPU
C
  IF (NSTEPU .GT. NSTEP) NSTEPU=NSTEP
  IF (NSTEPU .EQ. 0) GO TO 71
CMNT DTN(K) ARE THE VARIOUS NEW TIME STEPS
C
  READ (2,1) (DTN(K),K=1,NSTEPU)
C
CMNT NSETN(K) ARE THE VARIOUS CYCLES WHEN THE TIME STEP WILL CHANGE
C
  READ (2,2) (NSETN(K),K=1,NSTEPU)
C
  71 CONTINUE
CMNT READ IN THE FOLLOWING DATA FOR MIRROR PROBLEMS ONLY
  IF (NSL+NSLE .EQ. 0) GO TO 251
CMNT POTENT IS THE AMBIPOLAR POTENTIAL (KEV)
CMNT DPOT IS THE RELATIVE CHANGE IN THE POTENTIAL
CMNT POTRAT IS THE ELECTRON TO ION POTENTIAL RATIO
CMNT BRATIO IS THE MIRROR RATIO
C
  READ (2,1) POTENT,DPOT,POTRAT,BRATIO
C
CMNT ELENGTH IS THE LENGTH OF THE MIRROR MACHINE FOR THE FINITE-TIME LOSS TERM
CMNT FGBMESH IS THE INITIAL PSI SPACING DIVIDED BY THE UNIFORM PSI SPACING
C

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      READ (2,1) ELENGTH,FGBMESH
C
CMNT BETA0 IS THE MAXIMUM BETA ALLOWED (MIRRORS ONLY)
C
      READ (2,1) BETA0
C
CMNT NCUTFE=1 FOR ZEROING THE ELECTRON DISTRIBUTION ABOVE THE
CMNT POTENTIAL CUTOFF, =0 OTHERWISE
CMNT NPOTZ=1 FOR PHI(B) CALCULATION, 0 OTHERWISE
CMNT MIMAX IS THE MAXIMUM NUMBER OF ATTEMPTS PER TIME STEP TO SATISFY CHARGE
CMNT NEUTRALITY REQUIREMENTS - FOR FIXED POTENTIAL PROBLEM, SET TO 0
C
      READ (2,2) NCUTFE,NPOTZ,MIMAX
C
      GO TO 252
251 CONTINUE
CMNT SET MIRROR PARAMETERS TO DEFAULT VALUES
      POTENT=0. $ DPOT=1.E-2 $ POTRAT=1. $ ELENGTH=1.E+90
      BETA0=.99 $ NCUTFE=0 $ NPOTZ=0 $ FGBMESH=1.
      BRATIO=1.E+30 $ MIMAX=0
252 CONTINUE
CMNT PLTANG IS THE PLOTTING ANGLE FOR 3-D PLOTS
C
      READ (2,1) PLTANG
C
CMNT NSPLIT=1 FOR SPLITTING, =2 FOR A.D.I.
CMNT NELIO IS THE NUMBER OF ELECTRON TIME STEPS PER ION TIME STEP
C
      READ (2,2) NSPLIT,NELIO
C
CMNT RHOO IS THE IMPLICITNESS FACTOR FOR THE ELECTRONS
C
      READ (2,1) RHOO
C
      DO 3 K=0,NEQ
CMNT EMASS(K) IS THE MASS FOR SPECIES K (GRAMS)
CMNT ALWAYS USE EVEN MULTIPLES OF 1.67185E-24 FOR IONS
CMNT ALWAYS USE 9.1066E-28 FOR ELECTRONS
CMNT ANUMB(K) IS THE ATOMIC NUMBER FOR SPECIES K -- ALWAYS POSITIVE 4
CMNT REDEN(K) IS THE INITIAL DENSITY FOR SPECIES K (PART/CC)
C
      READ (2,1) EMASS(K),ANUMB(K),REDEN(K)
C
CMNT ENIT(K) IS THE ENERGY CORRESPONDING TO THE VELOCITY PEAK FOR THE INITIAL
CMNT DISTRIBUTION FUNCTION (GAUSSIAN) FOR SPECIES K (KEV)
CMNT IF ENIT(K) IS 0., THEN XNIT(K) IS THE INITIAL ENERGY FOR
CMNT A MAXWELLIAN SPECIES K
CMNT XNIT(K) IS THE VELOC. SPREAD FOR SPECIES K INITIALLY (IF ENIT(K) .NE. 0.)
CMNT YNIT(K) IS THE ANGULAR SPREAD FOR SPECIES K INITIALLY
CMNT VNIT(K) IS THE COSINE OF THE ANGULAR PEAK OF SPECIES K INITIALLY
C
      READ (2,1) ENIT(K),XNIT(K),YNIT(K),VNIT(K)
C
      DO 41 KS=1,NSOR
CMNT ESOR(KS,K), XSOR(KS,K),YSOR(KS,K) AND USOR(KS,K) DESCRIBE THE KS SOURCE
CMNT OF SPECIES K, AND CORRESPOND TO ENIT(K),XNIT(K),YNIT(K) AND
CMNT VNIT(K) IN MEANING
C
      READ (2,1) ESOR(KS,K),XSOR(KS,K),YSOR(KS,K),USOR(KS,K)
C

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41 CONTINUE
3 CONTINUE

C      WRITE (3,11) XMAX,XMAX1,FGHMESH,FGTMESH
C
11 FORMAT(5HXMAX=,E16.6,5X,6HXMAX1=,E16.6,
C /,8HFGHMESH=,E16.6,5X,8HFGTMESH=,E16.6)
C
C      WRITE (3,12) NSTOP,NPRINT,NPLOT,NRSTRT
C
12 FORMAT(6HNSTOP=,15,5X,7HNPRINT=,15,5X,6HNPLOT=,15,5X,7HNRSTRT=,15)
C
C      WRITE (3,7) NCNEC,NCN10,KCHOUT,1GTMESH
C
7 FORMAT(6HNCNEC=,15,5X,6HNCN10=,15,5X,7HCHOUT=,15,5X,8H1GTMESH=,
C 15)
C
C      WRITE (3,39) NSL,NSLE,NSLE2
C
39 FORMAT(4HNSL=,15,5X,5HNSLE=,15,5X,6HNSLE2=,15)
C
C      WRITE (3,13) DTR,VNORM
C
13 FORMAT(4HDTR=,E16.6,5X,6HVNORM=,E16.6)
IF (NSTEPU.EQ. 0) GO TO 72
C
C      WRITE (3,14) NSTEPU,(1K,DTR(K),NSETH(K)),K=1,NSTEPU)
C
14 FORMAT(7HNSTEPU=,15,/,12HX=,15,5X,4HDTR=,E16.6,5X,6HNSETH=,15)
72 CONTINUE
IF (NSL+NSLE.EQ. 0) GO TO 253
C
C      WRITE (3,15) POTENT,DPOT,POTRAT,NCUTFE,NPOTZ
C
15 FORMAT(21HAMBIPOLAR POTENTIAL =,E16.6,5X,5HDPOT=,E16.6,/,
C 7HPOTRAT=,E16.6,5X,7HNCUTFE=,15,5X,6HNPOTZ=,15)
C
C      WRITE (3,64) ELENGTH,FGBMESH
C
64 FORMAT(8HELENGTH=,E16.6,5X,8HFGBMESH=,E16.6)
C
C      WRITE (3,31) BETA0
C
31 FORMAT(6HBETA0=,E16.6)
C
C      WRITE (3,317) BRATIO,MIMAX
C
317 FORMAT(7HBRATIO=,E16.6,5X,6HMIMAX=,15)
253 CONTINUE
C
C      WRITE (3,24) PLTANG
C
24 FORMAT(7HPLTANG=,E16.6)
C
C      WRITE (3,411) NSPLIT,NEL10,RH00
C
411 FORMAT(7HNSPLIT=,15,5X,6HNEL10=,15,5X,5HRH00=,E16.6)
DO 4 K=0,NEQ
C
C      WRITE (3,16) K,EMASS(K),ANUMB(K),REDEN(K)

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C
16 FORMAT(//,2HX=.15//,5MASS=.E16.6,2X=.E16.6,5X,DENSITY=.
C (.E16.6)
C
WRITE (3,17) ENTINI,ENTIME,TIMEI,TIMEIE
C
17 FORMAT(5ENIT=.E16.6,5ENIT=.E16.6,5ENIT=.E16.6,5X,
C 5ENIT=.E16.6)
DO 42 NS=1,NSQR
C
WRITE (3,43) NS
C
43 FORMAT(//,10XSOURCE NO .18//)
C
WRITE (3,18) ESORIS,KI,ESORIS,KI,XSORIS,KI,USORIS,KI
C
18 FORMAT(5ESOR=.E16.6,5X,5ESOR=.E16.6,5X,5ESOR=.E16.6,5X,
C 5ESOR=.E16.6)
42 CONTINUE
43 CONTINUE
CMNT GOOD IS THE LOGARITHMIC DERIVATIVE OF THE MAGNETIC FIELD
C
READ (2,1) GOOD
C
C
WRITE (3,5) GOOD
C
5 FORMAT(5GOOD=.E16.6)
CMNT READ IN THE FOLLOWING DATA FOR TOROIDAL PROBLEMS ONLY
IF INSL=BLE .G1. GO TO 6
CMNT IFUDGE DESCRIBES THE VARIATION OF BZ VERSUS R IN THE TCT.
C
READ (2,1) IFUDGE
C
CMNT KIPMUT IS 1 FOR RECALCULATION OF ELECTRON TAU-P, 0 OTHERWISE
C
READ (2,2) KIPMUT
C
DO 401 K=0,NEQ
CMNT TAUENIKI IS THE ENERGY CONFINEMENT TIME FOR SPECIES K
CMNT TAUPKIKI,TAUENIKI,TAUPKIKI AND TAUPPRKI ARE USED TO
CMNT DESCRIBE THE PARTICLE CONFINEMENT TIME FOR SPECIES K
C
READ (2,1) TAUENIKI,TAUPKIKI,TAUENIKI,TAUPKIKI,TAUPPRKI
C
401 CONTINUE
C
WRITE (3,402) IK,TAUENIKI,TAUPKIKI,TAUENIKI,TAUPKIKI,
C TAUPPRKI),K=0,NEQ)
C
402 FORMAT(//,2HX=.15,5X,6HTAUK=.E16.6,5X,6HTAUPK=.E16.6,5X,
C 6HTAUK=.E16.6,5X,7HTAUPK=.E16.6,7,12X,7HTAUPPR=,
C .E16.6)
DO 448 KM=1,5
CMNT RDORAI(-5),RDORBI(-),RDORI(-),ROTCMG(-) DESCRIBE THE LOGARITHMIC
CMNT DERIVATIVE OF THE MAJOR RADIUS IN THE TCT.
C
READ (2,1) RDORAI(KM),RDORBI(KM),RDORI(KM),ROTCMG(KM)
C
448 CONTINUE

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C      WRITE (3,491) KTPNUT
C
C 491 FORMAT(7PKTPNUT=,15)
C
C      WRITE (3,442) RFUDGE, ((KM,RDORA(KM),RDORB(KM),
C      C RDORT(KM),RDTCHG(KM)),KM=1,5)
C
C 442 FORMAT(//,7HRFUDGE=,E16.6,
C /, (3HKM=,15.5X,2HA=,E16.6,5X,2HB=,E16.6,5X,
C 4HTAU=,E16.6,5X,5HTCHG=,E16.6))
C      GO TO 166
C
C 166 CONTINUE
CMNT SET TOROIDAL PARAMETERS TO DEFAULT VALUES
RFUDGE=2. $ KTPNUT=0
DO 167 K=0,NEQ
TAUEK(K)=1.E+90 $ TAUPK(K)=1.E+90 $ TAUEN(K)=1.E+90
TAUPK1(K)=1.E+90 $ TAUPPR(K)=1.
167 CONTINUE
DO 168 KM=1,5
RDORA(KM)=0. $ RDORB(KM)=0.
RDORT(KM)=1.E+90 $ RDTCHG(KM)=1.E+90
168 CONTINUE
RDTCHG(1)=0. $ DO 169 NCHE=1,NONCH
PQBPLE(NCHE)=0. $ PQFEO(NCHE)=0.
169 CONTINUE
166 CONTINUE
DO 451 KS=1,NSOR
DO 455 K=0,NEQ
CMNT TSON(KS,K) AND TSOFF(KS,K) ARE THE ON AND OFF TIMES FOR THE KS SOURCE
CMNT OF SPECIES K
C
C      READ (2,1) TSON(KS,K),TSOFF(KS,K)
C
C
C      WRITE (3,450) K,KS,TSON(KS,K),TSOFF(KS,K)
C
C 450 FORMAT(//,2HK=,15.5X,9HSOURCE NO,15.5X,8HON TIME=,E16.6,5X,
C 9HOFF TIME=,E16.6)
C 455 CONTINUE
DO 451 I=0,NEQ $ DO 451 K=0,NEQ
CMNT ABJ1(KS,I,K) ARE THE CONSTANT TERMS IN THE CURRENT FOR THE KS SOURCE
CMNT OF SPECIES I - THE K INDEX IS REDUNDANT
CMNT ABJ2(KS,I,K) IS THE CURRENT TERM FOR THE KS SOURCE OF SPECIES I WHICH
CMNT MULTIPLIES THE SQUARE ROOT OF THE DENSITY OF SPECIES K
CMNT ABJ3(KS,I,K) IS THE CURRENT TERM FOR THE KS SOURCE OF SPECIES I WHICH
CMNT MULTIPLIES THE DENSITY OF SPECIES K
CMNT CCEX(KS,I,K) IS THE CHARGE EXCHANGE TERM CORRESPONDING TO THE KS SOURCE 4
CMNT FOR SPECIES I, REFLECTING ACTION OF SPECIES K
C
C      READ (2,1) ABJ1(KS,I,K),ABJ2(KS,I,K),ABJ3(KS,I,K),CCEX(KS,I,K)
C
C
C      WRITE (3,452) I,K,ABJ1(KS,I,K),ABJ2(KS,I,K),ABJ3(KS,I,K),
C      C CCEX(KS,I,K)
C
C 452 FORMAT(2H1=,15.2X,2HK=,15.2X,3HJ1=,E16.6,2X,3HJ2=,E16.6,2X,
C 3HJ3=,E16.6,2X,4HCEX=,E16.6)
C 451 CONTINUE
CMNT KBUF IN IS 1 FOR READING IN (FROM DISC FILE) DISTRIBUTION FUNCTIONS

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CMNT      - 0 OTHERWISE - DENSITIES WILL BE SET ACCORDING TO DATA CARD
CMNT      KBUFOUT IS 1 FOR WRITING OUT (ONTO DISC FILE) DISTRIBUTION FUNCTIONS
CMNT      KBUFU(K) ARE USED ONLY IF KBUFIN = 1
CMNT      IF 0, SPECIES K IS NOT ON INPUT FILE
CMNT      IF 1, SPECIES K IS ON INPUT FILE AND SHOULD BE READ IN
CMNT      IF 2, SPECIES K IS ON INPUT FILE AND SHOULD BE IGNORED
C
      READ (2,2) KBUFIN,KBUFOUT,(KBUFU(K),K=0,NEQ)
C
C
      WRITE (3,474) KBUFIN,KBUFOUT,((K,KBUFU(K)),K=0,NEQ)
C
      474 FORMAT(1,7HKBUFIN=,15,5X,8HKBUFOUT=,15,7,12HK=,15,5X,
C 6HKBUFU=,15))
CMNT      NAMEBIN IS THE NAME OF THE INPUT FILE IF KBUFIN = 1
CMNT      NAMEBOUT IS THE NAME OF THE OUTPUT FILE IF KBUFOUT = 1
C
      READ (2,475) NAMEBIN,NAMEBOUT
C
      475 FORMAT(BA10)
C
      WRITE (3,476) NAMEBIN,NAMEBOUT
C
      476 FORMAT(BHNAMEBIN=,A10,5X,9HNAMEBOUT=,A10)
      PI=3.141592653539793 $ P(02=.5*PI $ TWOP=(PI*PI $ FOURPI=TWOP*TWOP)
      CHARGE=4.803E-10 $ ERGTKEV=1.602E-9
      DO 21 K=0,NEQ
      EIONS(K)=.5*EMASS(K)*VNORM**2/ERGTKEV
      DO 21 I=0,NEQ
      RATIO22(I,K)=(ANUMB(I)/ANUMB(K))**2
      21 RATIO(I,K)=EMASS(I)/EMASS(K)
CMNT      TOROIDAL D-T REACTION OF 17.6 MEV ASSUMED
      CT=1. $ VEFO=1. $ SBPLE=0. $ SFEO=0. $ EFUSION=1.76E+4
CMNT      INITIALIZE MESH PARAMETERS
      CALL XINIT
      IF (KSINGUL.EQ. 1) RETURN
CMNT      TERMINATE IF MESH CANNOT BE INITIALIZED
      CALL FINIT
CMNT      INITIALIZE DISTRIBUTION FUNCTIONS
      CALL FBUFINIT
CMNT      READ IN DISTRIBUTION FUNCTIONS FROM DISC FILE (IF DESIRED)
      CALL BOUNDARY
      IF (KBOUND.EQ. 1) RETURN
CMNT      TERMINATE IF BOUNDARY FAILURE
      CALL CHPDST
CMNT      SET ION DISTRIBUTIONS TO ZERO OUTSIDE LOSS BOUNDARY
      CALL GNADE
      IF (KGNANDE.EQ. 1) RETURN
      DO 23 K=0,NEQ
      GAM1=FOURPI*(ANUMB(K)*CHARGE)**4/EMASS(K)**2
      23 TNORM(K)=VNORM**3/(ANORMK(K)*GAM1)
      DO 301 I=0,NEQ $ DO 301 K=0,NEQ
      RATK(I,K)=ANORMK(I)/ANORMK(K)
      301 CONTINUE
CMNT      COMPUTE REACTION SIGMA-V BAR
      IF (NCSIG.EQ. 2) GO TO 332
      CALL SIGVID $ GO TO 333
      332 CALL SIGV3D
      333 CONTINUE
CMNT      PERFORM PRELIMINARY COMPUTATIONS FOR ALPHA PARTICLE HEATING

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      NDTAL=0 % CALL DTAL INIT
CMNT  COMPUTE SOURCE TERMS
      CALL SOURCE
      SFSE=0. % DO 337 K=0,NEQ
337  SFSE=SFSE+REDEN(K)*ENERGY(K)
CMNT  SET UP PERP-PAR VELOCITY MESH
      CALL PERPPAR
      NSIGM(1)=10H1-D VELOC. % NSIGM(2)=10H1-INTLO.
      NSIGM(3)=0 % IF (NCSIG.EQ. 1) GO TO 342
      IF (NCSIG.EQ. 2) GO TO 341
      NSIGM(3)=10H0 TRIT. E
      GO TO 342
341  NSIGM(1)=10H3-D VELOC.
342  CONTINUE
      RETURN
      END

C
C
      SUBROUTINE TLOOP
C
      USE COMM
CMNT  CHECK TO TERMINATE FOR FUTURE RESTART
      IF (N.EQ. NRSTRT) GO TO 31
      IF (ISENSE SWITCH 1) 31,32
31  CALL RESTART
32  CONTINUE
CMNT  CHECK TO RESET TIME STEP
      DO 1 K=1,NSTEPU
      IF (N.EQ. NSETN(K)) DTR=DTR*(K)
      CONTINUE
      TIME=TIME+DTR
      RETURN
      END

C
C
      SUBROUTINE RESTART
C
      USE COMM
CMNT  THIS SUBROUTINE TERMINATES THE CODE AND PREPARES IT FOR FUTURE RESTART
CMNT  PRINT OUT DATA
      CALL EEPRINT
CMNT  PLOT OUT DATA
      CALL EEPLT
CMNT  COMPUTE PH(18) AND ASSOCIATED FUNCTIONS (MIRRORS ONLY)
      CALL POTSHAPE
      CALL DENSINPT
CMNT  COMPUTE Q (MIRRORS ONLY)
      CALL QCALC
CMNT  WRITE OUT DISTRIBUTION FUNCTIONS ONTO DISC FILE (IF DESIRED)
      CALL FBUFOUT
      CALL ASSIGN(2,0,7,PRINTIONS,-1)
      CALL OFFMON
      CALL ASSIGN(2,0,7,PRINTIONS,0)
CMNT  READ IN NEW VALUES OF NSTOP,NPRINT,NPLOT,NRSTRT,NSTEPU,DTN(K),
CMNT  NSETN(K),ND(2),IPLT
C
      READ (2,2) NSTOP,NPRINT,NPLOT,NRSTRT
C
      2 FORMAT(16I5)
C

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      READ (2,2) NSTEPU
C
      IF (NSTEPU .EQ. 0) GO TO 6
C
      READ (2,1) (DTN(K),K=1,NSTEPU)
C
      READ (2,2) (NSETN(K),K=1,NSTEPU)
C
6 CONTINUE
1 FORMAT(5E16.6)
  DIMENSION ND(5) $ ND(1)=0 $ ND(3)=6 $ ND(4)=0
C
  READ (2,3) ND(2),IPLOT
C
3 FORMAT(2A10)
  ND(5)=1 $ CALL HSPIND1
  IF (IPLOT .NE. 1HK .OR. KMACH .EQ. 0) CALL DDB01D(2HAM,1)
  IF (IPLOT .EQ. 1HK) CALL KEEP011
  DIF (KMACH) LAB1,LAB1,LAB2
LAB2 CONTINUE
  IF (IPLOT .NE. 1HD .AND. IPLOT .NE. 1HK) CALL FRB01D(2HAM,1)
  CALL DDERS(0)
LAB1 CONTINUE
  CALL FRAME
C
  WRITE (3,4) NSTOP,NPRINT,NPLOT,NRSTRT
C
4 FORMAT(10HNEW VALUES,/,6HNSTOP=,1/.5X,7HNPRINT=,15.5X,6HNPLOT=,
  /,5.5X,7HNRSTRT=,15)
  IF (NSTEPU .EQ. 0) GO TO 7
C
  WRITE (3,5) NSTEPU,((K,DTN(K),NSETN(K)),K=1,NSTEPU)
C
5 FORMAT(7HNSTEPU=,15./,2HK=,15.5X,4HDTN=,E16.6,5X,6HNSETN=,15))
7 CONTINUE
  RETURN
  END
C
C
  SUBROUTINE FBUFINT
C
  USE COMM
  CMNT BUFFER IN DISTRIBUTION FUNCTIONS FROM DISC FILE (IF DESIRED)
  IF (KBUFIN .EQ. 0) RETURN
  CALL ASSIGN(5,0,NAMEBIN,0)
  IF (KBUFU(0) .EQ. 0) GO TO 1
  K=0
  BUFFER IN (5,1) (FE1(1),FE1(JX))
2 IF (UNIT,5) 2,3,4,5
C
4 WRITE (3,6) K $ RETURN
C
6 FORMAT(29HBRANCH 3 BUFFER IN ERROR - K=,15)
C
5 WRITE (3,7) K $ RETURN
C
7 FORMAT(29HBRANCH 4 BUFFER IN ERROR - K=,15)
3 IF (KBUFU(0) .EQ. 2) GO TO 1
  DO B J=1,JX

```

```

      9 FE(I)=FE(I)
      1 CONTINUE
      DO 10 K=1,NEQ
      IF (KBUFU(K).EQ. 0) GO TO 10
      BUFFER (N (5,1) (FT(1,1),FT(IYDM,JX)))
11 IF (UNIT,5) 11,12,4,5
12 IF (KBUFU(K).EQ. 2) GO TO 10
      CALL WRITELCM(FT,F(1,1,K),IYPIJX)
10 CONTINUE
      CALL ASSIGN(5,0,NAMEBIN,-1)
      CALL GNAMEDE
      RETURN
      END

C
C
      SUBROUTINE FBUFOUT
C
      USE COMM
CMNT  BUFFER OUT DISTRIBUTION FUNCTIONS ONTO DISC FILE (IF DESIRED)
      IF (KBUFOUT.EQ. 0) RETURN
      LOUT=NEQ+2+JX+NEQ*IYPIJX
      CALL ASSIGN(5,0,NAMEBOUT,LOUT)
      K=0
      BUFFER OUT (5,1) (FE(1),FE(JX))
      1 IF (UNIT,5) 1,2,3,4

C
      3 WRITE (3,5) K $ RETURN
C
      5 FORMAT(30HBRANCH 3 BUFFER OUT ERROR - K=,15)
C
      4 WRITE (3,6) K $ RETURN
C
      6 FORMAT(30HBRANCH 4 BUFFER OUT ERROR - K=,15)
      DO 7 K=1,NEQ
      CALL READLCM(FT,F(1,1,K),IYPIJX)
      BUFFER OUT (5,1) (FT(1,1),FT(IYDM,JX))
      8 IF (UNIT,5) 8,7,3,4
      7 CONTINUE
      CALL WRTEOF(5) $ CALL REWIND(5)
      CALL ASSIGN(5,0,NAMEBOUT,-1)
      RETURN
      END

C
C
      SUBROUTINE TDSTORE
C
      USE COMM
CMNT  STORE DATA IN TIME-DEPENDENT ARRAYS
      CT=CT*EXPF(-DTR*RDOR)
      VT=VEFO/CT**2
      IF (N.GT. NCHEC*(N/NCHEC)) RETURN
      IF (NCH.EQ. NONCH) NCH=0
      NCH=NCH+1
      PTIME(NCH)=TIME
      DO 1 K=0,NEQ
      PDENS(NCH,K)=REDEN(K) $ PENGY(NCH,K)=ENERGY(K)
      1 CONTINUE
      PPOTENT(NCH)=POTENT
      IF (NCSIG.EQ. 2) GO TO 3
      CALL SIGVID $ GO TO 4

```

```

3 CALL SIGV3D
4 CONTINUE
CMNT COMPUTE TOTAL SYSTEM DENSITY-ENERGY
SFSE=0. $ DO 444 K=0,NEQ
SFSE=SFSE+VT*REDEN(K)*ENERGY(K)
444 CONTINUE
PQTSE(INCH)=SFSE
IF (NSL+NSLE .GT. 0) RETURN
CMNT COMPUTE BULK PLASMA LOSS ENERGY
DO 446 K=0,NEQ
SBPLE=SBPLE+DTR*FLOATF(NCHEC)*VT/TAUEK(K)*REDEN(K)*ENERGY(K)
446 CONTINUE
REPROD=1. $ DO 447 K=1,NEQ
IF (K .GT. 2) GO TO 447
REPROD=REPROD*REDEN(K)
447 CONTINUE
CMNT COMPUTE FUSION ENERGY
SFEO=SFEO+DTR*FLOATF(NCHEC)*VT*REPROD*SIGVH*EFUSION
POBPLE(INCH)=SBPLE $ PQFEO(INCH)=SFEO
RETURN
END

C
C SUBROUTINE GETR(JX,XMAX,H,R,KSINGUL)
C
CMNT THIS SUBROUTINE COMPUTES A MESH RATIO
C
CMNT MESH RATIO MUST BE BOUNDED BY 10. AND 0.1
C
CMNT ACCURACY IS TO WITHIN 1 PART IN 14 PLACES
C
IF (H .GT. 1.E-90 .AND. XMAX .GT. H .AND. JX .GE. 3) GO TO 1
WRITE (3,2) H,XMAX,JX $ KSINGUL=1 $ RETURN
C
2 FORMAT(//,30HUNSATISFACTORY GETR PARAMETERS,/,2HH=,E24.14,5X,
C 5HXMAX=,E24.14,5X,3HJX=,15,/)
1 CONTINUE
EHL=H/XMAX $ JXM1=JX-1 $ JXM2=JX-2
TOL=10.*(1.+1.E-14)
TOL1=1./TOL
R=1. $ DELR=1.E-01
SUM=EHL $ DO 13 K=1,JXM2
13 SUM=R*SUM+EHL
IF (ABSF(SUM-1.) .LT. 1.E-14) GO TO 10
SIGN=1. $ IF (SUM .GT. 1.) SIGN=-1.
R=R+SIGN*DELR
SUML=SUM
IF (R .GT. TOL .OR. R .LT. TOL1) GO TO 11
SUM=EHL $ DO 14 K=1,JXM2
14 SUM=R*SUM+EHL
IF (ABSF(SUM-1.) .LT. 1.E-14) GO TO 10
IF ((SUM-1.)*(SUML-1.) .GT. 0.) GO TO 3
DELR=1.E-1*DELR $ SIGN=-SIGN
IF (DELR .LT. 9.E-15) GO TO 10
GO TO 3
C
11 WRITE (3,4) R $ KSINGUL=1 $ RETURN
C
4 FORMAT(//,26HUNSATISFACTORY R FROM GETR,5X,2HR=,E24.14,/)

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```

C      10 WRITE (3,5) JX,XMAX,H,R
C
C      5 FORMAT(//,23HSATIS-FACTORY MESH RATIO,/,3HJX=,15,5X,5HMAX=,
C      E24.14,5X,2HH=,E24.14,5X,2HR=,E24.14,/)
C      RETURN
C      END
C
C
C      SUBROUTINE PERPPAR
C
C      USE COMM
CMNT  COMPUTE PERP-PAR VELOCITY MESH
      PARAMETER(IPXY=41)
      PARAMETER(JPXY=IPXY+(IPXY-1)*KSYDM)
      COMMON/MVP1/XPERP(IPXY),XPAR(JPXY),DXPERP(IPXY),DXPAR(JPXY)
      DIMENSION FPN(IPXY,JPXY)
      EQUIVALENCE(FN,FPN)
      IPXYM=IPXY-1 $ JPXYM=JPXY-1 $ JJPXY=IPXY*JPXY
      JPSYM=1+IPXYM*KSYDM $ JPSYMP=JPSYM+1
      XPERP(1)=0. $ XPERP(IPXY)=XMAX1
      XPAR(JPSYM)=0. $ XPAR(JPXY)=XMAX1
      HPE=XMAX1/FLOAT(IPXYM) $ HPA=XMAX1/FLOAT(IPXYM)
      HPEU=FGMMESH*HPE $ HPAU=FGMMESH*HPA
      CALL GETR(IPXY,XMAX1,HPEU,RAM,KSINGUL)
      IF (KSINGUL.EQ.1) RETURN
      XPERP(2)=HPEU $ DO 1 IP=3,IPXYM
1     XPERP(IP)=XPERP(IP-1)+RAM*(XPERP(IP-1)-XPERP(IP-2))
      CALL GETR(IPXY,XMAX1,HPAU,RAM,KSINGUL)
      IF (KSINGUL.EQ.1) RETURN
      XPAR(JPSYMP)=HPAU $ DO 2 JP=JPSYMP+1,JPXYM
2     XPAR(JP)=XPAR(JP-1)+RAM*(XPAR(JP-1)-XPAR(JP-2))
      DO 102 JP=1,JPSYM-1
102    XPAR(JP)=-XPAR(JPXY+1-JP)
C
C      WRITE (3,3) ((IP,XPERP(IP)),IP=1,IPXY)
C
C      3 FORMAT(//,10HXPERP MESH,/,15,E16.6)
C
C      WRITE (3,4) ((JP,XPAR(JP)),JP=1,JPXY)
C
C      4 FORMAT(//,9HXPAR MESH,/,15,E16.6)
C      DO 17 IP=2,IPXYM
17     DXPERP(IP)=.5*(XPERP(IP+1)-XPERP(IP-1))
      DXPERP(1)=.5*(XPERP(2)-XPERP(1))
      DXPERP(IPXY)=.5*(XPERP(IPXY)-XPERP(IPXYM))
      DO 32 JP=2,JPXYM
32     DXPAR(JP)=.5*(XPAR(JP+1)-XPAR(JP-1))
      DXPAR(1)=.5*(XPAR(2)-XPAR(1))
      DXPAR(JPXY)=.5*(XPAR(JPXY)-XPAR(JPXYM))
      S1=ABSF(1.-EMASS(1)/3.3133E-24)
      S2=ABSF(1.-ANUMB(1))
      SCHK=S1+S2 $ NDEUT=0
      IF (SCHK.GT.1.E-10) RETURN
CMNT  NDEUT = 1 IF SPECIES 1 IS DEUTERIUM - 0 OTHERWISE
      NDEUT=1
      RETURN
CMNT  CONVERT DISTRIBUTION FUNCTION (DEUTERIUM ONLY) TO PERP-PAR DISTRIBUTION
      ENTRY CONV1
      NPR1=1 $ GO TO 43

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CMNT ENTER HERE IF NO PRINTOUT IS DESIRED
ENTRY CONV2
NPR1=0
43 CONTINUE
IF (NDEUT .EQ. 0) RETURN
CALL READLCM(FT,F(1,1,1),IYP1JX)
DO 5 IP=1,IPXY $ DO 5 JP=1,JPXY
FNP(IP,JP)=0. $ IF (IP .EQ. IPXY .OR. JP .EQ. JPXY) GO TO 5
IF (JP .EQ. 1 .AND. KSYDM .EQ. 1) GO TO 5
IF (IP .EQ. 1 .AND. JP .EQ. JPXY) GO TO 10
XMAG2=XPERP(IP)**2*XPAP(JP)**2
XMAG=(1.+1.E-13)*SQRT(XMAG2)
IF (XMAG .GE. XMAX1) GO TO 5
COSSE=XPAP(JP)/XMAG $ THET=ACOSF(COSSE)
IF (NSL .EQ. 0) GO TO 66
IF (THET .LT. Y(1) .OR. (PI-THET .LT. Y(1) .AND. KSYDM .EQ. 1))
C GO TO 5
66 CONTINUE
DO 6 I=1,IYM1
IF (THET .LT. Y(I) .OR. THET .GE. Y(I+1)) GO TO 6
GO TO 7
6 CONTINUE
I=IYM1
7 I2=I+1
DO 8 J=1,JX1M
IF (XMAG .LT. X(J) .OR. XMAG .GE. X(J+1)) GO TO 8
GO TO 9
8 CONTINUE
J=JX1M
9 J2=J+1
R1POS=(THET-Y(I))/DYP5(I) $ RJPOS=(XMAG-X(J))/DXP5(J)
R1POS1=1.-R1POS $ RJPOS1=1.-RJPOS
W00=R1POS1*RJPOS1 $ W01=R1POS1*RJPOS $ W10=R1POS*RJPOS1
W11=R1POS*RJPOS
FNP(IP,JP)=W00*FT(I,J)+W01*FT(I,J2)+W10*FT(I2,J)+W11*FT(I2,J2)
GO TO 5
10 S=0. $ DO 11 I=1,IY
11 S=S+FT(I,1)
FNP(IP,JP)=S/FLOAT(IY)
5 CONTINUE
IF (NPR1 .EQ. 0) RETURN
C
WRITE (3,42)
C
42 FORMAT(//,26HDEUTERIUM PERP-PAR DISTRIB,/)
DO 41 JP=1,JPXY
C
WRITE (3,40) JP,((IP,FNP(IP,JP)),IP=1,IPXY)
C
40 FORMAT(//,3HJP=.15,/,10X,15,E16.6,15,E16.6,15,E16.6,15,E16.6)
41 CONTINUE
RETURN
ENTRY PEPAPLT
CMNT PLOT PERP AND PAR DEUTERIUM VELOCITY DISTRIBUTIONS
IF (NDEUT .EQ. 0) RETURN
DIMENSION FPE(IPXY),FPA(JPXY)
CMNT COMPUTE PERP VELOCITY DISTRIBUTION
DO 12 IP=1,IPXY
S=0. $ DO 13 JP=1,JPXY
13 S=S+FNP(IP,JP)*DXPAR(JP)

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12 FPE(IP)=S
CMNT COMPUTE PAR VELOCITY DISTRIBUTION
DO 14 JP=1,JPXY
S=0. $ DO 15 IP=1,IPXY
15 S=S+FPN(IP,JP)*XPERP(IP)*DXPERP(IP)
14 FPA(JP)=S
CALL CARTMM(IPXY,DMIN,DMAX,FPE,1)
CALL CARTMM(JPXY,EMIN,EMAX,FPA,1)
CALL MAPS(0.,XMAX,0.,DMAX,.2,.999,.65,.999)
CALL TRACE(XPERP,FPE,IPXY)
CALL MAPS(XPAR,1,XMAX,0.,EMAX,.2,.999,.15,.5)
CALL TRACE(XPAR,FPA,JPXY)
CALL SETCH(1.,17.,1,0,1,1)

C
WRITE (100,16)

C
16 FORMAT(21HPERP VELOC DIST - TOP,17,23HPAR VELOC DIST - BOTTOM)
CALL SETCH(17.,1,1,0,1,0)

C
WRITE (100,38) TIME,N

C
38 FORMAT(5HTIME=,E16.6,5X,2HN=,15)
CALL FRAME
RETURN
END

C
SUBROUTINE CONTPLOT

C
USE COMM
C** PLOT CONTOURS FOR DEUTERIUM DISTRIBUTION FUNCTION IN PERP-PAR SPACE
PARAMETER(NCONT=21)
DIMENSION CONTP(NCONT)
DO 1 I=1,1Y $ DO 1 J=1,JX
CALL (J)=X(J)*SINN(I) $ CB(1,J)=X(J)*COSS(I)
1 CONTINUE
CALL READLCMFT,F(1,1,1),1Y,1JX
S=0. $ DO 2 I=1,1Y $ DO 2 J=1,JX
IF (S .EQ. F(1,I,J)) S=F(1,I,J)
2 CONTINUE
SMIN=LOGF(1.E-3*5) $ SMAX=LOGF(5)
DCONT=(SMAX-SMIN)/FLOAT(NCONT)
CONT(1)=SMIN+.5*DCONT $ DO 13 K=2,NCONT
13 CONT(K)=CONT(K-1)+DCONT
DO 14 K=1,NCONT
14 CONT(K)=EXP(F(1,K))
XLIM=-XMAX+FLOAT(KSYDM)
CALL MAPS(0.,XMAX,XLIM,XMAX,.4,.999,.4,.999)
CALL LINE(0.,XLIM,XMAX,XLIM)
CALL LINE(XMAX,XLIM,XMAX,XMAX)
CALL LINE(XMAX,XMAX,0.,XMAX)
CALL LINE(0.,XMAX,0.,XLIM)
CALL CONTOUR(NCONT,CONT,1,FT,1YDM,CA,1,1Y,1,CB,1,JX,1)
CALL SETCH(17.,1,1,0,1,0)

C
WRITE (100,15) TIME,N

C
15 FORMAT(30HDEUTERIUM CONTOUR PLOT - TIME=,E16.6,5X,2HN=,15)
CALL SETCH(17.,1,0,1,0,1)

C

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      WRITE (100,16) (CONT(K),K=1,NCONT)
C
16  FORMAT(8HCONTOURS,/,('E16.6'))
   CALL SETCH(50.,10.,1,0,1,0)
C
      WRITE (100,38)
C
38  FORMAT(6HV PERP)
   CALL SETCH(10.,50.,1,0,1,1)
C
      WRITE (100,39)
C
39  FORMAT(5HV PAR)
   CALL FRAME
   RETURN
   END
C
C
      SUBROUTINE GAMMAIN
C
      USE COMM
      COMPUTE COULOMB LOGARITHM
      IF (N .GT. 1) GO TO 1
      ALP=1./137. $ R0=2.82E-13 $ CLIGHT=3.E+10
      GACON1=2.*ALP/(SQRTF(3.*P))*R0*CLIGHT)
      GACON2=GACON1/(3.7943E-4*EMASS(0))
      DO 2 I=0,NEQ $ DO 2 K=0,NEQ
      GAM2(I,K)=EMASS(I)*EMASS(K)*GACON2/(EMASS(I)+EMASS(K))
2  CONTINUE
1  CONTINUE
      TEMPE=1.E+3*ENERGY(0) $ DENSE=REDEN(0)
      DEBY=SQRTF(TEMPE/DENSE)
      DO 3 I=0,NEQ $ DO 3 K=0,NEQ
      S1=ENERGY(I)/EMASS(I) $ SK=ENERGY(K)/EMASS(K)
      SF=S1 $ IF (SK .GT. S1) SF=SK
      VIKF=SQRTF(SF*ERGKEV)
      GAM3=GAM2(I,K)*DEBY*VIKF
      GAMMA(I,K)=LOGF(GAM3)-.5
3  CONTINUE
      RETURN
      END
C
C
      SUBROUTINE DTALINIT
C
      USE COMM
      CMNT TAKE ACCOUNT OF ALPHA PARTICLE HEATING
      IF (N .GT. 0 .AND. NDAL .EQ. 0) RETURN
      IF (N .GT. 0) GO TO 3
      IF (NEQ .LT. 3) RETURN
      IF (NSOR .EQ. 1) RETURN
      S1=ABSF(1,-EMASS(1)/3.3433E-24)
      S2=ABSF(1,-ANUMB(1))
      S3=ABSF(1,-EMASS(2)/5.0150E-24)
      S4=ABSF(1,-ANUMB(2))
      S5=ABSF(1,-EMASS(3)/6.6866E-24)
      S6=ABSF(1,-.5*ANUMB(3))
      SCHK=S1+S2+S3+S4+S5+S6
      IF (SCHK .GT. 1.E-10) RETURN
      DO 1 K=0,3

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```

      IF (REDEN(K) .LT. 1.E-89) RETURN
1 CONTINUE
C
      WRITE (3,2)
C
2 FORMAT(/,33HALPHA PARTICLE FORMATION INCLUDED,/)
CMNT NDAL = 1 IF ALPHA PARTICLE HEATING IS INCLUDED - 0 OTHERWISE
      NDAL=1
3 CONTINUE
      UM2=1.+RAT10N(1,2)*ENERGY(2)/ENERGY(1)
      UMU=UM2*EIONS(1)
      CALL FINDSIG(UMU,SDAL)
      CALL SIGVIDAL
      RETURN
      END
C
C
      SUBROUTINE SOURCEE
C
      USE COMM
CMNT COMPUTE SOURCE TERMS
      DO 1 K=1,NEQ
CMNT COMPUTE SOURCE FOR EACH ION SPECIES BY SUMMING OVER THE GAUSSIANS
      DO 31 I=1,IYOM $ DO 31 J=1,JX1
31 FT(1,J)=0.
      ENS=0. $ EJS=0.
      DO 32 KS=1,NSOR
      XND2=ESOR(KS,K)/EIONS(K) $ XOD=SQRTF(XOD2)
      XUSE=XSOR(KS,K)
      IF (ESOR(KS,K) .EQ. 0.) XUSE=1.5*EIONS(K)/XSOR(KS,K)
      DO 2 J=1,JX1
      FAX=-XUSE*(X(J)-XOD)**2
      DO 3 I=1,IY
      FACV=-YSOR(KS,K)*(COSS(1)-USOR(KS,K))**2
      SO(I,J)=EXP(-FAX+FACV)
3 CONTINUE
2 CONTINUE
      S=0. $ T=0. $ DO 4 I=1,IY $ DO 4 J=1,JX1
      TERM=SO(I,J)*CINT2(J)*CYNT2(I)
      S=S+TERM $ T=T+TERM*XSD(J)
4 CONTINUE
      ENSOR(KS,K)=EIONS(K)*T/S
      CUR=0.
CMNT INCLUDE APPROPRIATE CURRENT ONLY IF CORRESPONDING SOURCE IS ON
      IF (TIME .LT. TSON(KS,K) .OR. TIME .GE. TSOFF(KS,K)) GO TO 41
      DO 42 I=0,NEQ
      CUR=CUR+ABJ1(KS,K,1)+ABJ2(KS,K,1)*SQRTF(REDEN(1))+
      C ABJ3(KS,K,1)*REDEN(1)
42 CONTINUE
CMNT COMPUTE ALPHA PARTICLE SOURCE - THE ON AND OFF TIMES FOR SOURCE NO 1
CMNT , SPECIES 3, CONTROL THE ALPHA PARTICLE SOURCE
      IF (NDAL .EQ. 0 .OR. KS .NE. 1) GO TO 41
      PROD=SIGVHAL*REDEN(1)*REDEN(2)
      IF (K .EQ. 3) CUR=CUR+PROD
41 CONTINUE
      EJSOR(KS,K)=CUR
      ENS=ENS+ENSOR(KS,K)*EJSOR(KS,K)
      EJS=EJS+EJSOR(KS,K)

```

```

FACT=CUR/(S*ANORMK(K))
DO 5 J=1,JX1
DO 6 I=1,IY
6 SO(I,J)=SO(I,J)*FACT
IF (KSYDM .EQ. 1) GO TO 5
SO(IYPI,J)=SO(IYM1,J)
5 CONTINUE
DO 33 I=1,IYDM $ DO 33 J=1,JX1
33 FT(I,J)=FT(I,J)+SO(I,J)
32 CONTINUE
EJSTOT(K)=EJS $ ENSAVG(K)=ENS/(EJS+1.E-90)
CALL WRITELCM(FT,SOURCE(1,1,K),IYPIJX)
1 CONTINUE
CMNT COMPUTE ELECTRON SOURCE TERMS
K=0
DO 34 J=1,JX
34 FE1(J)=0.
ENS=0. $ EJS=0.
DO 35 KS=1,NSOR
XOD2=ESOR(KS,K)/EIONS(K) $ XOD=SQRTE(XOD2)
XUSE=XSOR(KS,K)
IF (ESOR(KS,K) .EQ. 0.) XUSE=1.5*EIONS(K)/XSOR(KS,K)
DO 12 J=1,JX
FACX=-XUSE*(X(J)-XOD)**2
12 SORE(J)=EXP(FACX)
S=0. $ T=0. $ DO 14 J=1,JX
TERM=SORE(J)*XSQ(J)*CINT(J)
S=S+TERM $ T=T+TERM*XSQ(J)
14 CONTINUE
ENSOR(KS,K)=EIONS(K)*T/S
S=FOURPI*S
CUR=0.
IF (TIME .LT. TSON(KS,K) .OR. TIME .GE. TSOFF(KS,K)) GO TO 43
DO 44 I=0,NEQ
CUR=CUR+ABJ1(KS,K,I)+ABJ2(KS,K,I)*SQRT(REDEN(I))+
C ABJ3(KS,K,I)*REDEN(I)
44 CONTINUE
43 CONTINUE
EJSOR(KS,K)=CUR
ENS=ENS+ENSOR(KS,K)*EJSOR(KS,K)
EJS=EJS+EJSOR(KS,K)
FACT=CUR/(S*ANORMK(K))
DO 15 J=1,JX
15 SORE(J)=FACT*SORE(J)
DO 36 J=1,JX
36 FE1(J)=FE1(J)+SORE(J)
35 CONTINUE
EJSTOT(K)=EJS
ENSAVG(K)=ENS/(EJS+1.E-90)
DO 37 J=1,JX
37 SORE(J)=FE1(J)
RETURN
END
C
C
SUBROUTINE FINIT
C
USE COMM
CMNT INITIALIZE DISTRIBUTION FUNCTIONS
DO 1 K=1,NEQ

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CMNT INITIALIZE ION DISTRIBUTION FUNCTIONS
XOD2=ENIT(K)/EIONS(K)
XOD=SQRT(XOD2)
IF (ENIT(K).EQ. 0.) XNIT(K)=1.5*EIONS(K)/XNIT(K)
DO 2 J=1,JX
FACX=-XNIT(K)*(X(J)-XOD)**2
DO 3 I=1,IY
FACY=-YNIT(K)*(COSS(I)-YNIT(K))**2
FN(I,J)=EXP(FACX+FACY)
IF (J.EQ. JX) FN(I,J)=0.
3 CONTINUE
IF (KSYDM.EQ. 1) GO TO 2
FN(IY1,J)=FN(IY1,J)
2 CONTINUE
1 CALL WRITELCM(FN,F(1,1,K),IY1,JX)
CMNT INITIALIZE ELECTRON DISTRIBUTION FUNCTION
K=0
XOD2=ENIT(K)/EIONS(K) $ XOD=SQRT(XOD2)
IF (ENIT(K).EQ. 0) XNIT(K)=1.5*EIONS(K)/XNIT(K)
DO 12 J=1,JX
FACX=-XNIT(K)*(X(J)-XOD)**2
12 FE(J)=EXP(FACX)
RETURN
END

C
C
C SUBROUTINE XINIT
C
C
CMNT USE COMM
INITIALIZE MESH PARAMETERS
IYM1=IY-1 $ IYM2=IY-2 $ JXM1=JX-1 $ JXM2=JX-2
IYM3=IY-3 $ JXM3=JX-3
JXIM=JX1-1 $ JXIM2=JX1-2 $ JXIM3=JX1-3
CMNT COMPUTE ANGULAR MESH
BRATIO1=1./BRATIO
THETA=ACOSF(SQRT(1.-BRATIO1))
IF (NSL.EQ. 0) THETA=0.
Y(1)=THETA $ Y(IY)=PI02+FLOAT(KSYDM)*PI02-THETA
HY2=(Y(IY)-THETA)/FLOAT(IYM1)
DO 7 I=2,IYM1
7 Y(I)=Y(I-1)+HY2
CMNT RECOMPUTE ANGULAR MESH IF NON-UNIFORM
IF (IGTMESH.EQ. 0) GO TO 21
TUSE=FGTMESH*HY2 $ TLEN=PI02-THETA
IYUS=IY-KSYDM*(IY/2)
CALL GETR(IYUS,TLEN,TUSE,AM,K5INGUL)
IF (K5INGUL.EQ. 1) RETURN
IYLM=IYUS-1 $ Y(IYUS)=PI02
GO TO (22,23),IGTMESH
22 Y(21)=Y(1)+TUSE
DO 24 I=3,IYLM
24 Y(I)=Y(I-1)+AM*(Y(I-1)-Y(I-2))
GO TO 21
23 Y(IYLM)=PI02-TUSE
DO 25 I=3,IYLM
I=IYLM-I+2
25 Y(I)=Y(I+1)+AM*(Y(I+1)-Y(I+2))
21 CONTINUE
IF (KSYDM.EQ. 0) GO TO 331
DO 332 I=IYUS+1,IYM1

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```

      II=IYP1-1
332 Y(I)=PI-Y(I)
      Y(IYP1)=Y(I) $ GO TO 333
331 CONTINUE
      Y(IYP1)=2.*Y(I)-Y(IYM1)
333 CONTINUE
CMNT COMPUTE VELOCITY MESH
      X(I)=0. $ X(JX)=XMAX
      X(JX1)=XMAX1 $ HX=XMAX1/JX1M
      HXFG=FGHMESH*HX $ X(2)=HXFG
      CALL GETR(JX1,XMAX1,HXFG,AM,K$INGUL)
      IF (K$INGUL .EQ. 1) RETURN
      DO 8 J=3,JX1M
      8 X(J)=X(J-1)+RAM*(X(J-1)-X(J-2))
      IF (JX1 .GE. JXM1) GO TO 19
      X(JX1+1)=X(JX1)+X(JX1)-X(JX1M)
      IF (JX1 .EQ. JXM2) GO TO 19
      JUSE=JX-JX1+1 $ XUSE=XMAX-XMAX1 $ HXE=X(JX1)-X(JX1M)
      CALL GETR(JUSE,XUSE,HXE,AM,K$INGUL)
      IF (K$INGUL .EQ. 1) RETURN
      DO 2 J=JX1+2,JX
      2 X(J)=X(J-1)+RAM*(X(J-1)-X(J-2))
      XMAX=X(JX)
19 CONTINUE

C
      WRITE (3,71) (J,X(J),J=1,JX)
C
71 FORMAT(//,6HX MESH,/,115,E16.6,15,E16.6,15,E16.6,15,E16.6)
C
      WRITE (3,72) (I,Y(I),I=1,IYP1)
C
72 FORMAT(//,6HY MESH,/,115,E16.6,15,E16.6,15,E16.6,15,E16.6)
CMNT COMPUTE OTHER MESH QUANTITIES
      DO 3 J=1,JXM1
      3 DXPS(J)=X(J+1)-X(J)
      DXPS(JX)=0. $ DXM5(1)=0.
      DO 4 J=1,JX
      4 DX(J)=.5*(DXPS(J)+DXM5(J))
      XSQ(J)=X(J)**2
      DX1(J)=1./DX(J)
      IF (J .EQ. 1) GO TO 4
      X1(J)=1./X(J) $ X21(J)=X1(J)**2 $ X31(J)=X1(J)*X21(J)
      4 CONTINUE
      DO 5 I=1,IY
      5 DYP5(I)=Y(I+1)-Y(I)
      DYP5(IYP1)=0. $ DYM5(1)=0.
      DO 6 I=1,IY
      6 DY(I)=.5*(DYM5(I)+DYP5(I))
      DY1(I)=1./DY(I)
      COSS(I)=COSF(Y(I)) $ SINN(I)=SINF(Y(I))
      6 CONTINUE
      IF (K$YDM .EQ. 0) GO TO 31
      DO 32 I=1,YHP1,IY
      32 II=IYP1-1 $ COSS(II)=-COSS(I) $ SINN(II)=SINN(I)
      COSS(IYH)=0. $ SINN(IYH)=.
      31 CONTINUE
CMNT COMPUTE INTEGRATION CONSTANTS FOR TRAPEZOIDAL INTEGRATION
      DO 161 I=1,IY
      161 CYNT(I)=DY(I)

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      DO 162 J=1,JX
162  CINT(J)=DX(J)
      IF (KSYDM.EQ. 1) GO TO 16
      DO 17 I=1,IYM1
17  CYNT(I)=2.*CYNT(I)
16  CONTINUE
      DO 163 I=1,IY
163  CYNT2(I)=THOPI*SINN(I)*CYNT(I)
      DO 164 J=1,JX
164  CINT2(J)=XSQ(J)*CINT(J)
      EXT(1,1)=(Y(1)-Y(3))/(Y(2)-Y(3))
      EXT(2,1)=(Y(1)-Y(2))/(Y(3)-Y(2))
      EXT(3,1)=0.
      EXT(1,2)=(Y(1Y)-Y(1YM2))/(Y(1YM1)-Y(1YM2))
      EXT(2,2)=(Y(1Y)-Y(1YM1))/(Y(1YM2)-Y(1YM1))
      EXT(3,2)=0.
      EXT(1,3)=(X(1)-X(3))/(X(2)-X(3))
      EXT(2,3)=(X(1)-X(2))/(X(3)-X(2))
      EXT(3,3)=0.
      EXT(1,4)=(X(JX1)-X(JX1M2))/(X(JX1M)-X(JX1M2))
      EXT(2,4)=(X(JX1)-X(JX1M))/(X(JX1M2)-X(JX1M))
      EXT(3,4)=0.
      HP=(BRATIO-1.)/FLOATF(LZ-1) $ BMAG(1)=1. $ BMAG(LZ)=BRATIO
      HPU=HP*FGBMESH $ BLEN=BRATIO-1.
      BMAG(2)=1.+HPU $ CALL GETR(LZ,BLEN,HPU,RAM,KSINGUL)
      IF (KSINGUL.EQ. 1) RETURN
      DO 74 L=3,LZ-1
74  BMAG(L)=BMAG(L-1)+RAM*(BMAG(L-1)-BMAG(L-2))
      DO 73 L=1,LZ
      PSI(L)=SQRTF(BMAG(L)) $ PS2(L)=SQRTF(BMAG(L)/BRATIO)
73  CONTINUE
      RETURN
      END

C
C
C      SUBROUTINE EEPRINT
C
C      USE COMM
CMNT  PRINT OUT VARIOUS DATA
C
C      WRITE (3,1) N,TIME
C
C      1 FORMAT(/,2HN=,15,5X,5HTIME=,E16.6)
C
C      WRITE (3,14) SFSE
C
C      14 FORMAT(/,21HTOTAL SYSTEM ENERGY =,E16.6,/)
C      IF (NSL+NSLE.GT. 0) GO TO 13
C
C      WRITE (3,22) SBPLE,SFEO
C
C      22 FORMAT(/,25HBULK PLASMA LOSS ENERGY =,E16.6,5X,15HFUSION ENERGY =,
C      E16.6)
C      GO TO 133
13  CONTINUE
C
C      WRITE (3,134) POTENT
C
C      134 FORMAT(10HPOTENTIAL=,E16.6,/)
133  CONTINUE

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C      WRITE (3,23) SIGVH
C      23 FORMAT(/,9HSIGMA V =,E16.6,/)
C      DO 2 K=0,NEQ
C      WRITE (3,6)
C      6 FORMAT(1H1)
C      WRITE (3,3) K,REDEN(K),ENERGY(K)
C      3 FORMAT(2HK=,15.5X,8HDENSITY=,E16.6,5X,7HENERGY=,E16.6,/)
C      DO 10 KS=1,NSOR
C      WRITE (3,9) KS,ENSOR(KS,K),EJSOR(KS,K)
C      9 FORMAT(/,10HSOURCE NO ,15.5X,7HENERGY=,E16.6,5X,8HCURRENT=,E16.6)
C      10 CONTINUE
C      WRITE (3,11) ENSAVG(K),EJSTOT(K)
C      11 FORMAT(/,15HAVG SOURCE EN =,E16.6,5X,22HTOTAL SOURCE CURRENT =,
C      E16.6,/)
C      IF (NSL+NSLE .GT. 0) GO TO 15
C      WRITE (3,12) TAU EK(K),TAUPK(K),TAUEN(K),TAUPK1(K),TAUPPR(K)
C      12 FORMAT(/,6HTAU EK=,E16.6,5X,6HTAUPK=,E16.6,5X,6HTAUEN=,E16.6,
C      5X,7HTAUPK1=,E16.6,/,27X,7HTAUPPR=,E16.6)
C      15 CONTINUE
C      IF (K .EQ. 0) GO TO 7
C      CALL READLCM(FN,F(1,1,K),IYPIJX)
C      DO 4 J=1,JXI
C      WRITE (3,5) J,X(J),(FN(I,J),I=1,IYDM)
C      5 FORMAT(/,2HJ=,15.2X,2HX=,E16.6,2X,2HF=,/, (6E16.6))
C      4 CONTINUE
C      GO TO 2
C      7 CONTINUE
C      WRITE (3,8) ((J,X(J),FE(J)),J=1,JX)
C      8 FORMAT(/,12HJ=,15.2X,2HX=,E16.6,2X,3HFE=,E16.6)
C      2 CONTINUE
C      WRITE (3,6)
C      IF (NSL+NSLE .EQ. 0) RETURN
C      DO 51 I=1,IYDM $ DO 51 J=1,JXI
C      51 FT(I,J)=FE(J)*ANORMK(0)
C      DO 52 K=1,NEQ
C      CALL READLCM(FN,F(1,1,K),IYPIJX)
C      DO 53 I=1,IYDM $ DO 53 J=1,JXI
C      53 FT(I,J)=FT(I,J)+FN(I,J)*ANORMK(K)
C      52 CONTINUE
C      DO 55 I=1,IYDM $ DO 55 J=1,JXI
C      55 FN(I,J)=0.
C      DO 54 I=2,IYMI $ DO 54 J=2,JXIM

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      IF (I.EQ. IYH) GO TO 54
      FN(I,J)=X(J)*(FT(I,J+1)-FT(I,J-1))/(2.*DX(J))-SINN(I)*
C (FT(I+1,J)-FT(I-1,J))/(2.*COSS(I)*DY(I))
54 CONTINUE
C
      WRITE (3,56)
C
56 FORMAT(//,18HTOTAL DISTRIBUTION,/)
      DO 57 J=1,JX1
C
      WRITE (3,58) J,(FT(I,J),I=1,IYDM)
C
58 FORMAT(//,2HJ=,15,2X,5HTOT=,/, (6E16.6))
57 CONTINUE
C
      WRITE (3,59)
C
59 FORMAT(//,24HENERGY MINIMIZATION TEST,/)
      DO 60 J=1,JX1
C
      WRITE (3,61) J,(FN(I,J),I=1,IYDM)
C
61 FORMAT(//,2HJ=,15,2X,5HDFDE=,/, (6E16.6))
60 CONTINUE
C
      WRITE (3,6)
C
      RETURN
      END
C
      SUBROUTINE EEPLT
C
      USE COMM
      PLOT OUT VARIOUS DATA
      PERPB(0)=2./3.*REDEN(0)*ENERGY(0)
      CMNT COMPUTE FRACTION OF PERP PRESSURE FOR EACH SPECIES
      T=PERPB(0)
      DO 11 K=1,NEQ
      CALL READLCM(FN,F(1,1,K),IYP1JX)
      S=0. $ DO 12 I=1,IY $ DO 12 J=1,JX1
12 S=S+FN(I,J)*XSQ(J)*SINN(I)**2*CINT2(J)*CYNT2(I)
      PERPB(K)=EIONS(K)*ANORMK(K)*S
11 T=T+PERPB(K)
      DO 13 K=0,NEQ
13 PERPB(K)=PERPB(K)/T
      DO 1 K=0,NEQ
      CMNT PLOT DISTRIBUTION FUNCTIONS
      IF (K.EQ. 0) GO TO 21
      CALL READLCM(FN,F(1,1,K),IYP1JX)
      CALL SETCH(1.,20.,0.0,1,1)
C
      WRITE (100.5) K,TIME
C
5 FORMAT(11HSPECIES NO ,15,5X,5HTIME=,E16.6)
      PTANG=PLTANG
      DO 41 J=1,JX1
      TEMPG(J)=X(J) $ DO 41 I=1,IYDM
41 FT(I,J)=FN(I,J)
      IF (PLTANG.LE. 180.) GO TO 42

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PTANG=PLTANG-180.
DO 43 J=1,JX1
JJ=JX1+1-J $ TEMPG(J)=X(JJ) $ DO 43 I=1,IYDM
43 FT(I,J)=FN(I,JJ)
42 CONTINUE
CALL PLOT3D(PTANG,TEMPG,Y,FT,1,1,1,JX1,IY,IYDM)
GO TO 22
21 CONTINUE
CALL SETCH(1,20,0,0,1,1)
C
WRITE (100,5) K,TIME
C
CALL CARTMM(JX,DMIN,DMAX,FE,1)
CALL MAPS(0,XMAX,0,DMAX,.2,.999,.2,.999)
CALL TRACE(X,FE,JX)
CALL FRAME
22 CONTINUE
IF (N.EQ. 0) GO TO 51
CMNT PLOT TIME DEPENDENT QUANTITIES
CALL CARTMM(NCH,DMIN,DMAX,PDENS(1,K),1)
CALL CARTMM(NCH,EMIN,EMAX,PENGY(1,K),1)
IF (DMAX.LE. DMIN+1.E-90) DMAX=1.1*DMAX
IF (EMAX.LE. EMIN+1.E-90) EMAX=1.1*EMAX
CALL MAPS(PTIME(1),PTIME(NCH),DMIN,DMAX,.2,.999,.65,.999)
CALL TRACE(PTIME,PDENS(1,K),NCH)
CALL MAPS(PTIME(1),PTIME(NCH),EMIN,EMAX,.2,.999,.15,.5)
CALL TRACE(PTIME,PENGY(1,K),NCH)
51 CONTINUE
CALL SETCH(17,4,1,0,1,0)
C
WRITE (100,6) REDEN(K),ENERGY(K),EJSTOT(K),ENSAVG(K),TIME,
C PERPB(K)
C
6 FORMAT(8HDENSITY=,E16.6,5X,7HENERGY=,E16.6,/,8HSOR CUR=,
C E16.6,5X,7HSOR EN=,E16.6,/,5HTIME=,E16.6,8X,6HPPERP=,
C E16.6)
CALL SETCH(1,17,1,0,1,1)
C
WRITE (100,7) K
C
7 FORMAT(2HK=,13,2X,6HENERGY,30X,7HDENSITY)
CALL FRAME
1 CONTINUE
IF (N.EQ. 0) GO TO 52
IF (NSL+NSLE.EQ. 0) GO TO 101
CALL CARTMM(NCH,DMIN,DMAX,PPOTENT,1)
IF (DMAX.LE. DMIN+1.E-90) DMAX=1.1*DMAX
CALL MAPS(PTIME(1),PTIME(NCH),DMIN,DMAX,.2,.999,.15,.5)
CALL TRACE(PTIME,PPOTENT,NCH)
101 CONTINUE
CALL CARTMM(NCH,YMIN,YMAX,PQTSE,1)
CALL MAPS(PTIME(1),PTIME(NCH),0,YMAX,.2,.999,.65,.999)
CALL TRACE(PTIME,PQTSE,NCH)
52 CONTINUE
CALL SETCH(17,1,1,0,1,0)
C
WRITE (100,10) TIME
C
10 FORMAT(5HTIME=,E16.6)
IF (NSL+NSLE.EQ. 0) GO TO 102

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      CALL SETCH(1,7,1,0,1,1)
C
      WRITE (100,20) POTENT
C
      20 FORMAT(21HAMBIPOLAR POTENTIAL =,E16.6)
      102 CONTINUE
      CALL SETCH(1,49,1,0,1,1)
C
      WRITE (100,103) SFSE
C
      103 FORMAT(21HTOTAL SYSTEM ENERGY =,E16.6)
      CALL FRAME
      IF (INSL+NSLE .GT. 0) GO TO 153
      IF (N .EQ. 0) GO TO 53
      CALL CARTMM(INCH,YMIN,YMAX,PDBPLE,1)
      CALL MAPS(PTIME(1),PTIME(NCH),0.,YMAX,.2,.999,.15,.5)
      CALL TRACE(PTIME,PDBPLE,NCH)
      CALL CARTMM(INCH,YMIN,YMAX,PQFEO,1)
      CALL MAPS(PTIME(1),PTIME(NCH),0.,YMAX,.2,.999,.65,.999)
      CALL TRACE(PTIME,PQFEO,NCH)
      53 CONTINUE
      CALL SETCH(1,7,1,0,1,1)
C
      WRITE (100,23) SBPLE,SFEO
C
      23 FORMAT(25HBULK PLASMA LOSS ENERGY =,E16.6,5X,15HFUSION ENERGY =,
      C E16.6)
      153 CONTINUE
      CALL SETCH(17,1,1,0,1,0)
C
      WRITE (100,10) TIME
C
      CALL SETCH(17,3,1,0,1,0)
C
      WRITE (100,57) SIGVH,(NSIGH(KLS),KLS=1,3)
C
      57 FORMAT(9HSIGMA V =,E16.6,5X,3A10)
      CALL FRAME
CMNT PLOT DEUTERIUM CONTOURS
      CALL CONTPLOT
      CALL CONVP2
CMNT PLOT PERP AND PAR DEUTERIUM DISTRIBUTION
      CALL PEPAPLOT
      RETURN
      END
C
C
      SUBROUTINE BOUNDARY
C
      USE COMM
CMNT COMPUTE ION LOSS-CONE BOUNDARY
      IF (INSL .EQ. 0) GO TO 51
      DO 1 K=1,NEQ
      XC2=ANUMB(K)*POTENT/EIONS(K)
      XMIN=SQRTF(XC2/(BRATIO-1.))
      DO 2 J=1,JX!M
      IF (XMIN .LE. X(J)+.5*DXPS(J)) GO TO 3
      2 CONTINUE
C
      WRITE (3,4) K,POTENT,XC2,XMIN

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C
4 FORMAT(21HBOUNDARY FAILURE - K=,I5,5X,7HPOTENT=,E16.6,5X,
C 4HXC2=,E16.6,5X,5HXM1N=,E16.6)
KBOUND=1 $ RETURN
3 JMIN(K)=J
DO 24 J=1,JMIN(K)
24 IO(J,K)=IYH
JMP1=JMIN(K)+1
DO 5 J=JMP1,JX1
PFAC=(1.+XC2/XSQ(J))*BRATIO1
TLC=ASINF(SQRT(PFAC))
I=1 $ IF (TLC .LE. Y(1)+.5*DYP5(1)) GO TO 6
DO 7 I=2,IYH
IF (TLC .GT. Y(I)-.5*DYMS(1) .AND. TLC .LE. Y(I)+.5*DYP5(1))
C GO TO 6
7 CONTINUE
C
C WRITE (3,4) K,POTENT,XC2,XMIN
C
C WRITE (3,8) TLC
C
8 FORMAT(4HTLC=,E16.6)
KBOUND=1 $ RETURN
6 IO(J,K)=I
5 CONTINUE
IMIN(K)=IO(JX1,K)
IF (IMIN(K) .LT. IYH) GO TO 31
C
C WRITE (3,4) K,POTENT,XC2,XMIN
C
C WRITE (3,32) IMIN(K)
C
32 FORMAT(5HIMIN=,I5)
KBOUND=1 $ RETURN
31 CONTINUE
IMP1=IMIN(K)+1
DO 9 I=IMIN(K),IYH
JO(I,K)=0
DO 10 J=JMIN(K),JX1
IF (IO(J,K) .EQ. 1) JO(I,K)=J
10 CONTINUE
9 CONTINUE
DO 11 I=IMP1,IYHM1
I=IMP1+IYHM1-I
IF (JO(I,K) .EQ. 0) JO(I,K)=JO(I+1,K)
11 CONTINUE
DO 12 I=1,IMIN(K)-1
JO(I,K)=JX1
DO 33 I=IYHP1,IY
II=IYPI-I
33 JO(I,K)=JO(II,K)
1 CONTINUE
GO TO 52
51 DO 53 K=1,NEQ
IMIN(K)=1 $ JMIN(K)=1 $ DO 54 I=1,IY
54 JO(I,K)=1
DO 55 J=1,JX1
55 IO(J,K)=1

```

```

53 CONTINUE
52 CONTINUE
  IF (N.GT. 1) RETURN
  DO 71 K=1,NEQ
C
    WRITE (3,72) K,IMIN(K),((J,10(J,K)),J=1,JX1)
C
    72 FORMAT(//,2HK=,15,5X,5HIMIN=,15,/, (2HJ=,15,5X,3H10=,15))
C
    WRITE (3,73) JMIN(K),((1,JO(1,K)),1=1,1Y)
C
    73 FORMAT(//,5HJMIN=,15,/, (2H1=,15,5X,3HJO=,15))
    71 CONTINUE
    RETURN
  END
C
C
C
  SUBROUTINE POTSHAPE
C
  USE COMM
CMNT  COMPUTE POTENTIAL AS A FUNCTION OF MAGNETIC FIELD
  IF (NSL+NSLE.EQ. 0) RETURN
  IF (NPOTZ.EQ. 0) RETURN
  NBM1=NB-1
  BETN=PI/FLOAT(NPTS) $ BETN2=.5*BETN
  LZM1=LZ-1
  DO 97 IW=1,NPTS
    ARGN=FLOAT(2*IW-1)*BETN2
    COSYN(IW)=COSF(ARGN)
  97 CONTINUE
  DO 1 1=1,1YH
    1 JMMU(1)=COSS(1YHP1-1)
    PPOT(1)=0. $ PPCT(LZ)=POTENT
CMNT  COMPUTE FUDGE FACTOR FOR COMPARING ION AND ELECTRON DENSITIES
    PHM=POTENT/EIONS(0) $ CUT=SQRTF(PHM)
    S=0. $ DO 102 KK=1,NEQ
  102 S=S+ANUMB(KK)*REQEN(KK)
    T=0. $ DO 321 J=1,JX
    FACT=1. $ IF (X(J).LE. CUT) GO TO 321
    FACT=SQRTF(1.-BRATIO*(1.-PHM*X21(J)))
  321 T=T+FACT*FE(J)*XSQ(J)*CINT(J)
    CHRAT=S/(FOURPI*ANORMK(0)*T)
    PHI(1)=0. $ HP=POTENT/FLOAT(NBM1)
    DO 2 K=2,NB
    2 PHI(K)=PHI(K-1)+HP
    KLIM=1
CMNT  FOR EACH VALUE OF PSI (MAG FIELD), COMPUTE VARIOUS PHI (POTENTIAL)
    DO 73 L=2,LZM1
    DO 3 K=KLIM,NB
    DNSI(K)=0. $ DNSK(K)=0.
    PS=BHAG(L)
    DO 101 KK=1,NEQ
    CALL READLCH(FN,F(1,1,KK),1YPIJX)
    PH=PHI(K)*ANUMB(KK)/EIONS(KK)
    DO 4 J=1,JX1
    VINT(J)=0. $ IF (J.EQ. 1) GO TO 4
    S=0. $ DO 5 IW=1,NPTS
    SJN=COSYN(IW)
    RATSW=X(J)/SQRTF(XSQ(J)+PH)
    UULIM=RATSW*PS1(L) $ ULLIM=RATSW*PS2(L)

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      IF (SJN .GT. UULIM .OR. SJN .LT. ULLIM) GO TO 5
      WJN=SJN/RATSW $ UMU2=1.-WJN**2/PS
      UMU=SQRTF(UMU2+1.E-13) $ DO 7 I1=1,IYHM1
      IF (UMU .LT. UMMU(I1) .OR. UMU .GE. UMMU(I1+1)) GO TO 7
      IUSE=I1 $ GO TO 8
7 CONTINUE
      IUSE=IYHM1
      W1=(UMU-UMMU(IUSE))/(UMMU(IUSE+1)-UMMU(IUSE))
      W0=1.-W1
      IVSE=IYHP1-IUSE
      FIONS=W0*FN(IVSE,J)+W1*FN(IVSE-1,J)
      S=S+FIONS*SJN
5 CONTINUE
      VINT(J)=BETN*S
4 CONTINUE
      S=0. $ DO 10 J=1,JX1
      T=X(J)*SQRTF(XSQ(J)+PH)
10 S=S+T*V(NT(J)*CINT(J)
      DNSI(K)=DNSI(K)+S*ANUMB(KK)*ANORMK(KK)/ANORMK(0)
101 CONTINUE
      PH=PHI(K)/EIONS(0)
      DO 21 JJ=1,JXM1
      IF (CUT .LT. X(JJ) .OR. CUT .GE. X(JJ+1)) GO TO 21
      JP=JJ $ GO TO 22
21 CONTINUE
      CUT=XMAX $ JP=JX
22 JPI=JP+1
      CUTL=SQRTF(PH)
      DO 23 JJ=1,JXM1
      IF (CUTL .LT. X(JJ) .OR. CUTL .GE. X(JJ+1)) GO TO 23
      JQ=JJ $ GO TO 24
23 CONTINUE
      CUTL=XMAX $ JQ=JX
24 JQ1=JQ+1
      DO 27 J=1,JQ
27 VENT(J)=0.
      DO 25 J=JQ1,JP
25 VENT(J)=SQRTF(1.-PH*X2I(J))
      DO 26 J=JPI,JX
26 VENT(J)=SQRTF(1.-PS/BRATIO+(PS/BRATIO*PHM-PH1)*X2I(J))
      S=0. $ DO 13 J=1,JX
      T=XSQ(J)*FE(J)*VENT(J)
13 S=S+T*CINT(J)
      DNSE(K)=S*CHRRAT
3 CONTINUE
      IF (TIME .GT. 0.) GO TO 173
C
      WRITE (3,174) L,((K,DNSI(K),DNSE(K)),K=KLIM,NB)
C
174 FORMAT(/,2HL=,15/,2HK=,15,2X,5HDNSI=,E16.6,2X,5HDNSE=,E16.6)
173 CONTINUE
CMNT INTERPOLATE TO FIND PHI OF PSI
      DO 31 K=KLIM,NB
31 DDIFF(K)=DNSI(K)-DNSE(K)
      DO 33 K=KLIM,NB
      PROD=DDIFF(K)*DDIFF(K+1)
      IF (PROD .LE. 0.) GO TO 34
33 CONTINUE
      S=ABSF(DDIFF(KLIM)) $ KHU=KLIM
      DO 133 K=KLIM+1,NB

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T=ABSF(DDIFF(K)) $ IF (S.LE. T) GO TO 133
S=T $ KHU=K
133 CONTINUE
PPOT(L)=PHI(KHU)
KLIM=KHU
GO TO 73
34 CONTINUE
DENOM=DDIFF(K)-DDIFF(K+1)
ENUM=PHI(K+1)-PHI(K)
IF (ABSF(DENOM).LT. 1.E-90) DENOM=1.E+90
PPOT(L)=PHI(K)+DDIFF(K)*ENUM/DENOM
KLIM=K
73 CONTINUE
IF (TIME.GT. 0.) RETURN
C
WRITE (3,175) ((L,BMAG(L),PPOT(L)),L=1,LZ)
C
175 FORMAT(2HL=,15,2X,4HPSI=,E16.6,2X,5HPPOT=,E16.6)
RETURN
END
C
C
SUBROUTINE DENSINPT
C
USE COMM
CMNT COMPUTE DENSITY AND PRESSURES AS A FUNCTION OF PSI. USING THE
CMNT PHI OF PSI PREVIOUSLY CALCULATED
IF (NSL+NSLE.EQ. 0) RETURN
IF (NPOTZ.EQ. 0) RETURN
BETN=PI/FLOAT(NPTS) $ BETN2=.5*BETN
LZM1=LZ-1
PHM=POTENT/EIONS(0) $ CUT=SQRTF(PHM)
DO 73 L=1,LZM1
DENSE(L)=0. $ PPERP(L)=0. $ PPAR(L)=0.
PS=BMAG(L)
DO 101 KK=1,NEQ
CALL READLCM(FN,F(1,1,KK),IYPIJX)
PH=PPOT(L)*ANUMB(KK)/EIONS(KK)
DO 4 J=1,JX1
VINT(J)=0. $ VINTPE(J)=0. $ VINTPA(J)=0.
IF (J.EQ. 1) GO TO 4
S=0. $ SE=0. $ SA=0.
DO 5 IW=1,NPTS
SUN=COSYN(IW) $ RATSW=X(J)/SQRTF(XSQ(J)+PH)
UULIM=RATSW*PS1(L) $ ULLIM=RATSW*PS2(L)
IF (SUN.GT. UULIM.OR. SUN.LT. ULLIM) GO TO 5
WJN=SUN/RATSW $ UMU2=1.-WJN**2/PS
UMU=SQRTF(UMU2+1.E-13) $ DO 7 [I=1,IYHM1
IF (UMU.LT. UMMU([I]) .OR. UMU.GE. UMMU([I+1])) GO TO 7
IUSE=I] $ GO TO 8
7 CONTINUE
IUSE=IYHM1
B W1=(UMU-UMMU(IUSE))/(UMMU(IUSE+1)-UMMU(IUSE))
W0=1.-W1
IYSE=IYHPI-IUSE
FIONS=W0*FN(IYSE,J)+W1*FN(IYSE-1,J)
T=FIONS*SUN
TE=T*EIONS(KK)*ERGKKEV*PS*XSQ(J)*(1.-UMU**2)
TA=2.*T*EIONS(KK)*ERGKKEV*(XSQ(J)*(1.-PS*(1.-UMU**2))+PH)
S=S+T $ SE=SE+TE $ SA=SA+TA

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```

5 CONTINUE
  VINT(J)=BETN*S $ VINTPE(J)=BETN*SE $ VINTPA(J)=BETN*SA
4 CONTINUE
  S=0. $ SE=0. $ SA=0.
  DO 10 J=1,JX1
    T=X(J)*SORTF(XSQ(J)+PH)
    T=T*VINT(J) $ TE=T*VINTPE(J) $ TA=T*VINTPA(J)
    S=S+T*CINT(J) $ SE=SE+TE*CINT(J) $ SA=SA+TA*CINT(J)
10 CONTINUE
  DNSIE(L)=DNSIE(L)+ANUMB(KK)*S*FOURPI*ANORMK(KK)
  PPERP(L)=PPERP(L)+SE*FOURPI*ANORMK(KK)
  PPAR(L)=PPAR(L)+SA*FOURPI*ANORMK(KK)
101 CONTINUE
  PH=PPOT(L)/EIONS(0)
  DO 21 JJ=1,JXM1
    IF (CUT .LT. X(JJ) .OR. CUT .GE. X(JJ+1)) GO TO 21
    JP=JJ $ GO TO 22
21 CONTINUE
  CUT=XMAX $ JP=JX
22 JP1=JP+1
  CUTL=SORTF(PH) $ DO 23 JJ=1,JXM1
    IF (CUTL .LT. X(JJ) .OR. CUTL .GE. X(JJ+1)) GO TO 23
    JQ=JJ $ GO TO 24
23 CONTINUE
  CUTL=XMAX $ JQ=JX
24 JQ1=JQ+1
  DO 27 J=1,JQ
    VENT(J)=0.
    DO 25 J=JQ1,JP
      VENT(J)=SQRTF(1.-PH*X21(J))
      FAC1=EMASS(0)*VNORM*2/3.*(XSQ(J)-PH)
      VENT(J)=FAC1*VENT(J)
25 CONTINUE
  DO 26 J=JP1,JX
    VENT(J)=0.
  S=0. $ DO 13 J=1,JX
    T=XSQ(J)*FE(J)*VENT(J)
13 S=S+T*CINT(J)
  PPERP(L)=PPERP(L)+S*FOURPI*ANORMK(0)
  PPAR(L)=PPAR(L)+S*FOURPI*ANORMK(0)
73 CONTINUE
  DNSIE(LZ)=0. $ PPERP(LZ)=0. $ PPAR(LZ)=0.
C
  WRITE (3,4)((L,BMAG(L),PPOT(L),DNSIE(L),PPERP(L),PPAR(L)),L=1,LZ)
C
41 FORMAT(/,(2HL=,15,2X,4HPS1=,E16.6,2X,4HPOT=,E16.6,2X,5HDENS=,
C E16.6,/,10X,6HPPERP=,E16.6,2X,5HPPAR=,E16.6))
  CALL FRAME
  CALL CARTMM(LZ,DMIN,DMAX,PPOT,1)
  CALL CARTMM(LZ,EMIN,EMAX,DNSIE,1)
  CALL MAPS(1.,BRATIO,DMIN,DMAX,.2,.999,.15,.5)
  CALL TRACE(BMAG,PPOT,LZ)
  CALL MAPS(1.,BRATIO,EMIN,EMAX,.2,.999,.65,.999)
  CALL TRACE(BMAG,DNSIE,LZ)
  CALL SETCH(17.,1.,1.0,1.0)
C
  WRITE (100,81) TIME
C
81 FORMAT(5HTIME=,E16.6,9H SECONDS)
  CALL SETCH(1.,17.,1.0,1.1)

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C      WRITE (100,82)
C
C      B2 FORMAT(14HN OF PSI - TOP)
C      CALL SETCH(2.,17.,1,0,1,1)
C
C      WRITE (100,83)
C
C      B3 FORMAT(19HPHI OF PSI - BOTTOM)
C      CALL FRAME
C      CALL CARTMM(LZ,DMIN,DMAX,PPERP,1)
C      CALL CARTMM(LZ,EMIN,EMAX,PPAR,1)
C      CALL MAPS(1.,BRATIO,DMIN,DMAX,.2,.999,.15,.5)
C      CALL TRACE(BMAG,PPERP,LZ)
C      CALL MAPS(1.,BRATIO,EMIN,EMAX,.2,.999,.65,.999)
C      CALL TRACE(BMAG,PPAR,LZ)
C      CALL SETCH(17.,1.,1,0,1,0)
C
C      WRITE (100,81) TIME
C
C      CALL SETCH(1.,17.,1,0,1,1)
C
C      WRITE (100,84)
C
C      B4 FORMAT(17HPPAR OF PSI - TOP)
C      CALL SETCH(2.,17.,1,0,1,1)
C
C      WRITE (100,85)
C
C      B5 FORMAT(21HPPERP OF PSI - BOTTOM)
C      CALL FRAME
C      EKM=1.E+90 $ DO 201 L=1,LZM1
C      DENOM=PPERP(L)-PPERP(L+1)
C      IF (DENOM .LE. 0.) GO TO 201
C      EK=(BMAG(L+1)**2-BMAG(L)**2)/DENOM
C      IF (EKM .GT. EK) EKM=EK
C 201 CONTINUE
C      ELM=1.E+90 $ DO 209 L=1,LZM1
C      DENOM=PPAR(L+1)-PPAR(L) $ IF (DENOM .LE. 0.) GO TO 209
C      EK=(BMAG(L+1)**2-BMAG(L)**2)/DENOM
C      IF (ELM .GT. EK) ELM=EK
C 209 CONTINUE
C      BETMAX=EKM*PPERP(1)/(1.+EKM*PPERP(1))
C      BET0=BETA0 $ IF (BET0 .GT. BETMAX) BET0=BETMAX
C      DO 202 L=1,LZ
C 202 PSVAC(L)=SQRTF(BMAG(L)**2+BET0*PPERP(L)/(PPERP(1)*(1.-BET0)))
C      RVAC=BRAT[0]*SQRTF(1.-BET0)
C      EKTP=PPERP(1)/DNSIE(1) $ EKTPK=EKTP/ERGTKV
C      CALL CARTMM(LZ,DMIN,DMAX,PSVAC,1)
C      CALL MAPS(1.,BRATIO,DMIN,DMAX,.2,.999,.5,.999)
C      CALL TRACE(BMAG,PSVAC,LZ)
C      CALL SETCH(1.,17.,1,0,1,1)
C
C      WRITE (100,203)
C
C      B23 FORMAT(13HPSIVAC OF PSI)
C      CALL SETCH(17.,7.,1,0,1,0)
C
C      WRITE (100,204) EKM,ELM,RVAC,BETMAX,BETA0,EKTP,EKTPK
C

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204 FORMAT(4HEKM=E16.6,2X,4HELM=E16.6,/,5HRVAC=E16.6,/,7HBETMAX=,
C E16.6,2X,6HBETA0=E16.6,/,7HKTPERP=E16.6,9H ERGS = E16.6,
C 5H KEV)
CALL SETCH(17,1,1,0,1,0)
C
WRITE (100,81) TIME
C
CALL FRAME
C
WRITE (3,205) EKM,ELM,RVAC,BETMAX,BETA0,EKTP,EKTPK,
C ((L,BMAG(L),PSVAC(L)),L=1,LZ)
C
205 FORMAT(/,4HEKM=E16.6,2X,4HELM=E16.6,2X,5HRVAC=E16.6,2X,
C 7HBETMAX=E16.6,/,6HBETA0=E16.6,5X,7HKTPERP=E16.6,9H ERGS = ,
C E16.6,5H KEV,/,7HPSIVAC=,/,15,2E16.6))
RETURN
END
C
C
SUBROUTINE XSWEEP
C
USE COMM
CMNT ADVANCE DISTRIBUTION FUNCTIONS
KMU=1
DO 85 KM=1,5
IF (TIME .GT. RDCHG(KM)) KMU=KM
85 CONTINUE
CMNT COMPUTE LOGARITHMIC DERIVATIVE OF THE MAJOR RADIUS
RDOR=RDORA(KMU)/(1.-RDORB(KMU))*EXP(TIME/RDORT(KMU))
CMNT COMPUTE LOSS TERMS DUE TO ALPHA PARTICLE HEATING
SALUD=0. $ SALUT=0.
IF (NDTAL .EQ. 0) GO TO 951
IF (TIME .LT. TSON(1,3) .OR. TIME .GE. TSOFF(1,3)) GO TO 951
SALUD=.5*TNORM(1)*REDEN(2)*VNORM
SALUT=.5*TNORM(2)*REDEN(1)*SIGVHAL
SALUD=SALUD*FLOATF(NSPLIT)
SALUT=SALUT*FLOATF(NSPLIT)
951 CONTINUE
CMNT ADVANCE EACH DISTRIBUTION FUNCTION
DO 100 K=0,NEQ
IF (K .EQ. 1) STPLOS=0.
IF (REDEN(K) .LT. 1.E-89) GO TO 100
DT=OTR/TNORM(K)
CMNT COMPUTE CHARGE EXCHANGE LOSS TERM
SCEX=0. $ DO 61 KS=1,NSOR
DO 61 I=0,NEQ
IF (TIME .LT. TSON(KS,1) .OR. TIME .GE. TSOFF(KS,1)) GO TO 61
SCEX=SCEX+CCEX(KS,K,I)
61 CONTINUE
SCEXU=.5*TNORM(K)*SCEX
RBGN=1./DT
IF (K .EQ. 0) GO TO 101
RBGN=RBGN*FLOATF(NSPLIT)
SCEXU=SCEXU*FLOATF(NSPLIT)
CALL READLCM(CA,CAL(1,1,K),IYPIJX)
CALL READLCM(CB,CBL(1,1,K),IYPIJX)
CALL READLCM(CC,CCL(1,1,K),IYPIJX)
CALL READLCM(CD,COL(1,1,K),IYPIJX)

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CALL READLCM(CE,CEL(1,1,K),IYPIJX)
CALL READLCM(CF,CFL(1,1,K),IYPIJX)
CALL READLCM(FT,F(1,1,K),IYPIJX)
CALL READLCM(SO,SOURCE(1,1,K),IYPIJX)
DO 1 I=1,IYDM $ DO 1 J=1,JX1
1 FN(I,J)=0.
CMNT COMPUTE FINITE-TIME MIRROR LOSS TERM (IF DESIRED)
DO 500 J=1,JX1
500 YMINN(J)=0.
IF (NSLE .EQ. 0) GO TO 499
XCA2=POTENT/EIONS(K) $ XC2=XCA2*ANUMB(K)/(BRATIO-1.)
DO 501 J=1,JX1
YMINN(J)=PI02
IF (XSQ(J) .LE. XC2) GO TO 501
SIN2=BRATIO*(1.+ANUMB(K)*XCA2*X21(J))
YMINN(J)=ASINF(SORTF(SIN2))
501 CONTINUE
CUSE=.5*TNORM(K)*VNORM/ELENGTH
CUSE=CUSE*FLOATF(NSPLIT)
499 CONTINUE
CMNT ADVANCE USING IMPLICIT VELOCITY DERIVATIVES
IMP1=IMIN(K)+1
ILIM=IY-KSYDM*IMIN(K)
DO 2 I=IMP1,ILIM
JS=JO(I,K) $ JSP=JS+1
EPIJS=0. $ FPIJS=0.
IF (NSL .EQ. 1) GO TO 71
SUMC=CB(1,1)+CB(1,2) $ DENOM=SUMC-DXM5(2)*CA(1,1)
EPI=(SUMC+CA(1,2)*DXM5(2))/DENOM
71 CONTINUE
DO 3 J=JSP,JXIM
TXSD=2.*XSQ(J)*DX(J)
ALP=(CA(1,J+1)+(CB(1,J)+CB(1,J+1))/DXP5(J))/TXSD
GAM=(-CA(1,J-1)+(CB(1,J-1)+CB(1,J))/DXM5(J))/TXSD
BET=RBGN+((CB(1,J+1)+CB(1,J))/DXP5(J)+(CB(1,J)+CB(1,J-1))/
C DXM5(J))/TXSD
BET=BET+SCEXU
IF (NSLE .EQ. 0) GO TO 304
IF (YI1) .LE. YMINN(J) .OR. (PI-YI1) .LE. YMINN(J) .AND. KSYDM
C .EQ. 1) BET=BET+CUSE*X(J)*ABSF(COSS(I))
304 CONTINUE

IF (NDTAL .EQ. 1 .AND. K .EQ. 1) BET=BET+SALUD*X(J)*SDTAL(J)
IF (NDTAL .EQ. 1 .AND. K .EQ. 2) BET=BET+SALUT

TXSDT=2.*TXSD*DY(1)
DEL=RBGN*FT(1,J)+(CC(1,J+1)*(FT(1+1,J+1)-FT(1-1,J+1))-
C CC(1,J-1)*(FT(1+1,J-1)-FT(1-1,J-1)))/TXSDT
DEL=DEL+.5*TNORM(K)*SO(1,J)
IF (NSPLIT .EQ. 1) GO TO 66
DH=CD(1+1,J)*FT(1+1,J)-CD(1-1,J)*FT(1-1,J)+(CE(1+1,J)*FT(1+1,J+1)
C -FT(1+1,J-1))-CE(1-1,J)*(FT(1-1,J+1)-FT(1-1,J-1)))/(2.*DX(J))
C +(CF(1,J)+CF(1+1,J))*(FT(1+1,J)-FT(1,J))/DYP5(1)-
C (CF(1,J)+CF(1-1,J))*(FT(1,J)-FT(1-1,J))/DYM5(1)
DHE=DH/(2.*XSQ(J)*SINN(1))*DY(1)
DEL=DEL+DHE+.5*TNORM(K)*SO(1,J)
66 CONTINUE
DEN=BET-GAM*EP(J-1)
EPIJ=ALP/DEN $ FPIJ=(DEL+GAM*FP(J-1))/DEN
3 CONTINUE

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      FN(I,JX1)=0.
      DO 4 JJ=JS,JXIM
      J=JS+JXIM-JJ
      4 FN(I,J)=EP(I,J)*FN(I,J+1)+FP(I,J)
      2 CONTINUE
      IF (KSYDM .EQ. 1) GO TO 301
      DO 31 J=1,JX1
      IF (NSL .EQ. 0) FN(I,J)=FN(2,J)
      31 FN(IYPI,J)=FN(IYM,J)
      GO TO 302
      301 IF (NSL .EQ. 1) GO TO 302
      DO 303 J=1,JX1
      FN(I,J)=FN(2,J) $ FN(IY,J)=FN(IYM,J)
      303 CONTINUE
      302 CONTINUE
      DO 5 I=1,IYDM $ DO 5 J=1,JX1
      IF (FN(I,J) .LT. 0.) FN(I,J)=0.
      FT(I,J)=FN(I,J) $ FN(I,J)=0.
      5 CONTINUE
      CMNT ADVANCE USING IMPLICIT ANGULAR DERIVATIVES
      JMP1=JMIN(K)+1
      DO 6 JJ=JMP1,JXIM
      J=JMP1+JXIM-JJ
      IS=IO(J,K) $ ISP=IS+1
      EP(IS)=0. $ FP(IS)=0.
      IF (NSL .EQ. 1) GO TO 72
      SUMC=CF(1,J)+CF(2,J) $ DENOM=SUMC-DYMS(2)*CD(1,J)
      EP(1)=(SUMC+CD(2,J)*DYMS(2))/DENOM
      72 CONTINUE
      ILIM=IY-KSYDM*IS
      DO 7 I=ISP,ILIM
      TXSD=2.*XSQ(J)*SINN(I)*DY(I)
      ALP=(CD(1+1,J)*(CF(1,J)+CF(1+1,J))/DYP5(I))/TXSD
      GAM=(-CD(1-1,J)+(CF(1-1,J)+CF(1,J))/DYMS(1))/TXSD
      BET=RBGN+((CF(1+1,J)+CF(1,J))/DYP5(1)+(CF(1-1,J)+CF(1,J))/
      C DYMS(1))/TXSD
      BET=BET+SCEXU
      IF (NSLE .EQ. 0) GO TO 305
      IF (Y(I) .LE. YMINN(J) .OR. (PI-Y(I) .LE. YMINN(J) .AND. KSYDM
      C .EQ. 1)) BET=BET+CUSE*X(J)*ABSF(COSS(I))
      305 CONTINUE
      IF (NDTAL .EQ. 1 .AND. K .EQ. 1) BET=BET+SALUD*X(J)*SDTAL(J)
      IF (NDTAL .EQ. 1 .AND. K .EQ. 2) BET=BET+SALUT
      TXSDT=2.*DX(I,J)*TXSD
      DEL=RBGN*FT(I,J)+(CE(1+1,J)*(FT(1+1,J+1)-FT(1+1,J-1))-
      C CE(1-1,J)*(FT(1-1,J+1)-FT(1-1,J-1)))/TXSDT
      DEL=DEL+.5*TNORM(K)*SD(I,J)
      IF (NSPLIT .EQ. 1) GO TO 67
      DG=CA(1,J+1)*FT(1,J+1)-CA(1,J-1)*FT(1,J-1)+(CC(1,J+1)*
      C (FT(1+1,J+1)-FT(1-1,J+1))-CC(1,J-1)*(FT(1+1,J-1)-FT(1-1,J-1)))/
      C (2.*DY(I))+(CB(1,J+1)+CB(1,J))*(FT(1,J+1)-FT(1,J))/DXP5(J)-
      C (CB(1,J)+CB(1,J-1))*(FT(1,J)-FT(1,J-1))/DXM5(J)
      DGE=DG/(2.*XSQ(J)*DX(J))
      DEL=DEL+DGE+.5*TNORM(K)*SD(1,J)
      67 CONTINUE
      DEN=BET-GAM*EP(1-1)
      EP(1)=ALP/DEN $ FP(1)=(DEL+GAM*FP(1-1))/DEN
      7 CONTINUE

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      IF (KSYDM .EQ. 1) GO TO 306
      FN(IYPI,J)=(EP(IYM1,J)*FP(IY)+FP(IYM1))/(1.-EP(IYM1)*EP(IY))
      GO TO 307
306 IF (NSL .EQ. 1) GO TO 307
      CNUM=(CF(IYM1,J)+CF(IY,J))/DYP5(IYM1)
      CNUM1=CNUM-CD(IYM1,J) $ CNUM2=CNUM+CD(IY,J)
      FN(IY,J)=(CNUM1*FP(IYM1))/(CNUM2-CNUM1*EP(IYM1))
307 CONTINUE
      DO 8 I1=IS,ILIM
        I=IS+ILIM-I1
        FN(I,J)=EP(I)*FN(I+1,J)+FP(I)
      8 CONTINUE
      6 CONTINUE
      IF (NSL .EQ. 1) GO TO 73
      DO 74 I=1,IYDM
        74 FN(I,1)=FN(IYH,2)
      73 CONTINUE
      RBGN=RBGN/FLOAT(NSLP1)
CMNT CHECK FOR TIME CHANGING MAGNETIC FIELD, MAJOR RADIUS, AND FINITE
CMNT PARTICLE AND ENERGY CONFINEMENT TIMES
      IF (ABSFBDOOB)*ABSFRDOR .EQ. 0. .AND. TAU EK(K) .GT. 1.E+89
      C .AND. TAU PK(K) .GT. 1.E+89) GO TO 141
CMNT COMPUTE PARTICLE CONFINEMENT TIME AS A FUNCTION OF VELOCITY
      XTAU=SQRTF(TAUEN(K)/EIONS(K))
      DO 261 J=1,JX1
        TETAU(J)=TAUPK(K)+(TAUPK1(K)-TAUPK(K))*(X(J)/XTAU)**TAUPPR(K)
      261 CONTINUE
      S=0. $ DO 263 J=1,JX1 $ DO 263 I=1,IY
      263 S=S+FN(I,J)*CINT2(J)*CYNT2(I)/TETAU(J)
      STPLOS=STPLOS+S*ANUMB(K)*ANORMK(K)*DTR
CMNT COMPUTE COMBINED COEFFICIENTS FOR ABOVE TERMS
      DO 142 J=1,JX1
        OTAUE=1./TAUEK(K) $ OTAUP=1./TETAU(J) $ OTAUEP=OTAUE
        X3=XSQ(J)*X(J) $ DO 143 I=1,IY
        SIN2C=SINN(I)**2 $ SIN2C=SIN2*COSS(I) $ R32=1.5-RFUDGE
        CC(I,J)=TNORM(K)*X3*(-.5*SIN2*BDOOB+.5*OTAUEP*RDOR*(RFUDGE-1.+
        C R32*SIN2))
        CE(I,J)=TNORM(K)*XSQ(J)*SIN2C*(-.5*BDOOB+R32*RDOR)
        FT(I,J)=FN(I,J)
        IF (FT(I,J) .LT. 0.) FT(I,J)=0.
        FN(I,J)=0.
      143 CONTINUE
      IF (KSYDM .EQ. 1) GO TO 142
      CC(IYPI,J)=CC(IYM1,J) $ CE(IYPI,J)=-CE(IYM1,J)
      FT(IYPI,J)=FN(IYPI,J)
      IF (FT(IYPI,J) .LT. 0.) FT(IYPI,J)=0.
      FN(IYPI,J)=0.
      142 CONTINUE
CMNT ADVANCE USING IMPLICIT VELOCITY DERIVATIVES
      ILIM=IY-KSYDM*(MIN(K)
      IMPI=IMIN(K)+1 $ DO 202 I=IMPI,ILIM
      JS=JO(I,K) $ JSP=JS+1 $ EP(JS)=0. $ FP(JS)=0.
      IF (NSL .EQ. 1) GO TO 271
      SUMC=CB(I,1)+CB(I,2) $ DENOM=SUMC-DXMS(2)*CA(I,1)
      EP(I)=(SUMC+CA(I,2)*DXMS(2))/DENOM
      271 CONTINUE
      DO 203 J=JSP,JX1M
        CAYP=TNORM(K)*(BDOOB-2.*RDOR-1./TETAU(J))
        TXSD=2.*XSQ(J)*DX(J) $ ALP=CC(I,J+1)/TXSD $ GAM=-CC(I,J-1)/TXSD
        BET=RBGN-.5*CAYP $ DEL=RBGN*FT(I,J)

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DEN=BET-GAM*EP(J-1)
CP(J)=ALP/DEN $ FP(J)=(DEL+GAM*FP(J-1))/DEN
203 CONTINUE
FN(1,JX1)=0. $ DO 204 JJ=JS,JX1M
J=JS+JX1M-JJ
204 FN(1,J)=EP(J)*FN(1,J+1)+FP(J)
202 CONTINUE
IF (KSYDM .EQ. 1) GO TO 311
DO 231 J=1,JX1
IF (NSL .EQ. 0) FN(1,J)=FN(2,J)
231 FN(IYPI,J)=FN(IYM1,J)
GO TO 312
311 IF (NSL .EQ. 1) GO TO 312
DO 313 J=1,JX1
FN(1,J)=FN(2,J) $ FN(IY,J)=FN(IYM1,J)
313 CONTINUE
312 CONTINUE
DO 205 I=1,IYDM $ DO 205 J=1,JX1
IF (FN(1,J) .LT. 0.) FN(1,J)=0.
FT(1,J)=FN(1,J) $ FN(1,J)=0.
205 CONTINUE
CMNT ADVANCE USING IMPLICIT ANGULAR DERIVATIVES
JMP1=JMIN(K)+1 $ DO 206 JJ=JMP1,JX1M
J=JMP1+JX1M-JJ $ IS=IO(J,K) $ ISP=IS+1
EP(1S)=0. $ FP(1S)=0. $ IF (NSL .EQ. 1) GO TO 272
SUMC=CF(1,J)+CF(2,J) $ DENOM=SUMC-DYM5(2)*CD(1,J)
EP(1)=(SUMC+CD(2,J)*DYM5(2))/DENOM
272 CONTINUE
CAYP=TNORM(K)*(BDOB-2.*RDOR-1./TETAU(J))
ILIM=IY-KSYDM*IS
DO 207 I=ISP,ILIM
TXSD=2.*XSQ(J)*SINN(I)*DY(I)
ALP=CE(1+I,J)/TXSD $ GAM=-CE(1-I,J)/TXSD
BET=RBGN-.5*CAYP $ DEL=RBGN*FT(1,J)
DEN=BET-GAM*EP(1-I)
EP(1)=ALP/DEN $ FP(1)=(DEL+GAM*FP(1-I))/DEN
207 CONTINUE
IF (KSYDM .EQ. 1) GO TO 316
FN(IYPI,J)=(EP(IYM1)*FP(IY)+FP(IYM1))/(1.-EP(IYM1)*EP(IY))
GO TO 317
316 IF (NSL .EQ. 1) GO TO 317
CNUM=(CF(IYM1,J)+CF(IY,J))/DYP5(IYM1)
CNUM1=CNUM-CD(IYM1,J) $ CNUM2=CNUM+CD(IY,J)
FN(IY,J)=(CNUM1*FP(IYM1))/(CNUM2-CNUM1*EP(IYM1))
317 CONTINUE
DO 208 I=IS,ILIM
I=IS+ILIM-I
208 FN(1,J)=EP(1)*FN(1+I,J)+FP(1)
206 CONTINUE
IF (NSL .EQ. 1) GO TO 273
DO 274 I=1,IYDM
274 FN(1,I)=FN(IYH,2)
273 CONTINUE
141 CONTINUE
CALL WRITELCM(FN,F(1,1,K),IYPIJX)
GO TO 100
101 CONTINUE
CMNT RECOMPUTE ELECTRON CONTRIBUTION TO ELECTRON COEFFICIENTS TO USE
CMNT MULTIPLE NUMBER OF ELECTRON TIME STEPS PER ION TIME STEP OPTION
CALL WRITELCM(AELL,AELST,JX)

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CALL WRITELCM(BELL,BELST,JX)
CALL WRITELCM(CELL,CELSST,JX)
RBN=RBGN*FLOATF(NEL10)
CALL COEFE
DO 904 J=1,JX
AELL(J)=AELL(J)-AEL(J)
BELL(J)=BELL(J)-BEL(J)
CELL(J)=CELL(J)-CCEL(J)
904 CONTINUE
CALL WRITELCM(AELL,AELT,JX)
CALL WRITELCM(BELL,BELT,JX)
CALL WRITELCM(CELL,CELT,JX)
DO 902 KLM=1,NEL10
CALL COEFE
CALL READLCM(AELL,AELT,JX)
CALL READLCM(BELL,BELT,JX)
CALL READLCM(CELL,CELT,JX)
DO 905 J=1,JX
AELL(J)=AELL(J)+AEL(J)
BELL(J)=BELL(J)+BEL(J)
CELL(J)=CELL(J)+CCEL(J)
905 CONTINUE
CMNT COMPUTE ELECTRON LOSS TERM
XCN2=POTENT*POTRAT/EIONS(0) $ XCN=SQRTF(XCN2)
DO 82 J=1,JX
CCEL(J)=0. $ IF (X(J) .LE. XCN) GO TO 82
IF (NSLE2 .EQ. 0) GO TO 82
REFF=BRATIO/(1.-XCN2*X21(J))
PROB=2.3025851/LOGF(REFF)
CCEL(J)=CELL(J)*PROB
82 CONTINUE
CMNT ADVANCE ELECTRON DIFFERENCE EQUATION
SUMC=BELL(1)+BELL(2) $ DENOM=SUMC-DXM5(2)*AELL(1)
EP(1)=(SUMC+AELL(2)*DXM5(2))/DENOM $ FP(1)=0.
DO 13 J=2,JXM1
TXSD=2.*XSQ(J)*DX(J)
ALP=(AELL(J+1)+(BELL(J)+BELL(J+1))/DXP5(J))/TXSD
GAM=(-AELL(J-1)+(BELL(J-1)+BELL(J))/DXM5(J))/TXSD
BET=RBGN+((BELL(J+1)+BELL(J))/DXP5(J)+(BELL(J)+BELL(J-1))/DXM5(J))
C /TXSD+CCEL(J)*X21(J)
BET=BET+2.*SCEXU
DEL=RBGN*FE(J)+TNORM(K)*SORE(J)
IF (RH00 .GE. 1.-!.E-14) GO TO 68
BCOR=BET-RBGN $ ONMRHO=1.-RH00
DEL=DEL-ONMRHO*(-ALP*FP(J+1)+BCOR*FE(J)-GAM*FE(J-1))
BET=RBGN+RH00*BCOR $ ALP=RH00*ALP $ GAM=RH00*GAM
68 CONTINUE
DEN=BET-GAM*EP(J-1)
EP(J)=ALP/DEN $ FP(J)=(DEL+GAM*FP(J-1))/DEN
13 CONTINUE
FE(JX)=0. $ DO 14 JJ=1,JXM1
J=JX-JJ
14 FE(J)=EP(J)*FE(J+1)+FP(J)
IF (NCUTFE .EQ. 0) GO TO 902
DO 645 J=1,JX
IF (X(J) .LT. XCN) GO TO 645
FE(J)=0.
645 CONTINUE
902 CONTINUE
RBN=RBGN/FLOATF(NEL10)

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CALL READLCM(AELL,AELST,JX)
CALL READLCM(BELL,BELST,JX)
CALL READLCM(CELL,CELST,JX)
IF (ABSF(BDOB)+ABSF(RDOB)) .EQ. 0. .AND. TAUKE(K) .GT. 1.E+89
C .AND. TAUPK(K) .GT. 1.E+89) GO TO 100
IF (KTPNUT .EQ. 0 .OR. N .EQ. 1) GO TO 265
CMNT COMPUTE ELECTRON TAU-P BASED ON ION LOSS (DUE TO FINITE TAU-P) FROM
CMNT PREVIOUS TIME STEP
S=0. $ DO 264 J=1,JX
264 S=S+FE(J)*XSQ(J)*CINT(J)
DENN=FOURPI*S*ANORMK(K)*DTR
TAUPK(K)=DENN/STPLOS
TAUPK1(K)=TAUPK(K)
TAUPPR(K)=1.
TAUEN(K)=1.E+90
265 CONTINUE
XTAU=SQRTF(TAUEN(K)/EIONS(K))
DO 262 J=1,JX
TETAU(J)=TAUPK(K)+(TAUPK1(K)-TAUPK(K))*(X(J)/XTAU)*TAUPPR(K)
262 CONTINUE
SUMC=BELL(1)+BELL(2) $ DENOM=SUMC-DXMS(2)*AELL(1)
EP(1)=(SUMC+AELL(2)*DXMS(2))/DENOM $ FP(1)=0.
DO 213 J=2,JXM1
OTAUE=1./TAUEK(K) $ OTAUP=1./TETAU(J) $ OTAUEP=OTAUE
FACT=TNORM(J)*((RDOB*RFUDGE-BDOB)/3.+5*OTAUEP)
CAYP=TNORM(J)*(BDOB-2.*RDOB-OTAUP)
TXSD=2.*XSQ(J)*DX(J)
ALP=X(J+1)*XSQ(J+1)*FACT/TXSD $ GAM=-X(J-1)*XSQ(J-1)*FACT/TXSD
SET=RBGN-CAYP $ DEL=RBGN*FE(J)
DEN=BET-GAM*EP(J-1)
EP(J)=ALP/DEN $ FP(J)=(DEL+GAM*FP(J-1))/DEN
2.3 CONTINUE
FE(JX)=0. $ DO 214 JJ=1,JXM1
J=JX-JJ
2.4 FE(J)=EP(J)*FE(J+1)+FP(J)
100 CONTINUE
RETURN
END

C
C
C SUBROUTINE COEF
C
USE COMM
CMNT COMPUTE COEFFICIENTS FOR FOKKER-PLANCK COLLISION TERM
DIMENSION UM(IY)
EQUIVALENCE(UM,COSS)
IF (KGETGFK .EQ. 1) GO TO 10
DO 20 M=MXP3M,MXP4
DO 1 J=2,JX
1 XM(J,M)=X(J)**M
20 XM(1,M)=0.
CMNT COMPUTE LEGENDRE POLYNOMIALS AND THEIR DERIVATIVES
DO 4 I=1,IY
PLEG(0,I)=1. $ DPLEG(0,I)=0.
DDPLEG(0,I)=0. $ DDDPLEG(0,I)=0.
IF (IMX .EQ. 0) GO TO 4
PLEG(1,I)=UM(I) $ DPLEG(1,I)=1.
DDPLEG(1,I)=0. $ DDDPLEG(1,I)=0.
DO 5 M=2,MMX
PLEG(M,I)=((2*M-1)*UM(I)*PLEG(M-1,I)-(M-1)*PLEG(M-2,I))/M

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DPLEG(M,1)=(2*M-1)*PLEG(M-1,1)+DPLEG(M-2,1)
DDPLEG(M,1)=(2*M-1)*DPLEG(M-1,1)+DDPLEG(M-2,1)
DDDPLEG(M,1)=(2*M-1)*DDPLEG(M-1,1)+DDDPLEG(M-2,1)
5 CONTINUE
4 CONTINUE
DO 7 MM=0,MX
M=MM*MXDM
FAC=FOURPI/(2*M+1)
COG(MM,1)=FAC/(2*M+3)
COG(MM,2)=FAC/(2*M-1)
COG(MM,3)=(M+2)*COG(MM,1)
COG(MM,4)=(M+1)*COG(MM,1)
COG(MM,5)=M*COG(MM,2)
COG(MM,6)=(M-1)*COG(MM,2)
COG(MM,7)=(M+1)*COG(MM,3)
COG(MM,8)=(M-1)*COG(MM,5)
COG(MM,9)=M*COG(MM,7)
COG(MM,10)=(M+3)*COG(MM,7)
COG(MM,11)=(M-2)*COG(MM,8)
COG(MM,12)=(M+1)*COG(MM,8)
COG(MM,13)=FAC*M
COG(MM,14)=FAC*(M+1)
COG(MM,15)=FAC
7 CONTINUE
KGETGFK=1
IYU=IY-KSYDM*IYHMI
10 CONTINUE
CMNT ENTER HERE AFTER FIRST TIME STEP
DO 91 I=1,IYDM $ DO 91 J=1,JX1
91 SO(I,J)=0.
DO 92 K=1,NEQ
CALL WRITELCM(SO,CAL(1,1,K),IYPIJX)
CALL WRITELCM(SO,CBL(1,1,K),IYPIJX)
CALL WRITELCM(SO,CCL(1,1,K),IYPIJX)
CALL WRITELCM(SO,CCL(1,1,K),IYPIJX)
CALL WRITELCM(SO,CFL(1,1,K),IYPIJX)
92 CONTINUE
DO 61 J=1,JX
AELL(J)=0. $ BELL(J)=0. $ CELL(J)=0.
AEL(J)=0. $ BEL(J)=0. $ CCELL(J)=0.
61 CONTINUE
CMNT INVERT DEL-SQUARED AND DEL-FOURTH FOR EACH SPECIES
DO 93 K=0,NEQ
IF (REDEN(K) .LT. 1.E-89) GO TO 93
IF (K.NE. 0) CALL READLCM(FT,F(1,1,K),IYPIJX)
CMNT COMPUTE MOMENTS CORRESPONDING TO VARIOUS LEGENDRE POLYNOMIALS
DO 14 MM=0,MX
M=MM*MXDM
IF (K.EQ. 0) GO TO 401
DO 12 J=1,JX1
S=0. $ DO 11 I=1,IY
11 S=S+CYNT(I)*FT(I,J)*PLEG(M,1)*SINN(I)
12 TEMPG(J)=.5*FLOATF(2*M+1)*S
DO 400 J=JX1+1,JX
400 TEMPG(J)=0.
GO TO 402
401 DO 403 J=1,JX
403 TEMPG(J)=0.
IF (M.GT. 0) GO TO 402

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DO 404 J=1,JX
404 TEMP(J)=FE(J)
402 CONTINUE
IX1=1-M $ IX2=2+M $ IX3=3-M $ IX4=4+M
IX5=3-IX1 $ IX6=3-IX2 $ IX7=3-IX3 $ IX8=3-IX4
SM=0. $ SN=0. $ SR=0. $ SE=0.
EMQF(JX,MM)=SM $ ENQF(1,MM)=SN $ ERQF(JX,MM)=SR $ EEQF(1,MM)=SE
DO 13 J=2,JX
JJ=JX+1-J
TM=.5*DXPS(JJ)*(XM(JJ,IX1)*TEMPG(JJ)+XM(JJ+1,IX1)*TEMPG(JJ+1))
TN=.5*DXMS(JJ)*(XM(JJ-1,IX2)*TEMPG(JJ-1)+XM(JJ,IX2)*TEMPG(JJ))
TR=.5*DXPS(JJ)*(XM(JJ,IX3)*TEMPG(JJ)+XM(JJ+1,IX3)*TEMPG(JJ+1))
TE=.5*DXMS(JJ)*(XM(JJ-1,IX4)*TEMPG(JJ-1)+XM(JJ,IX4)*TEMPG(JJ))
SM=SM+TM $ SN=SN+TN $ SR=SR+TR $ SE=SE+TE
EMQF(JJ,MM)=SM $ ENQF(J,MM)=SN $ ERQF(JJ,MM)=SR $ EEQF(J,MM)=SE
13 CONTINUE
DO 15 J=1,JX
EMQF(J,MM)=EMQF(J,MM)*XM(J,IX5)
ENQF(J,MM)=ENQF(J,MM)*XM(J,IX6)
ERQF(J,MM)=ERQF(J,MM)*XM(J,IX7)
EEQF(J,MM)=EEQF(J,MM)*XM(J,IX8)
15 CONTINUE
14 CONTINUE
CMNT COMPUTE CONTRIBUTIONS OF THESE MOMENTS TOWARDS THAT PART OF COEFFICIENTS
CMNT FOR ALL SPECIES DEPENDING ON SPECIES K
IF (K.EQ.0) GO TO 411
DO 16 J=2,JX1 $ DO 16 I=1,IY
S=0. $ SX=0. $ SY=0. $ SXX=0. $ SXY=0. $ SYY=0.
SXXX=0. $ SXXY=0. $ SXYX=0. $ SYYY=0. $ SH=0. $ SHX=0. $ SHY=0.
DO 17 M=0,MX
MM=M*MXDM
T=COG(M,1)*(EEQF(J,M)+EMQF(J,M))-COG(M,2)*(ENQF(J,M)+ERQF(J,M))
TX=X1(J)*(COG(M,3)*EMQF(J,M)-COG(M,4)*EEQF(J,M)-
C COG(M,5)*ERQF(J,M)+COG(M,6)*ENQF(J,M))
TXX=X21(J)*(COG(M,7)*(EEQF(J,M)+EMQF(J,M))-
C COG(M,8)*(ENQF(J,M)+ERQF(J,M)))
TXXX=X31(J)*(COG(M,9)*EMQF(J,M)-COG(M,10)*EEQF(J,M)-
C COG(M,11)*ERQF(J,M)+COG(M,12)*ENQF(J,M))
TH=X21(J)*COG(M,15)*(ENQF(J,M)+EMQF(J,M))
THX=X31(J)*(COG(M,13)*EMQF(J,M)-COG(M,14)*ENQF(J,M))
S=S+T*PLEG(MM,1) $ SX=SX+TX*PLEG(MM,1)
SXX=SXX+TXX*PLEG(MM,1) $ SY=SY+T*DPLEG(MM,1)
SXY=SXY+TX*DPLEG(MM,1) $ SYY=SYY+T*DDPLEG(MM,1)
SXXX=SXXX+TXXX*PLEG(MM,1) $ SXXY=SXXY+TXX*DPLEG(MM,1)
SXYX=SXYX+TX*DDPLEG(MM,1) $ SYYY=SYYY+T*DDDPLEG(MM,1)
SH=SH+TH*PLEG(MM,1) $ SHX=SHX+THX*PLEG(MM,1)
SHY=SHY+TH*DDPLEG(MM,1)
17 CONTINUE
GX=SX $ GY=-SINN(1)*SY $ GXX=SXX $ GXY=-SINN(1)*SXY
GYY=-UM(1)*SY+SINN(1)**2*SYY
GXXX=SXXX $ GXXY=-SINN(1)*SXXY
GXYX=-UM(1)*SXY+SINN(1)**2*SXYX
GYYY=SINN(1)*(SY+3.*UM(1)*SYY-SINN(1)**2*SYYY)
HX=SHX $ HY=-SINN(1)*SHY
CA(I,J)=.5*GXXX*XSQ(J)+X(J)*GXX-GX+.5*GXYX-X1(J)*(GYY-COSS(1)*SY)
C -.5*COSS(1)*SXY
CMNT FN IS THE H-CONTRIBUTION TO A
FN(I,J)=-HX*XSQ(J)
CB(I,J)=.5*XSQ(J)*GXX $ CC(I,J)=.5*(GXY-X1(J)*GY)
CD(I,J)=.5*X21(J)*(SINN(1)*GYYY+SY+COSS(1)*GYY)+

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C SINN(I)*(.5*GXXY+X1(J)*GXY)
CMNT FT IS THE H-CONTRIBUTION TO D
FT(I,J)=-SINN(I)*HY $ CE(I,J)=SINN(I)*CC(I,J)
CF(I,J)=.5*X1(J)*SINN(I)*X1(J)*6YY+GX)
16 CONTINUE
M=0
DO 63 J=2,JX
TX=X1(J)*(COG(M,3)*EMQF(J,M)-COG(M,4)*EEQF(J,M)-
C COG(M,5)*ERQF(J,M)+COG(M,6)*ENQF(J,M))
TXX=X21(J)*(COG(M,7)*(EEQF(J,M)+EMQF(J,M))-
C COG(M,8)*(ENQF(J,M)+ERQF(J,M)))
TXXX=X31(J)*(COG(M,9)*EMQF(J,M)-COG(M,10)*EEQF(J,M)-
C COG(M,11)*ERQF(J,M)+COG(M,12)*ENQF(J,M))
THX=X31(J)*(COG(M,13)*EMQF(J,M)-COG(M,14)*ENQF(J,M))
AEL(J)=.5*TXXX*XSQ(J)+X(J)*TXX-TX-THX*XSQ(J)*(1.+RAT10M(0,K))
BEL(J)=.5*XSQ(J)*TXX $ CCEL(J)=.5*X1(J)*TX
63 CONTINUE
GO TO 412
411 CONTINUE
M=0
DO 413 J=2,JX
TX=X1(J)*(COG(M,3)*EMQF(J,M)-COG(M,4)*EEQF(J,M)-
C COG(M,5)*ERQF(J,M)+COG(M,6)*ENQF(J,M))
TXX=X21(J)*(COG(M,7)*(EEQF(J,M)+EMQF(J,M))-
C COG(M,8)*(ENQF(J,M)+ERQF(J,M)))
TXXX=X31(J)*(COG(M,9)*EMQF(J,M)-COG(M,10)*EEQF(J,M)-
C COG(M,11)*ERQF(J,M)+COG(M,12)*ENQF(J,M))
THX=X31(J)*(COG(M,13)*EMQF(J,M)-COG(M,14)*ENQF(J,M))
IF (J.GT. JX1) GO TO 415
CA(IYU,J)=.5*TXXX*XSQ(J)+X(J)*TXX-TX
FN(IYU,J)=-THX*XSQ(J) $ CB(IYU,J)=.5*XSQ(J)*TXX
CC(IYU,J)=0. $ CD(IYU,J)=0. $ CE(IYU,J)=0.
FT(IYU,J)=0.
CF(IYU,J)=.5*X1(J)*TX
DO 414 I=1,IY
IF (I.EQ. IYU) GO TO 414
CA(I,J)=CA(IYU,J) $ FN(I,J)=FN(IYU,J) $ CB(I,J)=CB(IYU,J)
CC(I,J)=CC(IYU,J) $ CD(I,J)=CD(IYU,J) $ CE(I,J)=CE(IYU,J)
FT(I,J)=FT(IYU,J) $ CF(I,J)=SINN(I)*CF(IYU,J)
414 CONTINUE
415 CONTINUE
AEL(J)=.5*TXXX*XSQ(J)+X(J)*TXX-TX-THX*XSQ(J)*(1.+RAT10M(0,K))
BEL(J)=.5*XSQ(J)*TXX $ CCEL(J)=.5*X1(J)*TX
413 CONTINUE
412 CONTINUE
CMNT COMPUTE CONTRIBUTION OF K-TH ROSENBLUTH POTENTIAL TOWARD THE
CMNT COEFFICIENTS OF ALL SPECIES
DO 21 KK=1,NEQ
ANR1=GAMMA(KK,K)*RAT10Z2(K,KK)*RATK(K,KK)
ANR2=ANR1*(1.+RAT10M(KK,K))
CALL READLCM(SO,CAL(1,1,KK),IYPIJX)
DO 22 I=1,IY $ DO 22 J=2,JX1
22 SQ(I,J)=SQ(I,J)+ANR1*CA(I,J)+ANR2*FN(I,J)
CALL WRITELCM(SO,CAL(1,1,KK),IYPIJX)
CALL READLCM(SO,CBL(1,1,KK),IYPIJX)
DO 23 I=1,IY $ DO 23 J=2,JX1
23 SQ(I,J)=SQ(I,J)+ANR1*CB(I,J)
CALL WRITELCM(SO,CBL(1,1,KK),IYPIJX)
CALL READLCM(SO,CCL(1,1,KK),IYPIJX)
DO 24 I=1,IY $ DO 24 J=2,JX1

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24 SO(I,J)=SO(I,J)+ANR1*CC(I,J)
   CALL WRITELCM(SO,CCL(1,1,KK),IYPIJX)
   CALL READLCM(SO,CDL(1,1,KK),IYPIJX)
   DO 25 I=1,IY $ DO 25 J=2,JXI
25 SO(I,J)=SO(I,J)+ANR1*CD(I,J)+ANR2*FT(I,J)
   CALL WRITELCM(SO,CDL(1,1,KK),IYPIJX)
   CALL READLCM(SO,CCL(1,1,KK),IYPIJX)
   DO 26 I=1,IY $ DO 26 J=2,JXI
26 SO(I,J)=SO(I,J)+ANR1*CE(I,J)
   CALL WRITELCM(SO,CCL(1,1,KK),IYPIJX)
   CALL READLCM(SO,CFL(1,1,KK),IYPIJX)
   DO 27 J=1,IY $ DO 27 J=2,JXI
27 SO(I,J)=SO(I,J)+ANR1*CF(I,J)
   CALL WRITELCM(SO,CFL(1,1,KK),IYPIJX)
21 CONTINUE
   KK=0 $ ANR1=GAMMA(KK,K)*RATIO22(K,KK)*RATK(K,KK)
   DO 421 J=2,JX
   AELL(J)=AELL(J)+AEL(J)*ANR1
   BELL(J)=BELL(J)+BEL(J)*ANR1
   CELL(J)=CELL(J)+CEEL(J)*ANR1
421 CONTINUE
93 CONTINUE
CMNT COMPUTE BOUNDARY TERMS
   IF (KSYDM.EQ. 1) GO TO 114
   DO 111 K=1,NEQ
   CALL READLCM(CA,CAL(1,1,K),IYPIJX)
   CALL READLCM(CB,CBL(1,1,K),IYPIJX)
   CALL READLCM(CC,CCL(1,1,K),IYPIJX)
   CALL READLCM(CD,CDL(1,1,K),IYPIJX)
   CALL READLCM(CE,CCL(1,1,K),IYPIJX)
   CALL READLCM(CF,CFL(1,1,K),IYPIJX)
   DO 112 J=1,JXI
   CA(IYPI,J)=CA(IYMI,J) $ CB(IYPI,J)=CB(IYMI,J)
   CC(IYPI,J)=-CC(IYMI,J) $ CD(IYPI,J)=-CD(IYMI,J)
   CE(IYPI,J)=-CE(IYMI,J) $ CF(IYPI,J)=CF(IYMI,J)
112 CONTINUE
   CALL WRITELCM(CA,CAL(1,1,K),IYPIJX)
   CALL WRITELCM(CB,CBL(1,1,K),IYPIJX)
   CALL WRITELCM(CC,CCL(1,1,K),IYPIJX)
   CALL WRITELCM(CD,CDL(1,1,K),IYPIJX)
   CALL WRITELCM(CE,CCL(1,1,K),IYPIJX)
   CALL WRITELCM(CF,CFL(1,1,K),IYPIJX)
111 CONTINUE
114 CONTINUE
   RETURN
   END
C
C
C SUBROUTINE AMBI
C
C USE COMM
CMNT CHECK CHARGE NEUTRALITY REQUIREMENTS
   MI=0
   DO 1 K=0,NEQ
   DENSTOR(K)=REOEN(K)
CMNT STORE DISTRIBUTION FUNCTIONS IN CASE AMBIPOLAR POTENTIAL MUST BE CHANGED
   IF (K.EQ. 0) GO TO 1
   CALL READLCM(FT,F(1,1,K),IYPIJX)
   CALL WRITELCM(FT,F(1,1,K),IYPIJX)
1 CONTINUE

```

```

DO 71 J=1,JX
71 FE1(J)=FE1(J)
S=0. $ DO 2 K=1,NEQ
S=S+REDEN(K)*ANUMB(K)
2 CONTINUE
QSPLUS=S $ QSMINUS=REDEN(0)
10 M1=M1+1
CALL XSWEET
CALL GNADE
IF (KGNAND .EQ. 1) RETURN
S=0. $ DO 3 K=1,NEQ
S=S+REDEN(K)*ANUMB(K)
3 CONTINUE
QPLUS=S $ QMINUS=REDEN(0)
D1=QPLUS-QSPLUS $ D2=QMINUS-QSMINUS
C
WRITE (3,465) N,M1,QSPLUS,QPLUS,D1,QSMINUS,QMINUS,D2,POTENT
C
465 FORMAT(2HN=.15,2X,3HM1=.15,2X,BHOLD N1 =,E16.6,5X,BHNEW N1 =,
C E16.6,5X,SHDIFF=,E16.6,/,19X,BHOLD NE =,E16.6,5X,BHNEW NE =,
C E16.6,5X,SHDIFF=,E16.6,5X,7HPOTENT=,E16.6)
CMNT CHECK TO SEE IF WE WISH TO SKIP CHARGE NEUTRALITY REQUIREMENTS
IF (QSMINUS .EQ. QSPLUS .OR. N .EQ. 1 .OR. MIMAX .EQ. 0) GO TO 160
IF (NSL+NSLE .EQ. 0) GO TO 160
IF (M1 .GE. MIMAX) GO TO 460
IF (QSPLUS .LT. QSMINUS .AND. D1 .GT. 02) GO TO 160
IF (QSPLUS .GT. QSMINUS .AND. D1 .LT. 02) GO TO 160
CMNT COMPUTE NEW AMBIPOLAR POTENTIAL
IF (QSPLUS .LT. QSMINUS) POTENT=(1.-DPOT)*POTENT
IF (QSPLUS .GT. QSMINUS) POTENT=(1.+DPOT)*POTENT
CMNT RESET DISTRIBUTION FUNCTIONS TO VALUES AT BEGINNING OF TIME STEP
DO 4 K=1,NEQ
CALL HEADLCM(FT,F(1,1,K),1YP1JX)
CALL WRITELCM(FT,F(1,1,K),1YP1JX)
4 CONTINUE
DO 72 J=1,JX
72 FE1(J)=FE1(J)
CALL BOUNDARY $ IF (KBOUND .EQ. 1) RETURN
CALL CHPOST
CALL GNADE
IF (KGNAND .EQ. 1) RETURN
DO 5 K=1,NEQ
CALL READLCM(FT,F(1,1,K),1YP1JX)
FACT=DENSTOR(K)/REDEN(K)
DO 6 I=1,IYDM $ DO 6 J=1,JX
6 FT(I,J)=FACT*FT(I,J)
REDEN(K)=DENSTOR(K)
CALL WRITELCM(FT,F(1,1,K),1YP1JX)
CALL WRITELCM(FT,F(1,1,K),1YP1JX)
5 CONTINUE
GO TO 10
160 CONTINUE
CMNT RESCALE ELECTRON DISTRIBUTION IF KCHNUT IS 1
IF (KCHNUT .EQ. 0) RETURN
FRAC=QPLUS/QMINUS $ REDEN(0)=FRAC*REDEN(0)
DENS(0)=FRAC*DENS(0) $ QMINUS=QPLUS
DO 9 J=1,JX
9 FE1(J)=FRAC*FE1(J)
RETURN
460 KAMB1=1

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```

C      WRITE (3,461)
C
461  FORMAT(26HAMB1 POT REQ NOT SATISFIED)
      RETURN
      END
C
C      SUBROUTINE CHPDST
C
      USE COMM
CMNT  SET THE ION DISTRIBUTIONS TO ZERO OUTSIDE THE LOSS CONE BOUNDARY
      IF (NSL .EQ. 0) RETURN
      DO 1 K=1,NEQ
      CALL READLCM(FT,F(1,1,K),IYPIJX)
      DO 4 J=1,JXI
      DO 5 I=1,IO(J,K)
5  FT(I,J)=0.
      4  CONTINUE
      IF (KSYDM .EQ. 1) GO TO 2
      DO 3 J=1,JXI
      3  FT(IYPI,J)=FT(IYMI,J)
      GO TO 6
      2  DO 7 J=1,JXI $ DO 7 I=1,IO(J,K)
      II=IYPI-I
      7  FT(II,J)=0.
      6  CONTINUE
      CALL WRITELCM(FT,F(1,1,K),IYPIJX)
      1  CONTINUE
      RETURN
      END
C
C
C      SUBROUTINE GNADE
C
      USE COMM
CMNT  COMPUTE DENSITIES AND ENERGIES OF ALL SPECIES
      DO 1 K=1,NEQ
      CALL READLCM(FT,F(1,1,K),IYPIJX)
      GN=0. $ EN=0.
      DO 7 J=1,JXI $ DO 2 I=1,IY
      IF (FT(I,J) .LT. 0.) FT(I,J)=0.
      TERM=FT(I,J)*CINT2(J)*CYNT2(I)
      GN=GN+TERM $ EN=EN+TERM*XSQ(J)
      2  CONTINUE
      IF (KSYDM .EQ. 1) GO TO 7
      FT(IYPI,J)=FT(IYMI,J)
      7  CONTINUE
      CALL WRITELCM(FT,F(1,1,K),IYPIJX)
      IF (GN .EQ. 0.) GO TO 3
      ENGY(K)=EN/GN $ ENERGY(K)=ENGY(K)*EIONS(K)
      IF (IN .GT. 0) GO TO 13
      GNI=1./GN $ DO 11 J=1,JXI $ DO 11 I=1,IYDM
      11 FT(I,J)=FT(I,J)*GNI
      GN=1. $ CALL WRITELCM(FT,F(1,1,K),IYPIJX)
      13 CONTINUE
      DENS(K)=GN
CMNT  IF TIME = 0., COMPUTE DENSITY NORMALIZATION CONSTANTS RATHER THAN
CMNT  DENSITIES
      IF (IN .EQ. 0) GO TO 4

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```

      REDEN(K)=ANORMK(K)*DENS(K) $ GO TO 1
4  ANORMK(K)=REDEN(K)/DENS(K)
   GO TO 1
C
3  WRITE (3,5) K $ KGNANDE=1
C
5  FORMAT(17HZERO DENSITY - K=,15)
1  CONTINUE
   GN=0. $ EN=0. $ K=0
   DO 21 J=1,JX
     IF (FE(J) .LT. 0.) FE(J)=0.
     TERM=FE(J)*CINT(J)*XSQ(J)
     GN=GN+TERM $ EN=EN+TERM*XSQ(J)
21  CONTINUE
     IF (GN .EQ. 0.) GO TO 22
     ENGY(K)=EN/GN $ ENERGY(K)=ENGY(K)*EIONS(K)
     GN=FOURPI*GN
     IF (N .GT. 0) GO TO 23
     GNI=1./GN $ DO 31 J=1,JX
31  FE(J)=FE(J)*GNI
     GN=1.
23  CONTINUE
     DENS(K)=GN
     IF (N .EQ. 0) GO TO 24
     REDEN(K)=ANORMK(K)*DENS(K) $ RETURN
24  ANORMK(K)=REDEN(K)/DENS(K)
     RETURN
C
22  WRITE (3,5) K $ KGNANDE=1
C
     RETURN
C
     END
C
SUBROUTINE QCALC
C
USE COMM
CMNT COMPUTE Q FOR D-T RUNS
COMMON/MQCAL/LT,TEMPGT(JX)
DIMENSION SIGMA(JX)
DIMENSION ANSWER(2)
IF (NSL+NSLE .EQ. 0) RETURN
IENT=0 $ GO TO 41
ENTRY SIGV3D
CMNT ENTER HERE FOR REACTION SIGMA-V BAR ONLY
IENT=1
41  CONTINUE
     IF (NEQ .LT. 2) RETURN
     S1=ABSF(1,-EMASS(1)/3.3433E-24) $ S2=ABSF(1,-ANUMB(1))
     S3=ABSF(1,-EMASS(2)/5.0150E-24) $ S4=ABSF(1,-ANUMB(2))
     IF (S1+S2+S3+S4 .GT. 1.E-10) RETURN
     CALL READLCM(FT,F(1,1,1),IYPIJX)
     CALL READLCM(FN,F(1,1,2),IYPIJX)
     DO 1 J=1,JX
       T=0.
       S=0.
       DO 2 I=1,IY
         T=T+CYNT(I)*SINN(I)*FN(I,J)
2      S=S+CYNT(I)*SINN(I)*FT(I,J)
     TEMPGT(J)=T

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```

1  TEMPG(J)=S
   UMU=EIONS(1)
   DO 30 LT=1,2
   IF (LT.EQ.1) GO TO 31
   CALL FINDSIG(UMU,SIGMA)
   GO TO 32
31  CONTINUE
   DO 33 J=1,JX1
33  SIGMA(J)=1.
32  CONTINUE
   QANS=0.
   DO 20 J=1,JX1
20  QANS=QANS+CINT(J)*EVALS(J,SIGMA)
   ANSWER(LT)=QANS
30  CONTINUE
   SIGV=0. $ IF (ANSWER(1).EQ.0.) GO TO 7
   SIGV=VNORM*ANSWER(2)/ANSWER(1)
7   CONTINUE
   SIGVH=SIGV
CMNT EXIT FOR REACTION SIGMA-V BAR ONLY
   IF (IENT.EQ.0) GO TO 42
   RETURN
42  CONTINUE
CMNT MIRROR D-T REACTION OF 22.4 MEV ASSUMED
   EDT=2.24E+4
   ENUM=REDEN(1)*REDEN(2)*SIGV*EDT
   DENOM=0. $ DO 18 K=1,2 $ DO 18 KS=1,NSOR
   SENGY=ENSOR(KS,K) $ CUR=EJSOR(KS,K)
18  DENOM=DENOM+CUR*SENGY
   QDT=0. $ IF (DENOM.EQ.0.) GO TO 19
   QDT=ENUM/DENOM
19  CONTINUE
C
   WRITE (3,21) SIGV,QDT
C
21  FORMAT(/,13H51GV(3D-INT)=,E16.6,5X,2HQ=,E16.6)
   CALL FRAME
   CALL SETCH(10.,20.,1,0,1,0)
C
   WRITE (100,21) SIGV,QDT
C
   RETURN
C
END
C
FUNCTION EVALS(J,SIGMA)
C
   USE COMM
CMNT THIS SUBROUTINE IS USED FOR THE THREE-FOLD VELOCITY SIGMA-V BAR INTEGRAL
   COMMON/MQCAL/LT,TEMPGT(JX1)
   DIMENSION SIGMA(1)
   DIMENSION STFG(JX1),UPART(JX1)
   DO 1 KK=1,J
1  STFG(KK)=(XSQ(J)-XSQ(KK))*GETFG(J,KK)
   UPART(1)=0.
   DO 2 KK=2,J
   ADDIT=.5*DXM5(KK)*(STFG(KK-1)+STFG(KK))
   UPART(KK)=UPART(KK-1)+ADDIT
2  CONTINUE
   SUM=0.

```

```

DO 4 KK=2,J
ARGM=X(KK-1)*LT*SIGMA(KK-1)*UPART(KK-1)
ARGP=X(KK)*LT*SIGMA(KK)*UPART(KK)
SUM=SUM+.5*DXM5(KK)*(ARGM+ARGP)
4 CONTINUE
EVALS=SUM
RETURN
END

C
C
C      FUNCTION GETFG(J,KK)

C      USE COMM
CMNT  THIS SUBROUTINE IS USED FOR THE THREE-FOLD VELOCITY SIGMA-V BAR INTEGRAL
COMMON/MQCAL/LT,TEMPGT(JX)
ARG1=.5*(X(J)+X(KK))
ARG2=.5*(X(J)-X(KK))
J1=0 $ J2=0
DO 1 JM=1,JXIM
IF (X(JM) .LE. ARG1 .AND. ARG1 .LT. X(JM+1)) J1=JM
IF (X(JM) .LE. ARG2 .AND. ARG2 .LT. X(JM+1)) J2=JM
1 CONTINUE
IF (ARG1 .GE. X(JX1)) J1=JX1M
IF (ARG2 .GE. X(JX1)) J2=JX1M
FRAC1=(ARG1-X(J1))/DXP5(J1)
FRAC2=(ARG2-X(J2))/DXP5(J2)
ANS1=(1.-FRAC1)*TEMPG(J1)+FRAC1*TEMPG(J1+1)
ANS2=(1.-FRAC2)*TEMPG(J2)+FRAC2*TEMPG(J2+1)
ANS3=(1.-FRAC2)*TEMPG(J2)+FRAC2*TEMPG(J2+1)
ANS4=(1.-FRAC1)*TEMPG(J1)+FRAC1*TEMPG(J1+1)
GETFG=ANS1*ANS2+ANS3*ANS4
RETURN
END

C
C
C      SUBROUTINE FINDSIG(UMU,SIGMA)

C      USE COMM
CMNT  COMPUTE REACTION CROSS-SECTION FOR D-T
DIMENSION SIGMA(1)
SIGMA(1)=0.
DO 1 J=2,JX1
EPS=UMU*X5Q(J)
IF (EPS .GE. 20.) GO TO 41
TEMPQ=2.25E+4*EXP(-44.4/SQRT(EPS))/EPS $ GO TO 40
41 IF (EPS .GE. 30.) GO TO 42
TEMPQ=4.62E+4*EPS*EPS-0.137 $ GO TO 40
42 IF (EPS .GE. 50.) GO TO 43
TEMPQ=6.70E+4*EPS*EPS-0.320 $ GO TO 40
43 IF (EPS .GE. 87.) GO TO 44
TEMPQ=8.55E+02*EPS-2.93 $ GO TO 40
44 IF (EPS .GE. 107.) GO TO 45
TEMPQ=1.98E+4/((EPS-107.)*2+4000.) $ GO TO 40
45 IF (EPS .GE. 137.) GO TO 46
TEMPQ=3.56E+4/((EPS-107.)*2+7200.) $ GO TO 40
46 IF (EPS .GE. 185.) GO TO 47
TEMPQ=8.70-0.0314*EPS $ GO TO 40
47 IF (EPS .GE. 400.) GO TO 48
TEMPQ=7.050E+3/(EPS*SQRT(EPS)) $ GO TO 40
48 TEMPQ=255./(EPS-110.)

```



```

40 CONTINUE
   SIGMA(J)=1.E-24*TEMPO
1 CONTINUE
   RETURN
   END

C
C
SUBROUTINE SIGVID

C
   USE COMM
CMNT COMPUTE 1-D SIGMA-V BAR INTEGRAL
   DIMENSION SIGMA(JX1)
   IF (NEQ .LT. 2) RETURN
   S1=ABSF(1.-EMASS(1)/3.3433E-24) $ S2=ABSF(1.-ANUMB(1))
   S3=ABSF(1.-EMASS(2)/5.0150E-24) $ S4=ABSF(1.-ANUMB(2))
   IF (S1+S2+S3+S4 .GT. 1.E-10) RETURN
   NDHAL=1 $ GO TO 4
CMNT ENTER HERE FOR ALPHA PARTICLE HEATING
   ENTRY SIGVIDAL
   NDHAL=2
4 CONTINUE
   CALL READLCM(FT,F(1,1,1),IYP1JX)
   DO 1 J=1,JX1
   S=0. $ DO 2 I=1,IY
2 S=S+CYNT(I)*SINN(I)*FT(1,J)
1 TEMPG(J)=S
   UM2=(1.+RAT10M(1,2)*ENERGY(2)/ENERGY(1))
CMNT EXERCISE 0 TRITIUM ENERGY OPTION IF DESIRED
   IF (NCSIG .EQ. 0) UM2=1.
   UM=SQRTF(UM2)
   S=0. $ DO 3 J=1,JX1
3 S=S+CINT(J)*XSQ(J)*TEMPG(J)
   DENS=S $ FACTOR=UM*VNORM/DENS
   UMU=UM2*EIONS(1)
   CALL FINDSIG(UMU,SIGMA)
   S=0. $ DO 6 J=1,JX1
6 S=S+CINT(J)*SIGMA(J)*TEMPG(J)*X(J)*XSQ(J)
   SIGV=FACTOR*S
   GO TO (5,7), NDHAL
5 SIGVH=SIGV $ RETURN
7 SIGVHAL=SIGV
   RETURN
   END

C
C
SUBROUTINE COEFE

C
   USE COMM
CMNT COMPUTE ELECTRON CONTRIBUTION TO ELECTRON COEFFICIENTS
   SM=0. $ SN=0. $ SE=0.
   DO 2 J=2,JX
   JJ=JX+1-J
   TM=.5*DXP5(JJ)*(XM(JJ,1)*FE(JJ)+XM(JJ+1,1)*FE(JJ+1))
   TN=.5*DXM5(J)*(XM(J-1,2)*FE(J-1)+XM(J,2)*FE(J))
   TE=.5*DXM5(J)*(XM(J-1,4)*FE(J-1)+XM(J,4)*FE(J))
   SM=SM+TM $ SN=SN+TN $ SE=SE+TE
   EMQF(JJ,0)=SM $ ENQF(J,0)=SN $ EEQF(J,0)=SE
2 CONTINUE
   EMQF(JX,0)=0. $ ENQF(1,0)=0. $ EEQF(1,0)=0.
   DO 3 J=1,JX

```

```

EMQF(J,0)=EMQF(J,0)*XM(J,2)
ENQF(J,0)=ENQF(J,0)*XM(J,1)
EEQF(J,0)=EEQF(J,0)*XM(J,-1)
3 CONTINUE
ANR1=GAMMA(0,0)
DO 4 J=2,JX
TX=XI(J)*(COG(0,3)*EMQF(J,0)-COG(0,4)*EEQF(J,0)+
C COG(0,6)*ENQF(J,0))
TXX=X2I(J)*(COG(0,7)*(EEQF(J,0)+EMQF(J,0)))
TXXX=-X3I(J)*COG(0,10)*EEQF(J,0)
THX=-X3I(J)*COG(0,14)*ENQF(J,0)
AEL(J)=.5*TXXX*XSQ(J)+X(J)*TXX-TX-THX*XSQ(J)*2.
BEL(J)=.5*XSQ(J)*TXX $ CCEL(J)=.5*XII(J)*TX
AEL(J)=AEL(J)*ANR1 $ BEL(J)=BEL(J)*ANR1
CCEL(J)=CCEL(J)*ANR1
4 CONTINUE
RETURN
END

```