FIRE - A Computer Code to Simulate Cavity Gas Response to Inertial Confinement Target Explosions

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FUSION TECHNOLOGY INSTITUTE

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Table of Contents

I. Introduction

The FIRE code is a one dimensional, one fluid, two temperature lagrangian hydrodynamics code used to simulate the response of cavity gases in inertial confinement fusion reactors. It uses separate plasma and radiation temperatures to model the energy transfer in the cavity gas and uses real opacities and equations of state produced in tabular form by the MFP code. Given the initial temperature distribution produced in the gas by the target debris and X-rays, FIRE computes the heat flux and overpressure at the first wall as a result of the cavity gas response.

The simple two temperature model is more applicable to the cavity gas response than the standard one temperature model of codes such as CHART-D. It is also much less expensive to run than a full multifrequency group treatment of the radiative transfer.

II. Units and Zoning Conventions

The FIRE code uses the following units:

Length -- cm

Time -- second

Mass -- gram

Energy -- Joule

Temperature -- eV

Finite difference indexing is done as follows:

Time indexing: (n+1) A

(n + 1/2) B

(n) C

(n - 1/2) D

(n - 1) E

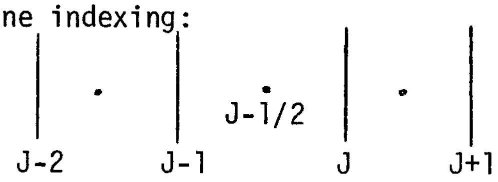
(n - 3/2) F

(n - 2) G

(n - 5/2) H

(n - 3) I.

Spatial zone indexing:



Zone boundary quantities have integer indices while zone centered quantities have half-integer indices. In the FORTRAN program each zone is indexed by the index of its outer boundary. Hence the center zone has index J=2.

III. Lagrangian Coordinates

The FIRE code uses lagrangian coordinates, meaning that the zone boundaries move with the fluid at its local velocity. The "lagrangian mass" defined as

$$dm_o = \rho(r)r^{\delta-1}\,dr \qquad \text{(III-1)}$$

is used in place of dr in the difference schemes (δ=1 planar, δ=2 cylindrical, δ=3 spherical coordinates). The most accurate finite difference treatment is obtained when equal mass rather than equal Δr zoning is used.

IV. Equation of Motion

The equation of motion is written in lagrangian coordinates as

$$\frac{\partial u}{\partial t} = - V \frac{\partial}{\partial r} (P+q) \qquad \text{(IV-1)}$$

$$\frac{\partial u}{\partial t} = - r^{\delta-1} \frac{\partial}{\partial m_o} (P+q) \qquad \text{(IV-2)}$$

where V is the specific volume of the gas ($1/\rho$), P is the total pressure (P_p+P_R), and q is the von Neumann artificial viscosity.

The explicit finite difference equation used to solve (IV-2) is given as

$$\frac{u_j^{n+1/2} - u_j^{n-1/2}}{\Delta t^n} = - (r^{\delta-1})_j^n \, [\Delta P_j^n + \Delta q_j^{n-1/2}]/\Delta m_{o_j} \qquad \text{(IV-3)}$$

hence

$$u_j^{n+1/2} = u_j^{n-1/2} - (r^{\delta-1})_j^n [\Delta P_j^n + \Delta q_j^{n-1/2}](\Delta t^n/\Delta m_{o_j}) \qquad \text{(IV-4)}$$

where

$$\Delta P_j^n = P_{j+1/2}^n - P_{j-1/2}^n \qquad \Delta q_j^{n-1/2} = q_{j+1/2}^{n-1/2} - q_{j-1/2}^{n-1/2}$$

$$\Delta m_{o_j} = (\Delta m_{o_{j+1/2}} + \Delta m_{o_{j-1/2}})/2$$

$$\Delta t^n = (\Delta t^{n+1/2} + \Delta t^{n-1/2})/2$$

$$q_{j-1/2}^{n-1/2} = 0 \quad \text{when} \quad \dot{V}_{j-1/2}^{n-1/2} > 0$$

$$\text{(IV-5)}$$

$$= \frac{\sqrt{2}\,(u_j^{n-1/2} - u_{j-1}^{n-1/2})}{V_{j-1/2}^{n-1/2}} \quad \text{when } \dot{V}_{j-1/2}^{n-1/2} < 0$$

New radii are then computed as

$$r_j^{n+1} = r_j^n + u_j^{n+1/2} \Delta t^{n+1/2} \ . \qquad \text{(IV-6)}$$

From these, new specific volumes are computed.

Equations (IV-4) and (IV-6) and the new specific volumes are computed in HYDRO. The artificial viscosity is computed in QUE and new number densities corresponding to the new specific volumes are computed in NUMDEN.

V. Energy Transfer Equations

Energy transfer is represented by two coupled diffusion equations for the plasma temperature and the radiation specific energy. These are given as

$$C_{vp} \frac{\partial T_p}{\partial t} = \frac{\partial}{\partial m_o} (r^{\delta-1} K_p \frac{\partial T_p}{\partial r}) - \frac{\partial P_p}{\partial T_p} \frac{\partial V}{\partial t} T_p + J_R - J_p \qquad (V\text{-}1)$$

$$\frac{\partial E_R}{\partial t} = \frac{\partial}{\partial m_o} (r^{\delta-1} K_R \frac{\partial E_R}{\partial r}) - P_R \frac{\partial}{\partial m_o} r^{\delta-1} u - J_R + J_p \qquad (V\text{-}2)$$

where

C_{vp} -- plasma specific heat at constant volume

K_p -- plasma conductivity

J_R -- radiant energy/gram absorbed by the plasma

J_p -- radiant energy/gram emitted by the plasma

E_R -- radiant specific energy

K_R -- radiation conductivity.

The absorption and emission terms are defined as

$J_R = \frac{C\ E_R}{\ell_1(T_R,T_p)}$ where ℓ_1 is the radiation Planck mean free path, and

$$J_p = (\frac{C}{\ell_1(T_R=T_p)})(\frac{4\sigma}{c\rho} T_p{}^4) = \frac{4\sigma\ T_p{}^4}{\rho\ell_1(T_R=T_p)} .$$

Note that for J_R the Planck mean free path is evaluated as a function of different plasma and radiation temperature while for J_p, the Planck mean free path is evaluated for equal plasma and radiation temperatures.

Equations (V-1) and (V-2) are solved simultaneously using a fully implicit finite difference scheme. The finite difference equations are

$$C_{vp_{j-1/2}} \left[\frac{T^{n+1}_{p_{j-1/2}} - T^{n}_{p_{j-1/2}}}{\Delta t^{n+1/2}} \right] = \frac{1}{\Delta m_{o_{j-1/2}}} \left[\frac{2\, r_j^{\delta-1}}{\frac{\Delta r_j^+}{K^+_{p_j}} + \frac{\Delta r_j^-}{K^-_{p_j}}} (T^{n+1}_{p_{j+1/2}} - T^{n+1}_{p_{j-1/2}}) \right.$$

$$\left. - \frac{2 r_{j-1}^{\delta-1}}{\frac{\Delta r^+_{j-1}}{K^+_{p_{j-1}}} + \frac{\Delta r^-_{j-1}}{K^-_{p_{j-1}}}} (T^{n+1}_{j-1/2} - T^{n+1}_{j-3/2}) \right] - (P_p)_{T_{j-1/2}} \dot{V}_{j-1/2} T^{n+1}_{p_{j-1/2}} \qquad \text{(V-3)}$$

$$+ \omega_{R_{j-1/2}} E^{n+1}_{R_{j-1/2}} - \omega_{p_{j-1/2}} T^{n+1}_{p_{j-1/2}} \quad .$$

$$\frac{E^{n+1}_{R_{j-1/2}} - E^{n}_{R_{j-1/2}}}{\Delta t^{n+1/2}} = \frac{1}{\Delta m_{o_{j-1/2}}} \left[\frac{2 r_j^{\delta-1}}{\frac{\Delta r_j^+}{K^+_{R_j}} + \frac{\Delta r_j^-}{K^-_{R_j}} + \frac{2\Delta E_{R_j}}{F_{R_j}}} (E^{n+1}_{R_{j+1/2}} - E^{n+1}_{R_{j-1/2}}) \right]$$

$$- \frac{2 r_{j-1}^{\delta-1}}{\frac{\Delta r^+_{j-1}}{K^+_{R_{j-1}}} + \frac{\Delta r^-_{j-1}}{K^-_{R_{j-1}}} + \frac{2\Delta E_{R_{j-1}}}{F_{R_{j-1}}}} (E^{n+1}_{R_{j-1/2}} - E^{n+1}_{R_{j-3/2}}) \qquad \text{(V-4)}$$

$$- \frac{(r_j^{\delta-1} u_j - r_{j-1}^{\delta-1} U_{j-1})}{3 V_{j-1/2} \Delta m_{o_{j-1/2}}} E_{R_{j-1/2}}^{n+1}$$

$$- \omega_{R_{j-1/2}} E_{R_{j-1/2}}^{n+1} + \omega_{p_{j-1/2}} T_{p_{j-1/2}}^{n+1}$$

where

$$\Delta r_j^+ = r_{j+1} - r_j \qquad \Delta r_j^- = r_j - r_{j-1}$$

$$\omega_{R_{j-1/2}} = \frac{C}{\ell_1(T_R,T_p)_{j-1/2}} \qquad \omega_{p_{j-1/2}} = \frac{4\sigma(T_{p_{j-1/2}}^{n+1/2}) V_{j-1/2}}{\ell_1(T_R = T_p)_{j-1/2}} .$$

These difference equations can be rewritten in matrix form as

$$\underline{\underline{\alpha}}_{j-1/2} (\underline{\theta}_{j-1/2}^{n+1} - \underline{\theta}_{j-1/2}^{n}) = \underline{\underline{a}}_j (\underline{\theta}_{j+1/2}^{n+1} - \underline{\theta}_{j-1/2}^{n+1}) - \tag{V-5}$$

$$\underline{\underline{a}}_{j-1} (\underline{\theta}_{j-1/2}^{n+1} - \underline{\theta}_{j-3/2}^{n+1}) - \underline{\underline{\gamma}}_{j-1/2} \underline{\theta}_{j-1/2}^{n+1} - \underline{\underline{\omega}}_{j-1/2} \underline{\theta}_{j-1/2}^{n+1}$$

where

$$\underline{\underline{\alpha}}_{j-1/2} \equiv \begin{pmatrix} C_{vp_{j-1/2}} & 0 \\ 0 & 1 \end{pmatrix} \frac{\Delta m_{oj-1/2}}{\Delta t^{n+1/2}} \tag{V-6}$$

$$\underline{\theta}_{j-1/2}^{n+1} \equiv \begin{pmatrix} T_{p_{j-1/2}}^{n+1} \\ E_{R_{j-1/2}}^{n+1} \end{pmatrix} \tag{V-7}$$

$$\underline{\underline{a}}_j \equiv \begin{pmatrix} \dfrac{2r_j^{\delta-1}}{\dfrac{\Delta r_j^+}{K_{p_j}^+} + \dfrac{\Delta r_j^-}{K_{p_j}^-}} & 0 \\ 0 & \dfrac{2r_j^{\delta-1}}{\dfrac{\Delta r_j^+}{K_{R_j}^+} + \dfrac{\Delta r_j^-}{K_{R_j}^-} + \dfrac{2\Delta E_{R_j}}{F_{R_j}}} \end{pmatrix} \qquad \text{(V-8)}$$

$$\underline{\underline{\gamma}}_{j-1/2} \equiv \begin{pmatrix} (P_p)_T \dot{V}_{j-1/2} & 0 \\ 0 & \dfrac{(r_j^{\delta-1} u_j - r_{j-1}^{\delta-1} u_{j-1})}{3\, V_{j-1/2}\, \Delta m_{o_{j-1/2}}} \end{pmatrix} \Delta m_{o_{j-1/2}} \qquad \text{(V-9)}$$

$$\underline{\underline{\omega}}_{j-1/2} \equiv \begin{pmatrix} \omega_p & -\omega_R \\ -\omega_p & \omega_R \end{pmatrix}_{j-1/2} \Delta m_{o_{j-1/2}} \qquad \text{(V-10)}$$

where all quantities without a superscript are evaluated at (n+1/2).

This matrix equation (V-5) can be written as

$$-\underline{\underline{A}}_{j-1/2}\underline{\theta}^{n+1}_{j+1/2} + \underline{\underline{B}}_{j-1/2}\underline{\theta}^{n+1}_{j-1/2} - \underline{\underline{C}}_{j-1/2}\underline{\underline{\theta}}^{n+1}_{j-3/2} = \underline{D}_{j-1/2} \qquad \text{(V-11)}$$

where

$$\begin{aligned}
\underline{\underline{A}}_{j-1/2} &= \underline{\underline{a}}_{j} \\
\underline{\underline{B}}_{j-1/2} &= \underline{\underline{\alpha}}_{j-1/2} + \underline{\underline{a}}_{j} + \underline{\underline{a}}_{j-1} + \underline{\underline{\gamma}}_{j-1/2} + \underline{\underline{\omega}}_{j-1/2} \\
\underline{\underline{C}}_{j-1/2} &= \underline{\underline{a}}_{j-1} \\
\underline{D}_{j-1/2} &= \underline{\underline{\alpha}}_{j-1/2}\, \underline{\theta}^{n}_{j-1/2}
\end{aligned} \tag{V-12}$$

Equation (V-6) is solved by assuming a solution of the form

$$\underline{\theta}^{n+1}_{j-1/2} = \underline{\underline{E}}_{j-1/2}\, \underline{\theta}^{n+1}_{j+1/2} + \underline{F}_{j-1/2} \tag{V-13}$$

where

$$\begin{aligned}
\underline{\underline{E}}_{j-1/2} &= (\underline{\underline{B}}_{j-1/2} - \underline{\underline{C}}_{j-1/2} * \underline{\underline{E}}_{j-3/2})^{-1} * \underline{\underline{A}}_{j-1/2} \\
\underline{F}_{j-1/2} &= (\underline{\underline{B}}_{j-1/2} - \underline{\underline{C}}_{j-1/2} * \underline{\underline{E}}_{j-3/2})^{-1} * (\underline{D}_{j-1/2} + \underline{\underline{C}}_{j-1/2} * \underline{F}_{j-3/2}) \ .
\end{aligned} \tag{V-14}$$

At the inner boundary

$$\begin{aligned}
\underline{\underline{E}}_{1/2} &= (\underline{\underline{B}}_{1/2})^{-1} * \underline{\underline{A}}_{1/2} \\
\underline{F}_{1/2} &= (\underline{\underline{B}}_{1/2})^{-1} * \underline{D}_{1/2} \ .
\end{aligned}$$

At the outer boundary

$$\underline{\theta}^{n+1}_{JMAX\ +\ 1/2} = \underline{\theta}^{n+1}_{b.c.} \tag{V-16}$$

The final solution of the equations (V-13) is done in ENERGY. The matrices and vectors $\underline{\underline{A}}$, $\underline{\underline{B}}$, $\underline{\underline{C}}$, $\underline{D}$, $\underline{\underline{E}}$, and $\underline{F}$ are computed in ABCDEF. The coefficient matrices $\underline{\underline{a}}$, $\underline{\underline{\alpha}}$, $\underline{\underline{\gamma}}$, and $\underline{\underline{\omega}}$ are computed in MATRIX. The boundary condition is determined in TEMPBC. The physical coefficients used to compute, $\underline{\underline{a}}$, $\underline{\underline{\alpha}}$, $\underline{\underline{\gamma}}$, and $\underline{\underline{\omega}}$ are discussed in the next section.

VI. Coefficients for Energy Equations

Numerous coefficients, often dependent on temperature, are used by the FIRE code in the solution of the energy flow equations.

Plasma Conductivity

$$K_{p_j}^{+} = \mathrm{CON}(1)\, T_{p_j}^{2}\, T_{p_{j+1/2}}^{1/2} / (4 + Z_{j+1/2}) \ell n\Lambda_{j+1/2}$$

$$K_{p_j}^{-} = \mathrm{CON}(1)\, T_{p_j}^{2}\, T_{p_{j-1/2}}^{1/2} / (4 + Z_{j-1/2}) \ell n\Lambda_{j-1/2}$$

Radiation Conductivity

$$K_{R_j}^{+} = \frac{C}{3}\frac{\ell}{V} = \mathrm{CON}(2)\ \ell_{j+1/2}/V_{j+1/2}$$

$$K_{R_j}^{-} = \mathrm{CON}(2)\ell_{j-1/2}/V_{j-1/2}$$

where $\ell(n_p, T_p, T_R)$ is the Rosseland radiation mean free path.

Radiation Flux Limit

$$F_{R_j} = \sigma T^4 = \mathrm{CON}(3) T_{R_j}^{4}$$

Plasma Absorption

$$\omega_{R_{j-1/2}} = \frac{C}{\ell_1(T_R, T_p)} = \mathrm{CON}(8)/\ell_1(T_R, T_p)_{j-1/2}$$

Plasma Emission

$$\omega_{p_{j-1/2}} = \frac{4\sigma\ V}{\ell_1(T_R = T_p)} = \mathrm{CON}(7)\ V_{j-1/2}/\ell_1(T_R = T_p)_{j-1/2}$$

The plasma and radiation conductivities are computed in KAPPA. The radiation flux limit is also computed in KAPPA. The plasma emission and absorption coefficients are computed in OMEGA. The $\ell n\Lambda$ term is computed in

LLAM. The charge state, Z, and the radiation mean free paths, ℓ, ℓ_1 (T_p, T_R) and $\ell_1(T_p = T_R)$ are computed along with the plasma specific heat and other equations of state quantitites in EOS. This is discussed in the next section.

VII. Equations of State

A total of 8 equation of state quantities are computed in FIRE. These are

P_R -- radiation pressure
T_R -- radiation temperature
E_p -- plasma specific internal energy
C_{vp} -- plasma specific heat
P_p -- plasma pressure
$(P_p)_T$ -- temperature derivative of plasma pressure
Z -- average charge state
ℓ -- Rosseland mean free path
ℓ_1 -- Planck mean free path

The radiation pressure is

$$P_R = \frac{1}{3}\frac{E_R}{\rho} = \frac{4\sigma}{3c} T_R^4$$

$$P_{R_{j-1/2}} = \mathrm{CON}(10) * T_{R_{j-1/2}}{}^4$$

The radiation temperature is computed from the specific energy using

$$T_{R_{j-1/2}} = (E_{R_{j-1/2}} / \mathrm{CON}(16) / V_{j-1/2})^{1/4}$$

The plasma pressure is given as

$$P_{p_{j-1/2}} = \mathrm{CON}(9)(1 + Z_{j-1/2}) * n_{i_{j-1/2}} * T_{p_{j-1/2}}$$

The temperature derivative of the plasma pressure is

$$(P_p)_{T_{j-1/2}} = \mathrm{CON}(12) * n_{i_{j-1/2}} *$$

$$(1 + Z_{j-1/2} + (\frac{\partial Z}{\partial T_p})_{j-1/2} * T_{p_{j-1/2}})$$

There are 4 equation of state tables used by the FIRE code. These tables provide

$$Z = Z(n,\ T_p) \qquad \text{Charge}$$

$$E_p = E_p(n,T_p) \qquad \text{Specific Internal Energy}$$

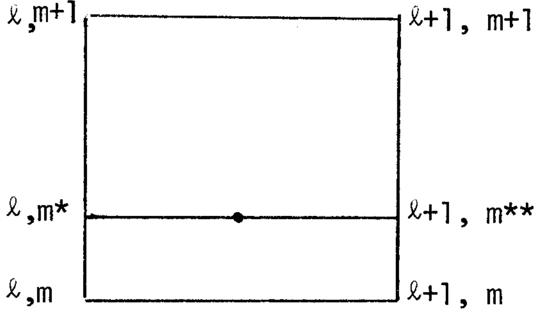
$$\ell = \ell(n,\ T_p,\ T_R) \qquad \text{Rosseland mfp}$$

$$\ell_1 = \ell_1(n,\ T_p,\ T_R) \qquad \text{Planck mfp}$$

and are generated by the MFP code. The tables for Z and E are two dimensional while the tables for ℓ and ℓ_1 are three dimensional. To interpolate in these tables we use logrithmic interpolation. That is, all of the quantities are interpolated using linear interpolation of these logarithms. Hence the tables give

$$\log Z(\log n,\ \log T_p) \text{ etc.}$$

This method works reasonably well for smooth data. So, in general we have 2 dimensions



k - T_R

ℓ - T_p

m - n_p

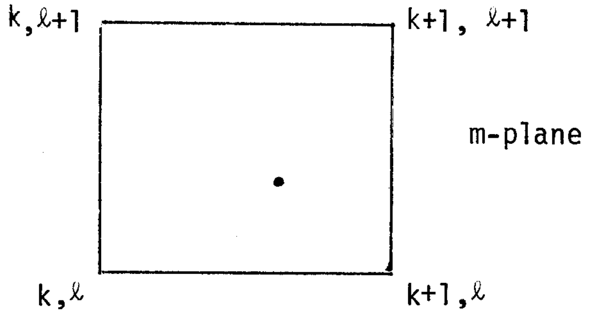
$$A(\ell,m^*) = A(\ell,m) + \frac{A(\ell,m+1) - A(\ell,m)}{n_p(m+1) - n_p(m)}(n_p - n_p(m))$$

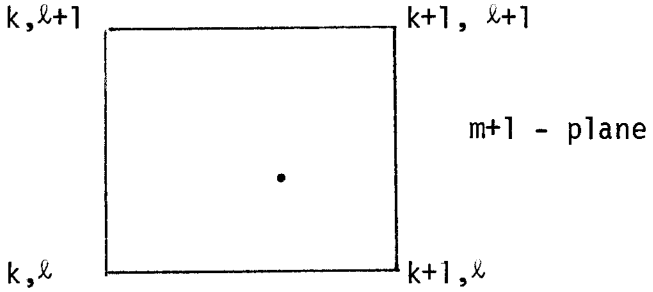
$$A(\ell,m^{**}) = A(\ell+1,m) + \frac{A(\ell+1,m+1) - A(\ell+1,m)}{n_p(m+1) - n_p(m)}(n_p - n_p(m))$$

$$A = A(\ell,m^*) + A_T\ (T_p - T_p(\ell))$$

$$A_T = \frac{A(\ell+1,m^{**}) - A(\ell,m^*)}{T_p(\ell+1) - T_p(\ell)}$$

In 3 dimensions this becomes the following





$$A(k,\ell^*) = A(k,\ell) + \frac{(A(k,\ell+1) - A(k,\ell))}{(T_p(\ell+1) - T_p(\ell))}\ (T_p - T_p(\ell))$$

$$A(k,\ell^{**}) = A(k+1,\ell) + \frac{(A(k+1,\ell+1) - A(k+1,\ell))}{(T_p(\ell+1) - T_p(\ell))}\ (T_p - T_p(\ell))$$

$$A = A(k,\ell^*) + A_T\ (T_R - T_R(k))$$

$$A_T = \frac{A(k+1,\ell^{**}) - A(k,\ell^*)}{(T_R(k+1) - T_R(k))}\ .$$

In three dimensions we do this twice, for m and m+1. This gives us A_m and A_{m+1} so the final result is

$$A = A_m + \frac{A_{m+1} - A_m}{n_p(m+1) - n_p(m)} \; (n_p - n_p(m)) \quad .$$

Note that we also want to find $\frac{\partial E}{\partial T_p} = C_{v_p}$. If we go back to our 2-D general interpolation and recall that we are actually computing

$$\log A(\log n_p, \log T_p)$$

then

$$\frac{\partial E}{\partial T_p} = \frac{\partial \log E}{\partial \log T_p} \; \frac{\partial E}{\partial \log E} \; \frac{\partial \log T}{\partial \; T}$$

$$\frac{\partial E}{\partial T_p} = \frac{\partial \log E}{\partial \log T_p} \; \frac{E}{T_p} \quad .$$

All of these quantities except T_R are computed in EOS. The radiation temperature T_R is computed in ENERGY after solving for the radiation specific internal energy.

VIII. Energy Conservation Check

At the end of each time step a check is made to insure that the difference equations are conserving energy. This is done by integrating the energy equations (the first law of thermodynamics) for the plasma and radiation. These are given by

$$\dot{E}_p + P_p\dot{V} = S_p + \dot{Q}_{PR} + \dot{Q}_{DP} \qquad \text{(VIII-1)}$$

$$\dot{E}_R + P_R\dot{V} = S_R - \dot{Q}_{PR} + \dot{Q}_{DR} - \dot{Q}_{RL} \qquad \text{(VIII-2)}$$

where

$$\dot{Q}_{PR} = \omega_R E_R - \omega_p T_p$$

$$\dot{Q}_{Px} = \frac{\partial}{\partial m_o} r^{\delta-1} K_x \frac{\partial(T_p, E_r)}{\partial r}$$

After integration over space and time these equations take the form

$$e_p^{n+1} + T^{n+1} = e_p^o + T^o + H_p^{n+1} + E_{RP}^{n+1} - F_p^{n+1} - W_p^{n+1} - G_R^{n+1} \qquad \text{(VIII-3)}$$

$$e_R^{n+1} = e_R^o + H_R^{n+1} - E_{RP}^{n+1} - F_R^{n+1} - W_R^{n+1} + G_R^{n+1} - E_{RL}^{n+1} \qquad \text{(VIII-4)}$$

$$e^{n+1} + T^{n+1} = e^o + T^o + H^{n+1} - F^{n+1} - W^{n+1} - E_{RL}^{n+1} \qquad \text{(VIII-5)}$$

Each of these terms are given as follows

$$e_x^{n+1} = \sum_{j=1}^{JMAX} (E_X)_{j-1/2}^{n+1} \Delta m_o \qquad \text{(VIII-6)}$$

$$T^{n+1} = \frac{1}{4} \Delta m_{o_{JMAX-1/2}} (U_{JMAX}^{n+1/2})^2 + \frac{1}{2} \sum_{j=1}^{JMAX} \Delta m_{o_j} (u_j^{n+1/2})^2 \qquad \text{(VIII-7)}$$

$$H_x^{n+1} = H_x^n + \Delta t^{n+1/2} \sum_{j=1}^{JMAX} (S_x)_{j-1/2}^{n+1/2} \Delta m_{o_{j-1/2}} \qquad \text{(VIII-8)}$$

$$E_{RP}^{n+1} = E_{RP}^n + \Delta t^{n+1/2} \sum_{j=1}^{JMAX} (\dot{Q}_{RP})_{j-1/2}^{n+1/2} \Delta m_{o_{j-1/2}} \qquad \text{(VIII-9)}$$

$$G_R^{n+1} = G_R^n + \Delta t^{n+1/2} \sum_{j=1}^{JMAX-1} u_j^{n+1/2} (r^{\delta-1})^{n+1/2} (*) \qquad \text{(VIII-10)}$$

$$[P_{R_{j+1/2}}^{n+1/2} - P_{R_{j-1/2}}^{n+1/2}] + \Delta t^{n+1/2} u_{JMAX}^{n+1/2} (r^{\delta-1})_{JMAX}^{n+1/2} [P_{R_{JMAX+1}} - P_{R_{JMAX-1}}]/2$$

where x = p or R

$$E_{RL}^{n+1} = E_r^n + \Delta t^{n+1/2} \sum_{j=1}^{JMAX} (\dot{Q}_{RL})_{j-1/2}^{n+1/2} \Delta m_{o_{j-1/2}} \qquad \text{(VIII-11)}$$

$$W_x^{n+1} = W_x^n + \Delta t^{n+1/2} (u_{JMAX}^{n+1/2} (r^{\delta-1})_{JMAX}^{n+1/2} P_{xJMAX}^{n+1/2}) \qquad \text{(VIII-12)}$$

$$F_x^{n+1} = F_x^n + \Delta t^{n+1/2} a_{x_{JMAX}}^{n+1/2} (T_{x_{JMAX+1/2}}^{n+1/2} - T_{x_{JMAX-1/2}}^{n+1/2}) \qquad \text{(VIII-13)}$$

The physical definitions of each term are

e_p, e_R -- total internal energy of the plasma and radiation at (n+1)

T -- total kinetic energy of the plasma at (n+1)

H_p, H_R -- total source of energy to the plasma and radiation up to (n+1). These are zero in the FIRE code at this time.

E_{RP} -- total energy exchanged from the plasma to the radiation up to time (n+1).

E_{RL} -- total radiant energy lost from the plasma through some pure loss mechanism. Not used in FIRE at this time.

W_p, W_R -- total work done on the outer boundary of the plasma by the plasma and radiation up to time (n+1). These are zero in the FIRE code because the outer edge of the plasma is contained by the first wall.

F_p, F_R -- total energy conducted to the first wall from the plasma and radiation up to time (n+1).

G_R -- work done by the plasma on the radiation to maintain the one fluid-two temperature approximation.

These integrations are done in ECHECK.

IX. Time Step Control

After each time step the next time step is determined so that a set of stability and accuracy constraints are maintained. This is determined by

$$\Delta t^{n+3/2} = \mathrm{Max}[\Delta t_{min}, \mathrm{Min}(\Delta t_{max}, K_1/R_1^{n+1}, K_2\Delta t^{n+1/2}/R_2^{n+1}, K_3\Delta t^{n+1/2}/R_3^{n+1}, K_4\Delta t^{n+1/2}/R_4^{n+1})] \qquad \text{(IX-1)}$$

where

$$R_1^{n+1} = \underset{j}{\mathrm{Max}}[(V_{j-1/2}^{n+1} P_{j-1/2}^{n+1})^{1/2}/\Delta r_{j-1/2}^{n+1/2}] \qquad \text{(IX-2)}$$

$$R_2^{n+1} = \underset{j}{\mathrm{Max}}[(V_{j-1/2}^{n+1} - V_{j-1/2}^{n})/V_{j-1/2}^{n+1}] \qquad \text{(IX-3)}$$

$$R_3^{n+1} = \underset{j}{\mathrm{Max}}[(T_{R_{j-1/2}}^{n+1} - T_{R_{j-1/2}}^{n})/T_{R_{j-1/2}}^{n+1/2}] \qquad \text{(IX-4)}$$

$$R_4^{n+1} = \underset{j}{\mathrm{Max}}[(T_{p_{j-1/2}}^{n+1} - T_{p_{j-1/2}}^{n})/T_{p_{j-1/2}}^{n+1/2}] \qquad \text{(IX-5)}$$

and the input parameters K_1, K_2, K_3, and K_4 determine the severity of the constraint. The default value for these is 0.05. The time step determination is done in TIMING.

X. Computer Code Description

The FIRE code is written in FORTRAN to be run on any mainframe computer. It is written in a top-down modular programming style as shown in Fig. X-1.

Variables

All real variables are implicit double precision giving about 14 decimal places of accuracy on an IBM or UNIVAC computer. It is important to note that all real constants are specified with the "D" scientific notation (i.e. 1. → 1.DO). This is necessary to insure that all calculations are performed in double precision since the IBM FORTRAN G and H compilers will not define constants as double precision unless the "D" notation is used. This seriously affects calculations that are expected to be in double precision.

Variable names are designed to correspond to this documentation with the following conventions used to identify their meanings.

i) The last two letters indicate whether the variable is zone centered or on a zone boundary and also indicate the time level.

1 -- zone boundary
2 -- zone center
A -- t^{n+1}
B -- $t^{n+1/2}$
C -- t^{n}
D -- $t^{n-1/2}$
E -- t^{n-1}
F -- $t^{n-3/2}$
G -- t^{n-2}
H -- $t^{n-5/2}$
I -- t^{n-3}

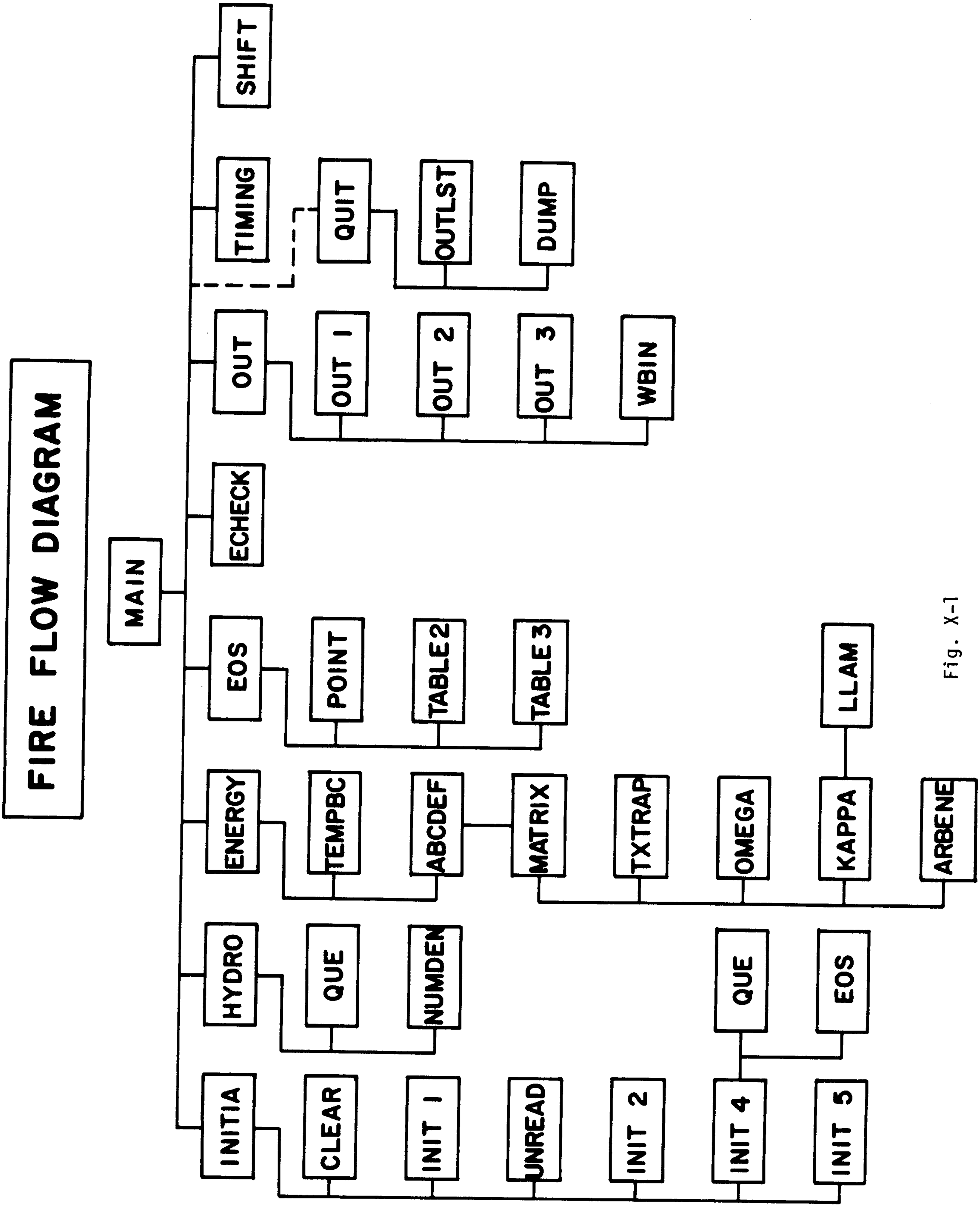

FIRE FLOW DIAGRAM
MAIN
INITIA
CLEAR
INIT 1
UNREAD
INIT 2
INIT 4
QUE
EOS
INIT 5
HYDRO
QUE
NUMDEN
ENERGY
TEMPBC
ABCDEF
MATRIX
TXTRAP
OMEGA
KAPPA
LLAM
ARBENE
EOS
POINT
TABLE 2
TABLE 3
ECHECK
OUT
OUT 1
OUT 2
OUT 3
WBIN
TIMING
QUIT
OUTLST
DUMP
SHIFT

Fig. X-1

ii) The first 4 or less letters indicate the physical quantity being represented.

R -- radiation quantity

N -- plasma quantity

Thus TR2B(J) is the radiation temperature in the center of the J^{th} zone at time $t^{n+1/2}$, and U1D(J) is the fluid velocity on the J^{th} zone boundary at time $t^{n-1/2}$. All variables necessary to the computation are contained in named common blocks. The variables are grouped such that a subroutine will find most of the variables that it needs in fewer than all of the common's. We list all of the variables (by common block) along with their meaning and units. All vectors have dimensions of 53 which allows for 50 spatial zones.

Common Blocks

COMMON/TIME/

1) TA t^{n+1}

2) TB $t^{n+1/2}$

3) TC t^{n}

4) TD $t^{n-1/2}$

5) DTB** $\Delta t^{n+1/2}$

6) DTC $\Delta t^{n} = (\Delta t^{n+1/2} + \Delta t^{n-1/2})/2$ (sec)

7) DTD $\Delta t^{n-1/2}$

8) DTE $\Delta t^{n-1} = (\Delta t^{n-1/2} + \Delta t^{n-3/2})/2$

9) DTF $\Delta t^{n-3/2}$

10) DTG $\Delta t^{n-2}(\Delta t^{n3/2} + \Delta t^{n-5/2})/2$

11) DTH $\Delta t^{n-5/2}$

12) DT $\Delta t^{n+3/2}$, the new time step

13) TMAX* Max problem time for the simulation

14) DTMIN** Min allowed time step

15) DTMAX** Max allowed time step

COMMON/TEMPER/

1) TN2A	$(T_p)^{n+1}_{j-1/2}$	
2) TN2B	$(T_p)^{n+1/2}_{j-1/2}$	
3) TN2C*	$(T_p)^{n}_{j-1/2}$	
4) TN2E	$(T_p)^{n-1}_{j-1/2}$	Plasma temperatures (eV)
5) TN2G	$(T_p)^{n-2}_{j-1/2}$	
6) TN2I	$(T_p)^{n-3}_{j-1/2}$	
7) TN1B	$(T_p)^{n+1/2}_{j}$	
8) TNSQ2B	$\sqrt{(T_p)^{n+1/2}_{j-1/2}}$	$(eV)^{1/2}$
9) TR2A	$(T_R)^{n+1}_{j-1/2}$	
10) TR2B	$(T_R)^{n+1/2}_{j-1/2}$	
11) TR2C*	$(T_R)^{n}_{j-1/2}$	Radiation temperatures (eV)
12) TR2E	$(T_R)^{n-1}_{j-1/2}$	
13) TR2G	$(T_R)^{n-2}_{j-1/2}$	
14) TR2I	$(T_R)^{n-3}_{j-1/2}$	

15) TR1B $(T_R)_j^{n+1/2}$

16) TRSQ2B $\sqrt{(T_R)_{j-1/2}^{n+1/2}}$ $(eV)^{1/2}$

17) TBC** temperature boundary condition (eV)

COMMON/CNTROL/

1) CON** - real constants used in FIRE
2) TGR0W** - max percentage that Δt can increase in one cycle
3) TEDIT** - time at which output freq. switches from IO(1) to IO(11) (s)
4) GEOFAC - a geometry factor; 1, 2π, 4π
5) TSCC** - Courant condition time step control
6) TSCV** - $\Delta V/V$ time step control
7) TSCTR** - $\Delta T_R/T_R$ time step control
8) R1 - worst case for Courant condition
9) R2 - worst case for $\Delta V/V$
10) R3R - worst case for $\Delta T_R/T_R$
11) R3N - worst case for $\Delta T_p/T_p$
12) T1
13) T2
14) T3
15) T4

} temporary vectors to be used for any purpose <u>within</u> a subroutine

16) IDELTA**- 1 = cartesian, 2 = cylindrical, 3 = spherical
17) IDELM1 - 0 = cartesian, 1 = cylindrical, 2 = spherical
18) NCYCLE - time cycle index
19) NMAX* - max number of time steps
20) JMAX*- max number of spatial zones

21) JMAXM1 - JMAX-1
22) JMAXP1 - JMAX+1 $\Bigg\}$ used for indexing
23) JMAXP2 - JMAX+2

24) ISW** - control switches

25) ILUNIT - output units for flux quantities

26) JCOUR - zone # of Courant condition worst case

27) JSPVOL - zone # of $\Delta V/V$ worst case

28) JRTEMP - zone # of $\Delta T_R/T_R$ worst case

29) JNTEMP - zone # of $\Delta T_p/T_p$ worst case

30) INDEX - a vector used for output indexing

31) IZONE - zone # of worst case of Courant, $\Delta V/V$, $\Delta T/T$

32) ITYPE - 1 - Courant, $2 = \Delta V/V$, $3 = \Delta T_R/T_R$, $4 = \Delta T_p/T_p$ worst restriction

33) IITYPE - 0 = physical, $-1 = \min\Delta t$, $1 = \max\Delta t$

34) IEDIT** - output cycle frequencies

35) IIZONE - zone # of worst case if the Δt is Δt_{max} or Δt_{min}

36) ICOND - primary time step constraint

37) ICOND2 - secondary time step constraint if primary is Δt_{min} or Δt_{max}

38) NVMAX - time step of maximum compression

39) IUNIT - cm^2, radian-cm, sterradian for $\delta = 1, 2, 3$

40) JVMAX - zone # of maximum compression

41) TSCTN**- $\Delta T_p/T_p$ time step control

42) IO* - output frequency vector

43) IOBIN**- output freq. of binary output

COMMON/HYDROD/

1) U1D	$u_j^{n-1/2}$	fluid velocity (cm/s)
2) U1B**	$u_j^{n+1/2}$	
4) DR2B	$\Delta r_{j-1/2}^{n+1/2}$	zone widths (cm)
5) DR2A	$\Delta r_{j-1/2}^{n+1}$	zone widths (cm)
6) R1C	r_j^n	
7) R1B	$r_j^{n+1/2}$	radius (cm)
8) R1A	r_j^{n+1}	
9) RS1C	$(r_j^n)^{\delta-1}$	
10) RS1B	$(r_j^{n+1/2})^{\delta-1}$	
11) RS1A	$(r_j^{n+1})^{\delta-1}$	
12) PR2C	$(P_R)_{j-1/2}^n$	
13) PR2B	$(P_R)_{j-1/2}^{n+1/2}$	radiation pressure (J/cm^3)
14) PR2A	$(P_R)_{j-1/2}^{n+1}$	
15) PN2C	$(P_p)_{j-1/2}^n$	
16) PN2B	$(P_p)_{j-1/2}^{n+1/2}$	plasma pressure (J/cm^3)
17) PN2A	$(P_p)_{j-1/2}^{n+1}$	
18) P2C	$P_{j-1/2}^n$	total pressure (J/cm^3)
19) P2A	$P_{j-1/2}^{n+1}$	

23) V2C $V^{n}_{j-1/2}$

24) V2B $V^{n+1/2}_{j-1/2}$

25) V2A $V^{n+1}_{j-1/2}$

26) VO initial specific volume

27) COMPR VO/V compression

28) VDOT2B $\dot{V}^{n+1/2}_{j-1/2}$ time derivative of sp. volume (cm^3/g-s)

29) DMASS2 $\Delta m_{o_{j-1/2}}$ Lagrangian mass

30) DMASS1 $\Delta m_{o_j} = (\Delta m_{o_{j-1/2}} + \Delta m_{o_{j+1/2}})/2$

32) Q2B $q^{n+1/2}_{j-1/2}$

33) VMAX max compression

34) TAVMAX time of maximum compression (s)

35) VOL2B zone volume $^{n+1/2}_{j-1/2}$ (cm^3)

36) VOL2A zone volume $^{n+1}_{j-1/2}$ (cm^3)

COMMON/ESCOM/

1) ER2C $E^{n}_{R_{j-1/2}}$ radiation specific energy (J/g)

2) ENT2B $(C_{V_{p}})^{n+1/2}_{j-1/2}$ plasma specific heat (J/eV-g)

3) ER2B $E_{R_{j-1/2}}^{n+1/2}$ (J/g)

4) PNT2B $(P_p)^{n+1/2}_{Tj-1/2}$ temperature derivative of plasma pressure (J/cm^3-eV)

5) ER2A $(E_R)^{n+1}_{j-1/2}$ radiation specific internal energy (J/g)

6) EN2A $(E_p)^{n+1}_{j-1/2}$ plasma specific internal energy (J/g)

7) DE2A $(n_e)^{n+1}_{j-1/2}$ electron number density (1/cm^3)

8) DN2A $(n_i)^{n+1}_{j-1/2}$ ion number density

9) DE2B** $(n_e)^{n+1/2}_{j-1/2}$ electron number density

10) DN2B* $(n_i)^{n+1/2}_{j-1/2}$ ion number density

11) ATW2B* $A^{n+1/2}_{j-1/2}$ average ion atomic weight (amu)

12) ZT2B temperature derivative of average charge

13) Z2B** $Z^{n+1/2}_{j-1/2}$ average charge (esu)

14) ZSQ2B $(Z^{n+1/2}_{j-1/2})^2$ average squared charge (esu)^2

15) VBC** specific volume boundary condition (cm^3/g)

$$\left.\begin{array}{l}\text{16) AD}\\ \text{17) AT}\\ \text{18) BD}\\ \text{19) BT}\end{array}\right\}\ \text{coefficients defining the grid for the equations of state}$$

20)EBC radiation specific energy boundary condition

21) TN2AL log $(T_{p_{j-1/2}}^{\;n+1})$

22) TR2AL log $(T_{R_{j-1/2}}^{\;n+1})$

23) DN2AL log $(n_{i_{j-1/2}}^{\;n+1})$

$$\left.\begin{array}{l}\text{24) KEOS}\\ \text{25) LEOS}\\ \text{26) MEOS}\end{array}\right\}\ \text{vectors used for indexing into the equation of state tables}$$

COMMON/ESCOM1/

1) ZTAB - $Z(T_p,n_p)$ Plasma charge state

2) ENTAB- $E_p(T_p,n_p)$ Plasma sp. int. energy (J/g)

3) RMFTAB-$\ell_1(T_p,T_R,n_p)$ Planck mfp (cm)

4) ROSTAB-$\ell(T_p,T_R,n_p)$ Rosseland mfp (cm)

COMMON/COEFF/

1) ROSS2B - $(\ell)^{n+1/2}_{j-1/2}$ Rosseland mean free path (cm)

2) KANM1B - $(K_p^-)^{n+1/2}_j$ Plasma thermal conductivity (J/cm-eV-s)

3) KANP1B - $(K_p^+)^{n+1/2}_j$

4) KARM1B - $(K_R^-)^{n+1/2}_j$ Radiation thermal conductivity (J/cm-eV-s)

5) KARP1B - $(K_R^+)^{n+1/2}_j$

6) OMP2B - $(\omega_p)^{n+1/2}_{j-1/2}$ Plasma emission coefficient

7) OMR2B - $(\omega_r)^{n+1/2}_{j-1/2}$ Plasma absorption coefficient

8) RMFP2B - $(\ell_1)^{n+1/2}_{j-1/2}$ Planck mean free path (cm)

9) RMFT2B - $(\ell_1)^{n+1/2}_{j-1/2}$ Planck mean free path for $T_p=T_R$ (cm)

21) LAMN2B - $(\ell n\Lambda_{ei})^{n+1/2}_{j-1/2}$ Spitzer log Λ

22) FLIM1B - radiation flux limit - σT^4 - (J/cm$^2\cdot$s)

23) RFLU1B - diffusion flux (J/cm$^2\cdot$s)

COMMON/COEFF1/

1) BET12B - $(\beta_1)^{n+1/2}_{j-1/2}$

2) BET22B - $(\beta_2)^{n+1/2}_{j-1/2}$

Beta Vector

3) AL112B - $(\alpha_{11})^{n+1/2}_{j-1/2}$

4) A1222B - $(\alpha_{22})^{n+1/2}_{j-1/2}$

Diagonal Elements of Alpha Matrix

5) OM112B - $(\omega_{11})^{n+1/2}_{j-1/2}$

6) OM222B - $(\omega_{22})^{n+1/2}_{j-1/2}$

Diagonal Elements of Omega Matrix

7) GM112B - $(\gamma_{11})^{n+1/2}_{j-1/2}$

8) GM222B - $(\gamma_{22})^{n+1/2}_{j-1/2}$

Diagonal Elements of Gamma Matrix

9) AA111B - $(a_{11})^{n+1/2}_{j}$

10) AA221B - $(a_{22})^{n+1/2}_{j}$

Diagonal Elements of "A" Matrix

11) OM122B - $(\omega_{12})^{n+1/2}_{j-1/2}$

12) OM212B - $(\omega_{21})^{n+1/2}_{j-1/2}$

OFF Diagonal Elements of Omega Matrix

COMMON/COEFF2/

1) E11 - (E_{11})

All Elements of the "E" Matrix

2) E12 - (E_{12})

3) E21 - (E_{21})

4) E22 - (E_{22})

5) F1 - (F_1) Both Components of the "F" Vector

6) F2 - (F_2)

7) B11 - (B_{11}) All Elements of the "B" Matrix

8) B12 - (B_{12})

9) B21 - (B_{21})

10) B22 - (B_{22})

11) D1 - (D_1) Both Elements of the "D" Vector

12) D2 - (D_2)

COMMON/ECKCOM/

1) T1A - $(T)_{j}^{n+1}$ kinetic energy of fluid (J/□)
2) GGGE2A - $(G_e)_{j-1/2}^{n+1}$ radiation-plasma work to maintain one fluid (J/□)
3) HHHR2B - $(H_R)_{j-1/2}^{n+1/2}$ radiation source (J/□)
4) HHHN2B - $(H_p)_{j-1/2}^{n+1/2}$ plasma source (J/□)
5) EEEC2A - $(E_c)_{j-1/2}^{n+1}$ radiation-plasma energy exchange (J/□)
6) EEER2A - $(E_r)_{j-1/2}^{n+1}$ energy lost purely to radiation (J/□)
7) EEEERO - E_{R_o} total initial radiation internal energy (J/□)
8) EEEENO - E_{p_o} total initial plasma internal energy (J/□)
9) EEEEER - $(E_R)^{n+1}$ total radiation internal energy (J/□)
10) EEEEEN - $(E_p)^{n+1}$ total plasma internal energy (J/□)
11) TTTTTTT - $(T)^{n+1}$ total fluid kinetic energy (J/□)
12) HHHHHR - $(H_R)^{n+1}$ total radiation source (J/□)
13) HHHHHN - $(H_p)^{n+1}$ total plasma source (J/□)
14) EEEEEC - $(E_c)^{n+1}$ total radiation plasma exchanged (J/□)
15) GGGGGE - $(G_e)^{n+1}$ total work done to maintain one fluid (J/□)
17) WWWWWR - $(W_R)^{n+1}$ total work done on radiation (J/□)
18) WWWWWN - $(W_p)^{n+1}$ total work done on plasma (J/□)
19) FFFFFR - $(F_R)^{n+1}$ total radiation heat lost across outer boundary (J/□)
20) FFFFFN - $(F_p)^{n+1}$ total plasma heat lost across outer boundary (J/□)
22) WWWWR - $(w_R)^{n+1}$ total work done on radiation on last cycle (J/□)
23) WWWWN - $(w_p)^{n+1}$ total work done on plasma on last cycle (J/□)
24) FFFFR - $(f_R)^{n+1}$ total radiation lost at outer bd. on last cycle (J/□)

25) FFFFN - $(f_p)^{n+1}$ total plasma energy lost at outer bd. on last cycle (J/□)

26) HHHHR - $(h_R)^{n+1}$ total radiation source on last cycle (J/□)

27) HHHHN - $(h_p)^{n+1}$ total plasma source on last cycle (J/□)

28) EEEEC - $(e_c)^{n+1}$ total radiation plasma heat exchange on last cycle (J/□)

29) GGGGE - $(g_e)^{n+1}$ total work to maintain one fluid on last cycle (J/□)

30) EHLHS - left side of plasma energy balance equation (J/□)

31) ETLHS - left side of total energy balance equation (J/□)

32) ERRHS - right side of radiation energy balance equation (J/□)

33) ENRHS - right side of plasma energy balance equation (J/□)

34) ETRHS - right side of total energy balance equation (J/□)

35) PMAX - Maximum pressure at the wall (J/cm^3)

36) TPMAX - Time of maximum pressure (s)

37) FMAX - Maximum radiation heat flux at the wall (J/cm^2-s)

38) TFMAX - Time of maximum heat flux (s)

39) FSAVE - Heat fluxes at first wall (J/cm^2-s)

40) PSAVE - Pressures at first wall (J/cm^3)

41) TSAVE - Times of heat fluxes and pressures (s)

42) NPMAX - Time step of max. pressure

43) NSAVE - Index into FSAVE, PSAVE, and TSAVE

44) NFMAX - Time step of max. heat flux

45) NDUMMY - Rounds out the common block to an even number of words

where □ is

δ	□
δ=1	cm^2
δ=2	cm-radian
δ=3	steradian

where * means mandatory input variable

** means input variable with a default value

Subroutines

The subroutines in FIRE each perform a specific function that usually closely relates to this documentation. Each subroutine is listed with a brief description of its purposes.

ABCDEF - computes the $\underline{\underline{A}}$, $\underline{\underline{B}}$, $\underline{\underline{C}}$, $\underline{D}$, $\underline{\underline{E}}$, and $\underline{F}$ matrices and vectors used to solve for the energy transfer.

ARBENE - computes an arbitrary energy input to the plasma or radiation. Currently not used.

CLEAR - sets all common blocks to zero before the start of a calculation.

DUMP - writes all common blocks to unit 2 at the end of a calculation.

ECHECK - computes the integral quantities used to evaluate the degree to which energy is conserved in the calculation.

ENERGY - computes T_p and E_R and then T_R.

EOS - computes the equation of state quantities.

HYDRO - solves the equation of motion for the fluid velocity, and then computes new radii, Δr's, zone volumes and specific volumes.

INITIA - Reads NAMELIST input and calls other initialization routines.

INIT1 - sets variable default values before reading input.

INIT2,4,5 - computes initial conditions and writes a summary of the initial conditions to unit 6.

KAPPA - computes plasma and radiation thermal conductivity and the radiation flux limit.

LLAM - computes Spitzer's log lambda.

MAIN - calls other routines to form the loop for one time step.

MATRIX - computes $\underline{\underline{a}}$, $\underline{\underline{\alpha}}$, $\underline{\underline{\gamma}}$ and $\underline{\underline{\omega}}$ matrices for use in the energy transfer calculation.

NUMDEN - computes number densities from the specific volume.

OMEGA - computes the plasma emission and absorption coefficients.

OUT, OUT1 - writes output to unit 6 at the end of specified time cycles.

POINT - finds pointers into the equation of state tables.

QUE - computes the artificial viscosity.

QUIT - wraps up the calculation at the end.

SHIFT - shifts values of variables at (n+1) to variables at (n) at the end of a time step.

TABLE2 - interpolates in the equation of state tables using pointers.

TEMPBC - computes the plasma temperature and radiation specific energy boundary conditions.

TIMING - computes new time step and determines whether the calculation is over.

TXTRAP - extrapolates temperatures to (n+1/2) for coefficient evaluation.

UNREAD - reads in the common blocks from unit 4 at the beginning of a restarted calculation.

WBIN - writes binary output to unit 8 for postprocessing.

Input/Output Units

The FIRE code uses 6 different I/0 units. These units are listed along with their specific function.

Unit #	Function
2	FIRE writes all COMMON blocks to this unit at the end of a calculation to allow a restart.
3	FIRE reads the equation of state tables from this unit.
4	FIRE reads the COMMON blocks from this unit at the beginning of a restart calculation.

Unit #	Function
5	FIRE reads the NAMELIST input from this unit.
6	FIRE writes lineprinter output to this unit.
8	FIRE writes binary output to this unit for postprocessing into plots.

Storage Requirements and Execution Time

FIRE requires about 40 K words of core storage on a UNIVAC 1110 computer and executes at a rate of approximately 3-5 msec/zone·cycle.

Adding a Variable to FIRE

When adding a variable to a COMMON block, the COMMON block length (set in INIT1) must be changed so that DUMP and UNREAD will write and read the correct number of words for a restart. Notice that the lengths are measured in double words. Hence this must be changed if a CDC machine is used in single precision.

XI. Input Manual

The FIRE code reads NAMELIST input (&INPUT) from I/O unit 5. The variables that must be inputted are given in Table XI-1. The variables with default values are given in Table XI-2. Theyneed only be inputted if another value is desired. Table XI-3 contains definitions of the integer switches used to control the code. Table XI-4 lists the real constants used by the code that can be changed by input. Table XI-5 gives the intermediate output vector that allows all internally computed quantities to be outputted for debugging. Table XI-6 lists the I/O units used by the FIRE code. Below is an example of the input for a typical calculation.

Example 1:

```
&INPUT  JMAX=50,
  NMAX=10000,
  TMAX=2.D-2,
  DR2B=10.D0,9.83D0,4.6D0,3.32D0,2.67D0,2.28D0,
  1.99D0,1.79D0,1.63D0,1.5D0,1.53D0,1.56D0,1.59D0,
  1.63D0,1.67D0,1.86D0,2.06D0,2.27D0,2.5D0,2.73D0,
  3.21D0,3.73D0,4.3D0,4.9D0,5.55D0,
  6.23D0,6.96D0,7.74D0,8.58D0,9.46D0,10.32D0,
  11.46D0,12.57D0,13.77D0,15.08D0,16.51D0,
  18.04D0,19.73D0,21.55D0,24.54D0,16.38D0,14.76D0,
  13.49D0,12.46D0,11.61D0,10.88D0,10.27D0,9.73D0,
  9.25D0,8.83D0,
  ATW2B=50*39.9D0,
  TBC=5.D-2,
  TN2C=11*8.3D0,39*6.5D-2,
  TR2C=11*8.3D0,39*6.5D-2,
  DN2B=1.134D19,49*1.67D18,
  IO=3*500,
  IOBIN=50,
  ISW(5)=50,
&END
```

The next example is the input for a restart of this calculation to allow it to run to 40 msec instead of 20 msec.

Example 2:

```
&INPUT IRS=1, &END
&INPUT TMAX=4.D-2,
&END
```

At the end of the first calculation the COMMON blocks were written to unit 2. This file or tape must be attached to unit 4 for the restarted calculation to read the COMMON blocks. When done, the restarted calculation will write its COMMON blocks to unit 2 again.

The last example is a simple calculation to allow a test of the code.

Example 3:

```
&INPUT   JMAX=10,
   NMAX=200,
   TMAX=2.D-2,
   DR2B=10*10.D0,
   ATW2B=10*40.D0,
   TN2C=10*50.D0,
   TR2C=10*50.D0,
   DN2B=10*1.67D18,
   IO=3*50,10,
&END
```

The output from this calculation is given next.

```
123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890••SEQ NO. 07
123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890••SEQ NO. 07
123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890••SEQ NO. 07
123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890••SEQ NO. 07
•  •  •  •  •  •  UNIVAC 1180 TIME/SHARING EXEC --- MULTI-PROCESSOH SYSTEM --- VER.  MACC 36.12  SITE •  MACC     •  •  •  •  •  •
RUNID: X04326         PROJECT: 12902           USER: 3745022495             CREATED ON JAN  7, 1980 AT 13:31:05    INPUT DEVICE:
               FILE NAME: PR@003X04326            PART NUMBER: 00           PRINTED ON JAN  7, 1980 AT 13:40:56   OUTPUT DEVICE: PR2

@RUN MOSES,12902,3745022495,$20.00,200
PRIORITY:   M              RUNID:X04326      PROJ: 12902        USER: 3745022495  TIME:  99999 SECS PAGES:   200       CARDS:   200
@ASG,A FIRE.
@ASG 3.
@COPY NEW*ARDATA1.,3.
FURPUR 27R3A04    L36 SLIB11 01/07/80 13:31:06
    11 BLOCKS COPIED.
@ELT,L FIRE.TEST
ELT007 RLIB62 01/07-13:31:08-(10,)
000001       009     &INPUT  JMAX=10,
000002       010        NMAX=200,
000003       006        TMAX=2.D-2,
000004       006        DR2B=10*10.D0,
000005       006        ATW2B=10*40.D0,
000006       006        TN2C=10*50.D0,
000007       006        TR2C=10*50.D0,
000008       006        DN2B=10*1.67D18,
000009       010        IO=3*50,10,
000010       006     &END

END ELT.
@XQT FIRE.FIRE
```

```
••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••
•                                                          •
•    FIRE - A CODE TO COMPUTE THE RESPONSE OF CAVITY-      •
•    GASES TO FUSION PELLET DEBRIS 2/19/79                 •
•                                                          •
•    WRITTEN BY GREGORY A. MOSES & ROBERT R. PETERSON      •
•                                                          •
••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••


SPHERICAL GEOMETRY - ENERGY QUANTITIES ARE ABSOLUTE


NO. OF ZONES..............................          10
OUTER BOUNDARY(CM)........................   .1000+003

STARTING TIME(S)..........................   .0000+000
STARTING CYCLE............................           1
NO. OF TIME CYCLES........................         200
MAX. PROBLEM TIME(S)......................   .2000-001
TIME STEP FOR FIRST  10 CYCLES(S).........   .1000-011
MIN. TIME STEP(S).........................   .1000-012
MAX. TIME STEP(S).........................   .2000-003
TIME STEP GROWTH LIMIT....................   .1500+001
TIME STEP CONTROL PARAMETERS..............
    COURANT...............................   .5000-001
    PERCENT V CHANGE......................   .5000-001
    PERCENT TN CHANGE.....................   .5000-001
    PERCENT TR CHANGE.....................   .5000-001


TEMPERATURE BC.(EV).......................  2.5000-002


PRIMARY OUTPUT FREQUENCIES

HYDRODYNAMICS.....   50
ENERGY............   50
NUMBER DENSITIES..   50
SHORT EDIT........   10

BINARY OUTPUT.....   -1


 INTERMEDIATE VARIABLE FREQUENCIES - IEDIT

( 1)  -1   ( 2)  -1   ( 3)  -1   ( 4)  -1   ( 5)  -1   ( 6)  -1   ( 7)  -1   ( 8)  -1   ( 9)  -1   (10)  -1
(11)  -1   (12)  -1   (13)  -1   (14)  -1   (15)  -1   (16)  -1   (17)  -1   (18)  -1   (19)  -1   (20)  -1
(21)  -1   (22)  -1   (23)  -1   (24)  -1   (25)  -1   (26)  -1   (27)  -1   (28)  -1   (29)  -1   (30)  -1
(31)  -1   (32)  -1   (33)  -1   (34)  -1   (35)  -1   (36)  -1   (37)  -1   (38)  -1   (39)  -1   (40)  -1
```

```
(41)  -1    (42)  -1    (43)  -1    (44)  -1    (45)  -1    (46)  -1    (47)  -1    (48)  -1    (49)  -1    (50)  -1
(51)  -1    (52)  -1    (53)  -1    (54)  -1    (55)  -1    (56)  -1    (57)  -1    (58)  -1    (59)  -1    (60)  -1
(61)  -1    (62)  -1    (63)  -1    (64)  -1    (65)  -1    (66)  -1    (67)  -1    (68)  -1    (69)  -1    (70)  -1
(71)  -1    (72)  -1    (73)  -1    (74)  -1    (75)  -1    (76)  -1    (77)  -1    (78)  -1    (79)  -1    (80)  -1
(81)  -1    (82)  -1    (83)  -1    (84)  -1    (85)  -1    (86)  -1    (87)  -1    (88)  -1    (89)  -1    (90)  -1
(91)  -1    (92)  -1    (93)  -1    (94)  -1    (95)  -1    (96)  -1    (97)  -1    (98)  -1    (99)  -1    (


 #   RADIUS       ZONE WIDTH   MASS DENS    MASS         E DENSITY    ION DENSITY R TEMP       ION TEMP     ATOMIC WT    CHARGE
     (CM)         (CM)         (G/CM3)      (G/     )    (1/CM3)      (1/CM3)      (EV)         (EV)         (AMU)        (ESU)

 0   0.0000-001
 1   1.0000+001   1.0000+001   1.1091-004   4.6457-001   1.8467+019   1.6700+018   5.0000+001   5.0000+001   4.0000+001   1.1058+001
 2   2.0000+001   1.0000+001   1.1091-004   3.2520+000   1.8467+019   1.6700+018   5.0000+001   5.0000+001   4.0000+001   1.1058+001
 3   3.0000+001   1.0000+001   1.1091-004   8.8269+000   1.8467+019   1.6700+018   5.0000+001   5.0000+001   4.0000+001   1.1058+001
 4   4.0000+001   1.0000+001   1.1091-004   1.7189+001   1.8467+019   1.6700+018   5.0000+001   5.0000+001   4.0000+001   1.1058+001
 5   5.0000+001   1.0000+001   1.1091-004   2.8339+001   1.8467+019   1.6700+018   5.0000+001   5.0000+001   4.0000+001   1.1058+001
 6   6.0000+001   1.0000+001   1.1091-004   4.2276+001   1.8467+019   1.6700+018   5.0000+001   5.0000+001   4.0000+001   1.1058+001
 7   7.0000+001   1.0000+001   1.1091-004   5.9001+001   1.8467+019   1.6700+018   5.0000+001   5.0000+001   4.0000+001   1.1058+001
 8   8.0000+001   1.0000+001   1.1091-004   7.8513+001   1.8467+019   1.6700+018   5.0000+001   5.0000+001   4.0000+001   1.1058+001
 9   9.0000+001   1.0000+001   1.1091-004   1.0081+002   1.8467+019   1.6700+018   5.0000+001   5.0000+001   4.0000+001   1.1058+001
10   1.0000+002   1.0000+001   1.1091-004   1.2590+002   1.8467+019   1.6700+018   5.0000+001   5.0000+001   4.0000+001   1.1058+001
                                            4.6457+002

 #   R PRESS      ION PRESS    R INT ENE    ION INT ENE VELOCITY
      (J/CM3)     (J/CM3)      (J/     )    (J/     )   (CM/S)

                                                        0.0000-001
 0
 1   2.8544+001   1.6129+002   3.5954+005   3.2914+006  0.0000-001
 2   2.8544+001   1.6129+002   2.5168+006   2.3040+007  0.0000-001
 3   2.8544+001   1.6129+002   6.8312+006   6.2537+007  0.0000-001
 4   2.8544+001   1.6129+002   1.3303+007   1.2178+008  0.0000-001
 5   2.8544+001   1.6129+002   2.1932+007   2.0078+008  0.0000-001
 6   2.8544+001   1.6129+002   3.2718+007   2.9952+008  0.0000-001
 7   2.8544+001   1.6129+002   4.5661+007   4.1801+008  0.0000-001
 8   2.8544+001   1.6129+002   6.0762+007   5.5625+008  0.0000-001
 9   2.8544+001   1.6129+002   7.8020+007   7.1424+008  0.0000-001
10   2.8544+001   1.6129+002   9.7435+007   8.9198+008  0.0000-001


                                      COEFFICIENTS USED IN FIRE - CON

         ION THERMAL CONT..........( 1)  1.2175+002      R THERMAL COND...........( 2)  1.0000+010
         R FLUX LIMIT..............( 3)  1.0300+005      FLUX LIMIT EPSILON TERM..( 4)  1.0000-006
         CONST LOG LAMBDA..........( 5)  0.0000-001                               ( 6)  0.0000-001
         PLASMA EMISS. COEF........( 7)  4.1200+005      PLASMA ABSORP. COEF......( 8)  3.0000+010
         ION PRESS(I.GAS)..........( 9)  1.6020-019      R PRESS(I.GAS)...........(10)  4.5670-006
                                   (11)  0.0000-001      ION PRESS DERIV(I.GAS)...(12)  1.6020-019
                                   (13)  0.0000-001      ION SP HEAT(I.GAS).......(14)  2.4030-019
         ION INT ENERGY(I.GAS).....(15)  2.4030-019      RAD SP. ENERGY COEF......(16)  1.3733-005
                                   (17)  0.0000-001      ION SHOCK HEATING........(18)  1.0000+000
                                   (19)  0.0000-001                               (20)  0.0000-001
         ARTIFICIAL VISCOSITY......(21)  1.4140+000                               (22)  0.0000-001
                                   (23)  0.0000-001                               (24)  0.0000-001
                                   (25)  0.0000-001                               (26)  0.0000-001
```

```
                              (27)  0.0000-001          UP-STREAM AVE FACTOR.....(28)  1.0000+000
TEMP LIMIT MFP DEFAULT...(29)  1.5000+000                                        (30)  0.0000-001
MAX LOW TEMP MFP..........(31)  1.0000+000


                  CALCULATION OPTIONS USED IN FIRE - ISW

         NON-LINEAR COEFF. EVAL...( 1)    1              NO. OF CONST TIME STEPS..( 2)  10
                                  ( 3)    0                                       ( 4)   0
         FREQ OF WALL OUTPUT......( 5)   20              HYDRODYNAMIC MOTION......( 6)   0
         ARBITRARY ENERGY INPUT...( 7)    0                                       ( 8)   0
                                  ( 9)    0              FREQ. OF DTB CALCULATION.(10)   1
                                  (11)    0              EOS OPTION...............(12)   0
                                  (13)    0              ARBITRARY RADIATION MFP..(14)   0
         ARBITRARY ROSSELAND MFP..(15)    0                                       (16)   0
                                  (17)    0                                       (18)   0
         KEEP LOW TEMP MFP LOW....(19)    0

                  EQUATION OF STATE TABLE INDICES


                  DENSITY SLOPE.........    5.0000-001
                  DENSITY BASE..........    1.6931+001
                  TEMPERATURE SLOPE....     1.6289-001
                  TEMPERATURE BASE.....    -3.9794-001
                  MIN DENSITY(1/CM3)...     8.5389+016
                  MAX DENSITY(1/CM3)...     2.7002+021
                  MIN TEMPERATURE(EV)       4.0000-001
                  MAX TEMPERATURE(EV)       4.9781+002
```

```
      CYCLE        TIME(S)       DELTA T(S)       CRITERION(@@@@) IN ZONE ( 0) OTHERWISE (@@@@) IN ZONE ( 0)
          10       1.0000-011    1.0000-012


  SHORT EDIT
  TOTAL ENERGY RADIATED TO THE WALL(J)...........  1.0+005
  ENERGY RADIATED TO THE WALL ON THIS TIME STEP.  1.0+004
  PRESSURE AT THE WALL(J/CM3)..................  1.9+002
  HEAT FLUX AT THE WALL(J/CM2-S)................  4.0+010


                  1       3       5       7       9      10
   RADIUS  1.0+001 3.0+001 5.0+001 7.0+001 9.0+001 1.0+002
  VELOCITY 5.3-016 1.4-014 2.8-013 5.0-012 6.7-011 0.0-001
   I TEMP  5.0+001 5.0+001 5.0+001 5.0+001 5.0+001 5.0+001
   R TEMP  5.0+001 5.0+001 5.0+001 5.0+001 5.0+001 5.0+001
   P  MFP  1.5+001 1.5+001 1.5+001 1.5+001 1.5+001 1.5+001
   R  MFP  1.1+003 1.1+003 1.1+003 1.1+003 1.1+003 1.1+003


  ENERGY CONSERVATION

        INT ENE + KIN ENE = RHS =      INT ENE O-T BDFLUX +T SOURCE+-T I->R EX

     R    3.6+008              3.6+008   3.6+008   1.0+005   0.0-001  -2.4+003
     I    3.3+009   2.7-019    3.3+009   3.3+009   7.2-002   0.0-001   2.4+003
     T    3.7+009              3.7+009
```

```
     CYCLE          TIME(S)       DELTA T(S)       CRITERION(TR/T) IN ZONE (10) OTHERWISE (TR/T) IN ZONE (10)
          20       1.8000-010   5.7665-011


SHORT EDIT
TOTAL ENERGY RADIATED TO THE WALL(J).............  1.8+006
ENERGY RADIATED TO THE WALL ON THIS TIME STEP.  5.8+005
PRESSURE AT THE WALL(J/CM3)......................  1.9+002
HEAT FLUX AT THE WALL(J/CM2-S)...................  4.0+010


                  1       3       5       7       9      10
 RADIUS   1.0+001 3.0+001 5.0+001 7.0+001 9.0+001 1.0+002
VELOCITY 7.7-011 3.4-010 7.6-010 1.5-009 3.0-009 0.0-001
 I TEMP   5.0+001 5.0+001 5.0+001 5.0+001 5.0+001 5.0+001
 R TEMP   5.0+001 5.0+001 5.0+001 5.0+001 5.0+001 5.0+001
 P   MFP  1.5+001 1.5+001 1.5+001 1.5+001 1.5+001 1.5+001
 R   MFP  1.1+003 1.1+003 1.1+003 1.1+003 1.1+003 1.1+003


ENERGY CONSERVATION

       INT ENE + KIN ENE = RHS =      INT ENE O-T BDFLUX +T SOURCE+-T I->R EX

   R     3.6+008              3.6+008   3.6+008   1.8+006   0.0-001  -5.7+005
   I     3.3+009   8.5-016    3.3+009   3.3+009   1.3+000   0.0-001   5.7+005
   T     3.6+009              3.6+009
```

```
      CYCLE          TIME(S)        DELTA T(S)       CRITERION(TR/T) IN ZONE (10) OTHERWISE (TR/T) IN ZONE (10)
          30        9.9828-009    3.3253-009


SHORT EDIT
TOTAL ENERGY RADIATED TO THE WALL(J)...........  9.8+007
ENERGY RADIATED TO THE WALL ON THIS TIME STEP.  3.2+007
PRESSURE AT THE WALL(J/CM3)....................  1.9+002
HEAT FLUX AT THE WALL(J/CM2-S).................  3.9+010


                1        3        5        7        9       10
 RADIUS   1.0+001 3.0+001 5.0+001 7.0+001 9.0+001 1.0+002
VELOCITY 3.9-008 1.5-007 2.7-007 4.0-007 5.6-007 0.0-001
 I TEMP   5.0+001 5.0+001 4.9+001 4.9+001 4.9+001 4.9+001
 R TEMP   5.0+001 5.0+001 5.0+001 4.9+001 4.9+001 4.9+001
 P  MFP   1.5+001 1.5+001 1.5+001 1.5+001 1.5+001 1.5+001
 R  MFP   1.1+003 1.1+003 1.1+003 1.1+003 1.1+003 1.1+003


ENERGY CONSERVATION

       INT ENE + KIN ENE = RHS =      INT ENE O-T BDFLUX +T SOURCE+-T I->R EX

   R      3.4+008                 3.4+008   3.6+008    9.8+007    0.0-001   -8.4+007
   I      3.2+009    3.8-011      3.2+009   3.3+009    7.1+001    0.0-001    8.4+007
   T      3.6+009                 3.6+009
```

```
      CYCLE        TIME(S)       DELTA T(S)       CRITERION(TR/T) IN ZONE (10) OTHERWISE (TR/T) IN ZONE (10)
         40        2.7079-007   1.2104-008


SHORT EDIT
TOTAL ENERGY RADIATED TO THE WALL(J)............  1.7+009
ENERGY RADIATED TO THE WALL ON THIS TIME STEP.  4.8+007
PRESSURE AT THE WALL(J/CM3)......................  8.5+001
HEAT FLUX AT THE WALL(J/CM2-S)...................  1.6+010


                 1       3       5       7       9      10
 RADIUS  1.0+001 3.0+001 5.0+001 7.0+001 9.0+001 1.0+002
VELOCITY 8.6-005 4.8-006 6.3-005-1.9-005-6.1-004 0.0-001
 I TEMP  3.5+001 3.9+001 4.5+001 4.8+001 4.5+001 3.0+001
 R TEMP  3.9+001 3.9+001 3.9+001 3.9+001 3.9+001 4.0+001
 P  MFP  1.0+001 1.9+001 3.7+001 4.9+001 3.5+001 4.8+000
 R  MFP  4.4+002 6.7+002 8.1+002 8.9+002 8.2+002 1.5+002


ENERGY CONSERVATION

       INT ENE + KIN ENE = RHS =      INT ENE 0-T BDFLUX +T SOURCE+-T I->R EX

   R     1.3+008                 1.3+008   3.6+008   1.7+009    0.0-001  -1.4+009
   I     2.3+009    2.2-005      1.8+009   3.3+009   1.4+003    0.0-001   1.4+009
   T     2.4+009                 2.0+009
```

```
   CYCLE          TIME(S)        DELTA T(S)       CRITERION(TR/T) IN ZONE ( 1) OTHERWISE (TR/T) IN ZONE ( 1)
        50        2.7526-007     1.0201-009

 #   RADIUS        ZONE WIDTH  MASS DENS    COMPRESSION  VELOCITY     R TEMP       ION TEMP     R PRESS      ION PRESS    ART VISC
     (CM)          (CM)        (G/CM3)      (VO/V)       (CM/S)       (EV)         (EV)         (J/CM3)      (J/CM3)      (J/CM3)

 0   0.0000-001                                          0.0000-001
 1   1.0000+001   1.0000+001   1.1091-004   1.0000+000   9.9378-005   4.3514+001   4.4112+001   1.6374+001   1.3006+002   0.0000-001
 2   2.0000+001   1.0000+001   1.1091-004   1.0000+000   6.8680-006   4.3448+001   4.2892+001   1.6275+001   1.2396+002   1.8977-012
 3   3.0000+001   1.0000+001   1.1091-004   1.0000+000   4.2268-006   4.3488+001   4.2935+001   1.6323+001   1.2417+002   0.0000-001
 4   4.0000+001   1.0000+001   1.1091-004   1.0000+000  -5.9284-005   4.3585+001   4.3071+001   1.6481+001   1.2485+002   8.9444-013
 5   5.0000+001   1.0000+001   1.1091-004   1.0000+000  -7.1927-005   4.3935+001   4.3691+001   1.7016+001   1.2794+002   3.5451-014
 6   6.0000+001   1.0000+001   1.1091-004   1.0000+000   2.8306-005   4.4120+001   4.4081+001   1.7305+001   1.2991+002   0.0000-001
 7   7.0000+001   1.0000+001   1.1091-004   1.0000+000   4.8176-005   4.4179+001   4.4063+001   1.7398+001   1.2992+002   0.0000-001
 8   8.0000+001   1.0000+001   1.1091-004   1.0000+000   2.2969-005   4.4227+001   4.4021+001   1.7474+001   1.2961+002   1.4090-013
 9   9.0000+001   1.0000+001   1.1091-004   1.0000+000  -3.1223-004   4.4320+001   4.4076+001   1.7621+001   1.2988+002   2.4915-011
10   1.0000+002   1.0000+001   1.1091-004   1.0000+000   0.0000-001   4.5012+001   4.5720+001   1.8747+001   1.3830+002   0.0000-001
                                                                      2.5000-002   2.5000-002

 #   R ENERGY      ION ENERGY   KIN ENERGY   R SOURCE     ION SOURCE   ION->R EX    FLUX LIM     HEAT FLUX
     (J/      )    (J/      )   (J/      )   (J/      )   (J/      )   (J/      )   (J/CM2-S)    (J/CM2-S)
 0                              0.0000-001
 1   2.0625+005   2.4288+006   9.1761-009   0.0000-001   0.0000-001   1.1525+005   3.5719+011   1.6372+011
 2   1.4350+006   1.5884+007   1.4244-010   0.0000-001   0.0000-001  -4.6768+005   3.5484+011  -4.7941+010
 3   3.9065+006   4.3218+007   1.1620-010   0.0000-001   0.0000-001  -1.2911+006   3.5783+011  -1.3712+011
 4   7.6809+006   8.4809+007   4.0002-008   0.0000-001   0.0000-001  -2.4539+006   3.6932+011  -2.5797+011
 5   1.3075+007   1.4475+008   9.1332-008   0.0000-001   0.0000-001  -1.9156+006   3.8239+011  -2.0687+011
 6   1.9836+007   2.2065+008   2.0287-008   0.0000-001   0.0000-001   1.7167+005   3.8771+011  -8.6923+010
 7   2.7832+007   3.0797+008   7.9790-008   0.0000-001   0.0000-001  -1.2114+006   3.8952+011  -6.9803+010
 8   3.7198+007   4.0843+008   2.3652-008   0.0000-001   0.0000-001  -5.4184+006   3.9248+011  -1.3824+011
 9   4.8163+007   5.2602+008   5.5254-006   0.0000-001   0.0000-001  -9.4273+006   4.1949+011  -3.5799+011
10   6.3992+007   7.1792+008   0.0000-001   0.0000-001   0.0000-001   2.7791+007   2.7472+010   2.7458+010

                                ENERGY CONSERVATION CHECK -- UNITS ARE (J/      )

     INT ENE      T KE          INT ENE(0)   T BDFLUX     T I->R EX    T SOURCE     BDFLUX       I->R EX      SOURCE

R    2.2332+008                 3.5954+008   1.7002+009   1.5640+009   0.0000-001   6.7862+006   5.8726+006   0.0000-001
I    2.4721+009   5.7899-006    3.2914+009   1.4521+003                0.0000-001   5.8927+000                0.0000-001

                                RADIATION       2.2332+008      2.2332+008
                                ION             2.4721+009      1.7274+009
                                TOTAL           2.6954+009      1.9507+009

 #   E DENSITY    ION DENSITY  CHARGE        ROSS MFP     RAD MFP      EQM T MFP
     (1/CM3)      (1/CM3)      (ESU)         (CM)         (CM)         (CM)

 1   1.6985+019   1.6700+018   1.0021+001    8.0276+002   1.7972+001   1.6698+001
 2   1.6204+019   1.6700+018   9.8026+000    7.6023+002   1.5835+001   1.6961+001
 3   1.6222+019   1.6700+018   9.8104+000    7.6170+002   1.5649+001   1.6953+001
```

```
  4  1.6267+019   1.6700+018  9.8348+000  7,6636+002  1.5886+001  1.6925+001
  5  1.6538+019   1.6700+018  9.9458+000  7,8833+002  1.6299+001  1.6793+001
  6  1.6730+019   1.6700+018  1.0016+001  8,0263+002  1.6625+001  1.6705+001
  7  1.6705+019   1.6700+018  1.0016+001  8,0279+002  1.6509+001  1.6705+001
  8  1.6636+019   1.6700+018  1.0005+001  8,0061+002  1.6303+001  1.6719+001
  9  1.6626+019   1.6700+018  1.0015+001  8,0277+002  1.6218+001  1.6706+001
 10  1.7423+019   1.6700+018  1.0307+001  8,6748+002  1.7744+001  1.6295+001

SHORT EDIT
TOTAL ENERGY RADIATED TO THE WALL(J)..........  1.7+009
ENERGY RADIATED TO THE WALL ON THIS TIME STEP.  6.8+006
PRESSURE AT THE WALL(J/CM3)...................  1.6+002
HEAT FLUX AT THE WALL(J/CM2-S)................  2.7+010


                  1       3       5       7       9      10
  RADIUS  1.0+001 3.0+001 5.0+001 7.0+001 9.0+001 1.0+002
VELOCITY 9.9-005 4.2-006-7.2-005 4.8-005-3.1-004 0.0-001
  I TEMP  4.4+001 4.3+001 4.4+001 4.4+001 4.4+001 4.6+001
  R TEMP  4.4+001 4.3+001 4.4+001 4.4+001 4.4+001 4.6+001
  P  MFP  1.8+001 1.6+001 1.6+001 1.7+001 1.6+001 1.8+001
  R  MFP  8.0+002 7.6+002 7.9+002 8.0+002 8.0+002 6.7+002

ENERGY CONSERVATION

      INT ENE + KIN ENE = RHS =      INT ENE O-T BDFLUX +T SOURCE+-T I->R EX

  R    2.2+008               2.2+008  3.6+008   1.7+009   0.0-001  -1.6+009
  I    2.5+009   5.8-006     1.7+009  3.3+009   1.5+003   0.0-001   1.6+009
  T    2.7+009               2.0+009
```

```
      CYCLE         TIME(S)        DELTA T(S)       CRITERION(TR/T) IN ZONE ( 1) OTHERWISE (TR/T) IN ZONE ( 1)
          60        3.5758-007    4.6571-010


 SHORT EDIT
 TOTAL ENERGY RADIATED TO THE WALL(J).............  2.1+009
 ENERGY RADIATED TO THE WALL ON THIS TIME STEP.  2.2+006
 PRESSURE AT THE WALL(J/CM3).....................  1.3+002
 HEAT FLUX AT THE WALL(J/CM2-S)..................  1.9+010


                 1         3         5         7         9        10
  RADIUS   1.0+001 3.0+001 5.0+001 7.0+001 9.0+001 1.0+002
 VELOCITY 4.0-004-1.1-007-7.5-005 3.9-005-3.2-004 0.0-001
  I TEMP   7.4+001 4.3+001 4.2+001 4.2+001 4.1+001 4.1+001
  R TEMP   4.2+001 4.2+001 4.2+001 4.2+001 4.1+001 4.1+001
  P  MFP   2.1+002 1.9+001 1.8+001 1.8+001 1.6+001 1.7+001
  R  MFP   1.1+003 7.6+002 7.4+002 7.3+002 7.0+002 7.0+002


 ENERGY CONSERVATION

       INT ENE + KIN ENE = RHS =      INT ENE O-T BDFLUX +T SOURCE+-T I->R EX

    R     1.7+008               1.7+008    3.6+008    2.1+009    0.0-001   -2.0+009
    I     2.1+009    6.4-006    1.3+009    3.3+009    1.8+003    0.0-001    2.0+009
    T     2.3+009               1.5+009
```

```
      CYCLE         TIME(S)       DELTA T(S)       CRITERION(TR/T) IN ZONE ( 1) OTHERWISE (TR/T) IN ZONE ( 1)
           70       3.6632-007    1.0971-009


SHORT EDIT
TOTAL ENERGY RADIATED TO THE WALL(J)............  2.2+009
ENERGY RADIATED TO THE WALL ON THIS TIME STEP.  5.1+006
PRESSURE AT THE WALL(J/CM3)..................  1.3+002
HEAT FLUX AT THE WALL(J/CM2-S)...............  1.8+010


                  1       3       5       7       9      10
 RADIUS   1.0+001 3.0+001 5.0+001 7.0+001 9.0+001 1.0+002
VELOCITY  1.1-003 3.1-006-7.3-005 4.6-005-3.2-004 0.0-001
 I TEMP   4.6+001 4.1+001 4.1+001 4.1+001 4.1+001 4.1+001
 R TEMP   4.4+001 4.1+001 4.1+001 4.1+001 4.1+001 4.1+001
 P  MFP   2.1+001 1.7+001 1.7+001 1.7+001 1.7+001 1.7+001
 R  MFP   8.9+002 7.1+002 7.1+002 7.1+002 7.1+002 7.1+002


ENERGY CONSERVATION

      INT ENE + KIN ENE = RHS =      INT ENE O-T BDFLUX +T SOURCE+-T I->R EX

   R    1.6+008              1.6+008   3.6+008   2.2+009   0.0-001   -2.0+009
   I    2.1+009   7.2-006    1.3+009   3.3+009   1.9+003   0.0-001    2.0+009
   T    2.2+009              1.5+009
```

```
     CYCLE          TIME(S)      DELTA T(S)      CRITERION(TR/T) IN ZONE ( 1) OTHERWISE (TR/T) IN ZONE ( 1)
          80        4.4245-007   9.1046-009


SHORT EDIT
TOTAL ENERGY RADIATED TO THE WALL(J)..........  2.5+009
ENERGY RADIATED TO THE WALL ON THIS TIME STEP.  3.3+007
PRESSURE AT THE WALL(J/CM3)...................  1.1+002
HEAT FLUX AT THE WALL(J/CM2-S)................  1.5+010

                  1          3          5          7          9        10
  RADIUS   1.0+001 3.0+001 5.0+001 7.0+001 9.0+001 1.C+002
VELOCITY   1.2-003 5.1-006-7.0-005 5.0-005-3.2-004 0.0-001
  I TEMP   3.4+001 3.9+001 3.9+001 3.9+001 3.9+001 3.9+001
  R TEMP   3.9+001 3.9+001 3.9+001 3.9+001 3.9+001 3.9+001
  P  MFP   9.1+000 1.8+001 1.8+001 1.8+001 1.8+001 1.8+001
  R  MFP   3.9+002 6.6+002 6.6+002 6.6+002 6.6+002 6.6+002


ENERGY CONSERVATION

      INT ENE + KIN ENE = RHS =      INT ENE 0-T BDFLUX +T SOURCE+-T I->R EX

  R    1.3+008              1.3+008  3.6+008  2.5+009  0.0-001  -2.3+009
  I    1.8+009   7.4-006    1.0+009  3.3+009  2.2+003  0.0-001   2.3+009
  T    1.9+009              1.2+009
```

```
     CYCLE         TIME(S)       DELTA T(S)      CRITERION(TR/T) IN ZONE ( 1) OTHERWISE (TR/T) IN ZONE ( 1)
          90       4.7033-007   8.8691-009


SHORT EDIT
TOTAL ENERGY RADIATED TO THE WALL(J)...........  2.6+009
ENERGY RADIATED TO THE WALL ON THIS TIME STEP.  3.0+007
PRESSURE AT THE WALL(J/CM3)....................  1.1+002
HEAT FLUX AT THE WALL(J/CM2-S).................  1.4+010


                 1       3       5       7       9      10
 RADIUS   1.0+001 3.0+001 5.0+001 7.0+001 9.0+001 1.0+002
VELOCITY 1.2-003 6.2-006-6.9-005 5.2-005-3.2-004 0.0-001
 I TEMP   3.8+001 3.8+001 3.8+001 3.8+001 3.8+001 3.8+001
 R TEMP   3.8+001 3.8+001 3.8+001 3.8+001 3.8+001 3.8+001
 P  MFP   1.7+001 1.7+001 1.7+001 1.7+001 1.7+001 1.7+001
 R  MFP   6.5+002 6.5+002 6.5+002 6.5+002 6.5+002 6.5+002


ENERGY CONSERVATION

      INT ENE + KIN ENE = RHS =      INT ENE O-T BDFLUX +T SOURCE+-T I.>R EX

   R     1.2+008                1.2+008   3.6+008   2.6+009   0.0-001  -2.4+009
   I     1.7+009   7.4-006      9.4+008   3.3+009   2.3+003   0.0-001   2.4+009
   T     1.8+009                1.1+009
```

```
    CYCLE        TIME(S)       DELTA T(S)        CRITERION(TR/T) IN ZONE ( 2) OTHERWISE (TR/T) IN ZONE ( 2)
        100      6.9056-007    3.9598-010

  #  RADIUS       ZONE WIDTH   MASS DENS    COMPRESSION VELOCITY     R TEMP       ION TEMP     R PRESS      ION PRESS    ART VISC
     (CM)         (CM)         (G/CM3)      (VO/V)      (CM/S)       (EV)         (EV)         (J/CM3)      (J/CM3)      (J/CM3)

  0  0.0000-001                                         0.0000-001
  1  1.0000+001   1.0000+001   1.1091-004   1.0000+000  1.2055-003   3.8087+001   4.2161+001   9.6054+000   1.2036+002   0.0000-001
  2  2.0000+001   1.0000+001   1.1091-004   1.0000+000  1.9613-004   3.7630+001   4.3709+001   9.1573+000   1.2803+002   2.2594-010
  3  3.0000+001   1.0000+001   1.1091-004   1.0000+000  9.9863-006   3.2454+001   3.2391+001   5.0664+000   8.1264+001   7.6834-012
  4  4.0000+001   1.0000+001   1.1091-004   1.0000+000 -6.2224-005   3.1503+001   3.1451+001   4.4983+000   7.8512+001   1.1563-012
  5  5.0000+001   1.0000+001   1.1091-004   1.0000+000 -6.2189-005   3.1255+001   3.1176+001   4.3582+000   7.7707+001   2.6642-019
  6  6.0000+001   1.0000+001   1.1091-004   1.0000+000  4.1438-005   3.1172+001   3.1124+001   4.3123+000   7.7555+001   0.0000-001
  7  7.0000+001   1.0000+001   1.1091-004   1.0000+000  6.1742-005   3.1135+001   3.1127+001   4.2918+000   7.7567+001   0.0000-001
  8  8.0000+001   1.0000+001   1.1091-004   1.0000+000  3.3654-005   3.1112+001   3.1130+001   4.2788+000   7.7575+001   1.7247-013
  9  9.0000+001   1.0000+001   1.1091-004   1.0000+000 -3.0259-004   3.1090+001   3.1133+001   4.2671+000   7.7584+001   2.5101-011
 10  1.0000+002   1.0000+001   1.1091-004   1.0000+000  0.0000-001   3.1064+001   3.1126+001   4.2528+000   7.7562+001   0.0000-001
                                                                     2.5000-002   2.5000-002

  #  R ENERGY     ION ENERGY   KIN ENERGY   R SOURCE     ION SOURCE   ION->R EX    FLUX LIM     HEAT FLUX
     (J/      )   (J/      )   (J/      )   (J/      )   (J/      )   (J/      )   (J/CM2-S)    (J/CM2-S)
  0                            0.0000-001
  1  1.2099+005   2.1764+006   1.3503-006   0.0000-001   0.0000-001   9.9000+004   1.6573+011   1.2178+011
  2  8.0742+005   1.6627+007   1.1616-007   0.0000-001   0.0000-001   4.7779+005   1.3869+011   1.2802+011
  3  1.2125+006   2.5377+007   6.4862-010   0.0000-001   0.0000-001  -3.9296+004   1.0715+011   7.2181+010
  4  2.0964+006   4.7970+007   4.4069-008   0.0000-001   0.0000-001  -7.9341+004   9.9283+010   3.6501+010
  5  3.3486+006   7.8386+007   6.8276-008   0.0000-001   0.0000-001  -1.3904+005   9.6886+010   1.4168+010
  6  4.9429+006   1.1674+008   4.3476-008   0.0000-001   0.0000-001  -1.6343+005   9.6167+010   5.7659+009
  7  6.8655+006   1.6294+008   1.3105-007   0.0000-001   0.0000-001  -1.5594+005   9.5893+010   3.5111+009
  8  9.1083+006   2.1685+008   5.1380-008   0.0000-001   0.0000-001  -1.4771+005   9.5716+010   3.2672+009
  9  1.1663+007   2.7847+008   5.1896-006   0.0000-001   0.0000-001  -1.1930+005   9.5495+010   4.2967+009
 10  1.4517+007   3.4768+008   0.0000-001   0.0000-001   0.0000-001  -8.2161+004   6.1421+009   6.1299+009

                          ENERGY CONSERVATION CHECK -- UNITS ARE (J/     )

     INT ENE      T KE         INT ENE(0)   T BDFLUX     T I->R EX    T SOURCE     BDFLUX       I->R EX      SOURCE

  R  5.4683+007                3.5954+008   3.1156+009   2.8107+009   0.0000-001   5.9730+005  -3.4942+005   0.0000-001
  I  1.2932+009   6.9950-006   3.2914+009   2.8875+003                0.0000-001   7.6803-001                0.0000-001

                               RADIATION      5.4683+007     5.4683+007
                               ION            1.2932+009     4.8073+008
                               TOTAL          1.3479+009     5.3541+008

  #  E DENSITY    ION DENSITY  CHARGE       ROSS MFP     RAD MFP      EQM T MFP
     (1/CM3)      (1/CM3)      (ESU)        (CM)         (CM)         (CM)

  1  1.6382+019   1.6700+018   9.6711+000   7.4476+002   2.9317+001   1.7099+001
  2  1.6767+019   1.6700+018   9.9490+000   7.8266+002   3.7519+001   1.6789+001
  3  1.3987+019   1.6700+018   8.3777+000   3.0439+002   1.6152+001   1.6292+001
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   4  1.3908+019   1.6700+018  8.3308+000  2,5161+002  1.5253+001  1.5357+001
   5  1.3884+019   1.6700+018  8.3168+000  2,3771+002  1.4882+001  1.5036+001
   6  1.3881+019   1.6700+018  8.3142+000  2,3529+002  1.4680+001  1.4974+001
   7  1.3883+019   1.6700+018  8.3144+000  2,3561+002  1.4964+001  1.4979+001
   8  1.3883+019   1.6700+018  8.3145+000  2,3584+002  1.5019+001  1.4982+001
   9  1.3884+019   1.6700+018  8.3147+000  2,3606+002  1.5069+001  1.4986+001
  10  1.3884+019   1.6700+018  8.3143+000  2,3576+002  1.5096+001  1.4977+001

 SHORT EDIT
 TOTAL ENERGY RADIATED TO THE WALL(J)...........  3.1+009
 ENERGY RADIATED TO THE WALL ON THIS TIME STEP.  6.0+005
 PRESSURE AT THE WALL(J/CM3)...................  8.2+001
 HEAT FLUX AT THE WALL(J/CM2-S)................  6.1+009


                   1         3         5         7         9        10
  RADIUS   1.0+001 3.0+001 5.0+001 7.0+001 9,0+001 1.0+002
 VELOCITY 1.2-003 1.0-005-6.2-005 6.2-005-3,0-004 0.0-001
  I TEMP   4.2+001 3.2+001 3.1+001 3.1+001 3,1+001 3.1+001
  R TEMP   3.8+001 3.2+001 3.1+001 3.1+001 3,1+001 3.1+001
  P  MFP   2.9+001 1.6+001 1.5+001 1.5+001 1,5+001 1.5+001
  R  MFP   7.4+002 3.0+002 2.4+002 2.4+002 2,4+002 2.4+002

 ENERGY CONSERVATION

       INT ENE + KIN ENE = RHS =      INT ENE D-T BDFLUX +T SOURCE+-T I->R EX

   R    5.5+007              5.5+007   3.6+008   3.1+009   0.0-001  -2.8+009
   I    1.3+009    7.0-006   4.8+008   3.3+009   2.9+003   0.0-001   2.8+009
   T    1.3+009              5.4+008
```

```
     CYCLE         TIME(S)       DELTA T(S)      CRITERION(TR/T) IN ZONE ( 2) OTHERWISE (TR/T) IN ZONE ( 2)
         110       7.0867-007    3.9155-009

SHORT EDIT
TOTAL ENERGY RADIATED TO THE WALL(J)...........  3.1+009
ENERGY RADIATED TO THE WALL ON THIS TIME STEP.   5.7+006
PRESSURE AT THE WALL(J/CM3)....................  8.0+001
HEAT FLUX AT THE WALL(J/CM2-S).................  5.8+009

                  1        3        5        7        9       10
 RADIUS   1.0+001 3.0+001 5.0+001 7.0+001 9.0+001 1.0+002
VELOCITY  1.2-003 3.7-005-5.8-005 6.4-005-3.0-004 0.0-001
 I TEMP   3.2+001 3.1+001 3.1+001 3.1+001 3.1+001 3.1+001
 R TEMP   3.3+001 3.1+001 3.1+001 3.1+001 3.1+001 3.1+001
 P  MFP   1.4+001 1.5+001 1.5+001 1.5+001 1.5+001 1.4+001
 R  MFP   2.7+002 2.4+002 2.3+002 2.2+002 2.2+002 2.2+002

ENERGY CONSERVATION

       INT ENE + KIN ENE = RHS =     INT ENE 0-T BDFLUX +T SOURCE+-T I->R EX

   R    5.2+007            5.2+007   3.6+008   3.1+009   0.0-001  -2.8+009
   I    1.3+009   7.7-006  4.6+008   3.3+009   2.9+003   0.0-001   2.8+009
   T    1.3+009            5.1+008
```

```
      CYCLE          TIME(S)       DELTA T(S)       CRITERION(TR/T) IN ZONE ( 1) OTHERWISE (TR/T) IN ZONE ( 1)
         120         7.5843-007    1.6966-009


   SHORT EDIT
   TOTAL ENERGY RADIATED TO THE WALL(J)..........   3.2+009
   ENERGY RADIATED TO THE WALL ON THIS TIME STEP.   2.0+006
   PRESSURE AT THE WALL(J/CM3)...................   7.6+001
   HEAT FLUX AT THE WALL(J/CM2-S)................   4.8+009


                      1       3       5       7       9      10
    RADIUS    1.0+001 3.0+001 5.0+001 7.0+001 9.0+001 1.0+002
   VELOCITY   1.2-003 4.1-005-5.5-005 6.8-005-3.0-004 0.0-001
    I TEMP    2.9+001 3.0+001 3.0+001 2.9+001 2.9+001 2.9+001
    R TEMP    3.0+001 3.0+001 3.0+001 2.9+001 2.9+001 2.9+001
    P  MFP    1.2+001 1.3+001 1.3+001 1.3+001 1.3+001 1.3+001
    R  MFP    1.6+002 1.7+002 1.7+002 1.7+002 1.7+002 1.6+002


   ENERGY CONSERVATION

          INT ENE + KIN ENE = RHS =      INT ENE 0-T BDFLUX +T SOURCE+-T I->R EX

     R     4.3+007              4.3+007   3.6+008   3.2+009   0.0-001   -2.9+009
     I     1.2+009   7.6-006    4.0+008   3.3+009   3.0+003   0.0-001    2.9+009
     T     1.3+009              4.4+008
```

```
     CYCLE        TIME(S)      DELTA T(S)      CRITERION(TR/T) IN ZONE ( 1) OTHERWISE (TR/T) IN ZONE ( 1)
        130       8.3436-007   9.8148-010


SHORT EDIT
TOTAL ENERGY RADIATED TO THE WALL(J)...........  3.3+009
ENEPGY RADIATED TO THE WALL ON THIS TIME STEP.  9.3+005
PRESSURE AT THE WALL(J/CM3)....................  7.0+001
HEAT FLUX AT THE WALL(J/CM2-S)..................  3.8+009


                 1       3       5       7       9       10
 RADIUS   1.0+001 3.0+001 5.0+001 7.0+001 9.0+001 1.0+002
VELOCITY  1.2-003 4.5-005-4.9-005 7.6-005-2.8-004 0.0-001
 I TEMP   2.7+001 2.8+001 2.8+001 2.8+001 2.8+001 2.8+001
 R TEMP   2.8+001 2.8+001 2.8+C01 2.8+001 2.8+001 2.8+001
 P  MFP   8.5+000 9.9+000 1.0+001 1.0+001 9.8+000 9.7+000
 R  MFP   1.0+002 1.2+002 1.2+002 1.2+002 1.1+002 1.1+002


ENEFGY CONSERVATION

       INT ENE + KIN ENE = RHS =     INT ENE O-T BDFLUX +T SOURCE+-T I.>R EX

   R    3.4+007                3.4+007   3.6+C08   3.3+009   0.0-001  -3.0+009
   I    1.1+009   7.4-006      3.3+008   3.3+C09   3.1+003   C.0-001   3.0+009
   T    1.2+009                3.6+C08
```

```
          CYCLE         TIME(S)        DELTA T(S)
             140        9.4601-007     3.7874-008       CRITERION(TR/T) IN ZONE (10) OTHERWISE (TR/T) IN ZONE (10)

    SHORT EDIT
    TOTAL ENERGY RADIATED TO THE WALL(J).............  3.4+009
    ENERGY RADIATED TO THE WALL ON THIS TIME STEP.     2.8+007
    PRESSURE AT THE WALL(J/CM3)......................  6.4+001
    HEAT FLUX AT THE WALL(J/CM2-S)...................  3.2+009


                       1         3         5         7         9        10
    RADIUS     1.0+001 3.0+001 5.0+001 7.0+001 9.0+001 1.0+002
    VELOCITY   1.2-003 4.9-005-4.1-005 8.8-005-2.7-004 0.0-001
     I TEMP    2.6+001 2.6+001 2.6+001 2.6+001 2.6+001 2.6+001
     R TEMP    2.6+001 2.6+001 2.6+001 2.6+001 2.6+001 2.6+001
     P  MFP    6.5+000 6.5+000 6.6+000 6.5+000 6.3+000 6.1+000
     R  MFP    7.6+001 7.7+001 7.7+001 7.6+001 7.3+001 7.2+001

   ENERGY CONSERVATION

          INT ENE + KIN ENE = RHS =        INT ENE D-T BDFLUX +T SOURCE+-T I->R EX
     R     2.7+007
     I     1.1+009      7.0-006     2.7+007   3.6+008   3.4+009   0.0-001   -3.0+009
     T     1.1+009                  2.5+008   3.3+009   3.3+003   0.0-001    3.0+009
                                    2.7+008
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   CYCLE          TIME(S)        DELTA T(S)      CRITERION(TR/T) IN ZONE ( 1) OTHERWISE (TR/T) IN ZONE ( 1)
      150         1.1459-006     9.5858-010

 #  RADIUS         ZONE WIDTH     MASS DENS      COMPRESSION    VELOCITY       R TEMP         ION TEMP       R PRESS        ION PRESS      ART VISC
    (CM)           (CM)           (G/CM3)        (VO/V)         (CM/S)         (EV)           (EV)           (J/CM3)        (J/CM3)        (J/CM3)

 0  0.0000-001                                                  0.0000-001
 1  1.0000+001     1.0000+001     1.1091-004     1.0000+000     1.1836-003     2.2890+001     2.2864+001     1.2537+000     5.4363+001     0.0000-001
 2  2.0000+001     1.0000+001     1.1091-004     1.0000+000     6.5554-004     2.2989+001     2.2971+001     1.2757+000     5.4642+001     0.0000-001
 3  3.0000+001     1.0000+001     1.1091-004     1.0000+000     8.8677-005     2.3167+001     2.3162+001     1.3155+000     5.5144+001     7.1256-011
 4  4.0000+001     1.0000+001     1.1091-004     1.0000+000    -1.8751-005     2.3267+001     2.3274+001     1.3383+000     5.5437+001     2.5591-012
 5  5.0000+001     1.0000+001     1.1091-004     1.0000+000    -1.4453-005     2.3227+001     2.3233+001     1.3292+000     5.5330+001     4.0945-015
 6  6.0000+001     1.0000+001     1.1091-004     1.0000+000     9.9266-005     2.3157+001     2.3163+001     1.3133+000     5.5145+001     0.0000-001
 7  7.0000+001     1.0000+001     1.1091-004     1.0000+000     1.2740-004     2.3072+001     2.3077+001     1.2941+000     5.4920+001     0.0000-001
 8  8.0000+001     1.0000+001     1.1091-004     1.0000+000     1.0883-004     2.2965+001     2.2969+001     1.2703+000     5.4637+001     0.0000-001
 9  9.0000+001     1.0000+001     1.1091-004     1.0000+000    -2.1623-004     2.2843+001     2.2845+001     1.2435+000     5.4312+001     2.3430-011
10  1.0000+002     1.0000+001     1.1091-004     1.0000+000     0.0000-001     2.2726+001     2.2727+001     1.2183+000     5.4003+001     0.0000-001
                                                                               2.5000-002     2.5000-002


 #  R ENERGY       ION ENERGY     KIN ENERGY     R SOURCE       ION SOURCE     ION->R EX      FLUX LIM       HEAT FLUX
    (J/     )      (J/     )      (J/     )      (J/     )      (J/     )      (J/     )      (J/CM2-S)      (J/CM2-S)
 0                                0.0000-001
 1  1.5791+004     9.7634+005     1.3015-006     0.0000-001     0.0000-001    -3.5952+003     2.7888+010    -2.3663+009
 2  1.1248+005     6.8512+006     1.2977-006     0.0000-001     0.0000-001    -1.9216+004     2.8917+010    -4.3289+009
 3  3.1482+005     1.8678+007     5.1145-008     0.0000-001     0.0000-001    -9.7303+003     3.0051+010    -3.0351+009
 4  6.2372+005     3.6466+007     4.0017-009     0.0000-001     0.0000-001     6.0043+004     3.0290+010     1.1062+009
 5  1.0213+006     6.0063+007     3.6879-009     0.0000-001     0.0000-001     4.3399+004     2.9940+010     1.4422+009
 6  1.5054+006     8.9459+007     2.4949-007     0.0000-001     0.0000-001     4.9148+004     2.9533+010     1.6315+009
 7  2.0701+006     1.2460+008     5.5799-007     0.0000-001     0.0000-001     7.4677+004     2.9035+010     2.0628+009
 8  2.7041+006     1.6540+008     5.3094-007     0.0000-001     0.0000-001     8.5435+009     2.8424+010     2.3544+009
 9  3.3989+006     2.1177+008     2.6500-006     0.0000-001     0.0000-001     5.7285+004     2.7799+010     2.1596+009
10  4.1587+006     2.6375+008     0.0000-001     0.0000-001     0.0000-001     3.6849+004     1.7259+009     1.7122+009

                                  ENERGY CONSERVATION CHECK -- UNITS ARE (J/     )

    INT ENE        T KE           INT ENE(O)     T BDFLUX       T I->R EX      T SOURCE       BDFLUX         I->R EX        SOURCE

 R  1.5925+007                    3.5954+008     3.4896+009     3.1460+009     0.0000-001     4.1225+005     3.7429+005     0.0000-001
 I  9.7801+008     6.6464-006     3.2914+009     3.4463+003                    0.0000-001     7.2024-001                    0.0000-001

                                  RADIATION           1.5925+007      1.5925+007
                                  ION                 9.7801+008      1.4547+008
                                  TOTAL               9.9394+008      1.6139+008

 #  E DENSITY      ION DENSITY    CHARGE         ROSS MFP       RAD MFP        EQM T MFP
    (1/CM3)        (1/CM3)        (ESU)          (CM)           (CM)           (CM)

 1  1.3161+019     1.6700+018     7.8872+000     5.8940+001     3.8027+000     3.8116+000
 2  1.3171+019     1.6700+018     7.8914+000     5.9002+001     3.8612+000     3.8678+000
 3  1.3190+019     1.6700+018     7.8990+000     5.9114+001     3.9702+000     3.9717+000
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  4  1.3203+019  1.6700+018  7.9033+000  5.9181+001  4.0364+000  4.0338+000
  5  1.3198+019  1.6700+013  7.9017+000  5.9158+001  4.0132+000  4.0110+000
  6  1.3193+019  1.6700+018  7.8990+000  5.9119+001  3.9737+000  3.9718+000
  7  1.3187+019  1.6700+018  7.8956+000  5.9071+001  3.9266+000  3.9248+000
  8  1.3180+019  1.6700+018  7.8913+000  5.9011+001  3.8680+000  3.8667+000
  9  1.3171+019  1.6700+018  7.8864+000  5.8942+001  3.8020+000  3.8014+000
 10  1.3163+019  1.6700+018  7.8817+000  5.8876+001  3.7409+000  3.7407+000

SHORT EDIT
TOTAL ENERGY RADIATED TO THE WALL(J)...........  3.5+009
ENERGY RADIATED TO THE WALL ON THIS TIME STEP.  4.1+005
PRESSURE AT THE WALL(J/CM3)...................  5.5+001
HEAT FLUX AT THE WALL(J/CM2-S)................  1.7+009


                 1       3       5       7       9      10
 RADIUS   1.0+001 3.0+001 5.0+001 7.0+001 9.0+001 1.0+002
VELOCITY  1.2-003 6.9-005-1.4-005 1.3-004-2.2-004 0.0-001
 I TEMP   2.3+001 2.3+001 2.3+001 2.3+001 2.3+001 2.3+001
 R TEMP   2.3+001 2.3+001 2.3+001 2.3+001 2.3+001 2.3+001
 P  MFP   3.8+000 4.0+000 4.0+000 3.9+000 3.8+000 3.7+000
 R  MFP   5.9+001 5.9+001 5.9+001 5.9+001 5.9+001 5.9+001

ENERGY CONSERVATION

       INT ENE + KIN ENE = RHS =     INT ENE 0-T BDFLUX +T SOURCE+-T I->R EX

   R     1.6+007               1.6+007   3.6+008   3.5+009   0.0-001  -3.1+009
   I     9.8+008   6.6-006     1.5+008   3.3+009   3.4+003   0.0-001   3.1+009
   T     9.9+008               1.6+008
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      CYCLE        TIME(S)      DELTA T(S)      CRITERION(TR/T) IN ZONE ( 6) OTHERWISE (TR/T) IN ZONE ( 6)
         160      1.3088-006   5.5276-008


  SHORT EDIT
  TOTAL ENERGY RADIATED TO THE WALL(J)..........   3.5+009
  ENERGY RADIATED TO THE WALL ON THIS TIME STEP.   1.7+007
  PRESSURE AT THE WALL(J/CM3)...................   4.9+001
  HEAT FLUX AT THE WALL(J/CM2-S)................   1.4+009


                   1       3       5       7       9      10
   RADIUS  1.0+001 3.0+001 5.0+001 7.0+001 9.0+001 1.0+002
  VELOCITY 1.2-003 1.1-004 1.5-005 1.5-004-1.9-004 0.0-001
   I TEMP  2.1+001 2.0+001 2.0+001 2.1+001 2.1+001 2.0+001
   R TEMP  2.1+001 2.1+001 2.1+001 2.1+001 2.1+001 2.1+001
   P  MFP  2.8+000 2.4+000 2.6+000 2.9+000 2.7+000 2.7+000
   R  MFP  5.8+001 5.7+001 5.7+001 5.8+001 5.8+001 5.7+001


  ENERGY CONSERVATION

       INT ENE + KIN ENE = RHS =      INT ENE D-T BDFLUX +T SOURCE+-T I->R EX

    R    1.1+007            1.1+007   3.6+008   3.5+009   0.0-001   -3.2+009
    I    9.3+008   6.5-006  9.3+007   3.3+009   3.6+003   0.0-001    3.2+009
    T    9.4+008            1.0+008
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      CYCLE         TIME(S)        DELTA T(S)       CRITERION(TR/T) IN ZONE ( 2) OTHERWISE (TR/T) IN ZONE ( 2)
          170       1.3627-006    7.0669-011


SHORT EDIT
TOTAL ENERGY RADIATED TO THE WALL(J)............  3.6+009
ENERGY RADIATED TO THE WALL ON THIS TIME STEP.  1.8+004
PRESSURE AT THE WALL(J/CM3)....................  4.7+001
HEAT FLUX AT THE WALL(J/CM2-S)..................  9.9+008


                  1       3       5       7       9      10
 RADIUS   1.0+001 3.0+001 5.0+001 7.0+001 9.0+001 1.0+002
VELOCITY 1.1-003 6.9-005-3.0-005 1.6-004-1.7-004 0.0-001
 I TEMP   2.2+001 1.5+001 1.7+001 2.1+001 2.0+001 2.0+001
 R TEMP   2.2+001 1.6+001 1.7+001 2.1+001 2.0+001 2.0+001
 P  MFP   3.0+000 1.1+000 1.9+000 2.9+000 2.6+000 2.6+000
 R  MFP   5.8+001 4.6+001 5.6+001 5.8+001 5.7+001 5.7+001


ENERGY CONSERVATION

      INT ENE + KIN ENE = RHS =      INT ENE 0-T BDFLUX +T SOURCE+-T I->R EX

   R     9.1+006                9.1+006   3.6+008    3.6+009    0.0-001   -3.2+009
   I     9.1+008    6.9-006     8.1+007   3.3+009    3.6+003    0.0-001    3.2+009
   T     9.1+008                9.0+007
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```
      CYCLE        TIME(S)       DELTA T(S)       CRITERION(TR/T) IN ZONE ( 2) OTHERWISE (TR/T) IN ZONE ( 2)
          180      1.3746-006    3.9869-009

  SHORT EDIT
  TOTAL ENERGY RADIATED TO THE WALL(J)..........  3.6+009
  ENERGY RADIATED TO THE WALL ON THIS TIME STEP.  9.8+005
  PRESSURE AT THE WALL(J/CM3)...................  4.7+001
  HEAT FLUX AT THE WALL(J/CM2-S)................  9.8+008

                   1       3       5       7       9       10
   RADIUS   1.0+001 3.0+001 5.0+001 7.0+001 9.0+001 1.0+002
  VELOCITY  1.1-003-2.0-005-7.5-005 1.7-004-1.7-004 0.0-001
   I TEMP   2.1+001 1.7+001 1.9+001 2.0+001 2.0+001 2.0+001
   R TEMP   2.1+001 1.7+001 1.9+001 2.0+001 2.0+001 2.0+001
   P  MFP   2.9+000 1.9+000 2.5+000 2.6+000 2.6+000 2.6+000
   R  MFP   5.8+001 5.5+001 5.7+001 5.7+001 5.7+001 5.7+001

  ENERGY CONSERVATION

       INT ENE + KIN ENE = RHS =      INT ENE O-T BDFLUX +T SOURCE+-T I+>R EX

    R     8.8+006             8.8+006   3.6+008   3.6+009   0.0-001  -3.2+009
    I     9.0+008   7.8-006   7.8+007   3.3+009   3.6+003   0.0-001   3.2+009
    T     9.1+008             8.7+007
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      CYCLE        TIME(S)       DELTA T(S)       CRITERION(TR/T) IN ZONE ( 2) OTHERWISE (TR/T) IN ZONE ( 2)
         190       1.4121-006    5.9842-010


SHORT EDIT
TOTAL ENERGY RADIATED TO THE WALL(J)...........  3.6+009
ENERGY RADIATED TO THE WALL ON THIS TIME STEP.  1.3+005
PRESSURE AT THE WALL(J/CM3)...................  4.6+001
HEAT FLUX AT THE WALL(J/CM2-S)................  8.9+008


                 1       3       5       7       9       10
 RADIUS   1.0+001 3.0+001 5.0+001 7.0+001 9.0+001 1.0+002
VELOCITY 1.1-003-8.2-005-8.8-005 1.7-004-1.6-004 0.0-001
 I TEMP   2.0+001 1.9+001 1.9+001 1.9+001 1.9+001 1.9+001
 R TEMP   2.0+001 1.9+001 2.0+001 1.9+001 1.9+001 1.9+001
 P   MFP  2.6+000 2.6+000 2.5+000 2.5+000 2.5+000 2.5+000
 R   MFP  5.7+001 5.7+001 5.7+001 5.7+001 5.7+001 5.7+001


ENERGY CONSERVATION

      INT ENE + KIN ENE = RHS =      INT ENE 0-T BDFLUX +T SOURCE+-T I->R EX

   R    8.1+006              8.1+006   3.6+008   3.6+009   0.0-001  -3.2+009
   I    8.9+008    8.2-006   7.0+007   3.3+009   3.6+003   0.0-001   3.2+009
   T    9.0+008              7.8+007
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     CYCLE        TIME(S)       DELTA T(S)      CRITERION(TR/T) IN ZONE ( 2) OTHERWISE (TR/T) IN ZONE ( 2)
        200       1.4648-006    5.2440-009

 #   RADIUS       ZONE WIDTH   MASS DENS    COMPRESSION VELOCITY     R TEMP       ION TEMP     R PRESS      ION PRESS    ART VISC
     (CM)         (CM)         (G/CM3)      (VO/V)       (CM/S)      (EV)         (EV)         (J/CM3)      (J/CM3)      (J/CM3)

 0   0.0000-001                                          0.0000-001
 1   1.0000+001   1.0000+001   1.1091-004   1.0000+000   1.0644-003  1.8888+001   2.2718+001   5.8128-001   5.3979+001   0.0000-001
 2   2.0000+001   1.0000+001   1.1091-004   1.0000+000   1.0114-003  1.9876+001   1.6551+001   7.1280-001   3.7713+001   0.0000-001
 3   3.0000+001   1.0000+001   1.1091-004   1.0000+000  -1.0027-004  1.8241+001   2.1072+001   5.0559-001   4.9665+001   2.7406-010
 4   4.0000+001   1.0000+001   1.1091-004   1.0000+000   6.0997-005  1.9138+001   1.8724+001   6.1265-001   4.3621+001   0.0000-001
 5   5.0000+001   1.0000+001   1.1091-004   1.0000+000  -7.7191-005  1.9280+001   1.8619+001   6.3099-001   4.3352+001   4.2342-012
 6   6.0000+001   1.0000+001   1.1091-004   1.0000+000   1.4719-004  1.9004+001   1.9375+001   5.9570-001   4.5296+001   0.0000-001
 7   7.0000+001   1.0000+001   1.1091-004   1.0000+000   1.7734-004  1.8997+001   1.9037+001   5.9485-001   4.4426+001   0.0000-001
 8   8.0000+001   1.0000+001   1.1091-004   1.0000+000   1.5840-004  1.8983+001   1.8920+001   5.9307-001   4.4125+001   0.0000-001
 9   9.0000+001   1.0000+001   1.1091-004   1.0000+000  -1.5221-004  1.8905+001   1.8922+001   5.8332-001   4.4130+001   2.1394-011
10   1.0000+002   1.0000+001   1.1091-004   1.0000+000   0.0000-001  1.8826+001   1.8834+001   5.7365-001   4.3905+001   0.0000-001
                                                                     2.5000-002   2.5000-002

 #   R ENERGY     ION ENERGY   KIN ENERGY   R SOURCE     ION SOURCE   ION->R EX    FLUX LIM     HEAT FLUX
     (J/     )    (J/     )    (J/     )    (J/     )    (J/     )    (J/     )    (J/CM2-S)    (J/CM2-S)
 0                             0.0000-001
 1   7.3218+003   9.7303+005   1.0926-006   0.0000-001   0.0000-001  -1.2451+005   1.3998+010   1.2930+009
 2   6.2850+004   5.6551+006   3.0892-006   0.0000-001   0.0000-001   7.6414+005   1.3955+010  -2.7568+009
 3   1.2100+005   1.7766+007   6.5390-008   0.0000-001   0.0000-001  -1.5390+006   1.4322+010   1.4530+009
 4   2.8553+005   3.2500+007   4.2342-008   0.0000-001   0.0000-001   5.6936+005   1.4053+010   6.6646+008
 5   4.8483+005   5.3423+007   1.0519-007   0.0000-001   0.0000-001   1.2880+006   1.3936+010  -1.7775+008
 6   6.8281+005   6.1393+007   5.4850-007   0.0000-001   0.0000-001  -9.6310+005   1.3893+010   5.1212+008
 7   9.5157+005   1.1254+008   1.0811-006   0.0000-001   0.0000-001   3.3659+004   1.3740+010   6.5784+008
 8   1.2625+006   1.4927+008   1.1248-006   0.0000-001   0.0000-001   5.3036+005   1.3556+010   6.5649+008
 9   1.5944+006   1.9168+008   1.3131-006   0.0000-001   0.0000-001   1.1967+005   1.3356+010   7.7018+008
10   1.9582+006   2.3879+008   0.0000-001   0.0000-001   0.0000-001   2.4188+005   5.2748+008   8.2067+008

                               ENERGY CONSERVATION CHECK -- UNITS ARE (J/     )

     INT ENE      T KE         INT ENE(0)   T BDFLUX     T I->R EX    T SOURCE     BDFLUX       I->R EX      SOURCE

R    7.4110+006                3.5954+008   3.5840+009   3.2319+009   0.0000-001   1.0625+006   9.2043+005   0.0000-001
I    8.8398+008   6.4624-006   3.2914+009   3.6265+003                0.0000-001   2.1972+000                0.0000-001

                               RADIATION       7.4110+006     7.4110+006
                               ION             8.8398+008     5.9526+007
                               TOTAL           8.9139+008     6.6937+007

 #   E DENSITY    ION DENSITY  CHARGE       ROSS MFP     RAD MFP      EGM T MFP
     (1/CM3)      (1/CM3)      (ESU)        (CM)         (CM)         (CM)

 1   1.2799+019   1.6700+018   7.8814+000   6.0915+001   5.5451+000   3.7361+000
 2   1.3059+019   1.6700+018   7.5172+000   5.2335+001   9.7731-001   1.7056+000
 3   1.2804+019   1.6700+018   7.8135+000   5.9620+001   4.2581+000   3.0171+000
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 4   1.2921+[illegible]     1.6700+018  7.7080+000  5.6497+001   2.1891+000  2.3264+000
 5   1.2932+[illegible]     1.6700+018  7.7031+000  5.6291+001   2.0892+000  2.3032+000
 6   1.2890+[illegible]     1.6700+018  7.7384+000  5.7311+001   2.6161+000  2.4846+000
 7   1.2898+[illegible]     1.6700+018  7.7228+000  5.6937+001   2.4132+000  2.3995+000
 8   1.2898+[illegible]     1.6700+018  7.7173+000  5.6814+001   2.3501+000  2.3716+000
 9   1.2890+[illegible]     1.6700+018  7.7174+000  5.6865+001   2.3781+000  2.3721+000
10   1.2884+[illegible]     1.6700+018  7.7133+000  5.6815+001   2.3546+000  2.3516+000


SHORT EDIT
TOTAL ENERGY RADIATED TO THE WALL(J)..........  3.6+009
ENERGY RADIATED TO THE WALL ON THIS TIME STEP.  1.1+006
PRESSURE AT THE WALL(J/CM3)...................  4.4+001
HEAT FLUX AT THE WALL(J/CM2-S)................  8.2+008


                   1       3       5       7       9      10
 RADIUS   1.[illegible] 3.0+001 5.0+001 7.0+001 9.0+001 1.0+002
VELOCITY  1.[illegible]3-1.0-004-7.7-005 1.8-004-1.5-004 0.0-001
 I TEMP   2.3[illegible]1 2.1+001 1.9+001 1.9+001 1.9+001 1.9+001
 R TEMP   1.[illegible]1 1.8+001 1.9+001 1.9+001 1.9+001 1.9+001
 P  MFP   5.5[illegible]0 4.3+000 2.1+000 2.4+000 2.4+000 2.4+000
 R  MFP   6.[illegible]1 6.0+001 5.6+001 5.7+001 5.7+001 5.7+001


ENERGY CONSERVATION

      INT ENE + KIN ENE = RHS =     INT ENE 0-T BDFLUX +T SOURCE+-T I->R EX

  R    7.4+[illegible]6               7.4+006   3.6+008   3.6+009   0.0-001  -3.2+009
  I    8.8+[illegible]8   8.5-006     6.0+007   3.3+009   3.6+003   0.0-001   3.2+009
  T    8.9+[illegible]8               6.7+007


MAX OVER-PRESSURE=  1.6129+002 (J/CM3)  TIME=  1.0000-012 (S)   CYCLE=   1


MAX HEAT FLUX=  8.0568+010 (J/CM2*S)   TIME=  1.0000-012 (S)   CYCLE=   1


PRESSURE AND HEAT FLUX AT THE FIRST WALL


TIME(S)
  1.8000-10   2.7079-07   3.5758-07   4.4245-07   6.9056-07   7.5843-07   9.4601-07   1.3088-06   1.3746-06   1.4648-06
  0.0000

PRESSURE(J/CM3)
  1.6126+02   7.3378+01   1.1439+02   1.0453+02   7.7562+01   7.2522+01   6.1802+01   4.8171+01   4.6289+01   4.3905+01
  0.0000

HEAT FLUX(J/CM2*S)
  8.0219+10   3.1694+10   3.7298+10   2.9163+10   1.2004+10   9.5992+09   5.8176+09   2.4290+09   1.9615+09   1.6124+09
  0.0000
@FIN
    RUNID:  X04326   PROJECT: 12902            USER; 3745022495
```

```
13:31:27    X04326 FIN

  ITEM                                   AMOUNT       COST

CPU TIME                           00:00:08.742         $0.49
FILE I/O REQUESTS                           276         $0.08
FILE I/O WORDS                           157322         $0.02
MEMORY USAGE                              0.170         $0.14
CARDS IN                                      8         $0.00
PAGES PRINTED                                28         $1.26
SOFTWARE SUPPORT                              9         $0.20
JOB CHARGE                                    1         $0.03

TOTAL COST                                              $2.22

    THE ABOVE DOLLAR AMOUNTS ARE APPROXIMATE AND ARE BASED ON RATES FOR STANDARD RUNS
PROJ BALANCE                                           $69.70

    INITIATION  TIME:   13:31:05 JAN  7,1980

    TERMINATION TIME:   13:31:27 JAN  7,1980

   PREVIOUS RUN TIME:   13:31:21 JAN  7,1980

123456789012    29 PAGES COST     $1.30   PROJ BALANCE     $69.66    X04326   901234567890123456789012345678901234567890••SEQ NO. 07
123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890••SEQ NO. 07
123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890••SEQ NO. 07
123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890••SEQ NO. 07
```

Table XI-1

Input Variables

Variable	Type	Default Value	Description
JMAX	(I)	--	Number of spatial zones $3 \leq$ JMAX ≤ 50
NMAX	(I)	--	Maximum number of time steps
TMAX	(R)	--	Maximum problem time (s)
IO	(IV)	--	Output frequencies IO(1) -- hydrodynamics IO(2) -- energy IO(3) -- mfp's and # densities IO(4) -- short edit IO(11) same as IO(1)-(4) except IO(12) after time TEDIT IO(13) (see TEDIT description) IO(14)
DR2B	(RV)	--	Δr of each zone (cm)
DN2B	(RV)	--	Ion number density (cm^{-3})
TN2C	(RV)	--	Plasma temperature (eV)
TR2C	(RV)	--	Radiation temperature (eV)
ATW2B	(RV)	--	Atomic weight (amu)

Table XI-2

Optional Input Variables

Variable	Type	Default Value	Description
IDELTA	I	3	Geometry = 1 planar = 2 cylindrical = 3 spherical
DTB	R	10^{-12}	Initial time step (s)
DTMIN	R	10^{-1}*DTB	Minimum time step (s)
DTMAX	R	10^{-2}*TMAX	Maximum time step (s)
TSCC	R	5×10^{-2}	Time Step Controls - Courant
TSCV	R	"	$\Delta V/V$
TSCTR	R	"	$\Delta T_R/T_R$
TSCTN	R	"	$\Delta T_p/T_p$
TEDIT	R	0	If TEDIT $\neq$ 0 then before time TEDIT IO(1) - (4) are used and after IEDIT IO(11) - (14) are used as output frequencies.
IOBIN	I	-1	Binary output frequency written to unit 8 for postprocessing.
TGROW	(R)	1.5	Time step is allowed to increase no more than TGROW * DTB on each successive cycle.
TBC	(R)	2.5×10^{-2}	Temperature boundary condition (eV).
VBC	(R)	0.1	Specific volume boundary condition (cm^3/g).
U1B	(RV)	0	Initial velocity (cm/s).
IRS	(I)	0	Restart calculation flag = 0 Normal calculation = 1 Restarted calculation.

Table XI-2 (cont.)

Variable	Type	Default Value	Description
ISW	(IV)	--	See Table XI-3 for definitions of these switches.
CON	(IV)	--	See Table XI-4 for the definitions of these numerical coefficients.
IEDIT	(IV)	-1	See Table XI-5 for the definitions of these intermediate output frequencies.
ROSS2B	(RV)	--	Rosseland mean free path must be inputted if ISW(12)=1 or ISW(15)=1.
RMFP2B	(RV)	--	Planck mean free path must be inputted if ISW(12)=1 or ISW(14)=1.
RMFT2B	(RV)	--	Planck mean free path for $T_R = T_p$ must be inputted if ISW(12)=1 or ISW(14)=1.

Table XI-3

Control Switches

ISW	Description
1	= 0 Nonlinear coefficients are evaluated using a temperature extrapolation to $T^{n+1/2}$ = 1* Nonlinear coefficients are evaluated using T^n
2	= 10* Number of constant time steps used at the beginning of a calculation
3	Not used
4	Not used
5	= 20* Frequency of tabulation of overpressure and heat flux at the first wall
6	= 0* Hydrodynamic motion is computed = 1 No hydro motion - allows a pure temperature diffusion problem
7	= 0* No energy input = 1 Energy is added to the system using subroutine ARBENE
8	Not used
9	Not used
10	= 1* Frequency of time step calculation
11	Not used
12	= 0* Equation of state tables are read from unit 3 = 1 Ideal gas equation of state is used RMFP2B, RMFT2B, and ROSS2B must be inputted via NAMELIST
13	Not used

Table XI-3 (cont.)

ISW	Description
14	= 0* Planck mean free path is computed from tables = 1 Planck mean free path is computed as a constant
15	= 0* Rosseland mean free path is computed from tables = 1 Rosseland mean free path is inputted as a constant
16	Not used
17	Not used
18	Not used
19	= 0* Normal calculation = 1 If TR < CON(29) then ROSS2B and RMFT2B cannot be less than CON(31)

*Denotes the default value.

Table XI-4

Real Constants Used in FIRE

CON	Default	Description
1	1.2175×10^2	Plasma thermal conductivity
2	1×10^{10}	Radiation thermal conductivity
3	1.03×10^5	Radiation flux limit
4	1×10^{-6}	Small term to avoid zero divide in flux limited radiation conduction term AA221B
5	0	If non-zero then it is used as a constant value of log Λ. Normally log Λ is computed.
6		Not used
7	4.12×10^5	Plasma emission term (radiation)
8	3×10^{10}	Plasma absorption term (radiation)
9	1.602×10^{-19}	Plasma pressure
10	4.567×10^{-6}	Radiation pressure
11		Not used
12	1.602×10^{-19}	Plasma pressure derivative
13		Not used
14	2.403×10^{-19}	Plasma specific heat
15	2.403×10^{-19}	Plasma specific internal energy
16	4.5778×10^{-6}	Radiation specific internal energy
17		Not used
18	1.0	Ion shock heating term
19		Not used
20		Not used

Table XI-4 (cont.)

CON	Default	Description
21	1.414	Artificial viscosity
22		Not used
23		Not used
24		Not used
25		Not used
26		Not used
27		Not used
28	1.0	If the ratio of radiation energy entering a zone by diffusion to the energy initially in the zone is greater than CON(28) then the radiation temperature of the zone from whence the radiation comes is used to compute the mean free paths in this zone (up-stream averaging).
29	1.5	If ISW(19) = 1 then the radiation mean free paths in zones with TR < CON(29) can be no greater than CON (31).
30		Not used
31	1.0	See CON(29)

Table XI-5

Description of the Intermediate Output Switches in IEDIT

IEDIT	Subroutine	Variables
1	ABCDEF	A11, A22, B11, B12, B21, B22, C11, C22, D1, D2, E11, E12, E21, E22, F1, F2
2	MATRIX	AL112B, AL222B
3	MATRIX	OM112B, OM122B, OM212B, OM222B
4	MATRIX	GM112B, GM222B
5	MATRIX	AA111B, AA221B
6	MATRIX	BET12B, BET22B
7		Not used
8	TXTRAP	TR2B, TN2B
9		Not used
10	OMEGA	OMR2B, OMP2B
11	KAPPA	KARM1B, KARP1B, KANM1B, KANP1B, LAMN2B, FLIM1B
12		Not used
13		Not used
14	HYDRO	U1B, R1A, R1B, DR2A, DR2B, RS1A, RS1B, V2A, V2B, VDOT2B
15	QUE	Q2B
16	TEMPBC	T(1) → T1(9), TR2A (JMAXP1), TN2A (JMAXP1)
17		
18		
19	NUMDEN	DN2B, DE2B, DN2A, DE2A
20		
21		

Table XI-6

Input-Output Units

Unit #	Function
2	FIRE write all COMMON blocks to this unit at the end of a calculation to allow a restart
3	FIRE reads equation of state tables from this unit
4	FIRE reads the COMMON blocks from this unit at the beginning of a restarted calculation
5	FIRE reads NAMELIST input from this unit
6	FIRE write lineprinter output to this unit
8	FIRE writes binary output to this unit for postprocessing into plots.

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