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IMPROVEMENTS IN THE CHART D RADIATION-HYDRODYNAMIC CODE II: A REVISED PROGRAM

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ABSTRACT

CHART D is a very flexible code for computing coupled hydrodynamic motion and radiation diffusion. The finite difference analogs of the Lagrangian equations of motion with energy transport terms are solved in one-dimensional rectangular, cylindrical, or spherical coordinates. Elastic-plastic, porous, and high-explosive materials are treated. Thermal and electron conduction, spall, and rejoin calculations are provided. Realistic equations of state and means for coupling to externally generated energy deposition profiles are included. Complete input instructions and details of code models and structure are given.

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IMPROVEMENTS IN THE CHART D RADIATION-HYDRODYNAMIC CODE II: A REVISED PROGRAM

I. INTRODUCTION

CHART D is a FORTRAN code for computing hydrodynamic motion when coupled to energy transport. One-dimensional geometry with either plane, cylindrical, or spherical symmetry is available. Somewhat conventional Lagrangian finite difference methods are employed, but the program contains many features not found in other production codes. One outstanding characteristic is the equation-of-state calculations.

The main formulation for energy movement within material is based on the radiation diffusion approximation. However, any transport phenomenon which is determined by the temperature gradient can easily be treated. Provisions are included for both phonon and hot electron conduction.

Three previous reports have been issued concerning CHART D and its equations of state.[1-3] Henceforth, these reports are referred to as R1, R2, and R3. Unfortunately, the first two of these are obsolete to the extent that they have little relation to the present code. Many modifications have been made to both the physical content and numerical methods. One indication of this can be noted by comparing the program listings in R1 and in Appendix G of this report. The original version was 3030 cards in length while the current listing is 7338 cards. Furthermore, a large fraction of the 3030 has been replaced.

This report is intended to replace both R1 and R3. The material in nearly every section of R1 has been modified to some extent and several new calculations have been included. Elastic-plastic and porous material computations are now available. Since the porous material computation is like no other existing calculation, it is examined in greater detail than are the other sections. In general, it was felt that more efficient code use could be achieved with a completely revised manual. As a result, some sections of the current paper are similar to those in R1.

Two additional reports are being issued.[4,5] The first of these is a replacement for R2. A much improved set of analytic equation-of-state subroutines has been developed. Several new features are included and the reliability is greatly improved. As before, the construction is such that the entire package can easily be installed in other hydrodynamic codes. The last of the accompanying reports describes several user aid programs.

Considerable effort has been devoted to insure that a very flexible code was produced. The inputs are designed to accept as large a range of problems as possible without undue complexity.

In some of the models employed, rather arbitrary decisions have been forced by a lack of complete understanding of the physics. Future developments could prove many of these in error. However, it is important that the current coding provide the mechanisms for treatment. More often than not, this requires much more effort than changing the exact details of the model.

The code has been extensively tested but, because of the many available options, some errors might still exist due to interaction of the lesser used features. If such errors are located, corrections will be issued to all known users.

An attempt has been made to keep all sections of this report as independent as possible. However, the material in Section II and the appropriate part of Section III should be studied before proceeding to the others. These detail the basic relations and numerical methods expanded on in the following sections.

The units employed throughout the code are cgs with temperature in electron volts (1 eV $\simeq$ 11605°K). Because of the stored numerical data tables and many physical constants involved, this feature cannot easily be changed. The notation will be as follows except as noted in the text.

ρ = density (gm/cc)

T = temperature (eV)

t = time (sec)

X = position (cm)

V = velocity (cm/sec)

P_m = material pressure (dynes/cm^2)

P_r = radiation pressure (dynes/cm^2)

$P = P_m + P_r$ = total pressure (dynes/cm^2)

Q = artificial viscosity (dynes/cm^2)

E_m = specific material internal energy (ergs/gm)

E_r = radiation energy density (ergs/cc)

F = radiation flux (ergs/cm^2 sec)

S = specific entropy (ergs/gm eV)

$\dot{\mathscr{S}}$ = specific internal energy production rate (ergs/gm sec)

C_s = sound speed (cm/sec)

δ = geometry switch

δ = 1 for plane geometry

δ = 2 for cylindrical geometry

δ = 3 for spherical geometry

M = mass (gm/cm^2, δ = 1; gm/cm, δ = 2; gm, δ = 3)

λ = Rosseland mean free path (cm)

K = Rosseland mean opacity (cm^2/gm)

II. RADIATION-HYDRODYNAMIC CONSERVATION LAWS

The three conservation laws which control nonrelativistic flows of a fluid with energy transport are:

conservation of mass,

$$\frac{\partial \rho}{\partial t} = -\rho \nabla \cdot \vec{V} , \tag{2.1}$$

conservation of momentum,

$$\frac{\partial \vec{V}}{\partial t} = - \frac{1}{\rho} \nabla (P_m + P_r + Q) , \tag{2.2}$$

and

conservation of energy,

$$\frac{\partial}{\partial t} \left\{ E_m + \frac{E_r}{\rho} \right\} = - (P_m + P_r + Q) \frac{\partial}{\partial t} \left(\frac{1}{\rho}\right) - \frac{1}{\rho} \nabla \cdot \vec{F} + \mathscr{S} , \tag{2.3}$$

where the subscript m refers to material and r to radiation field. Except as noted below, all quantities are as defined in Section I. The specific energy production rate $\mathscr{S}$ provides a mechanism for the introduction or removal of energy in a material. For example, this could describe the deposition of energy incurred from an electron beam generator.

The artificial viscosity Q is a convenience first introduced by Von Neumann and Richtmyer for numerical treatment of shock waves. Without this term, the above expressions could not treat shock waves in a continuous manner. Complete details are given in the text of Richtmyer and Morton.[6] The form employed in CHART D is

$$Q = B_\ell C_s \frac{\partial \rho}{\partial t} + B_q^{\ 2} \rho \left\{ \frac{1}{\rho} \frac{\partial \rho}{\partial t} \right\}^2 , \text{ if } \frac{\partial \rho}{\partial t} > 0$$

$$= 0 , \text{ if } \frac{\partial \rho}{\partial t} \leq 0 , \tag{2.4}$$

where B_ℓ and B_q are constants. Modifications required for numerical calculations are given below.

Throughout this paper it is assumed that the material is in a state of local thermodynamic equilibrium (LTE). Under this approximation, E_r and P_r depend only on the local temperature,

$$E_r = \frac{4\sigma T^4}{c} = \frac{4\pi B}{c} \tag{2.5}$$

and

$$P_r = \frac{4\sigma T^4}{3c} = \frac{1}{3} E_r , \tag{2.6}$$

with c the velocity of light, σ the Stefan-Boltzmann constant, and B the blackbody intensity function. These forms are particularly convenient, since the radiation terms may be added to the material terms in the equation-of-state calculation and not considered elsewhere. The notation can be shortened by defining

$$E(\rho, T) = E_m(\rho, T) + E_r(T)/\rho \tag{2.7}$$

and

$$P(\rho, T) = P_m(\rho, T) + P_r(T) . \tag{2.8}$$

Similar relations exist for heat capacities, entropies, etc.

II-1. Energy Transport Relations

The transport term in the energy conservation relation ($\nabla \cdot \vec{F}$) describes the flow of energy within the material. While the form given by (2.3) is quite general, it is assumed in the present work that the flux F can be related to a gradient of the material temperature. In particular, under the radiation diffusion approximation, the flux is given by

$$\vec{F} = -\frac{4}{3}\pi \lambda_r \nabla B = -\frac{4}{3}\sigma \lambda_r \nabla T^4 , \tag{2.9}$$

where λ_r is the Rosseland mean free path. Since (2.9) is an approximation, it can sometimes yield physically unrealistic results. Flux limiters to treat this problem are detailed in Section III.

The Rosseland mean opacity is defined as

$$K_r = \frac{\int_0^\infty \frac{\partial B_\nu}{\partial T} d\nu}{\int_0^\infty \left\{K_a^{\,\nu}\left[1 - \exp(h\nu/kT)\right] + K_s^{\,\nu}\right\}^{-1} \frac{\partial B_\nu}{\partial T} d\nu} , \tag{2.10}$$

where ν is the frequency, K_a^ν is the true absorption coefficient, $K_s^{\,\nu}$ is the true scattering coefficient, and

$$B_\nu = \frac{2h\nu^3}{c^3 \{\exp(h\nu/kT) - 1\}} \tag{2.11}$$

Planck's and Boltzmann's constants are h and k, respectively. It follows that

$$B = \int_0^\infty B_\nu \; d\nu = \frac{\sigma T^4}{\pi} , \tag{2.12}$$

in agreement with (2.5). The Rosseland mean free path is related to K_r by the expression

$$\lambda_r = \frac{1}{\rho K_r} . \tag{2.13}$$

By suitable redefinition of the mean free path in (2.9), other energy transport mechanisms may be included in the same formulation. Consider, for example, normal thermal conduction and hot electron conduction in a plasma, described by the characteristic functions H and L. The total energy flux is given by

$$\begin{aligned} \vec{F}_{tot} &= \vec{F}_{rad} + \vec{F}_H + \vec{F}_L \\ &= -\frac{4}{3}\lambda_r \sigma \nabla T^4 - H\nabla T - L\nabla T . \end{aligned} \tag{2.14}$$

This expression can be rewritten as

$$\vec{F}_{tot} = -\frac{4}{3}\sigma \left\{\lambda_r + \lambda_H + \lambda_L\right\} \nabla T^4 , \tag{2.15}$$

where

$$\lambda_H = \frac{3H}{16\sigma T^3} \equiv \frac{1}{\rho K_H} \tag{2.16}$$

and

$$\lambda_L = \frac{3L}{16\sigma T^3} \equiv \frac{1}{\rho K_L} \quad . \tag{2.17}$$

Then, by defining an effective Rosseland mean as

$$\frac{1}{K_{eff}} = \frac{1}{K_r} + \frac{1}{K_H} + \frac{1}{K_L} = \rho\lambda_{eff} \quad , \tag{2.18}$$

Eq. (2.9) may be used to treat the additional phenomena without greatly changing the mathematical structure of the equations. Unfortunately this method does have some problems with regard to flux limiters as related in Section III.

II-2. Additional Relations

In addition to the above relations, several other functions must be defined. An equation of state (EOS) must be given for each material. In CHART D two types of EOS are available. These are tabular and in-line analytic forms. In both it is assumed that all thermodynamic functions can be calculated when the temperature and density are defined. In the sense employed here, K_{eff}, given by (2.18), is also assumed to be part of the EOS. Complete details of the EOS calculations are presented elsewhere. The computation is so constructed that many of the hydrodynamic and transport calculations are independent of the exact forms of the EOS.

As with any set of differential equations such as the above conservation laws, initial and boundary conditions must be provided to define the problem. The function $\dot{\mathscr{S}}$ is of this type. Several quantities relating to the edges of the material must also be considered. Details of the options available are given in Section VIII and at other points where they are required in the analysis.

II-3. Space-Time Mesh

In order to consider the above relations in finite difference form, it is necessary to define a space-time mesh. In plane geometry the spatial part of the mesh is a set of parallel planes perpendicular to the X axis. Under the Lagrangian formulation, these planes move in space in order to maintain the same position in the moving material. The region between adjacent planes or boundaries is called a zone. In cylindrical geometry these boundaries form concentric cylinders, in spherical geometry, concentric spheres.

The time part of the mesh is defined as follows. The conditions at one time (t_j) are completely known. The finite difference equations are then used to compute the conditions at some slightly later time (t_{j+1}). The procedure is then repeated for the next time (t_{j+2}). The resulting mesh is illustrated in Fig. 2.1. Note in the scheme employed in CHART D that $X_1 > X_2 > \ldots > X_i > \ldots > X_N > X_{N+1}$, where N is the total number of zones in the calculation.

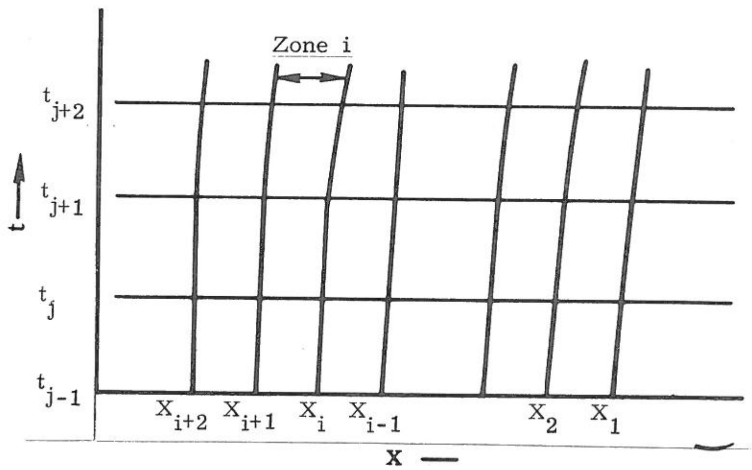

Fig. 2.1 The space-time mesh.

A mesh point is defined as the pair (X_i, t_j). Zone i lies between boundaries X_i and X_{i+1}. Some quantities are calculated at mesh points while others are centered between mesh points. The notation is as follows. A quantity Φ computed at the mesh point (X_i, t_j) is labeled as Φ_i^j. Those centered between mesh points could be $\Phi_i^{j+1/2}$, $\Phi_{i+1/2}^j$, or $\Phi_{i+1/2}^{j+1/2}$.

The main advantage of the Lagrangian form of the equations of motion is that of automatic mass conservation and knowing exactly what material is contained in a given zone. As the boundaries move with the material, the same material is always in the zone. Hence mass and order are conserved. The mass of zone i will be denoted by M_i. The appropriate EOS is known by the index i. Further details are given in Section VIII.

II-4. Difference Equations

The logic of proper centering of the difference equations is discussed in detail elsewhere and will not be repeated here.[6,7] Only the forms employed are given in their order of use. Define

$$\Delta t = t_{j+1} - t_j \,,$$

$$\Delta t'' = t_j - t_{j-1} \,, \tag{2.19}$$

$$\Delta t' = \frac{1}{2} (\Delta t + \Delta t'') \,.$$

The computation of the time step Δt is given below.

The acceleration at each normal interior boundary is first computed by

$$a_i^j = 2A_i \left\{ P_{i+1/2}^j + Q_{i+1/2}^{j-1/2} - P_{i-1/2}^j - Q_{i-1/2}^{j-1/2} \right\} \Big/ (M_i + M_{i-1}) \ , \tag{2.20}$$

where the A_i are geometry factors given by

$$\begin{aligned} A_i &= 1 \ , \quad \delta = 1 \ , \\ &= 2\pi X_i \ , \quad \delta = 2 \ , \\ &= 4\pi X_i^2 \ , \quad \delta = 3 \ . \end{aligned} \tag{2.21}$$

In the case where there is no material adjacent to boundary i on the right (either the edge of the problem or spall), Eq. (2.20) is replaced by

$$a_i^j = 2A_i \left\{ P_{i+1/2}^j + Q_{i+1/2}^{j-1/2} - P_i^j \right\} \Big/ M_i \ . \tag{2.22}$$

Alternately, if there is no material on the left,

$$a_i^j = 2A_i \left\{ P_i^j - P_{i-1/2}^j - Q_{i-1/2}^{j-1/2} \right\} \Big/ M_{i-1} \ . \tag{2.23}$$

The new velocities and positions are then determined by

$$V_i^{j+1/2} = V_i^{j-1/2} + a_i^j \, \Delta t' \tag{2.24}$$

and

$$X_i^{j+1} = X_i^j + V_i^{j+1/2} \, \Delta t \ . \tag{2.25}$$

Note that X in (2.25) is the space fixed Eulerian coordinate and not the Lagrangian coordinate. Since the zone mass is constant, the new density is

$$\rho_i^{j+1} = M_i \Big/ G_i \left[(X_i^{j+1})^\delta - (X_{i+1}^{j+1})^\delta \right] \ , \tag{2.26}$$

where G_i is also a geometry factor given by

$$\begin{aligned} G_i &= 1 \ , \quad \delta = 1 \ , \\ &= \pi \ , \quad \delta = 2 \ , \\ &= \frac{4}{3}\pi \ , \quad \delta = 3 \ . \end{aligned} \tag{2.27}$$

Eq. (2.26) is subject to excessive roundoff error when $\delta = 2$ or 3. This problem is resolved by factoring the difference term on the right-hand side.

The new viscosities are

$$Q_i^{j+1/2} = \frac{1}{2}\left\{\rho_i^j + \rho_i^{j+1}\right\} \Delta V \left\{B_q^2 \, \Delta V + B_\ell \left[C_s\right]_i^j\right\} ,$$

$$\text{if } \Delta V < 0 \; ; \tag{2.28}$$

$$= 0 \, , \text{ if } \Delta V \geq 0 \, ,$$

where

$$\Delta V = V_i^{j+1/2} - V_{i+1}^{j+1/2} \; . \tag{2.29}$$

This form results from combining (2.1) and (2.4) and scaling B_ℓ and B_q by the zone thickness so that their numerical values are problem-independent.[7]

After review of these expressions it should be clear that all quantities necessary for consecutive use to advance the solution are known except for P_1^j and P_{N+1}^j. They are required in (2.22) and (2.23) at the front and back surfaces. Input values must be supplied as problem boundary conditions to relate the material to its environment. The methods are discussed in Section VIII.

At this point all of the conservation laws except the energy relation have been employed. Most of the physics of the solution is involved in the remaining expression. It should be noted that up to this point the solution has not involved energy transport or the specifics of the material. No reference has yet been made to the EOS. If the EOS is sufficiently simple, it can be substituted into (2.3) or its difference form and solved for the remaining unknown when transport effects are ignored. This normally requires an elementary closed analytic expression. Unfortunately, real materials are seldom so simple. The details of several methods of treatment are found in the next section. Later modifications required for elastic and porous materials are covered.

III. METHODS OF SOLUTION OF THE ENERGY CONSERVATION RELATION

In this section the numerical methods and physical constraints necessary for solution of (2.3) are developed. There are four systems contained in CHART D, three with radiation and one without it. The differences in these calculations and regions of applicability are detailed below.

None of the radiation computations is as related in R1. The method given in the earlier report had been designed to work in the multigroup radiation transport version of CHART D and performed well under conditions where the diffusion approximation was exact. However, convergence difficulties were soon encountered. The following improvements were made before the distribution of R1.

It is necessary to assume that the material is in a state of local thermodynamic equilibrium (LTE) as previously mentioned. This is not only required for the radiation calculation but for the thermodynamics as well. Without LTE, equations of state are meaningless concepts. This EOS is used with (2.3) to complete the advance of the solution to the new time (t_{j+1} as related in Section II). Here, a new set of zone temperatures is determined, and from the EOS all thermodynamic functions are known. The pure hydrodynamic case (ignoring the $\nabla \cdot \vec{F}$ term) is by far the simplest and is considered first to illustrate the properties of the CHART D equations of state.

III-1. Pure Hydrodynamic Solution (No Radiation Terms)

If radiation flow terms are not important, Eq. (2.3) is written as

$$\frac{\partial E}{\partial t} = - (P + Q) \frac{\partial}{\partial t} \left(\frac{1}{\rho}\right) + \dot{\mathscr{S}} . \qquad (3.1)$$

The finite difference form of this expression is

$$E_i^{j+1} - E_i^j = \left\{\frac{1}{2}\left(P_i^{j+1} + P_i^j\right) + Q_i^{j+1/2}\left\{\frac{\rho_i^{j+1} - \rho_i^j}{\rho_i^j \rho_i^{j+1}}\right\} + \dot{\mathscr{S}}_i^{j+1/2} \right\} \Delta t . \qquad (3.2)$$

All quantities at time t_j are known and all have been determined at time t_{j+1} as related in Section II except E_i^{j+1} and P_i^{j+1}.

It is clear that each zone may be considered independently with (3.2), since only zone i quantities are referenced. The index i could be suppressed. However, for consistency with the following material, the i subscript is retained.

The variables E_i^{j+1} and P_i^{j+1} are not independent since they are related by the EOS. As the new density ρ_i^{j+1} is known, the problem is to determine the new zone temperature T_i^{j+1} which will produce energy and pressure values which satisfy (3.2). With definition of the constants

$$\alpha_i = E_i^j + \left\{\frac{1}{2} P_i^j + Q_i^{j+1/2}\left\{\frac{\rho_i^{j+1} - \rho_i^j}{\rho_i^j \rho_i^{j+1}}\right\} + \dot{\mathscr{S}}_i^{j+1/2} \right\} \Delta t \qquad (3.3)$$

and

$$\beta_i = \frac{1}{2}\left\{\frac{\rho_i^{j+1} - \rho_i^j}{\rho_i^j \rho_i^{j+1}}\right\} , \tag{3.4}$$

Eq. (3.2) can be written as

$$E_i^{j+1} = \beta_i P_i^{j+1} + \alpha_i , \tag{3.5}$$

which can easily be solved by a Newton iteration. If T_ℓ is the ℓth iterative value of the temperature, the $(\ell + 1)$ th value is

$$T_{\ell+1} = T_\ell - \frac{E(T_\ell) - \beta_i P(T_\ell) - \alpha_i}{\left(\frac{\partial E}{\partial T}\right)_\rho \Big|_{T_\ell} - \beta_i \left(\frac{\partial P}{\partial T}\right)_\rho \Big|_{T_\ell}} , \tag{3.6}$$

with all functions evaluated at density ρ_i^{j+1}. The derivatives in (3.6) are normally returned from a call to the equation-of-state subroutines. The convergence condition is

$$|T_{\ell+1} - T_\ell| \leq 10^{-6} T_\ell \tag{3.7}$$

and is usually satisfied even in very strong shocks in one or two iterations. The initial guess for the temperature is obtained by a constant entropy projection from the previous zone temperature T_i^j, with corrections for sources and artificial viscosity as given in R1:

$$T_{new} = T + \left(\frac{\partial T}{\partial \rho}\right)_S \Delta\rho + \left\{\mathscr{S}\Delta t - Q\nabla\left(\frac{1}{\rho}\right)\right\} \Big/ \left(\frac{\partial E}{\partial T}\right)_\rho , \tag{3.8}$$

where all quantities on the right-hand side are evaluated from previous values and

$$\left(\frac{\partial T}{\partial \rho}\right)_S = \frac{T\left(\frac{\partial P}{\partial T}\right)_\rho}{\rho^2 \left(\frac{\partial E}{\partial T}\right)_\rho} . \tag{3.9}$$

As with all iterations of this type, it is possible that (3.6) will not converge. This occurs very infrequently and is usually associated with the melt transition. Since, as a rule, anything that can go wrong will, the above iteration is backed up by a slower but dependable upper and lower bound method.

III-2. Solution of a Tri-Diagonal Set of Equations

Before considering Eq. (2.3) with radiation terms, it is useful to develop the mathematical prescription used to attack the system of coupled equations. The form of (2.3) will result in a set of tri-diagonal equations which can be solved with a backward-forward substitution method as developed by Richtmyer and Morton.[6]

Consider the system of N equations

$$
\begin{aligned}
&\mathscr{B}_1 X_1 - \mathscr{C}_1 X_2 + G_1 = 0 \ , \\
&-\mathscr{A}_i X_{i-1} + \mathscr{B}_i X_i - \mathscr{C}_i X_{i+1} + G_i = 0 \ , \ i = 2, \ldots, N-1 \ , \\
&-\mathscr{A}_N X_{N-1} + \mathscr{B}_N X_N + G_N = 0 \ ,
\end{aligned}
\tag{3.10}
$$

with the set of X_i being the N unknowns. The $\mathscr{A}_i$, $\mathscr{B}_i$, $\mathscr{C}_i$, and G_i are known constants. It is assumed that

$$
\mathscr{A}_i \geq 0 \ , \ \mathscr{B}_i \geq 0 \ , \ \mathscr{C}_i \geq 0 \tag{3.11}
$$

for all i. The solution is obtained by two passes through the set of equations. In a forward pass (i increasing) the quantities

$$
E_1 = \frac{\mathscr{C}_1}{\mathscr{B}_1} \ , \quad F_1 = -\frac{G_1}{\mathscr{B}_1} \ , \tag{3.12}
$$

$$
E_i = \frac{\mathscr{C}_i}{\mathscr{B}_i - \mathscr{A}_i E_{i-1}} \ , \tag{3.13}
$$

and

$$
F_i = \frac{\mathscr{A}_i F_{i-1} - G_i}{\mathscr{B}_i - \mathscr{A}_i E_{i-1}} \tag{3.14}
$$

are determined inductively to i = N - 1. It then follows that

$$
X_N = \frac{\mathscr{A}_N F_{N-1} - G_N}{\mathscr{B}_N - \mathscr{A}_N E_{N-1}} \ , \tag{3.15}
$$

and in a backward pass that

$$
X_i = E_i X_{i+1} + F_i \ . \tag{3.16}
$$

In principle, this method will always determine the solution of (3.10). However, difficulties can be encountered with the magnitudes of the numbers generated by (3.13), and bounds must be employed to ensure against computer overflows. The usefulness of the above solution can be guaranteed by requiring in addition to (3.11) that

$$\mathscr{B}_i \geq \mathscr{A}_i + \mathscr{C}_i \quad . \tag{3.17}$$

Since $\mathscr{A}_1 = 0$, it follows that

$$E_1 = \frac{\mathscr{C}_1}{\mathscr{B}_1} \leq 1 \quad , \tag{3.18}$$

and if $E_{i-1} \leq 1$, then $E_i \leq 1$ for

$$E_i \leq \frac{\mathscr{C}_i}{\mathscr{B}_i - \mathscr{A}_i} \leq \frac{\mathscr{C}_i}{\mathscr{C}_i} = 1 \quad . \tag{3.19}$$

In two of the following calculations, (3.17) will be considered in the radiation time-step control. This time step will have nothing to do with stability or accuracy but only ensures solution of the coupled zone energy equations without computer overflows.

III-3. Radiation Boundary Conditions

As with the boundary pressures discussed in Section II-4, the user must furnish boundary conditions that specify the radiation terms at the front and back surfaces. Either may be treated as a perfect reflector or by allowing radiation to flow both into and out of the problem. Under the reflection option the flux at the surface is zero.

If energy flow at the surface is allowed, the outward flux per unit area is

$$F_{out} = \sigma T^4 \quad , \tag{3.20}$$

where T is the boundary temperature. The incident flux must be specified by the user. At boundary 1 the inward flux is taken to be of the form

$$F_{in} = S_f \, \sigma \, T_{bf}^{\;4} \quad , \tag{3.21}$$

where S_f and T_{bf} are user-controlled. Normally, S_f is unity but can be used to scale input fluxes from a time-varying blackbody source of temperature T_{bf}. The quantities S_b and T_{bb} serve the same purpose at boundary N + 1. If no values are specified, T_{bf} and T_{bb} are given the value zero, meaning that there is no incident flux. The reflecting option is formally included by setting S to a negative number.

Insofar as CHART D is concerned, the extremities of the problem are the first and last material boundaries. Special care must be taken in cylindrical and spherical problems with central voids. Such a void is not considered as a part of the region of interest. Any radiation entering the void exits the problem and is lost to further calculations. Realistically, any radiation energy entering the void would reenter the material after transversing the void. To properly treat this case the interior surface should be made reflecting.

III-4. Implicit Diffusion Method

The difference form of (2.3) is

$$E_i^{j+1} = \beta_i P_i^{j+1} + \alpha_i - \frac{\Delta t}{M_i}\left\{\left(AF\right)_i^{j+1/2} - \left(AF\right)_{i+1}^{j+1/2}\right\} , \tag{3.22}$$

where (3.3) and (3.4) are used and M_i is the mass of zone i. A is a geometry factor given by

$$\begin{aligned} A &= 1 \quad , \quad \delta = 1 , \\ &= 2\pi X \quad , \quad \delta = 2 , \\ &= 4\pi X^2 \quad , \quad \delta = 3 . \end{aligned} \tag{3.23}$$

In the implicit scheme, the difference form of (2.9) is

$$F_i^{j+1/2} = -\frac{\eta_i}{16}\left\{\left(T_{i-1}^{j+1} + T_{i-1}^{j}\right)^4 - \left(T_i^{j+1} + T_i^{j}\right)^4\right\} , \tag{3.24}$$

where

$$\eta_i = \frac{8\sigma}{3\left\{\dfrac{\Delta X_i^j}{\lambda_i^j} + \dfrac{\Delta X_{i-1}^j}{\lambda_{i-1}^j}\right\}} . \tag{3.25}$$

The expression for η_i should be evaluated at $t_{j+1/2}$. However, it has been found that a considerable amount of computation can be saved by using values at t_j without affecting the results, since the dominant features in (3.24) are the T^4 terms.

Eqs. (3.24) and (3.25) are appropriate only for continuous material. At an interior void or fracture, (3.24) can be used with

$$\eta_i = \sigma . \tag{3.26}$$

This follows by applying (3.20) in both directions where, of course, zero transit time across the void is assumed. Inactive material regions can be treated by setting η_i to zero.

When used in optically thin material regions ($\lambda_R \gtrsim \Delta X$), the diffusion approximation may yield unreasonably large fluxes. Flux limiters are employed to ensure physically believable values. The details are discussed below with the result that the values of λ_i and η_i must be bounded. In the case of pure radiation flow ($\lambda = \lambda_R$), use of the limiter implies that λ_R cannot exceed some value on the order of ΔX. A larger λ could result in a flux in excess of cE_r. Different forms are necessary when thermal conduction effects are included.

To shorten the notation, define

$$\gamma_i = A_j^{j+1/2} \eta_i \Delta t/16 \tag{3.27}$$

and $\tau_i = T_i^j$. The superscript j+1 can be dropped and (3.22) written as

$$\begin{aligned} G_i = E_i - \alpha_i - \beta_i P_i - \frac{\gamma_{i+1}}{M_i} (T_{i+1} + \tau_{i+1})^4 \\ + \frac{(\gamma_{i+1} + \gamma_i)}{M_i} (T_i + \tau_i)^4 - \frac{\gamma_i}{M_i} (T_{i-1} + \tau_{i-1})^4 , \end{aligned} \tag{3.28}$$

where, if all T_i are properly chosen, all G_i will vanish.

The boundary zones (i = 1 and N) are controlled by slightly different expressions containing the user input parameters. Where the functions presented in III-3 are used, the corresponding expressions are

$$\begin{aligned} G_1 = E_1 - \alpha_1 - \beta_1 P_1 - \frac{\gamma_2}{M_1} (T_2 + \tau_2)^4 \\ + \frac{(\gamma_2 + \gamma_1)}{M_1} (T_1 + \tau_1)^4 - \frac{\gamma_1 S_f}{M_1} (T_{bf} + \tau_{bf})^4 , \end{aligned} \tag{3.29}$$

and

$$\begin{aligned} G_N = E_N - \alpha_N - \beta_N P_N - \frac{\gamma_{N+1} S_b}{M_N} (T_{bb} + \tau_{bb})^4 \\ + \frac{(\gamma_{N+1} + \gamma_N)}{M_N} (T_N + \tau_N)^4 - \frac{\gamma_N}{M_N} (T_{N-1} + \tau_{N-1})^4 , \end{aligned} \tag{3.30}$$

with $\eta_1 = \eta_{N+1} = 0$. The reflecting option is included by setting $\eta = \gamma = 0$.

The above expressions form a set of N equations with N unknowns. Since the heat capacity is not constant, no simple method of solution is possible. An N variable Newton iteration is employed. The defining expressions are

$$G_1 + \frac{\partial G_1}{\partial T_1} \Delta T_1 + \frac{\partial G_1}{\partial T_2} \Delta T_2 = 0 \ ,$$

$$G_i + \frac{\partial G_i}{\partial T_{i-1}} \Delta T_{i-1} + \frac{\partial G_i}{\partial T_i} \Delta T_i + \frac{\partial G_i}{\partial T_{i+1}} \Delta T_{i+1} = 0, \ i=2 \ , \ \ldots \ , \ N-1 \ , \tag{3.31}$$

$$G_N + \frac{\partial G_N}{\partial T_{N-1}} \Delta T_{N-1} + \frac{\partial G_N}{\partial T_N} \Delta T_N = 0 \ ,$$

with ΔT the change in T from one iteration to the next. This system of equations may be treated by the method presented in Section III-2, where

$$\mathscr{A}_i = - \frac{\partial G_i}{\partial T_{i-1}} \ , \ i=2 \ , \ \ldots \ , \ N \ ,$$

$$\mathscr{B}_i = \frac{\partial G_i}{\partial T_i} \ , \ i=1 \ , \ \ldots \ , \ N \ , \tag{3.32}$$

and

$$\mathscr{C}_i = - \frac{\partial G_i}{\partial T_{i+1}} \ , \ i=1 \ , \ \ldots \ , \ N-1 \ .$$

This iteration is continued until all temperatures have converged under a condition similar to that of Eq. (3.7). Care is taken to suppress unnecessary equation-of-state calculations. In the event that the iteration will not converge, the calculation is recycled with a smaller time step.

The time step allowed by this method is obtained by substitution of Eq. (3.32) into Eq. (3.17). Unfortunately, this result involves both the new densities and temperatures which cannot be determined until the time increment is known. A practical solution to this difficulty is to drop the term $\beta_i \frac{\partial P_i}{\partial T_i}$, which is normally small compared to $\frac{\partial E_i}{\partial T_i}$, and to use the old zone temperatures in place of the new values. The result is

$$\frac{1}{\Delta t_1} \geq \frac{2\left\{-A_1 \eta_1 \tau_1^{\ 3} - A_2 \eta_2 (\tau_1^{\ 3} - \tau_2^{\ 3})\right\}}{M_1 \frac{\partial E_1}{\partial T_1}} \tag{3.33}$$

and

$$\frac{1}{\Delta t_i} \geq \frac{2\left\{A_i\eta_i(\tau_{i-1}^3 - \tau_i^3) - A_{i+1}\eta_{i+1}(\tau_i^3 - \tau_{i+1}^3)\right\}}{M_i \frac{\partial E_i}{\partial T_i}}, \tag{3.34}$$

$$i=2, \ldots, N-1 .$$

The expression for zone N is not required. The radiation time step Δt_{rad} is the smallest value given by these relations. No difficulty has ever occurred with this method.

The numerical values of the fluxes are not normally required. However, on special cycles the values are computed from (3.24) for edit purposes. They are also required in a periodic calculation to determine whether the radiation computation is important and if the method of Section III-1 could be used equally well.

III-5. Explicit Diffusion Method

In many problems of interest, the effects of transport processes are small within a given computational cycle but, when viewed over many cycles, may drastically alter the situation. The implicit method could be used, although it would be inefficient in terms of computational effort. The explicit method is best suited for this type of problem and, if properly employed, can result in considerable savings.

In the explicit method, the treatment is as in the implicit calculation, except that the fluxes are centered at t_j instead of at $t_{j+1/2}$. Equation (3.24) is replaced by

$$F_i^{j+1/2} = F_i^j = -\eta_i \left\{(T_{i-1}^j)^4 - (T_i^j)^4\right\} . \tag{3.35}$$

The advantage of this method is that the new zone temperatures are computationally uncoupled. A set of equations similar to (3.5), with an additional known term, is obtained for the energy balance calculation. By replacement of α_i in (3.3) by

$$\alpha_i + \frac{\Delta t}{M_i}\left\{A_{i+1}\eta_{i+1}\tau_{i+1}^4 - (A_{i+1}\eta_{i+1} + A_i\eta_i)\tau_i^4 + A_i\eta_i\tau_{i-1}^4\right\}, \tag{3.36}$$

the solution can be determined by the same calculation used in the pure hydrodynamic case.

The difficulty with this method is that the associated time step required is normally much smaller than that used in the implicit method. However, if the time step for the entire calculation is controlled by the Courant hydrodynamic condition and not by the radiation value, the explicit method should be employed. Unfortunately, the time step appropriate to this situation is difficult to obtain and is determined completely by accuracy requirements. It has been found that the relation

$$\frac{1}{\Delta t_i} \geq \frac{|A_i F_i - A_{i+1} F_{i+1}|}{\xi M_i (E_i + E_o)} \tag{3.37}$$

works well, where all functions are determined at t_j, ξ is a constant ($\xi = 0.01$ is currently employed), and E_o allows for rapid heating of cold zones. This condition requires the net energy flux in or out of a zone to be a small fraction of the total zone energy. As before, Δt_{rad} is the smallest value given by Eq. (3.37).

III-6. Approximate Implicit Diffusion Method

The principal difficulty with the implicit solution is that the coupled equations which must be solved are nonlinear in the new temperatures. The heat capacity is generally not constant over a given time increment. Under the method described here several approximations are made to ease the solution. Unfortunately with these approximations, energy is not exactly conserved and final corrections are necessary. In the process some of the speed of computation over the implicit method is lost.

Consider the flux given by Eq. (2.9). Here, this is written as

$$F = -\frac{16}{3} \sigma \lambda T^3 \nabla T \quad , \tag{3.38}$$

with a difference form of

$$F_i^{j+1/2} = \frac{1}{4} \eta_i (\tau_i + \tau_{i-1})^3 \left\{ (T_{i-1} + \tau_{i-1}) - (T_i + \tau_i) \right\} \, , \tag{3.39}$$

where η_i and τ_i are defined in Section III-4. Note that the T^3 term in Eq. (3.38) has been evaluated at t_j. The corresponding expressions at the front and back boundaries are

$$F_1^{j+1/2} = \eta_1 \left\{ \frac{1}{2} \tau_1{}^3 (T_1 + \tau_1) - \frac{1}{16} S_f (T_{bf} + \tau_{bf})^4 \right\} \tag{3.40}$$

and

$$F_{N+1}^{j+1/2} = \eta_{N+1} \left\{ -\frac{1}{2} \tau_N^{\ 3} (T_N + \tau_N) + \frac{1}{16} S_b (T_{bb} + \tau_{bb})^4 \right\} . \qquad (3.41)$$

Boundary options are treated as before.

Approximations must also be used on the energy conservation relation. Define

$$\Phi_i = E_i(\tau_i, \rho_i^{j+1}) , \qquad (3.42)$$

$$\Psi_i = P_i(\tau_i, \rho_i^{j+1}) . \qquad (3.43)$$

Note that these energy and pressure values are obtained from the new zone density but with the old temperature. In general, Φ_i is not the same as E_i^j. The approximate values are

$$E_i^{j+1} \approx \Phi_i + \Phi_i' (T_i - \tau_i) \qquad (3.44)$$

and

$$P_i^{j+1} \approx \Psi_i + \Psi_i' (T_i - \tau_i) , \qquad (3.45)$$

where

$$\Phi_i' = \left(\frac{\partial E}{\partial T}\right)_\rho \bigg|_{\tau_i, \rho_i^j} \qquad (3.46)$$

and

$$\Psi_i' = \left(\frac{\partial P}{\partial T}\right)_\rho \bigg|_{\tau_i, \rho_i^j} . \qquad (3.47)$$

When the above expressions are substituted into (3.22), the result is

$$-\frac{\gamma_i}{M_i} T_{i-1} + \left\{ \Phi_i' - \beta_i \Psi_i' + \frac{\gamma_i + \gamma_{i+1}}{M_i} \right\} T_i - \frac{\gamma_{i+1}}{M_{i+1}} T_{i+1} + G_i = 0 , \qquad (3.48)$$

where

$$\gamma_i = \frac{1}{4} A_i \eta_i (\tau_i + \tau_{i-1})^3 \Delta t \quad , \tag{3.49}$$

$$\begin{aligned} G_i = \Phi_i - \Phi_i' \tau_i - \alpha_i - \beta_i (\Psi_i - \Psi_i' \tau_i) \\ + \frac{1}{M_i} \left\{ \gamma_i (\tau_i - \tau_{i-1}) - \gamma_{i+1} (\tau_{i+1} - \tau_i) \right\} \quad , \end{aligned} \tag{3.50}$$

and α_i and β_i are given by (3. 3) and (3. 4). The expressions at the front and back are

$$\left\{ \Phi_1' - \beta_1 \Psi_1' + \frac{1}{M_1} \left[\frac{1}{2} A_1 \eta_1 \Delta t \tau_1^3 + \gamma_2 \right] \right\} T_1 - \frac{\gamma_2}{M_1} T_2 + G_1 = 0 \quad , \tag{3.51}$$

$$\begin{aligned} G_1 = \Phi_1 - \Phi_1' \tau_1 - \alpha_1 - \beta_1 (\Psi_1 - \Psi_1' \tau_1) \\ + \frac{1}{M_1} \left\{ A_1 \eta_1 \Delta t \left[\frac{1}{2} \tau_1^4 - \frac{1}{16} S_f (T_{bf} + \tau_{bf})^4 \right] - \gamma_2 (\tau_1 - \tau_1) \right\} \quad , \end{aligned} \tag{3.52}$$

$$-\frac{\gamma_N}{M_N} T_{N-1} + \left\{ \Phi_N' - \beta_N \Psi_N' + \frac{1}{M_N} \left[\gamma_N + \frac{1}{2} A_{N+1} \eta_{N+1} \Delta t \tau_N^3 \right] \right\} T_N + G_N = 0 \quad , \tag{3.53}$$

and

$$\begin{aligned} G_N = \Phi_N - \Phi_N' \tau_N - \alpha_N - \beta_N (\Psi_N - \Psi_N' \tau_N) \\ + \frac{1}{M_N} \left\{ \gamma_N (\tau_N - \tau_{N-1}) - A_{N+1} \eta_{N+1} \Delta t \left[\frac{1}{2} \tau_N^4 - \frac{1}{16} S_b (T_{bb} + \tau_{bb})^4 \right] \right\} \quad . \end{aligned} \tag{3.54}$$

In this case, G_i is a known constant and the method of solution developed in Section III-2 may be used to directly determine the new temperatures.

The next step is to determine the allowed time increment from (3. 17). As before, the pressure term is dropped and one finds that the condition is always satisfied regardless of Δt, since

$$\mathscr{B}_i = \mathscr{A}_i + \mathscr{C}_i + \Phi_i' \tag{3.55}$$

and Φ_i' is positive (Φ_i' is a heat capacity). Thus far this method looks very good, since it can be used at the Courant hydrodynamic stability limit. Unfortunately, when the approximations given by (3.44) and (3.45) are examined, it is clear that this calculation will not conserve energy since the heat capacities are in general not constant.

The scheme used with the above method is to complete the calculation as outlined above. The flux values are then calculated and used as in the explicit computation to exactly conserve energy. Normally, this method will allow a much larger time step than will the explicit method. The time increment allowed for the next cycle is determined by the differences in temperatures resulting from the above calculation and those obtained after the final correction. The value Δt_{rad} is increased slightly if all errors are 2 percent or less; otherwise, it is decreased slightly. The amount of the increase or decrease is a variable function of the error.

III-7. Selection of the Fastest Method

At any given time in a given problem, one of the previous methods would prove superior to the others in the sense of advancing the solution the furthest for the same computational effort. In general, the implicit method is best for radiation-dominated problems, and the explicit method is best when energy flow is a small perturbation to the hydrodynamic motion. The third method fits somewhere between the two.

An option is provided in CHART D in which the code will perform each calculation every 250 cycles and attempt to determine which one will progress the solution the furthest in time for the same computational time. Unfortunately, the rules are not well defined and the best method can only be determined in extreme cases. Intermediately, some switching back and forth can be found.

There are some dangers in this method. If the explicit method is being used and a drastic contingency occurs, Δt_{rad} can be cut many orders of magnitude before the comparison check determines that another method should be used. For example, consider a wave diffusing through a very dense material where the explicit calculation is sufficient. If the wave advanced to the edge of the dense material and then began traveling in a nearly transparent material (air for example), large time-step cuts would result before it would be discovered that an implicit method should be used. To guard against this difficulty, the code always selects the implicit method for the first 250 cycles.

III-8. Flux Limiters

In optically thin materials ($\lambda_R \gtrsim \Delta X$) where large temperature gradients exist, the diffusion approximation may yield unreasonably large values of flux. The question here is how to limit the fluxes to physically attainable values. The radiation energy density (ergs/cc) is E_r. The maximum flux possible

$$F_{max} = cE_r \tag{3.56}$$

would occur if all energy was flowing in the same direction. By employing (2.5), (2.9), and (3.56), the result is that

$$\frac{4\lambda\sigma}{3\Delta X} \leq \frac{cE_r}{|\Delta T^4|} \quad . \tag{3.57}$$

If it is assumed that ΔT^4 is of the order of T^4, this yields

$$\eta_i \leq 4\sigma \quad , \tag{3.58}$$

where η_i is given by (3.25). Equation (3.20), on the other hand, would lead to the condition that

$$\eta_i \leq \sigma \; . \tag{3.59}$$

It has also been mentioned that the Rosseland mean free paths can be modified to include forms of energy transport, i.e., electronic and phonon conduction. The use of (3.57) would in effect suppress these phenomena. The decision was made to employ (3.57) in CHART D, but with the total energy density (material plus radiation) instead of only the radiation term. This is a change from the method in R1 and was made to stop the suppression of thermal conduction. The result in difference form is

$$\eta_i \leq \frac{c\left\{\rho_i E_i + \rho_{i-1} E_{i-1}\right\}}{2T_i^4 \left| 1 - \left(\frac{T_{i-1}}{T_i}\right)^4 \right|} \; . \tag{3.60}$$

It is suggested, however, that the results of this calculation be observed with care. Situations can be constructed in which (3.60) will not limit the flux properly. However, at both high and low temperature, it will approximately treat the problem correctly. Other expressions can simply be included as the need arises.

IV. ELASTIC-PLASTIC MATERIAL

Thus far, it has been assumed that the material under consideration is isotropic. Unfortunately, solids, unlike liquids and gases, do not demonstrate isotropic response to all stimuli. Accordingly, the preceding method is correct only when pressures are sufficiently high that the effects connected with the strength of the solid are not important. If loads are small, it becomes necessary to take into account the elastic properties of the solid which distinguish it from a liquid. Many codes have been written to consider such effects. However, there exists a large class of problems in which both transport and strength phenomena are important. This area has been largely ignored.

An elastic, perfectly plastic model similar to that employed in the production forms of the code WONDY[7, 8] is used in CHART D. Since many code users are familiar with the notation in the WONDY manual and because of the wide availability of required constants, the following development will be patterned after that of Herrmann et al.[7] There are, however, many differences in both physical content and numerical detail. It should be noted from the development in Section III that each zone cannot be considered independently of the rest. The $\nabla \cdot \vec{F}$ term forces simultaneous solution. For this reason, the calculation in this section is treated as an add-on or perturbation to the principle solution.

Define σ_ℓ as the stress in the $\ell^{\underline{th}}$ direction taken positive on compression. As in the development given by Herrmann, the tensor nature of σ is suppressed; reference is made only to the diagonal elements. It should be noted that σ_ℓ is defined as the negative of that of Herrmann et al.[7] The pressure is taken to be

$$P = \frac{1}{3}(\sigma_x + \sigma_y + \sigma_z) \ , \tag{4.1}$$

where x is the coordinate of motion. For any of the three allowed geometries and one-dimensional motion, the generalized form of (2.2) is written as

$$\rho \frac{\partial V}{\partial t} = - \frac{\partial}{\partial x}(\sigma_x + Q) + (\delta - 1)\frac{\Phi}{x} \ , \tag{4.2}$$

where δ is the geometry switch and

$$\Phi = \sigma_y - \sigma_x \ . \tag{4.3}$$

It is convenient to define the stress deviators by

$$\sigma_\ell^{\,d} = P - \sigma_\ell \ . \tag{4.4}$$

From observation of (4. 1), it is evident that

$$\sum_{\ell} \sigma_{\ell}^{d} = 0 \quad . \tag{4.5}$$

In terms of these deviators, Eqs. (4. 2) and (4. 3) may be expressed as

$$\rho \frac{\partial V}{\partial t} = - \frac{\partial}{\partial x} (P + Q - \sigma_x^{d}) + (\delta - 1) \frac{\Phi}{x} \tag{4.6}$$

and

$$\Phi = \sigma_x^{d} - \sigma_y^{d} = 2\sigma_x^{d} + \sigma_z^{d} \quad . \tag{4.7}$$

In plane and spherical geometry there is an inherent symmetry for

$$\sigma_y = \sigma_z \quad , \tag{4.8}$$

so that the simplifications

$$\sigma_y^{d} = \sigma_z^{d} = - \frac{1}{2} \sigma_x^{d} \tag{4.9}$$

and

$$\Phi = \frac{3}{2} \sigma_x^{d} \tag{4.10}$$

are possible for $\delta = 1$ or 3. The stretching is defined as

$$\left. \begin{aligned} d_x &= \frac{\partial V}{\partial x} \\ d_y &= d_z = 0 \end{aligned} \right\} \quad , \quad \delta = 1 \quad , \tag{4.11}$$

$$\left. \begin{aligned} d_x &= \frac{\partial V}{\partial x} \\ d_y &= \frac{V}{x} \\ d_z &= 0 \end{aligned} \right\} \quad , \quad \delta = 2 \quad , \tag{4.12}$$

and

$$\left.\begin{array}{l} d_x = \dfrac{\partial V}{\partial x} \\ \\ d_y = d_z = \dfrac{V}{x} \end{array}\right\} \delta = 3 \ . \tag{4.13}$$

The volumetric strain rate or dilatation is

$$d = \sum_{\ell} d_{\ell} = \nabla \cdot \vec{V} = -\frac{1}{\rho}\frac{\partial \rho}{\partial t} \ , \tag{4.14}$$

where (2.1) and the definition of $\nabla \cdot \vec{V}$ have been employed. The stretching deviators are defined as

$$d_{\ell}^{\ d} = d_{\ell} - \frac{1}{3} d = d_{\ell} + \frac{1}{3\rho}\frac{\partial \rho}{\partial t} \ , \tag{4.15}$$

where

$$\sum_{\ell} d_{\ell}^{\ d} = 0 \ . \tag{4.16}$$

From the above expressions, it is evident that, for all δ ,

$$d_x^{\ d} = \frac{\partial V}{\partial x} + \frac{1}{3\rho}\frac{\partial \rho}{\partial t} \ . \tag{4.17}$$

The rate at which mechanical work is performed per unit mass by the stress is given by

$$\begin{aligned} P &= -\frac{1}{\rho}\sum_{\ell} \sigma_{\ell} d_{\ell} \\ &= \frac{P}{\rho^2}\frac{\partial \rho}{\partial t} + \frac{1}{\rho}\sum_{\ell} \sigma_{\ell}^{\ d} d_{\ell}^{\ d} \ . \end{aligned} \tag{4.18}$$

If the quantity

$$P_d = \frac{1}{\rho}\sum_{\ell} \sigma_{\ell}^{\ d} d_{\ell}^{\ d} \tag{4.19}$$

is introduced, it is clear that the appropriate generalization of (2.3) is

$$\frac{\partial E}{\partial t} = -(P + Q)\frac{\partial}{\partial t}\left(\frac{1}{\rho}\right) - \frac{1}{\rho}\nabla \cdot \vec{F} + \dot{\mathscr{S}} + P_d \ , \tag{4.20}$$

where the notation is that of (2.7) and (2.8). The deviator stress power may be written in the more concise form

$$P_d = \frac{1}{\rho} \sum_{\ell=x,z} \left\{ \sigma_\ell^d d_\ell^d + \sum_{k=x,z} \sigma_\ell^d d_k^d \right\} \tag{4.21}$$

by considering (4.5) and (4.16). Again, sufficient simplification arises when $\delta = 1$ or 3,

$$d_y^d = d_z^d = -\frac{1}{2} d_x^d \ , \tag{4.22}$$

and

$$P_d = \frac{3\sigma_x^d d_x^d}{2\rho} \ . \tag{4.23}$$

IV-1. Constitutive Relations

Constitutive relations must now be considered. As previously mentioned, the thermodynamic equations of state employed in CHART D are of the form

$$P = P(\rho, T) \tag{4.24}$$

and

$$E = E(\rho, T) \ , \tag{4.25}$$

where T is the temperature. The problem here is the description of the deviator terms. The general form is

$$\sigma_\ell^d = f(d_x^d, \ d_y^d, \ d_z^d, \ \rho, T, \ .....) \ , \tag{4.26}$$

where ..... represents any number of things.

As in Herrmann et al.,[7] the form

$$\frac{\partial \sigma_x^d}{\partial t} = 2G \, d_x^d \tag{4.27}$$

is used, where $G(\rho, T)$ is the shear modulus and is a function of state of the solid. For $\delta = 2$, a similar relation is used for σ_z^d. At sufficiently high pressures, the material will yield and exhibit plasticity. This is reflected as an upper bound to the magnitude of the deviators. The Von Mises yield condition is

$$f_y \equiv \sum_\ell (\sigma_\ell^d)^2 \le \frac{2}{3} Y^2 \ , \tag{4.28}$$

where $Y(\rho, T)$ is a state function of the solid known as the flow stress. Examination of (4.5) reveals that

$$f_y = 2\left\{\sigma_x^d \sigma_x^d + \sigma_x^d \sigma_z^d + \sigma_z^d \sigma_z^d\right\} \leq \frac{2}{3} Y^2 , \tag{4.29}$$

and for $\delta = 1$ or 3,

$$f_y = \frac{3}{2} (\sigma_x^d)^2 \leqq \frac{2}{3} Y^2 . \tag{4.30}$$

The sound speed appropriate to elastic material is

$$C_s = \left\{\frac{3(1 - \nu)}{1 + \nu}\right\}^{1/2} C_{ts} , \tag{4.31}$$

where C_{ts} is the thermodynamic or bulk sound speed and ν is Poisson's ratio. An exact definition of ν is found in the text of Zel'dovich and Raizer.[9] For most materials,

$$0 < \nu \leq \frac{1}{2} , \tag{4.32}$$

with the upper limit appropriate for hydrodynamic media. In general, ν is also a function of state with a form similar to that of (4.26).

A common assumption is that the shear modulus may be related to the thermodynamic sound speed and Poisson's ratio by the expression

$$\begin{aligned} G &= \frac{3(1 - 2\nu)\, \rho\, C_{ts}^2}{2(1 + \nu)} \\ &= \frac{(1 - 2\nu)\, \rho\, C_s^2}{2(1 - \nu)} , \end{aligned} \tag{4.33}$$

where (4.31) is employed. This is the only form currently available in CHART D, although others may be included if the need arises.

The remaining problem is to specify the two state functions, ν and Y. Because of past work in the field, both are assumed to have the form $\nu(\rho, E)$ and $Y(\rho, E)$. Let ν_o and Y_o be the values of these functions at the normal reference point and

$$\eta = 1 - \frac{\rho_o}{\rho} . \tag{4.34}$$

It is then assumed that

$$Y(\rho, E) = Y_o(1 + Y_1\eta)\, F(E) \tag{4.35}$$

and

$$\nu(\rho, E) = \nu_o\, F(E) + \frac{1}{2}\{1 - F(E)\}\ , \tag{4.36}$$

where Y_1 is a constant. Let $\mathscr{E}_m$ be the specific energy at the point of melt at zero pressure, α be the fraction of the melt energy where the material starts to lose its strength ($\alpha \leq 1$), and

$$F(E) = 1,\ E \leq \alpha\mathscr{E}_m\ ,$$

$$F(E) = \frac{1 - E/\mathscr{E}_m}{1 - \alpha}\ ,\ \alpha\mathscr{E}_m < E < \mathscr{E}_m\ , \tag{4.37}$$

$$F(E) = 0,\ E \geq \mathscr{E}_m\ .$$

There is an additional requirement that $F(E) = 0$ whenever the material is in a mixed-phase state. The forms of these expressions are admittedly arbitrary. On the other hand, they do approach the correct limits and are well-behaved between limits. Again, these expressions are easily modified if the need arises.

IV-2. Coding, Inputs, and Storage

The difference forms of the above expressions employed in CHART D are similar to those given by Herrmann et al.[7] and will not be repeated in detail here. There are three principal additions to the previously reported code.[1]

1. The addition terms in the momentum equation, (4.6), are included directly in the finite difference expression.
2. The sound speed is corrected by (4.31).
3. The deviators are updated and the additions to the energy equation are determined.

All coding for Steps 2 and 3 is included in an add-on subroutine called ELPL. Step 3 forms the main body of the calculation. For each zone, the deviator work ($P_d\Delta t$) is added to the old zone energy so that the main energy balance calculation need not be modified.

There are six input parameters for each material which exhibits elastic-plastic behavior. In the initialization edit, the variables are named YIELD (I), I = 1, 6. In the notation of the last section,

$$
\begin{aligned}
&\text{YIELD (1)} = Y_o, \text{ Eq. (4.35)} ,\\
&\text{YIELD (2)} = Y_1, \text{ Eq. (4.35)} ,\\
&\text{YIELD (3)} = \mathscr{E}_m, \text{ Eq. (4.37)} ,\\
&\text{YIELD (4)} = \rho_o, \text{ Eq. (4.34)} ,\\
&\text{YIELD (5)} = \nu_o, \text{ Eq. (4.36)} ,\\
&\text{YIELD (6)} = \alpha, \text{ Eq. (4.37)} ,
\end{aligned}
\tag{4.38}
$$

Standard default values are available for $\mathscr{E}_m$ and ρ_o by inputing zero values. Under normal conditions both should be used. To properly understand the variable $\mathscr{E}_m$, it must be pointed out that in all of the CHART D equations of state, the zero point of energy is defined at zero pressure and temperature so that the standard reference point (room temperature) will have a positive internal energy; $\mathscr{E}_m$ should reflect this reference value. If the default value is used, $\mathscr{E}_m$ is set equal to the energy of the liquid at the triple line. YIELD (3) should not be set to a negative quantity, since the code will interpret the material as distended media as shown in Section V.

During the problem initialization, the above variables are modified and finally stored in an array YIELD (J, I), I=1, 8, where J is the material layer number. The stored variables for the Jth layer are

$$
\begin{aligned}
&\text{YIELD (J, 1)} = Y_o ,\\
&\text{YIELD (J, 2)} = Y_1 ,\\
&\text{YIELD (J, 3)} = \mathscr{E}_m ,\\
&\text{YIELD (J, 4)} = 1/\rho_o ,\\
&\text{YIELD (J, 5)} = \nu_o ,\\
&\text{YIELD (J, 6)} = \alpha ,\\
&\text{YIELD (J, 7)} = T_m ,\\
&\text{YIELD (J, 8)} = \text{not used,}
\end{aligned}
\tag{4.39}
$$

where

T_m is the melt or triple line temperature.

Even in the case that the material is treated hydrodynamically, T_m is still determined and stored, since it is used to suppress unnecessary calculations in the fracture computations.

To complete the description, the variables $\sigma_x{}^d$ and $\sigma_z{}^d$ are stored for each zone in the arrays SXD(I) and SZD(I), where I is the zone number. Since the P array contains the pressure, all stresses can be determined from (4.4).

V. POROUS MATERIALS

The porous material model employed in CHART D is in some respects similar to that developed by Herrmann.[10, 11] However, there are several fundamental differences which yield vastly different responses under certain conditions. The largest deviations occur in problems involving constant volume heating and melting.

CHART D and other radiation hydrodynamic codes which employ density and temperature as independent material variables possess some inherent advantages over the normal wave propagation codes in treating distended materials. A knowledge of the temperature and related improvements in equations of state are necessary to properly describe the melt and transition to a mixed liquid-vapor state. The model presented here will treat this phenomenon. Some examples are given in Section V-6.

As in Herrmann's model, the one presented here is hydrodynamic in the sense that no attempt is made to compute transverse components of the stress; the pressure and all stress components are identical. Elastic wave propagation is determined by a special computation developed below. In most cases involving temperatures below melt, the model reduces to a calculation similar to that of the earlier method. (It is assumed that the reader is familiar with Herrmann's reports.[10, 11]).

One important difference is that the current model does not seem to require an additional artificial viscosity term for numerical stability. It has also been determined that entropy changes are properly included without it. As a result, the shock widths are generally smaller with the present model, approximately the same or slightly greater than normal shock waves. However, in some problems, numerical oscillations can occur behind a medium strength shock wave. These oscillations are not numerically unstable in that they are of the same nature and are damped in the same manner as oscillations behind shocks in normal materials as calculated by finite difference methods. If the size of these oscillations is unsatisfying to the user, an increase in the linear viscosity coefficient or decrease in the time step will smooth the results. This will also increase the wavefront width or computational time, respectively.

The entire porous material computation is treated as an add-on calculation performed after the main energy balance. This is done so that the method of solution of the coupled zone energy relations necessitated by the transport terms need not be modified. This procedure is somewhat inefficient in that more computations are required. On the other hand, it does save a large amount of coding. Each hydrodynamic zone can be considered independently in this manner. Hence the zone index is suppressed in all of the following relations.

Consider a distended material of average density ρ and temperature T. The solid material forming this substance is of density ρ_s. The distention ratio is defined as

$$\alpha = \frac{\rho_s}{\rho} \geq 1 \quad . \tag{5.1}$$

As suggested by Herrmann and thermodynamic logic, the thermodynamic properties of the distended material are calculated from the equation of state of the solid material by

$$E_d(\rho, T) = E_s(\rho_s, T) = E_s(\alpha\rho, T) \tag{5.2}$$

and

$$P_d(\rho, T) = P_s(\rho_s, T) = P_s(\alpha\rho, T) \quad , \tag{5.3}$$

where E is the specific energy, P is the pressure, T is the temperature, d refers to the distended properties, and s refers to solid. Alternate forms have been suggested for (5.3); however, (5.3) seems to possess the best theoretical basis. Only thermodynamic quantities referring to the solid equation of state will be used below so that the s subscript is suppressed.

The first problem is to determine a modified form of the energy conservation law for this correction method. The set of equations solved in the main energy balance calculation (2.3) is

$$\frac{\partial E}{\partial t} = - \left\{ P + Q \right\} \frac{\partial}{\partial t}\left(\frac{1}{\rho}\right) - \frac{1}{\rho} \nabla \cdot \vec{F} + \dot{\mathscr{S}} \quad , \tag{5.4}$$

as previously related. To shorten the notation, let n refer to new zone quantities (at end of time increment Δt), o refer to old zone quantities (at beginning of time increment Δt), and write the finite difference form of (5.4) as

$$\hat{E}_n = - \frac{1}{2} \hat{P}_n \Delta \left(\frac{1}{\rho}\right) + R \quad , \tag{5.5}$$

with $\hat{E}_n$ the new value of E, $\hat{P}_n$ the new value of P, and R representing the remainder of the terms in the finite difference expression. The new density ρ_n is a known constant for this calculation. In regions where porous material effects are important, R is only weakly dependent on the distention. The old distention ratio α_o is used in the main energy balance solution of (5.5), as discussed in Section III, so that

$$\hat{E}_n = E_m(\alpha_o \rho_n, \hat{T}_n) \tag{5.6}$$

and

$$\hat{P}_n = P_m(\alpha_o \rho_n, \hat{T}_n) \quad , \tag{5.7}$$

where $\hat{T}_n$ is the solution temperature. The correct form of (5.5) that should have been used is

$$E_n = -\frac{1}{2} P_n \Delta(\frac{1}{\rho}) + R \quad , \tag{5.8}$$

where

$$E_n = E_m(\alpha_n \rho_n, T_n) \quad , \tag{5.9}$$

$$P_n = P_m(\alpha_n \rho_n, T_n) \quad , \tag{5.10}$$

and α_n is the new distention ratio. The only difference in (5.5) and (5.8) is the change in distention in the time element Δt. Subtracting (5.5) from (5.8), the result is

$$E_n = \hat{E}_n + \gamma(P_n - \hat{P}_n) \quad , \tag{5.11}$$

with

$$\gamma = -\frac{1}{2} \Delta(\frac{1}{\rho}) = \frac{\rho_n - \rho_o}{2\rho_n \rho_o} \quad . \tag{5.12}$$

Equation (5.11) expresses the conservation of energy and forms one of the constraint relations used in all of the correction methods found below. Upon entering the porous material subroutines, the values of $\hat{E}_n$, $\hat{P}_n$, $\hat{T}_n$, and ρ_n are known. The quantities to be determined are E_n, P_n, T_n, and α_n.

As in Herrmann's model, porous materials are considered to exhibit both regions of elastic and plastic deformations. Below some pressure determined by the local distention and temperature, the material is elastic. Small recoverable changes in distention are allowed. At higher pressures nonrecoverable crushing is encountered. Separating these regions is the "crush pressure" $\mathscr{P}_k(\alpha, T)$ which is a state function of the distended material.

At higher temperatures and energy densities as the material melts, an alternate method must be employed. Letting the crush pressure approach zero as the material melts will not correctly describe the process. For sufficiently large distentions ($\alpha \gtrsim 1.1$, determined by thermal expansion), the end product of the melt of a porous material is a mixed-phase liquid-vapor state properly described by the CHART D equations of state. When a porous material melts, all that is required is to set the distention ratio to unity (the total density is constant) and it is then treated as a porous liquid with the pores filled with vapor. This bit of material is not considered further in the porous material calculation.

V-1. Elastic Region

One of the main problems in the elastic calculation is to ensure the correct elastic wave velocity. The sound speed in the distended material is written as

$$C = h(\alpha)C_o \ , \tag{5.13}$$

where C_o is the bulk sound speed in the solid material of density ρ_s and appropriate temperature. In some sense, $h(\alpha)$ is a state function of the foam. Following Herrmann, it is assumed that $h(\alpha)$ is linear in α:

$$h(\alpha) = \left(\frac{C_{eo}}{C_{oo}}\right)\left\{\frac{\alpha - 1}{\alpha_e - 1}\right\} + \left\{\frac{\alpha_e - \alpha}{\alpha_e - 1}\right\} \ , \tag{5.14}$$

where e refers to the initial or reference state of distention, C_{eo} is the elastic wave velocity at the initial distention and C_{oo} is the bulk sound speed in the solid part of the initial foam. There is little justification for the form of (5.14) except that it approaches the correct limits, is well-behaved between limits, and fits the available data as well as any other function. On the other hand, most calculations are not particularly sensitive to the assumed form, and it can easily be modified if the need arises.

It is now noted that

$$C^2 = \left(\frac{\partial P}{\partial \rho}\right)_S = \left(\frac{\partial P}{\partial \rho_s}\right)_S \frac{\partial \rho_s}{\partial \rho} = C_o^{\ 2} \ \frac{\partial \rho_s}{\partial \rho} \tag{5.15}$$

and

$$\frac{\partial \rho_s}{\partial \rho} = \alpha + \rho \frac{\partial \alpha}{\partial \rho} \ , \tag{5.16}$$

so that, under adiabatic conditions,

$$\rho \frac{\partial \alpha}{\partial \rho} = h^2 - \alpha \tag{5.17}$$

by comparison with (5.13). This relation is used in finite difference form to compute changes in distention in the elastic region:

$$\alpha_n = \alpha_o + \frac{2(\rho_n - \rho_o)}{(\rho_n + \rho_o)}\left\{h^2(\alpha_o) - \alpha_o\right\} \ . \tag{5.18}$$

In this manner the proper wave velocity is ensured under conditions of abiabatic loading. It should be noted that this expression is slightly different from that used in the method of Herrmann ($\Delta\alpha \sim \frac{d\alpha}{dP} \Delta P$). To first order, the two expressions are identical in adiabatic situations. However, nonadiabatic stimulus can lead to quite different response. This point is discussed in Section V-4.

Under normal conditions, (5.18) yields small changes in distention in any given time increment. However, large changes in α could be computed for high shock pressures. In this case, one would find that the local crush pressure has been exceeded and further corrections are required. Therefore, changes in α computed by (5.18) are limited to 5 percent of α.

With this new value of distention, a solution of (5.9), (5.10), and (5.11) may be found to determine the temperature T_n. A Newton iteration quickly yields the solution, since T_n is always near $\hat{T}_n$. If the new pressure P_n is smaller than the crush pressure, the computation for this zone is complete. Otherwise, another method must be employed.

For most materials, the bulk sound speed of the solid C_o is greater than the wave velocity in the porous state C_e. However, in some cases the reverse is true. This will not cause any problems with the numerical calculation. On the other hand, if

$$C_{eo} > \sqrt{\alpha_e}\ C_{oo} , \tag{5.19}$$

strange behavior will result. From (5.14) and (5.17) it then follows that

$$\frac{\partial\alpha}{\partial\rho} > 0 , \tag{5.20}$$

which indicates that the voids tend to enlarge relative to the solid under elastic compression. The same oddity is encountered in Herrmann's calculation since, from (5.19), it follows that

$$\frac{\partial\alpha}{\partial P} > 0 . \tag{5.21}$$

No check for (5.19) has been included in CHART D since, under some conditions, it might be necessary to describe a substance. However, the user is warned of this response.

V-2. Crush Pressure

The crush pressure $\mathscr{P}_k$ is assumed to be describable by the form

$$\mathscr{P}_k(\alpha, T) = \mathscr{P}_k^*(\alpha)\, K(E) . \tag{5.22}$$

The energy dependence was chosen for historical reasons. Two analytic forms of $\mathscr{P}_k^*(\alpha)$ are currently available in CHART D. The quadratic form, similar to that employed in WONDY (written in inverse form), is

$$\mathscr{P}_k^*(\alpha) = \mathscr{P}_s - (\mathscr{P}_s - \mathscr{P}_e) \sqrt{\frac{\alpha - 1}{\alpha_e - 1}} \ , \tag{5.23}$$

where $\mathscr{P}_s$ is the pressure required to completely crush the distended material. $\mathscr{P}_e$ is close to but not exactly the elastic wave precursor amplitude in this expression. Between P = 0 and the initial yield pressure under adiabatic loading $\mathscr{P}_{ei}$ (the precursor amplitude), there is a small change in distention. Define this initial yield distention as α_p; then, approximately, from (5.18) and (5.23)

$$\alpha_p = \alpha_e + \frac{\mathscr{P}_{ei}\left(\left(\frac{C_{eo}}{C_{oo}}\right)^2 - \alpha_e\right)}{\rho_e C_{eo}^2} \tag{5.24}$$

and

$$\mathscr{P}_e = \mathscr{P}_{ei} + (\mathscr{P}_{ei} - \mathscr{P}_s)\left\{\sqrt{\frac{\alpha_e - 1}{\alpha_p - 1}} - 1\right\} . \tag{5.25}$$

The quantity P_{ei} is easily measured and is used as an input parameter. The quantities α_p and $\mathscr{P}_e$ can then be determined from the above relations. Neither α_p nor $\mathscr{P}_{ei}$ are required after this computation and are not retained. The parameter $\mathscr{P}_e$ is more important than this manipulation indicates. It is shown below that $\mathscr{P}_e$ determines the initial yield and pressure generated in a foam by constant volume heating under the present model.

At a later point in the numerical solution, the derivative of (5.23) is required:

$$\frac{d\mathscr{P}_k^*}{d\alpha} = \frac{\mathscr{P}_e - \mathscr{P}_s}{2\sqrt{(\alpha - 1)(\alpha_e - 1)}} . \tag{5.26}$$

Unfortunately, this expression is not bounded as $\alpha \to 1$. This condition was imposed in the analysis given by Herrmann. In the present analysis, this feature would cause grave numerical problems. To eliminate the difficulty, in a small region near $\alpha = 1$ Eq. (5.23) is replaced by a linear section with bounded derivative. Define a distention α_ℓ by

$$\alpha_\ell = \frac{1}{\beta}(\beta - 1 + \alpha_e) \ , \tag{5.27}$$

where β is a constant greater than unity. The value of $\mathscr{P}_k^*(\alpha_\ell)$ is given the notation $\mathscr{P}_\ell$, where

$$\mathscr{P}_\ell = \mathscr{P}_s - \frac{(\mathscr{P}_s - \mathscr{P}_e)}{\sqrt{\beta}} \quad . \tag{5.28}$$

In the range $\alpha < \alpha_\ell$ the expression

$$\mathscr{P}_k^*(\alpha) = \mathscr{P}_\ell \left\{ \frac{\alpha - 1}{\alpha_\ell - 1} \right\} + \mathscr{P}_s \left\{ \frac{\alpha_\ell - \alpha}{\alpha_\ell - 1} \right\} \tag{5.29}$$

is employed in place of (5.23). The value of β is set in a data statement (β = 25 is in current use). The resulting function is shown in Fig. 5.1.

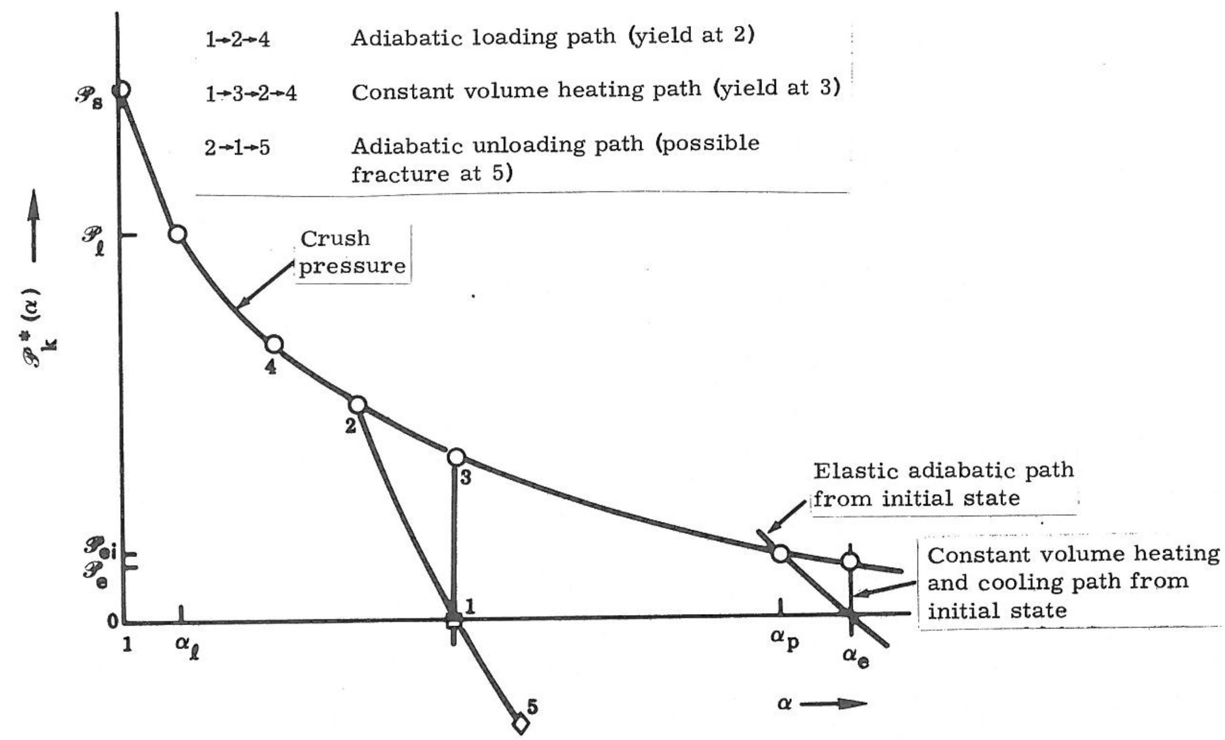

Fig. 5.1 Pressure-distention relation.

An alternate to (5.23) is

$$\mathscr{P}_k^*(\alpha) = \mathscr{P}_e + \hat{a}\,\ell n\left\{\frac{\alpha - 1}{\alpha_e - 1}\right\} , \tag{5.30}$$

which has been shown by Boade[12] to represent many materials better than does (5.23). In Boade's notation[12] the relation

$$\hat{a} = -\,1/a \tag{5.31}$$

is assumed, where a is the required input parameter. A correction similar to (5.25) is necessary. The result is

$$\mathscr{P}_e = \mathscr{P}_{ei} - \hat{a}\,\ell n\left\{\frac{\alpha_p - 1}{\alpha_\ell - 1}\right\} , \tag{5.32}$$

with α_p given by (5.24).

The analytical nature of (5.30) is even more aggravating than that of (5.23), since $\alpha \to 1$, in that the function as well as its derivative are unbounded. Here, a linear function is used between α_ℓ and 1, determined so that the function and its derivative are continuous at α_ℓ.

The result is

$$\mathscr{P}_\ell = \mathscr{P}_e - \hat{a}\,\ell n\beta , \tag{5.33}$$

and for $\alpha < \alpha_\ell$,

$$\mathscr{P}_k^*(\alpha) = \mathscr{P}_\ell - \hat{a}\left\{\frac{\alpha_\ell - \alpha}{\alpha_\ell - 1}\right\} . \tag{5.34}$$

This yields an ultimate crush strength $\left[P_k^*(1)\right]$ of

$$\mathscr{P}_\ell - \hat{a} = \mathscr{P}_e - \hat{a}(1 + \ell n\,\beta) . \tag{5.35}$$

Admittedly, this procedure is arbitrary; it is, however, no more so than either (5.23) or (5.30). By increasing the value of β, the linear section can be made as small as desired.

We now return to (5.22) to consider the function K(E). Unfortunately, little is known about the energy or temperature dependence of $\mathscr{P}_k$, since most experimental data are limited to the Hugoniot. It is even doubtful that the functional dependence of (5.22) is correct. One might suspect that K(E) = 1 is a good approximation until incipient melt and that K(E) $\rightarrow 0$ rapidly as melt is completed. This question deserves investigation, since the function K(E) (or the correct form of $\mathscr{P}_k(\alpha, T)$) may dominate the pressure generated in heating processes.

Two forms are currently available and controlled by the input parameter k_o'. If

$$k_o' > 0 \quad , \tag{5.36}$$

then

$$K(E) \equiv 1 \tag{5.37}$$

until completed melt. Generally, this is the form preferred by the authors. The other form is defined for

$$-2 \le k_o' \le -1 \quad , \tag{5.38}$$

since

$$K(E) = 1 - (2 + k_o')\left\{\frac{\frac{E}{\mathscr{E}_m} - \delta}{1 - \delta}\right\} + (1 + k_o')\left\{\frac{\frac{E}{\mathscr{E}_m} - \delta}{1 - \delta}\right\}^2 \quad , \quad \frac{E}{\mathscr{E}_m} > \delta \tag{5.39}$$

and

$$K(E) = 1 \quad \text{for} \quad \frac{E}{\mathscr{E}_m} \le \delta \quad , \tag{5.40}$$

where $\mathscr{E}_m$ is the energy of completed melt and δ is a constant. The reason for the change in (5.39) from Herrmann's paper is related to the nature of the CHART D equations of state. In all available types, the zero point of energy is taken to be at zero temperature and pressure. The normal room temperature reference point has a positive internal energy. To relate energies to the reference point would require additional storage. The value of δ is set in a data statement ($\delta = 0.5$ is in current use).

No true melt transition was included in the early forms of the CHART D EOS. Such an option is available in the current forms and can create a problem with the above model. If the material is maintained at pressure, a temperature considerably above the zero pressure melt temperature could result while the internal energy was less than $\mathscr{E}_m$. While the dynamic crushing behavior in this region is not well known, local melting should occur around the voids, and it would seem that the material could not be very strong. Clearly, further modifications are necessary.

At first glance one might be tempted to use (5.39) to describe this behavior. However, the relatively large volume changes incurred in constant pressure melting result in a decreased value of α and a greatly increased value of $\mathscr{P}_k^*(\alpha)$. This might indicate a stronger material even though K(E) was decreasing. As this behavior seems unrealistic, a cutoff has been coded which limits the value of $\mathscr{P}_k(\alpha, T)$ to be no larger than 1 atm for any material having a temperature in excess of that of reference melt. The 1-atm value was chosen for numerical reasons. The iteration schemes have trouble computing small values.

V-3. Plastic Region

If the value of P_n determined in the elastic calculation is in excess of the local crush pressure $\mathscr{P}_k(\alpha_n, T_n)$, the material has yielded and further calculations are necessary. The material is now required to lie on the crush pressure curve for some as yet unknown value of α. Let

$$P_n = \mathscr{P}_k\left(\frac{\rho_s}{\rho_n}, E\right). \tag{5.41}$$

This expression must now be solved with (5.11) where the two unknowns are ρ_s and T_n, with ρ_n a known constant. A two-variable Newton method is employed. At this point, (5.26) is used. While the E in (5.41) should be E_n as in (5.11), it has been found that it is not necessary to change K(E) for each iteration. Recalculating (5.39) and its derivative for each iteration seems to do little except slow the process when the results of several computational cycles are observed.

Upon completion of this iteration, a new distention is obtained from

$$\alpha_n = \frac{\rho_s}{\rho_n} . \tag{5.42}$$

If $\alpha_n > 1$, the computation is complete. In the case that (5.42) yields a value of $\alpha_n \leq 1$, complete crushing is assumed. The distention is then set to unity and a new solution of (5.11) is determined. It should be noted that the linear section of $\mathscr{P}_k^*$ provides a convenient extension to $\alpha < 1$ for the above iteration.

V-4. Constant Volume Heating and Melt of Porous Material

In many interesting problems, the porous material is heated to melt and above before being crushed by thermal pressures. Herrmann has pointed out that his model was not designed to treat this phenomenon.[11] The method of inclusion in CHART D is quite elementary and is possible only because of the improved equations of state.

If the energy E_n is greater than the melt energy, the distention ratio is set to unity. Since the total density is constant, the net effect of this procedure is to change at melt from a porous solid to a porous liquid model where the pores are filled with vapor. The fractions of vapor and liquid are determined by thermodynamic equilibrium relations. Another solution of (5.11) is determined where ρ_n is known and T_n is computed.

The path followed by a porous material undergoing constant volume heating is shown in Fig. 5.2. The points 1, 2, 3, and 4 represent porous solid states which really should not be shown on the thermodynamic diagram. The thermodynamic functions are determined from the solid equation of state at points 1', 2', 3', and 4'. Sufficient thermal pressure is generated at point 2 to begin closing the pores. When the form of (5.18) is examined, it is clear that during the heating stage between 1 and 2 neither the distention ratio nor the solid material density change. At point 2 the pressure is $\mathscr{P}_k(\alpha_e, E) = \mathscr{P}_e K(E)$. The additional specific energy over reference is approximately $\mathscr{P}_e / \Gamma_o \rho_s$, where Γ_o is the Grüneisen coefficient of the solid.

Between points 2 and 4 the computation in Section V-3 will yield small changes in distention even though the average material density remains constant. The solid material is expanding into the pores. In the model the function K(E) and the change in distention control the generated pressures. It is safe to say that the response in real materials is not particularly well understood in this region but it must be similar to that of the model.

At point 4 the material begins to melt. Following the discussion at the end of Section V-2, the pressure is now constrained to not exceed 1 atm. The temperature remains approximately constant until the melt is completed.

On completion of melt, the distention ratio is set to unity, and this bit of material is no longer treated as a porous material. At 5 and 6 the material is in a mixed-phase liquid-vapor state. Details of the equation of state in this region are discussed elsewhere.[4, 13] The pressure is determined by the vapor pressure of the liquid. In general, near melt the vapor pressure is essentially zero insofar as hydrodynamic processes are concerned. Relatively large amounts of energy can be added between points 5 and 6 with no, or very small, pressure increases. This is attributable to the energy sink in the melt transition and changing mass fractions of vapor and liquid at higher temperatures. Continued heating will condense the vapor and, at point 7 and above, the situation returns to normal in that only one phase exists. High pressures may be generated in this region.

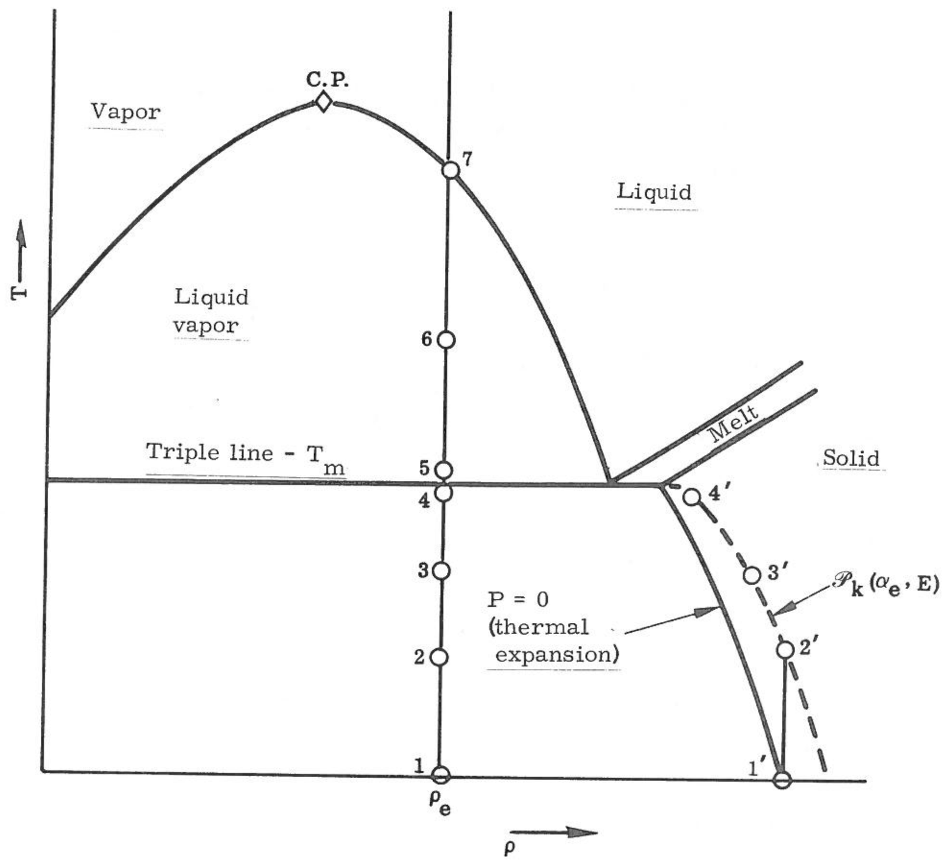

Fig. 5.2 Phase diagram of a simple material.

It should be clear that the preceding example is a highly idealized situation. In any real problem, gradients in heating rates would cause large departures from the assumption of constant volume. In Section V-6, the results of calculations of this type are discussed.

The employment of (5.18) in the current model instead of the corresponding expression given by Herrmann[10] was originally for numerical reasons. The new density ρ_n is known, while the new pressure P_n is not. An iteration is thereby eliminated and, to first-order under adiabatic loading, the methods are the same. However, slightly different response below the elastic yield point is encountered under nonadiabatic conditions. As previously pointed out, the current method yields the ratio of P/E at constant volume that is independent of distention below initial yield. Under Herrmann's method this ratio is dependent on the elastic wave velocity.[11] In Fig. 5.2 this corresponds to tilting the line 1'-2' slightly to the left (between 2' and the P = 0 curve). At present, there is little evidence to suggest that one form is superior to the other. Models can be constructed to yield qualitatively either behavior. However, it does not seem reasonable that P/E should be strongly dependent on the elastic wave velocity, with other material characteristics disregarded. This point deserves study. It is likely that (5.18) should be modified to include the effects of void shape, relaxation time, and static solid properties. One possible solution might be to add to the right-hand side of (5.18) a term depending on entropy differentials. This approach would require additional input information and has not been studied in detail.

V-5. Inputs, Storage, and Computational Procedure

Since the porous material calculation and the elastic-plastic calculation discussed in Section IV cannot be used for a particular material at the same time, the input variables for both are entered in the same location. As in Section IV, the input variables are named YIELD(I), I=1, 6 where, in the present situation,

YIELD(1) = ρ_{so} , Solid material density ,

YIELD(2) = k'_o , Section V-2 ,

YIELD(3) = -1 , Switch to distinguish as porous material ,

YIELD(4) = $\mathscr{P}_{ei}$, Eq. (5.25) or (5.32) ,

$$\text{YIELD(5)} = \begin{cases} \mathscr{P}_s , & \text{For Eq. (5.23)} , \\ -a , & \text{For Eq. (5.30)} , \end{cases}$$

YIELD(6) = C_{eo} , Eq. (5.14) ,

with ρ_{so} the initial solid material density and in agreement with the solid equation of state. During the initialization these inputs are modified and stored in the array YIELD(J, I), I=1, 8, where J is the material layer number. For the Jth porous material layer, the stored variables are

YIELD(J, 1) = α_e , Eq. (5.14) ,

YIELD(J, 2) = k'_o , Section V-2 ,

YIELD(J, 3) = $-\dfrac{C_{eo}}{C_{oo}}$, Eq. (5.14) ,

YIELD(J, 4) = $\mathscr{P}_e$, Eq. (5.25) or (5.32) ,

$$\text{YIELD(J, 5)} = \begin{cases} \mathscr{P}_s , & \text{for Eq. (5.23)} , \\ \hat{a} , & \text{for Eq. (5.30)} , \end{cases}$$

YIELD(J, 6) = ρ_{TL} ,

YIELD(J, 7) = T_m ,

YIELD(J, 8) = $\mathscr{G}_m$, Eq. (5.39) ,

where ρ_{TL} is the density of the liquid at the triple temperature T_m. The distention ratio for each zone is stored in an array DRATIO(I), where I is the zone number. The principal part of the coding is contained in a subroutine called FOAM. The flow of the calculation for each zone in a porous layer is shown in Fig. 5.3.

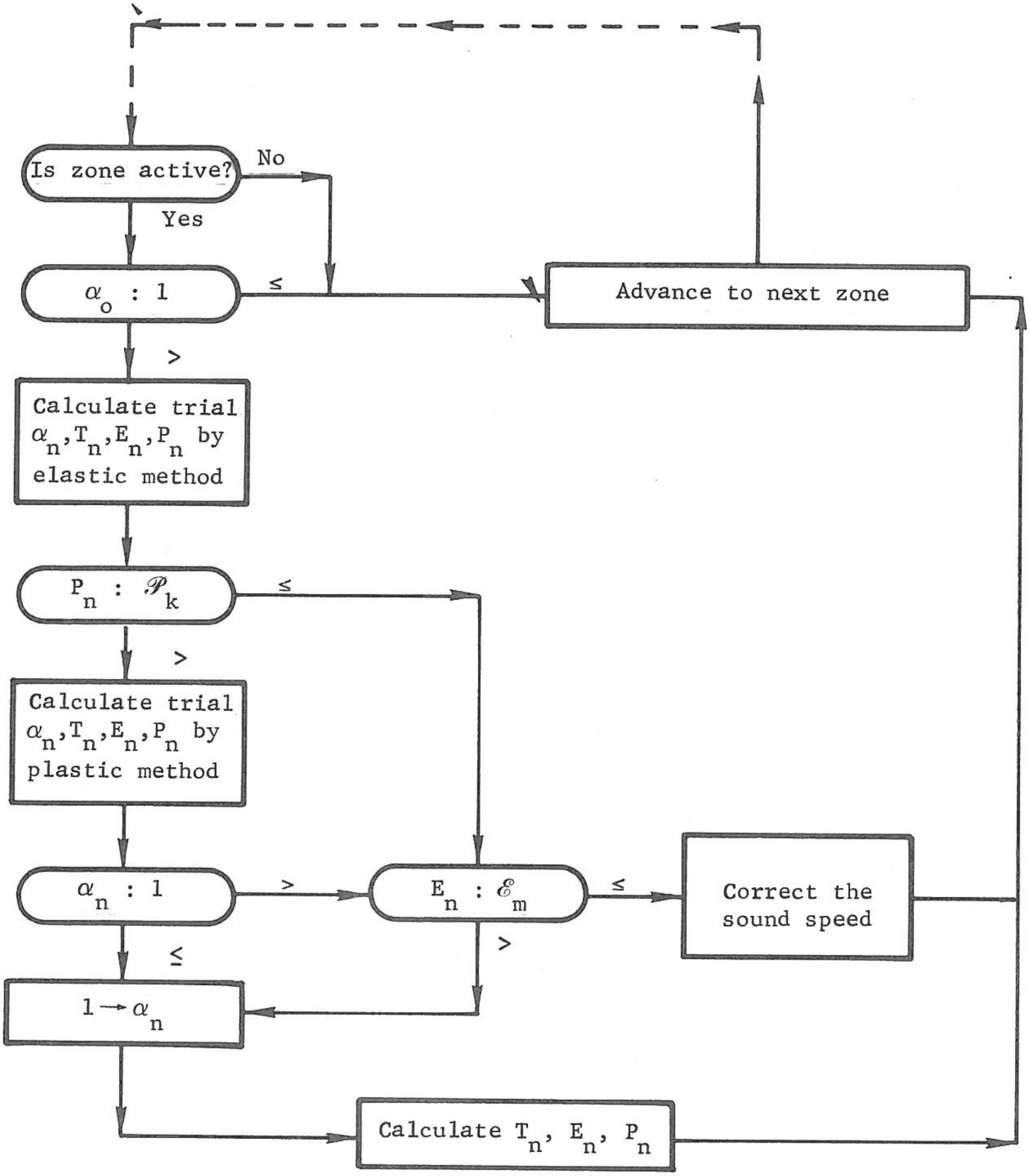

Fig. 5.3 Flow diagram for each zone in a porous material layer.

There is one limitation in CHART D that has nothing to do with the model. Because of a need to conserve storage, the array containing the burn fraction for high explosives was equivalenced to the array DRATIO. This means that porous high explosives are not allowed. With slight recoding this situation can be treated.

V-6. Sample Calculations

In order to illustrate the method, the results of two sample calculations are presented. These problems were run in the normal manner from the user LGO tape and the results given here were produced by the first attempt. No smoothing or polishing of the output was attempted. The results are similar to what should be expected in production runs.

The material chosen is pure aluminum with an analytic equation of state, including a melt transition. The features of the equation of state are discussed elsewhere.[4] In the listing in the appendix, these material data are stored under library number 6. The initial density of the foam is 2 gm/cc ($\alpha_e = 1.35$), and the porous constants are taken from one of Herrmann's papers.[10] The quadratic form of $\mathscr{P}_k^*(\alpha)$, Eqs. (5.23) and (5.37), are employed. The required inputs are:

$$\begin{aligned} \rho_{so} &= 2.7 \text{ gm/cc} \ , \\ k'_o &= 1 \ , \\ \mathscr{P}_{ei} &= 5 \times 10^8 \text{ dynes/cm}^2 \ , \\ \mathscr{P}_s &= 6.5 \times 10^9 \text{ dynes/cm}^2 \ , \\ C_{eo} &= 4.2 \times 10^5 \text{ cm/sec} \ . \end{aligned} \tag{5.43}$$

The specific energy and pressure at the initial foam and solid densities are shown in Figs. 5.4 and 5.5. The zero pressure melt transition can be seen slightly above 0.08 ev. Complete details are given in the authors' accompanying paper.[4]

The pressure below melt at 2 gm/cc is determined by the dynamic behavior. The values of $\mathscr{P}_e$ and $\mathscr{P}_s$ are shown in Fig. 5.5 since they control the pressure. The initial yield occurs near $\mathscr{P}_e$. It should be noted that K(E) also affects the result.

The Hugoniot may be determined from the state functions. In the present situation there are several cases to be considered. Either a one- or two-wave structure will be encountered, depending on the pressures involved. At sufficiently high pressures, the velocity of the plastic wave is greater than that of the elastic wave and, as a result, no elastic wave is formed. On the other extreme, with pressures less than the initial yield, no compaction wave exists. Intermediately, waves of complete and partial compaction are found.

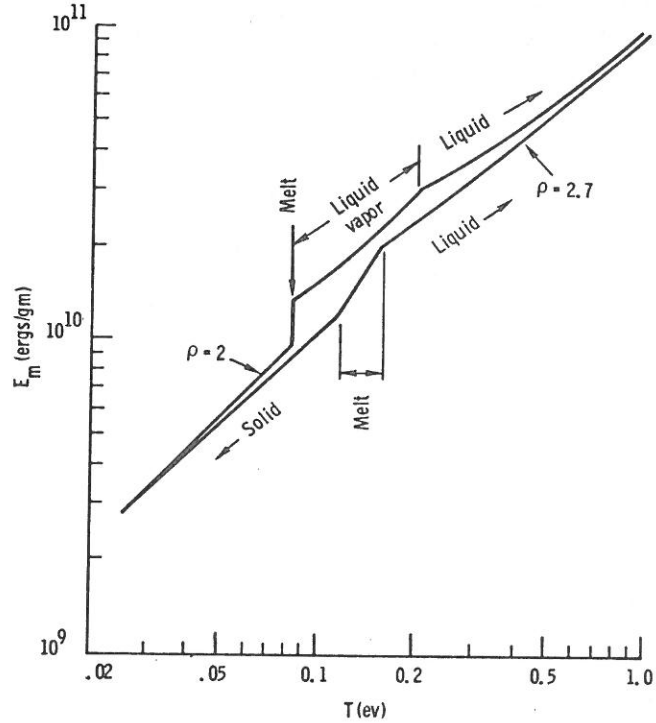

Fig. 5.4 Energy-temperature relation for aluminum at constant density.

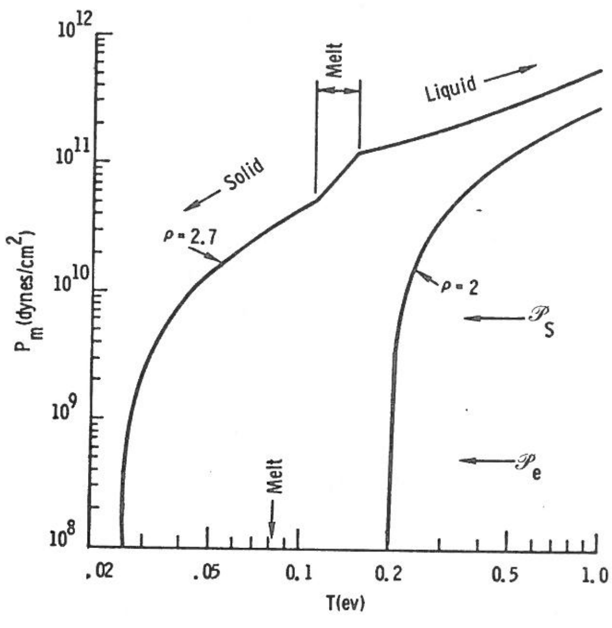

Fig. 5.5 Pressure-temperature relation for aluminum at constant density.

First consider the single-wave condition. The solution to the conservation laws is well known (the Rankine-Hugoniot relations):

$$E_2 - E_o = \frac{1}{2}(P_2 + P_o)\left\{\frac{\rho_2 - \rho_o}{\rho_o \rho_2}\right\} , \tag{5.44}$$

$$V_2 = \left\{\frac{P_2 - P_o}{\rho_o'\left(1 - \frac{\rho_o}{\rho_2}\right)}\right\}^{1/2} , \tag{5.45}$$

and

$$U_2 = V_2\left(1 - \frac{\rho_o}{\rho_2}\right) , \tag{5.46}$$

where o refers to initial conditions, 2 refers to postshock, U is the material velocity, and V is the shock velocity. Following the initial yield, this solution is correct only if V_2, given by (5.45), is greater than C_{eo}. Otherwise, an elastic wave will precede the compressional wave.

When pressures are in excess of yield but insufficient for the previous solution, a two-wave shock structure exists. The jump conditions must be applied at each front. With 1 referring to the immediate state, the result is also well-known:

$$U_1 = \frac{\mathscr{P}_e - P_o}{\rho_o C_{eo}} , \tag{5.47}$$

$$V_1 = C_{eo} , \tag{5.48}$$

$$\rho_1 = \rho_o / (1 - U_1/C_{eo}) , \tag{5.49}$$

$$E_1 - E_o = \frac{(\mathscr{P}_e + P_o) U_1}{2\rho_o C_{eo}} , \tag{5.50}$$

$$V_2 = U_1 + \left\{\frac{P_2 - \mathscr{P}_e}{\rho_1\left(1 - \frac{\rho_1}{\rho_2}\right)}\right\}^{1/2} , \tag{5.51}$$

$$U_2 = U_1 + (V_2 - U_1)(1 - \frac{\rho_1}{\rho_2}) , \tag{5.52}$$

and

$$E_2 - E_o = \frac{(\mathscr{P}_e + P_o)\, U_1}{2\rho_o C_{eo}} + \frac{1}{2}\,(P_2 + \mathscr{P}_e)\left\{\frac{\rho_2 - \rho_1}{\rho_1\,\rho_2}\right\} \quad . \tag{5.53}$$

This solution is appropriate only if $V_2 \le C_{eo}$.

The solutions of the above expressions can be obtained from the test program CKEOS for types of CHART D equations of state.[5] The explicit forms of $\mathscr{P}_k^*(\alpha)$ are not included, so that points with final states below complete crushing are not valid ($P < \mathscr{P}_s$). The results for the material under consideration are given in Tables 5.1 and 5.2.

The first problem chosen was that of a plane slab of the above material impacting a rigid wall with an initial velocity of 8.52966×10^4 cm/sec. This corresponds to one of the data sets shown in Table 5.2. In the space-fixed reference frame, the velocities of the elastic and plastic waves are 3.347×10^5 and 2.1245×10^5 cm/sec, respectively. The total thickness is 1.35 cm, with 300 equal-size zones. The results were plotted by the MASPLT program,[5] and samples are shown in Figs. 5.6 through 5.8. They are in good agreement with the exact solutions. The oscillations discussed earlier in this section may be observed in Fig. 5.6. As previously mentioned, an increase in the linear viscosity coefficient or a decrease in the time step will smooth the results. However, the first method of smoothing will increase the width of the shock front. The second will be costly in terms of computing time.

The second problem illustrates the nearly constant volume heating and melting of the same slab of material used in the previous example, although the slab is initially at rest. An energy deposition profile is assumed of the form

$$E_d = 0 \ , \qquad 0 \le X \le 0.3375 \text{ cm} \ ,$$

$$E_d = 2 \times 10^{10}\left\{\frac{X - 0.3375}{1.0125}\right\}\left(\frac{\text{ergs}}{\text{gm}}\right) \ , \quad 0.3375 \le X \le 1.35 \text{ cm} \ .$$

This shape was chosen to space somewhat equally the plotted data. A total of 200 zones was used. A constant deposition rate was employed over 10^{-7} seconds. Sample results are shown in Figs. 5.9 through 5.12 and are as discussed in Section V-4. It should be noted that the shape of the pressure pulse after the initial yield at $\mathscr{P}_e$ is quite dependent on the exact form of K(E). Since K(E) = 1 in this case, the maximum pressure generated was determined solely by the changing value of α in (5.23).

Table 5.1. Hugoniot for theoretical density aluminum.

HUGONIOT   DISTENTION= 1.00000E+00   AL   LIB 6

ETA	RHO	T	P	E	VS	VM	S
1.00000E+00	2.70000E+00	2.56779E-02	9.09424E-03	2.80514E+09	5.42397E+05	0.	1.11640E+11
1.07241E+00	2.89550E+00	3.00000E-02	6.51002E+10	3.61913E+09	5.97578E+05	4.03482E+04	1.13426E+11
1.12575E+00	3.03951E+00	3.50000E-02	1.23659E+11	5.36304E+09	6.40330E+05	7.15248E+04	1.20170E+11
1.16153E+00	3.13614E+00	4.00000E-02	1.68575E+11	7.14654E+09	6.70040E+05	9.31816E+04	1.28398E+11
1.18866E+00	3.20938E+00	4.50000E-02	2.05877E+11	8.85627E+09	6.93123E+05	1.10010E+05	1.36638E+11
1.21073E+00	3.26897E+00	5.00000E-02	2.38409E+11	1.04895E+10	7.12265E+05	1.23970E+05	1.44497E+11
1.22947E+00	3.31957E+00	5.50000E-02	2.67653E+11	1.20561E+10	7.28785E+05	1.36022E+05	1.51883E+11
1.24585E+00	3.36380E+00	6.00000E-02	2.94471E+11	1.35663E+10	7.43422E+05	1.46705E+05	1.58799E+11
1.26046E+00	3.40325E+00	6.50000E-02	3.19415E+11	1.50282E+10	7.56636E+05	1.56352E+05	1.65276E+11
1.27369E+00	3.43897E+00	7.00000E-02	3.42856E+11	1.64484E+10	7.68731E+05	1.65186E+05	1.71352E+11
1.28581E+00	3.47169E+00	7.50000E-02	3.65064E+11	1.78324E+10	7.79921E+05	1.73362E+05	1.77065E+11
1.29702E+00	3.50194E+00	8.00000E-02	3.86231E+11	1.91841E+10	7.90359E+05	1.80992E+05	1.82453E+11
1.30745E+00	3.53011E+00	8.50000E-02	4.06510E+11	2.05073E+10	8.00165E+05	1.88160E+05	1.87546E+11
1.31723E+00	3.55652E+00	9.00000E-02	4.26020E+11	2.18048E+10	8.09427E+05	1.94934E+05	1.92373E+11
1.32644E+00	3.58139E+00	9.50000E-02	4.44854E+11	2.30792E+10	8.18217E+05	2.01366E+05	1.96959E+11
1.33516E+00	3.60492E+00	1.00000E-01	4.63088E+11	2.43322E+10	8.26593E+05	2.07495E+05	2.01325E+11
1.35133E+00	3.64858E+00	1.10000E-01	4.98002E+11	2.67818E+10	8.42284E+05	2.18982E+05	2.09475E+11
1.36609E+00	3.68846E+00	1.20000E-01	5.31159E+11	2.91650E+10	8.56789E+05	2.29608E+05	2.16950E+11
1.37972E+00	3.72523E+00	1.30000E-01	5.62847E+11	3.14909E+10	8.70319E+05	2.39523E+05	2.23850E+11
1.39238E+00	3.75943E+00	1.40000E-01	5.93285E+11	3.37664E+10	8.83030E+05	2.48842E+05	2.30256E+11
1.40423E+00	3.79142E+00	1.50000E-01	6.22639E+11	3.59971E+10	8.95038E+05	2.57651E+05	2.36234E+11
1.41538E+00	3.82152E+00	1.60000E-01	6.51048E+11	3.81878E+10	9.06440E+05	2.66017E+05	2.41834E+11
1.42592E+00	3.84997E+00	1.70000E-01	6.78618E+11	4.03422E+10	9.17310E+05	2.73997E+05	2.47103E+11
1.43591E+00	3.87697E+00	1.80000E-01	7.05439E+11	4.24638E+10	9.27709E+05	2.81633E+05	2.52076E+11
1.44543E+00	3.90267E+00	1.90000E-01	7.31586E+11	4.45551E+10	9.37688E+05	2.88964E+05	2.56784E+11
1.45452E+00	3.92722E+00	2.00000E-01	7.57120E+11	4.66186E+10	9.47289E+05	2.96018E+05	2.61255E+11
1.46323E+00	3.95072E+00	2.10000E-01	7.82100E+11	4.86565E+10	9.56548E+05	3.02825E+05	2.65510E+11
1.47159E+00	3.97328E+00	2.20000E-01	8.06568E+11	5.06706E+10	9.65497E+05	3.09404E+05	2.69569E+11
1.47962E+00	3.99498E+00	2.30000E-01	8.30565E+11	5.26624E+10	9.74161E+05	3.15776E+05	2.73449E+11
1.48737E+00	4.01589E+00	2.40000E-01	8.54125E+11	5.46333E+10	9.82562E+05	3.21957E+05	2.77165E+11
1.49484E+00	4.03607E+00	2.50000E-01	8.77284E+11	5.65848E+10	9.90724E+05	3.27962E+05	2.80731E+11
1.50207E+00	4.05559E+00	2.60000E-01	9.00067E+11	5.85179E+10	9.98662E+05	3.33805E+05	2.84157E+11
1.50907E+00	4.07449E+00	2.70000E-01	9.22504E+11	6.04344E+10	1.00639E+06	3.39498E+05	2.87456E+11
1.51586E+00	4.09281E+00	2.80000E-01	9.44606E+11	6.23340E+10	1.01393E+06	3.45047E+05	2.90634E+11
1.52244E+00	4.11060E+00	2.90000E-01	9.66401E+11	6.42184E+10	1.02129E+06	3.50466E+05	2.93702E+11
1.52885E+00	4.12788E+00	3.00000E-01	9.87905E+11	6.60881E+10	1.02847E+06	3.55761E+05	2.96665E+11
1.53507E+00	4.14470E+00	3.10000E-01	1.00914E+12	6.79441E+10	1.03550E+06	3.60940E+05	2.99532E+11
1.54114E+00	4.16108E+00	3.20000E-01	1.03011E+12	6.97869E+10	1.04238E+06	3.66010E+05	3.02308E+11
1.54705E+00	4.17704E+00	3.30000E-01	1.05084E+12	7.16173E+10	1.04912E+06	3.70978E+05	3.04999E+11
1.55282E+00	4.19261E+00	3.40000E-01	1.07133E+12	7.34358E+10	1.05572E+06	3.75847E+05	3.07609E+11
1.55845E+00	4.20782E+00	3.50000E-01	1.09161E+12	7.52433E+10	1.06220E+06	3.80626E+05	3.10144E+11
1.56396E+00	4.22268E+00	3.60000E-01	1.11168E+12	7.70399E+10	1.06856E+06	3.85317E+05	3.12607E+11
1.56934E+00	4.23721E+00	3.70000E-01	1.13155E+12	7.88266E+10	1.07480E+06	3.89927E+05	3.15003E+11
1.57461E+00	4.25144E+00	3.80000E-01	1.15124E+12	8.06036E+10	1.08094E+06	3.94458E+05	3.17335E+11
1.57977E+00	4.26537E+00	3.90000E-01	1.17075E+12	8.23714E+10	1.08697E+06	3.98914E+05	3.19607E+11
1.58482E+00	4.27902E+00	4.00000E-01	1.19009E+12	8.41308E+10	1.09291E+06	4.03301E+05	3.21821E+11

Table 5.2. Hugoniot for distended aluminum, $\rho_o = 2.$

HUGONIOT DISTENTION= 1.35000E+00 AL LIB 6

ETA	RHO	T	P	E	VS	VM	S
7.40741E-01	2.00000E+00	2.56779E-02	9.09424E-03	2.80514E+09	4.20000E+05	0.	1.11640E+11
1.00474E+00	2.71280E+00	3.00000E-02	6.21128E+09	3.24379E+09	1.04980E+05	2.79134E+04	1.27236E+11
1.01069E+00	2.72887E+00	3.50000E-02	1.38435E+10	3.75801E+09	1.58839E+05	4.26968E+04	1.42422E+11
1.01643E+00	2.74436E+00	4.00000E-02	2.13992E+10	4.28250E+09	1.97112E+05	5.36940E+04	1.55458E+11
1.02197E+00	2.75932E+00	4.50000E-02	2.88810E+10	4.81621E+09	2.27944E+05	6.29242E+04	1.66862E+11
1.02733E+00	2.77379E+00	5.00000E-02	3.62916E+10	5.35817E+09	2.54162E+05	7.10716E+04	1.76986E+11
1.03251E+00	2.78778E+00	5.50000E-02	4.36339E+10	5.90756E+09	2.77160E+05	7.84663E+04	1.86081E+11
1.03753E+00	2.80134E+00	6.00000E-02	5.09100E+10	6.46364E+09	2.97748E+05	8.52966E+04	1.94331E+11
1.04240E+00	2.81449E+00	6.50000E-02	5.81226E+10	7.02578E+09	3.16450E+05	9.16828E+04	2.01875E+11
1.04713E+00	2.82726E+00	7.00000E-02	6.52739E+10	7.59339E+09	3.33627E+05	9.77064E+04	2.08821E+11
1.05173E+00	2.83967E+00	7.50000E-02	7.23661E+10	8.16597E+09	3.49538E+05	1.03426E+05	2.15255E+11
1.05620E+00	2.85173E+00	8.00000E-02	7.94009E+10	8.74305E+09	3.64381E+05	1.08886E+05	2.21245E+11
1.06055E+00	2.86348E+00	8.50000E-02	8.63808E+10	9.32423E+09	3.78308E+05	1.14119E+05	2.26847E+11
1.06478E+00	2.87492E+00	9.00000E-02	9.33074E+10	9.90914E+09	3.91439E+05	1.19154E+05	2.32106E+11
1.06891E+00	2.88607E+00	9.50000E-02	1.00183E+11	1.04974E+10	4.03872E+05	1.24011E+05	2.37062E+11
1.07294E+00	2.89695E+00	1.00000E-01	1.07008E+11	1.10889E+10	4.15687E+05	1.28708E+05	2.41746E+11
- - - - - - - -		TWO TO ONE-WAVE TRANSITION		- - - - - - - - - -			
1.08068E+00	2.91783E+00	1.10000E-01	1.20474E+11	1.22792E+10	4.37604E+05	1.37652E+05	2.50415E+11
1.08805E+00	2.93774E+00	1.20000E-01	1.33751E+11	1.34787E+10	4.57719E+05	1.46106E+05	2.58284E+11
1.09512E+00	2.95682E+00	1.30000E-01	1.46860E+11	1.46860E+10	4.76359E+05	1.54148E+05	2.65483E+11
1.10189E+00	2.97511E+00	1.40000E-01	1.59810E+11	1.58998E+10	4.93755E+05	1.61832E+05	2.72116E+11
1.10841E+00	2.99270E+00	1.50000E-01	1.72611E+11	1.71192E+10	5.10084E+05	1.69198E+05	2.78264E+11
1.11468E+00	3.00963E+00	1.60000E-01	1.85271E+11	1.83432E+10	5.25489E+05	1.76284E+05	2.83993E+11
1.12072E+00	3.02596E+00	1.70000E-01	1.97796E+11	1.95709E+10	5.40084E+05	1.83116E+05	2.89355E+11
1.12656E+00	3.04172E+00	1.80000E-01	2.10195E+11	2.08019E+10	5.53963E+05	1.89720E+05	2.94395E+11
1.13221E+00	3.05696E+00	1.90000E-01	2.22474E+11	2.20355E+10	5.67204E+05	1.96114E+05	2.99148E+11
1.13767E+00	3.07172E+00	2.00000E-01	2.34637E+11	2.32713E+10	5.79874E+05	2.02317E+05	3.03644E+11
1.14297E+00	3.08602E+00	2.10000E-01	2.46691E+11	2.45088E+10	5.92028E+05	2.08344E+05	3.07911E+11
1.14811E+00	3.09990E+00	2.20000E-01	2.58641E+11	2.57477E+10	6.03715E+05	2.14208E+05	3.11970E+11
1.15310E+00	3.11337E+00	2.30000E-01	2.70491E+11	2.69877E+10	6.14974E+05	2.19921E+05	3.15840E+11
1.15795E+00	3.12647E+00	2.40000E-01	2.82245E+11	2.82285E+10	6.25843E+05	2.25492E+05	3.19538E+11
1.16231E+00	3.13823E+00	2.50000E-01	2.97650E+11	2.97944E+10	6.40567E+05	2.32333E+05	3.24501E+11
1.16617E+00	3.14865E+00	2.60000E-01	3.18524E+11	3.18551E+10	6.60731E+05	2.41039E+05	3.31309E+11
1.17008E+00	3.15923E+00	2.70000E-01	3.39778E+11	3.39741E+10	6.80438E+05	2.49676E+05	3.37985E+11
1.17406E+00	3.16997E+00	2.80000E-01	3.61415E+11	3.61528E+10	6.99726E+05	2.58254E+05	3.44540E+11
1.17810E+00	3.18087E+00	2.90000E-01	3.83438E+11	3.83922E+10	7.18629E+05	2.66785E+05	3.50984E+11
1.18208E+00	3.19162E+00	3.00000E-01	4.02760E+11	4.03987E+10	7.34421E+05	2.74203E+05	3.56383E+11
1.18571E+00	3.20143E+00	3.10000E-01	4.13394E+11	4.15897E+10	7.42147E+05	2.78512E+05	3.59003E+11
1.18928E+00	3.21105E+00	3.20000E-01	4.23972E+11	4.27806E+10	7.49715E+05	2.82756E+05	3.61538E+11
1.19278E+00	3.22049E+00	3.30000E-01	4.34497E+11	4.39713E+10	7.57133E+05	2.86936E+05	3.63995E+11
1.19621E+00	3.22976E+00	3.40000E-01	4.44971E+11	4.51619E+10	7.64409E+05	2.91056E+05	3.66377E+11
1.19958E+00	3.23886E+00	3.50000E-01	4.55396E+11	4.63523E+10	7.71550E+05	2.95117E+05	3.68690E+11
1.20289E+00	3.24781E+00	3.60000E-01	4.65772E+11	4.75426E+10	7.78562E+05	2.99124E+05	3.70938E+11
1.20615E+00	3.25660E+00	3.70000E-01	4.76104E+11	4.87328E+10	7.85452E+05	3.03076E+05	3.73123E+11
1.20935E+00	3.26525E+00	3.80000E-01	4.86392E+11	4.99230E+10	7.92225E+05	3.06979E+05	3.75249E+11
1.21250E+00	3.27376E+00	3.90000E-01	4.96637E+11	5.11132E+10	7.98886E+05	3.10831E+05	3.77320E+11
1.21561E+00	3.28213E+00	4.00000E-01	5.06844E+11	5.23035E+10	8.05440E+05	3.14638E+05	3.79338E+11

ELASTIC WAVE DATA

RHO= 2.00283849E+00

U= 5.95238095E+02

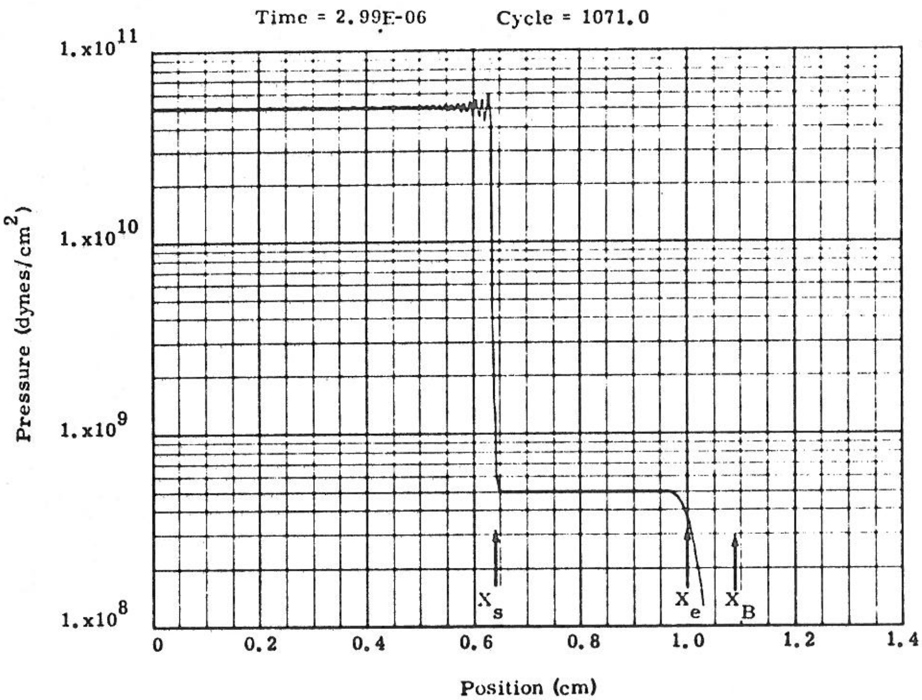

Fig. 5.6 Sample results from test problem 1. X_S, X_e and X_B are the exact values of the positions of the shock front, elastic wave, and back surface.

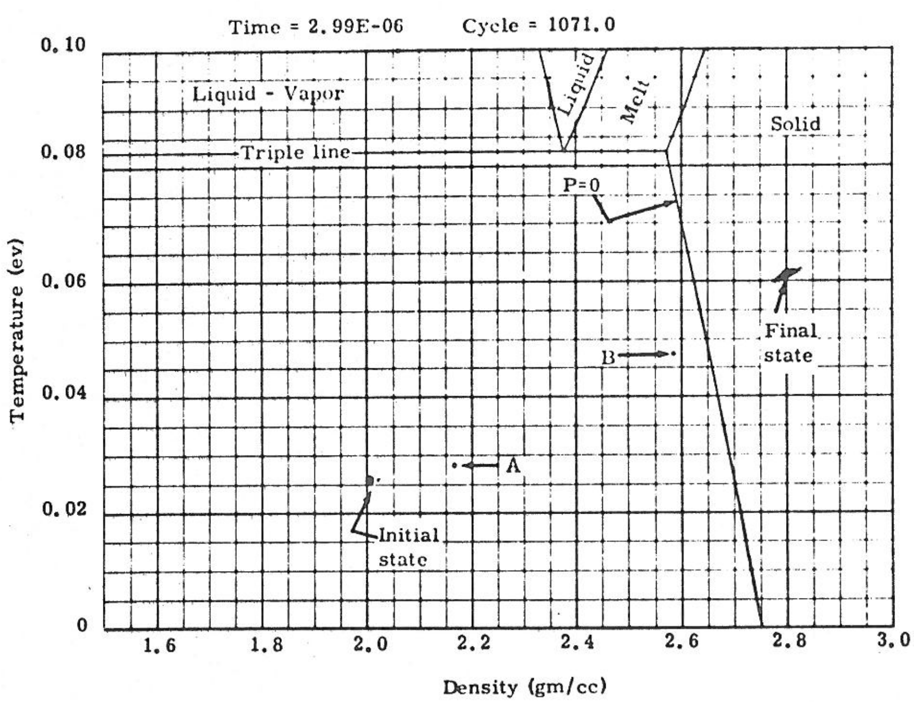

Fig. 5.7 Sample results from test problem 1. A and B are zones being crushed.

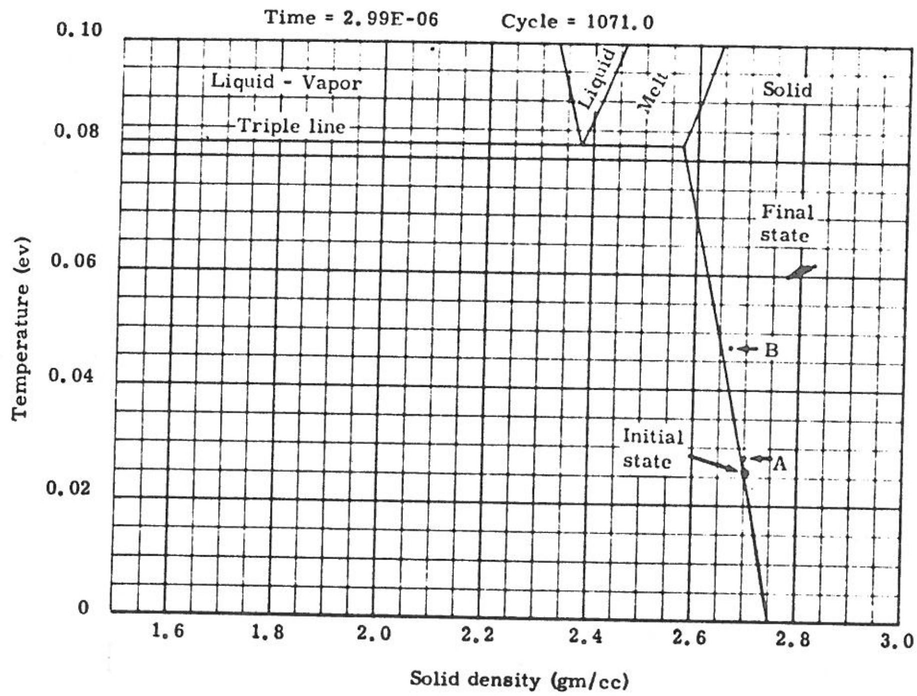

Fig. 5.8 Sample results from test problem 1.
A and B are zones being crushed.

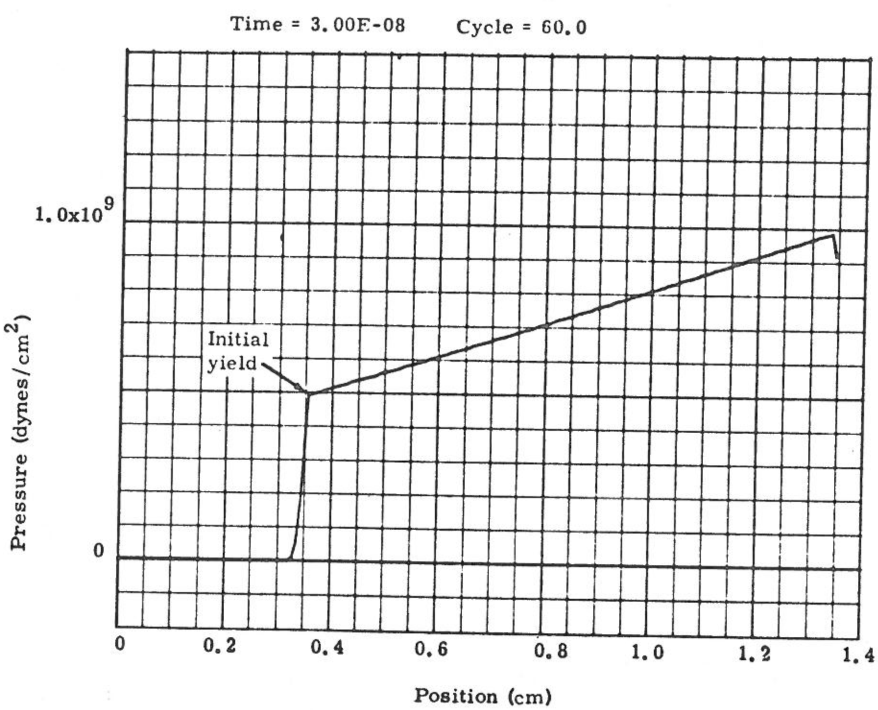

Fig. 5.9 Sample results from test problem 2.
No material has melted at this time.

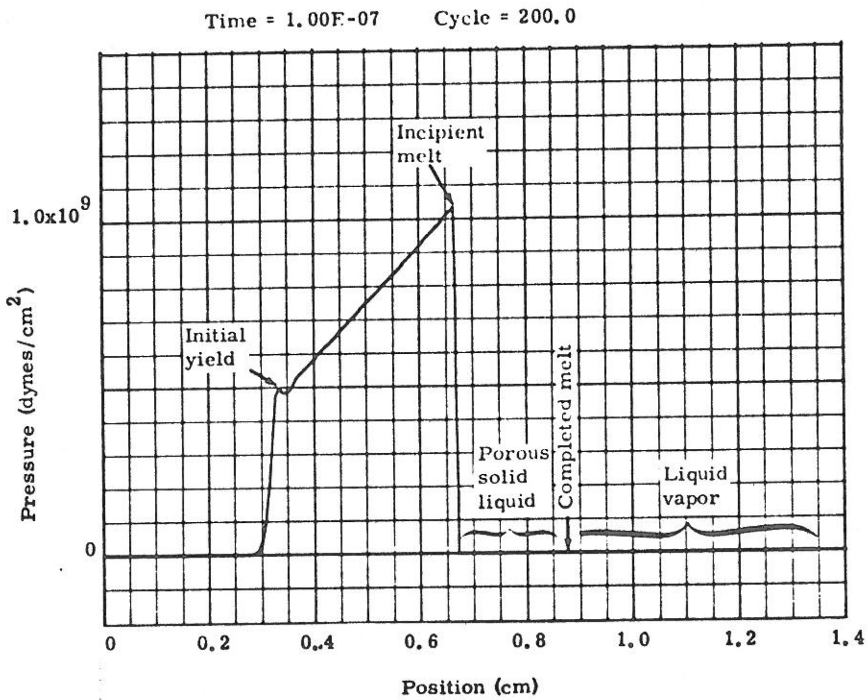

Fig. 5.10 Sample results from test problem 2.

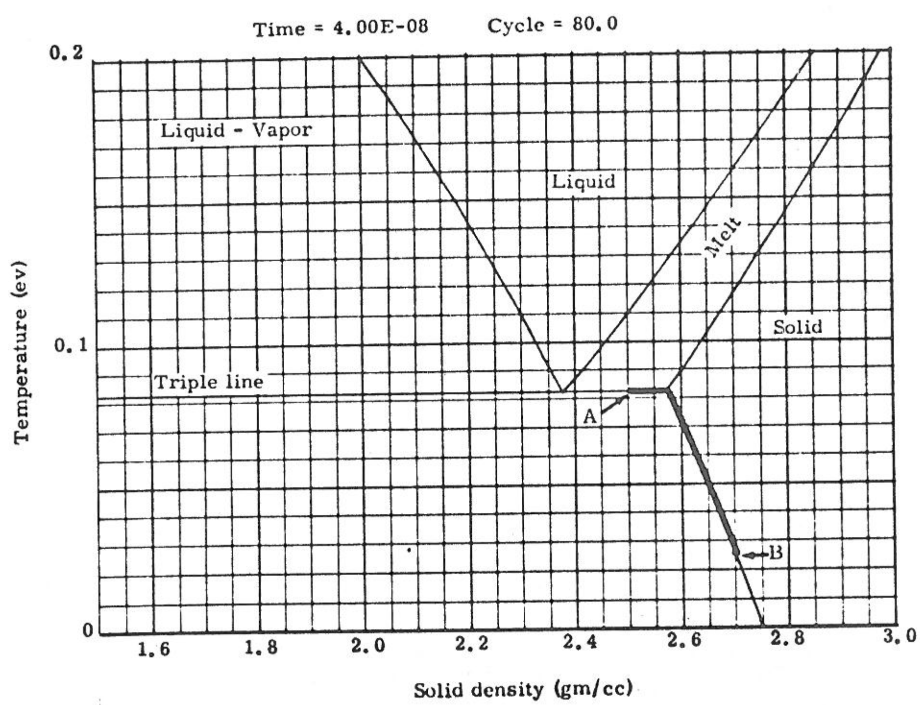

Fig. 5.11 Sample results from test problem 2. A represents the material at X=1.35 cm and B the initial state. The point of initial yield is near B.

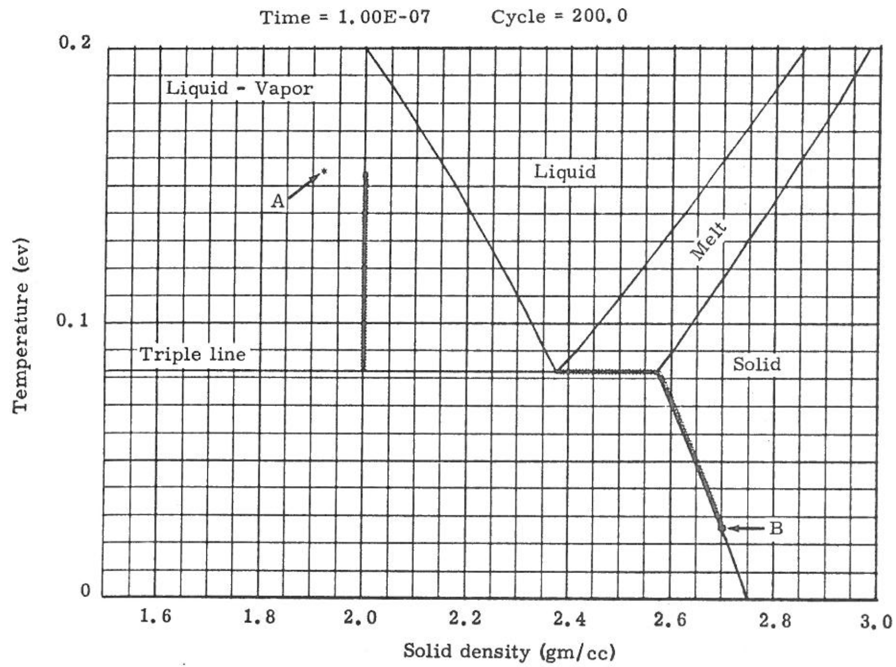

Fig. 5.12 Sample results from test problem 2. A represents the material at X=1.35 cm and B the initial state. The time is the same as that in Fig. 5.10

VI. TABULAR EQUATIONS OF STATE AND OPACITIES

Two forms of equations of state (EOS) are available in CHART D. The inline or analytic EOS is described in an accompanying report.[4] These forms are easy to use and input and are very flexible. However, there are several disadvantages. For complex calculations the tabular form discussed here may increase the total computational speed by a factor of two or more. It is also impossible to represent data which are too complex in the in-line calculation. The best possible radiation opacities are an example. The tabular form fills this need. On the other hand, the tables are difficult to produce and are quite inflexible. The user has no control over the thermodynamic properties and generally must depend on someone else to produce the table.

The actual numbers employed for the thermodynamic functions are generated, edited, and stored on tape external to CHART D. CHART D simply reads the tape and interpolates for the appropriate values. Here, the interpolation methods and storage arrangements are given. Details of the sources of the numbers are found elsewhere. Figures 6.1 and 6.2 illustrate a typical thermodynamic surface for a material which is a solid at standard conditions.

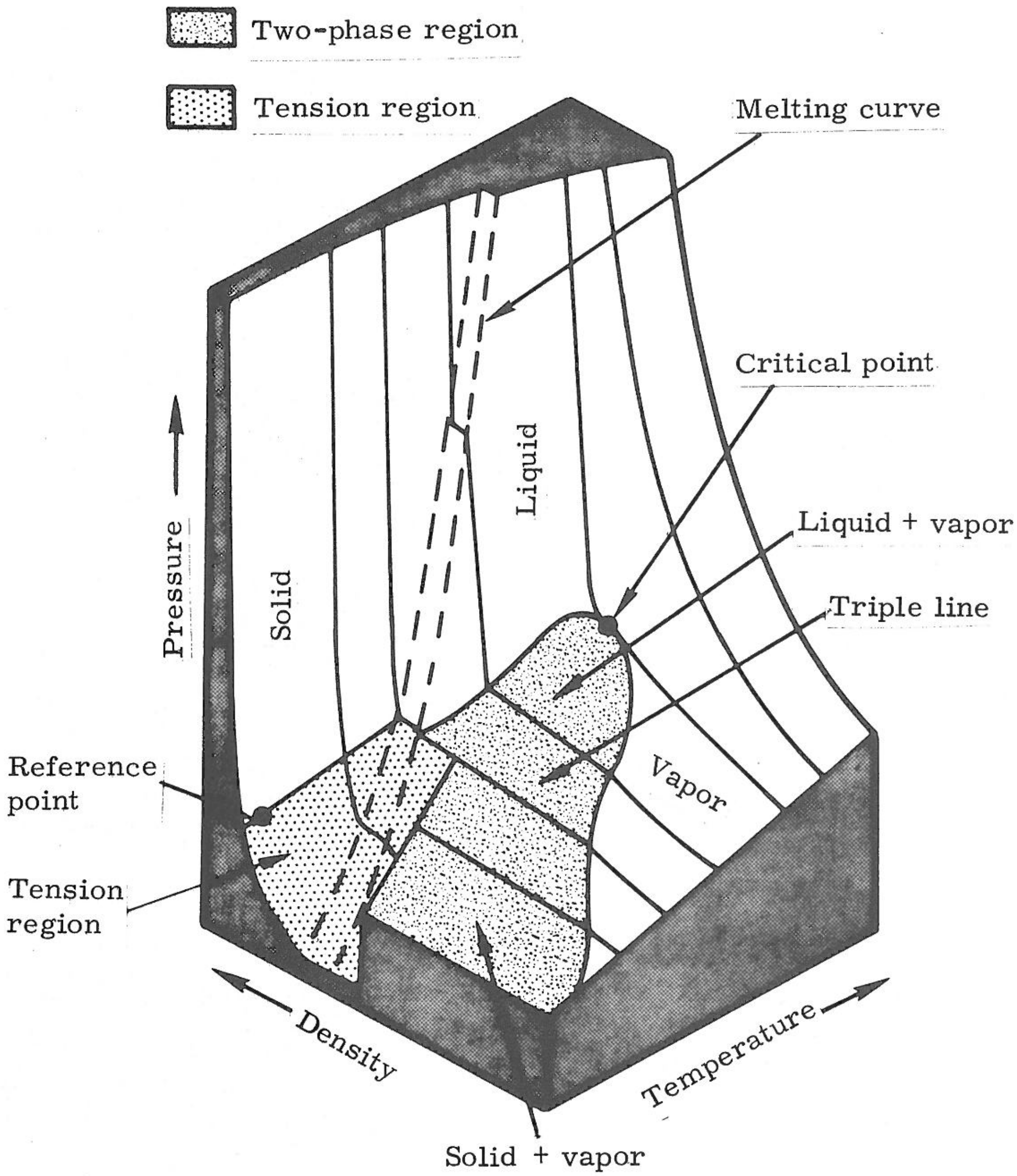

Fig. 6.1 A typical P, ρ, T thermodynamic surface.

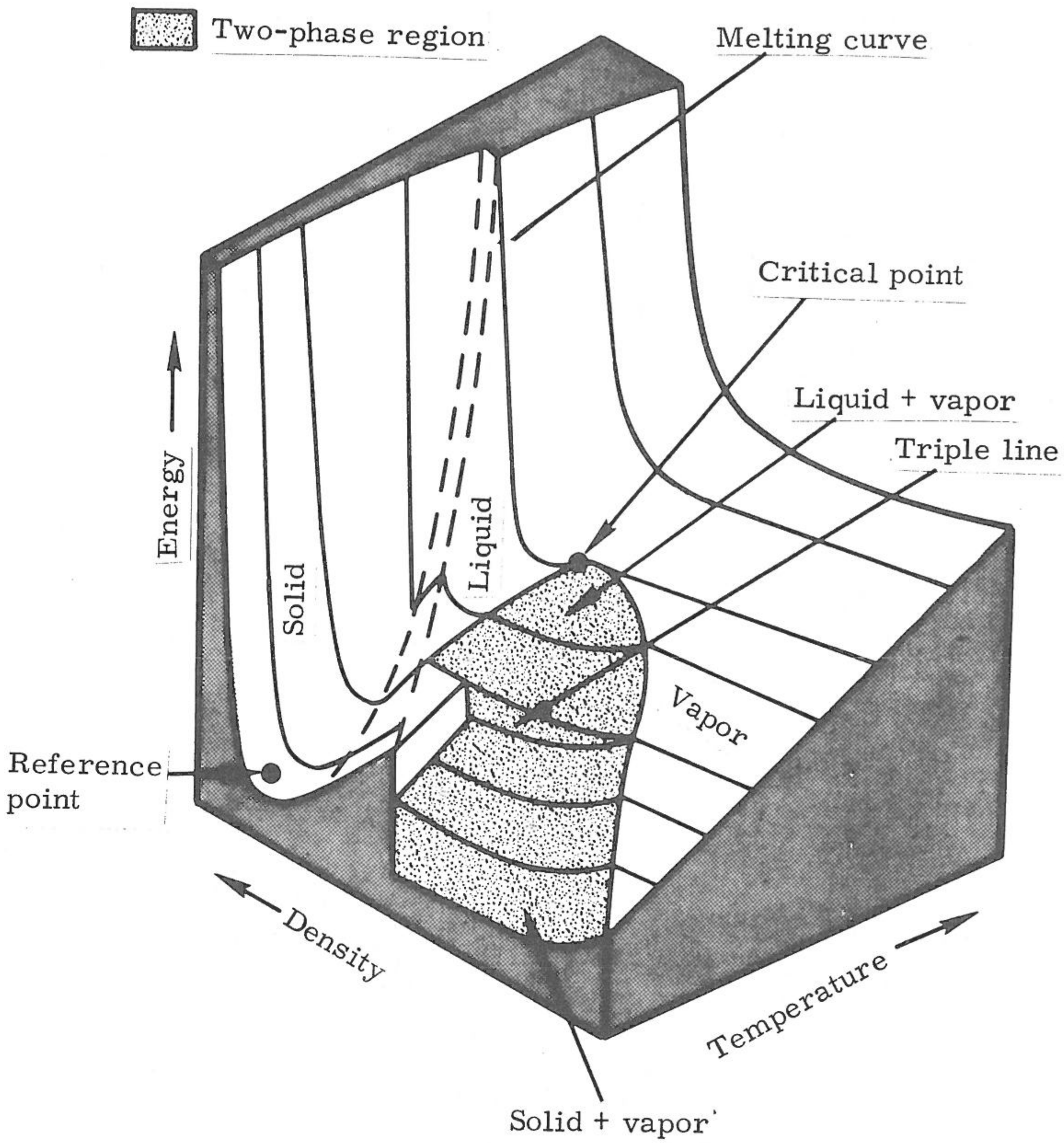

Fig. 6.2 A typical E, ρ, T thermodynamic surface.

Ideally, all thermodynamic information could be obtained from a single fitted function if the appropriate variables were employed. For a code using ρ and T as independent variables, the natural choice would be the Helmholtz free energy F. All of the required quantities could then be computed by using the relations

$$P = \rho^2 \frac{\partial F}{\partial \rho} \quad , \tag{6.1}$$

$$S = - \frac{\partial F}{\partial T} \quad , \tag{6.2}$$

$$E = F + TS \quad , \tag{6.3}$$

$$C_v = \frac{\partial E}{\partial T} = - T \frac{\partial^2 F}{\partial T^2} \quad , \tag{6.4}$$

$$\frac{\partial P}{\partial T} = \rho^2 \frac{\partial^2 F}{\partial \rho \partial T} \quad , \tag{6.5}$$

and

$$\frac{\partial P}{\partial \rho} = 2\rho \frac{\partial F}{\partial \rho} + \rho^2 \frac{\partial^2 F}{\partial \rho^2} \quad , \tag{6.6}$$

where S is the specific entropy. The bulk sound speed is defined as

$$C_s = \sqrt{\left(\frac{\partial P}{\partial \rho}\right)_s} \quad . \tag{6.7}$$

From various thermodynamic relations, it can be shown that

$$C_s = \left\{ \left(\frac{\partial P}{\partial \rho}\right)_T + \frac{T\left(\frac{\partial P}{\partial T}\right)_\rho^2}{\rho^2 C_v} \right\}^{1/2} \quad . \tag{6.8}$$

It then follows, from the function F(ρ, T), that all desired information is available. A fit of this type was included in the code reported on in R1. However, the mathematical problem of fitting a function in two dimensions is difficult enough in itself. The above problem also places strong requirements on all five of the first and second derivatives of this function. As a result, the method of R1 was discarded as the complexity of the data was increased and more effort was required to fit the data. Generation of the input data is still done in the above manner. Now, however, separate and considerably simpler fits are used for P, E, S, and C_s.

It is first convenient to separate the thermodynamic functions into two parts in which one part describes the zero temperature isotherm, or cold component, and the other describes the complete temperature dependence. This has several advantages that will later be apparent. Let the subscript c represent the cold functions and t the thermal components. The free energy is written as

$$F_t(\rho, T) = F(\rho, T) - E_c(\rho) \quad . \tag{6.9}$$

It then follows that

$$P_t(\rho, T) = P(\rho, T) - P_c(\rho) \quad , \tag{6.10}$$

$$S_t(\rho, T) = S(\rho, T) \quad , \tag{6.11}$$

$$E_t(\rho, T) = E(\rho, T) - E_c(\rho) \quad , \tag{6.12}$$

$$C_{vt} = \frac{\partial E_t}{\partial T} = \frac{\partial E}{\partial T} = C_v \quad , \tag{6.13}$$

$$\frac{\partial P_t}{\partial T} = \frac{\partial P}{\partial T} \quad , \tag{6.14}$$

and

$$\frac{\partial P_t}{\partial \rho} = \frac{\partial P}{\partial \rho} - \frac{dP_c}{d\rho} \quad , \tag{6.15}$$

where the relation

$$P_c(\rho) = \rho^2 \frac{dE_c}{d\rho} \tag{6.16}$$

is assumed. The thermal component functions vanish as $T \to 0$. In fact, all of the functions shown by Eqs. (6.10) through (6.15) are positive for $T > 0$. As can be observed in Section VI-1, this is useful for logarithmic interpolation. The cold terms are detailed in Section VI-2.

VI-1. Thermal Components

The first step is to define a density-temperature mesh. The size and spacing of the mesh is determined by the region of interest and the accuracy desired of the interpolated values. Such a grid is shown in Fig. 6.3, with the index i representing the density ρ_i and j representing the temperature T_j. A mesh point is given by the pair (ρ_i, T_j). For storage purposes it is convenient to give each mesh point a single index k defined by

$$k = (i - 1) N_T + j \ , \tag{6.17}$$

where

$$i = 1, \ldots, N_\rho \tag{6.18}$$

and

$$j = 1, \ldots, N_T \ . \tag{6.19}$$

The value N_T is the total number of T mesh lines and N_ρ is the total number of ρ mesh lines. By sweeping through the mesh, k takes on all values from 1 to $N_\rho N_T$. At each of these mesh points, values of $\ell n(P_t)$, $\ell n(E_t)$, S_t, $\ell n(C_s)$, and $\ell n(K_r)$ are stored in one-dimensional arrays referenced by the index k.

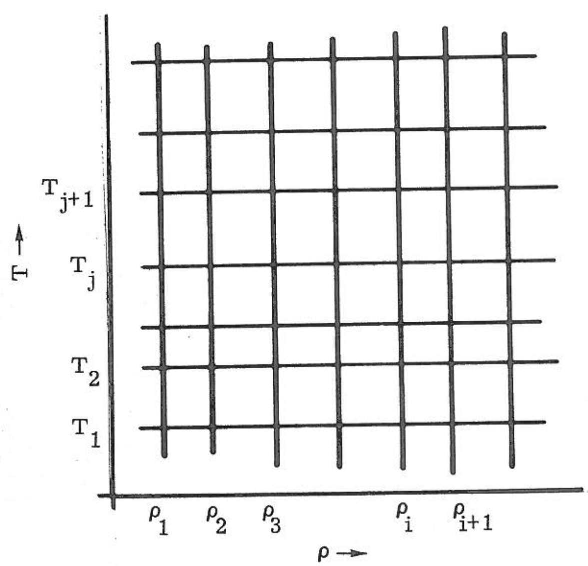

Fig. 6.3 ρ-T mesh for tabular EOS.

When the EOS subroutine is called with ρ and T values, a fast search system first locates the grid lines bounding the given numbers. The method remembers the last known position in the mesh of this bit of material and searches outward from that point. Let

$$X = \ell n\ (T) \tag{6.20}$$

and

$$Y = \ell n\ (\rho)\ . \tag{6.21}$$

The interpolation formula is a bilinear form in X and Y. For a function Φ the result is

$$\Phi = \Big[\Big\{\Phi_{i,j}\ (X_{i+1} - X) + \Phi_{i+1,j}\ (X - X_i)\Big\}\ (Y_{j+1} - Y)$$

$$+ \Big\{\Phi_{i,j+1}\ (X_{i+1} - X) + \Phi_{i+1,j+1}\ (X - X_i)\Big\}\ (Y - Y_j)\Big] \tag{6.22}$$

$$\Big/\Big\{(Y_{j+1} - Y_j)\ (X_{i+1} - X_i)\Big\}\ ,$$

where the true index of Φ in the storage array is determined by (6.17).

Five independent interpolations are made, one each for $\ell n(P_t)$, $\ell n(E_t)$, S_t, $\ell n(C_s)$, and $\ell n(K_r)$. The required derivatives C_{vt} and $\frac{\partial P_t}{\partial \rho}$ can easily be determined from the appropriate interpolation. The value of $\frac{\partial P_t}{\partial \rho}$ is not required because of the independent interpolation for C_s.

For some materials, the results are improved if the energy is shifted upward before storage and interpolation, and downward after. This function is performed by the variable E_{mov} and has only been used on EOS with large groups of molecules.

VI-2. Zero-Temperature Isotherm

The dependences of E_c and P_c are easier to treat than those of the thermal components. Several systems were tried and found usable. The best system, however, seemed to be the analytic forms contained in the EOS program THERMOS,[13] which is the main source of EOS data for CHART D. These expressions are somewhat similar to those contained in the analytic EOS package.[4] The coefficients in the relations are calculated in THERMOS and passed to CHART D in an array called A. Methods of determining the coefficients and justification of the expressions are given elsewhere. Here, only the forms are detailed; however, it should be pointed out that they are flexible enough to fit nearly any experimental data.

Let ρ_{oo} be the density at zero temperature and pressure. The compression is

$$\eta = \rho/\rho_{oo} \ . \tag{6.23}$$

Three compression regions are defined:

Region 1 , $\eta_1 \leq \eta \leq \eta_2$,

Region 2, $\eta > \eta_2$,

Region 3, $\eta < \eta_1$,

where $\eta_1 < 1$ and $\eta_2 > 1$. In each region a different form is taken for P_c. The value E_c may be determined by integration of (6.16). The expressions are:

Region 1

$$P_c = \eta^{2/3}\left\{A_7 \exp(-A_8\eta^{-1/3}) - A_9 \exp(-A_{10}\eta^{-1/3})\right\} \ , \tag{6.24}$$

$$E_c = A_{16}\left\{\exp(-A_8\eta^{-1/3}) - A_{14}\right\} - A_{17}\left\{\exp(-A_{10}\eta^{-1/3}) - A_{15}\right\} \ ; \tag{6.25}$$

Region 2

$$P_c = A_1\eta^{5/3}\exp(-A_2\eta^{-1/3}) - A_3 - A_4\eta^{1/3} - A_5\eta^{2/3} - A_{19}\eta \ , \tag{6.26}$$

$$\begin{aligned} E_c = A_6 + \frac{1}{\rho_{oo}}\Big\{&3A_1\eta^{2/3}\,\mathscr{E}_3\,(A_2\eta^{-1/3}) + A_3\eta^{-1} + \frac{3}{2}A_4\eta^{-2/3} \\ &+ 3A_5\eta^{-1/3} - A_{19}\,\ell n(\eta)\Big\} \ ; \end{aligned} \tag{6.27}$$

Region 3

$$\begin{aligned} P_c = {}&\eta^{2/3}\left\{A_7\exp(-A_8\eta^{-1/3}) - A_9\exp(-A_{10}\eta^{-1/3})\right\} \\ &+ A_{11}\,(1 - \frac{\eta}{\eta_1})^3\,\eta^2\,(\frac{\eta}{\eta_1} - 0.2) \ , \end{aligned} \tag{6.28}$$

$$E_c = A_{16} \left\{ \exp(-A_8 \eta^{-1/3}) - A_{14} \right\} - A_{17} \left\{ \exp(-A_{10} \eta^{-1/3}) - A_{15} \right\}$$

$$- A_{18} \, \eta \, (1 - \frac{\eta}{\eta_1})^4 \; ; \tag{6.29}$$

where

$$A_{14} = \exp(- A_8) \; , \tag{6.30}$$

$$A_{15} = \exp(- A_{10}) \; , \tag{6.31}$$

$$A_{16} = \frac{3 \, A_7}{\rho_{oo} A_8} \; , \tag{6.32}$$

$$A_{17} = \frac{3 \, A_9}{\rho_{oo} \, A_{10}} \; , \tag{6.33}$$

$$A_{18} = \frac{A_{11}}{5 \, \rho_{oo}} \; , \tag{6.34}$$

and

$$\mathscr{E}_3 (x) = \int_1^\infty t^{-3} \, e^{-xt} \, d\,t \tag{6.35}$$

is the third exponential integral. It should be noted that in Region 1 a Morse type of interaction is assumed. In Region 3, the additional term can be used to yield a Van der Waals interaction at low densities. As stated before, justification of these forms is given elsewhere.[4, 13] Currently, no other forms are available. There is, however, a dummy array in the tape format and storage system so that modifications can be easily included if the need arises.

VI-3. Mixed-Phase Regions

A typical phase diagram of a simple material is shown in Fig. 6.4. The largest and most difficult to treat in the sense of fitting of the mixed-phase regions on the state surface are the liquid-vapor and solid-vapor coexistent regions. The liquid-solid (melting) and any solid-solid phase transitions normally involve volume changes of less than 5 or 10 percent. On the other hand, boiling of liquid or solid (sublimation) typically involves volume differentials of many orders of magnitude. For this reason a much more detailed treatment is given.

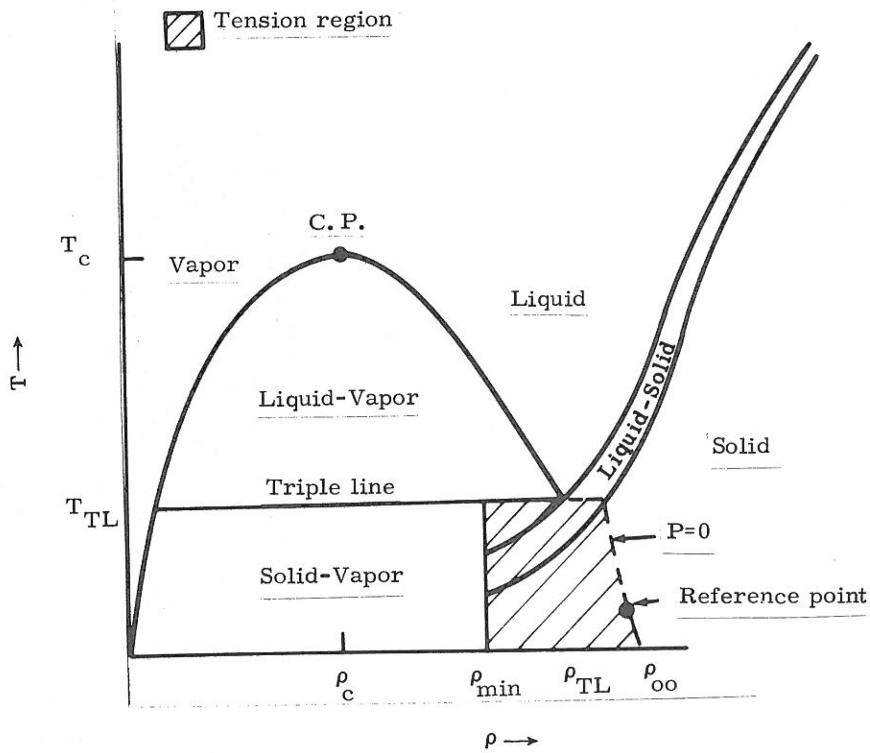

Fig. 6.4 Phase diagram of a simple material.

The procedure chosen to attack this problem is similar to that employed in the analytic EOS package.[4] Fits are generated to the phase boundary densities in the form $\rho_{liquid} = \rho_\ell(T)$ and $\rho_{vapor} = \rho_v(T)$. The points used to determine the fit are calculated by matching the Gibbs potentials and pressures of the vapor and liquid (or solid) phases at the same temperature. The density and temperature at the critical point are ρ_c and T_c.

The temperature mesh used for this is related to that of Section VI-1. Each interval $X_i < X \le X_{i+1}$ is divided into four equal parts, where $X = \ell n(T)$. At each of these temperatures, the values of $\ell n(\rho_\ell)$ are stored in arrays β_{1i}, β_{2i}, β_{3i}, and β_{4i}, with $\ell n(\rho_v)$ in β_{5i}, β_{6i}, β_{7i}, and β_{8i}. A linear logarithmic interpolation is employed for intermediate temperatures.

When $T_i < T < T_c < T_{i+1}$, another interpolation is necessary. Here the forms are

$$\rho_\ell = \rho_c + \beta_{10} (T_c - T)^{1/3} \tag{6.36}$$

and

$$\rho_v = \rho_c - \beta_{12} (T_c - T)^{1/3} , \tag{6.37}$$

where

$$\beta_{10} = \{\rho_\ell(T_i) - \rho_c\}/(T_c - T_i)^{1/3} \tag{6.38}$$

and

$$\beta_{12} = \{\rho_c - \rho_v(T_i)\}/(T_c - T_i)^{1/3} \ . \tag{6.39}$$

At lower temperature when $0 < T < T_1$, the expressions are

$$\rho_\ell = \rho_{oo} + \beta_9 T \tag{6.40}$$

and

$$\rho_v = \beta_{11} T \ , \tag{6.41}$$

where

$$\beta_9 = \{\rho_\ell(T_1) - \rho_{oo}\}/T_1 \tag{6.42}$$

and

$$\beta_{11} = \rho_v(T_1)/T_1 \ . \tag{6.43}$$

Clearly, no relations are necessary for the region $T \geq T_c$.

When the EOS subroutines are called with ρ and T defined, a quick check is made to determine if the values are anywhere near the mixed-phase region. If they are, the proper interpolation and component phase densities are determined. The inequality

$$\rho_v < \rho < \rho_\ell \tag{6.44}$$

must be satisfied for the mixed-phase relations to apply.

The mass fractions of vapor and liquid are

$$M_v = \frac{\rho_v}{\rho}\left\{\frac{\rho_\ell - \rho}{\rho_\ell - \rho_v}\right\} \tag{6.45}$$

and

$$M_\ell = 1 - M_v = \frac{\rho_\ell}{\rho}\left\{\frac{\rho - \rho_v}{\rho_\ell - \rho_v}\right\} \ . \tag{6.46}$$

The mixed-phase thermodynamic functions are

$$E = M_\ell E_\ell + M_v E_v \quad , \tag{6.47}$$

$$S = M_\ell S_\ell + M_v S_v \quad , \tag{6.48}$$

$$P = P_v = P_\ell \quad , \tag{6.49}$$

$$\frac{\partial P}{\partial \rho} = 0 \quad , \tag{6.50}$$

$$\frac{\partial P}{\partial T} = \left\{ \frac{\rho_\ell \cdot \rho_v}{\rho_\ell - \rho_v} \right\} \left\{ S_v - S_\ell \right\} \quad , \tag{6.51}$$

and

$$C_v = \frac{\partial E}{\partial T} = (E_\ell - E_v) \frac{dM_\ell}{dT}$$

$$+ M_\ell \frac{dE_\ell}{dT} + M_v \frac{dE_v}{dt} \quad . \tag{6.52}$$

Equation (6.51) is the Clausius-Clapeyron relation. The total derivatives in (6.52) are determined along the two-phase boundaries. With some effort, it can be shown that

$$\frac{dE_i}{dT} = C_{vi} + \frac{1}{\rho_i^2} \left\{ P_i - T \frac{\partial P_i}{\partial T} \right\} \frac{d\rho_i}{dT} \quad , \tag{6.53}$$

where i represents either ℓ or v, and $\frac{d\rho_i}{dT}$ is determined from the boundary interpolation, and

$$\frac{dM_\ell}{dT} = \frac{1}{\rho(\rho_v - \rho_\ell)} \left\{ \rho_\ell \left[\frac{\rho_\ell - \rho}{\rho_\ell - \rho_v} \right] \frac{d\rho_v}{dT} + \rho_v \left[\frac{\rho - \rho_v}{\rho_\ell - \rho_v} \right] \frac{d\rho_\ell}{dT} \right\} \quad . \tag{6.54}$$

This completes the evaluation of the two-phase thermodynamics.

By thermodynamic logic, the tension region (P < 0) shown in Fig. 6.4 should be a part of the solid-vapor area of the state surface. However, for

$$T < T_{TL} \tag{6.55}$$

and

$$\rho > \rho_{min} \quad , \tag{6.56}$$

the solid and liquid functions are employed to yield tensions. This is necessary to ensure proper unloading behavior in solids in which relaxation times are too large to be of interest. In all realistic situations, the discontinuity in the state functions produced by this method cannot be reached. The material will fracture first. The fracture models are discussed in Section VII.

VI-4. Extrapolation Outside of Table Mesh

It seems that, no matter how large the mesh of a table, sooner or later the code will request a point external to the outer mesh boundaries. This problem becomes more apparent by observing that the calculation in Section VI-3 might require a vapor-phase density much smaller than the true material density. Extrapolation expressions have been developed to extend the thermodynamic functions outside the mesh in any direction. Different relations are used in each of the eight regions shown in Fig. 6.5. The following list provides the expressions. They, of course, apply only to the thermal components of Section VI-1. The cold terms can be evaluated at all densities from the expressions in Section VI-2. The functions are continuous at each line separating the different areas. It is necessary to define one new constant. The term C_{vh} is the heat capacity to be employed at high temperatures. In most cases,

$$C_{vh} = \frac{3}{2} (\overline{Z} + 1) \, k \, N_o \quad , \tag{6.57}$$

where $\overline{Z}$ is the average atomic number of the material, N_o is the number of atoms per gram, and k is the Boltzmann constant. To shorten the notation, the argument variables on the left-hand side of all expressions are suppressed. This means for example that $E = E(\rho, T)$.

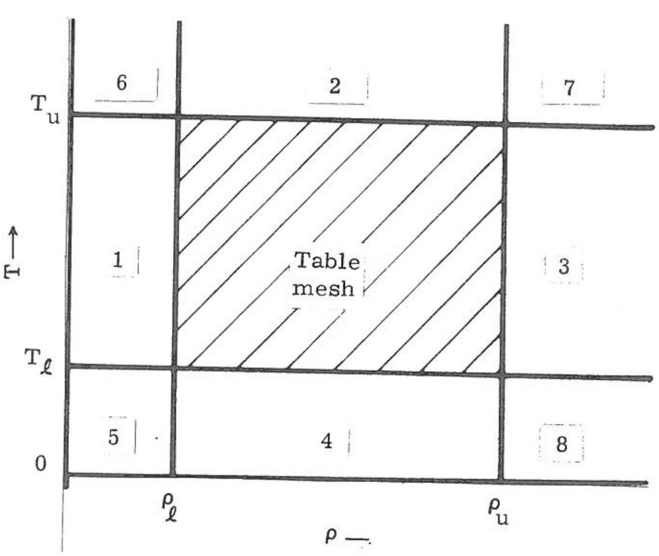

Fig. 6.5 Regions for extrapolation outside of table mesh.

Region 1

$$\rho < \rho_\ell \;, \quad T_\ell \le T \le T_u \;, \tag{6.58}$$

$$E = E\,(\rho_\ell,\; T) \;, \tag{6.59}$$

$$P = \frac{\rho}{\rho_\ell}\, P\,(\rho_\ell,\; T) \;, \tag{6.60}$$

$$S = S(\rho_\ell,\; T) - \frac{P(\rho_\ell, T)}{\rho_\ell\, T}\, \ell n\left(\frac{\rho}{\rho_\ell}\right) , \tag{6.61}$$

$$C_v = C_v\,(\rho_\ell,\; T) \;, \tag{6.62}$$

$$\frac{\partial P}{\partial T} = \frac{\rho}{\rho_\ell}\, \frac{\partial P}{\partial T}\bigg|_{\rho_\ell, T} \;, \tag{6.63}$$

$$C_s = C_s\,(\rho_\ell, T) \;, \tag{6.64}$$

$$\mathbf{K}_r = \mathbf{K}_r\,(\rho_\ell, T) \;. \tag{6.65}$$

Region 2

$$\rho_\ell \le \rho \le \rho_u \;, \quad T > T_u \;, \tag{6.66}$$

$$E = E(\rho, T_u) + C_{vh}\,(T - T_u) \;, \tag{6.67}$$

$$P = P(\rho,\; T_u) + \frac{2}{3}\, C_{vh}\, \rho(T - T_u) \;, \tag{6.68}$$

$$S = S(\rho, T_u) + C_{vh}\, \ell n\,(T/T_u) \;, \tag{6.69}$$

$$C_v = C_{vh} \;, \tag{6.70}$$

$$\frac{\partial P}{\partial T} = \frac{2}{3}\, C_{vh}\, \rho \;, \tag{6.71}$$

$$C_s = C_s\,(\rho, T_u)\, \sqrt{T/T_u} \;, \tag{6.72}$$

$$\mathbf{K}_r = \left\{\mathbf{K}_r(\rho, T_u) - 0.2\right\} \left\{\frac{T_u}{T}\right\}^3 + 0.2 \ge \mathrm{MIN}\left\{\mathbf{K}_r(\rho, T_u),\; 0.2\right\} \;. \tag{6.73}$$

Region 3

$$\rho > \rho_u , \quad T_\ell \le T \le T_u , \tag{6.74}$$

$$E = E(\rho_u, T) , \tag{6.75}$$

$$P = \frac{\rho}{\rho_u} P(\rho_u, T) , \tag{6.76}$$

$$S = S(\rho_u, T) - \frac{P(\rho_u, T)}{\rho_u T} \ell n \left(\frac{\rho}{\rho_u}\right) , \tag{6.77}$$

$$C_v = C_v(\rho_u, T) , \tag{6.78}$$

$$\frac{\partial P}{\partial T} = \frac{\rho}{\rho_u} \frac{\partial P}{\partial T}\bigg|_{\rho_u, T} , \tag{6.79}$$

$$C_s = C_s(\rho_u, T) , \tag{6.80}$$

$$K_r = K_r(\rho_u, T) . \tag{6.81}$$

Region 4

$$\rho_\ell \le \rho \le \rho_u , \quad 0 < T < T_\ell , \tag{6.82}$$

$$E = \frac{T}{T_\ell} E(\rho, T_\ell) , \tag{6.83}$$

$$P = \frac{T}{T_\ell} P(\rho, T_\ell) , \tag{6.84}$$

$$S = S(\rho, T_\ell) - \frac{E(\rho, T_\ell)}{T_\ell} \ell n \left(\frac{T_\ell}{T}\right) , \tag{6.85}$$

$$C_v = \frac{E(\rho, T_\ell)}{T_\ell} , \tag{6.86}$$

$$\frac{\partial P}{\partial T} = \frac{P(\rho, T_\ell)}{T_\ell} , \tag{6.87}$$

$$C_s = C_s(\rho, T_\ell) , \tag{6.88}$$

$$K_r = K_r(\rho, T_\ell) . \tag{6.89}$$

Region 5

$$\rho < \rho_\ell \ , \ T < T_\ell \ , \tag{6.90}$$

$$E = \frac{T}{T_\ell} E(\rho_\ell, T_\ell) \ , \tag{6.91}$$

$$P = \frac{\rho T}{\rho_\ell T_\ell} P(\rho_\ell, T_\ell) \ , \tag{6.92}$$

$$S = S(\rho_\ell, T_\ell) - \frac{P(\rho_\ell, T_\ell)}{\rho_\ell T_\ell} \ell n \left(\frac{\rho}{\rho_\ell}\right) - \frac{E(\rho_\ell, T_\ell)}{T_\ell} \ell n \left(\frac{T_\ell}{T}\right) \ , \tag{6.93}$$

$$C_v = \frac{E(\rho_\ell, T_\ell)}{T_\ell} \ , \tag{6.94}$$

$$\frac{\partial P}{\partial T} = \frac{\rho}{\rho_\ell T_\ell} P(\rho_\ell, T_\ell) \ , \tag{6.95}$$

$$C_s = C_s(\rho_\ell, T_\ell) \ , \tag{6.96}$$

$$\mathbf{K}_r = \mathbf{K}_r(\rho_\ell, T_\ell) \ . \tag{6.97}$$

Region 6

$$\rho < \rho_\ell \ , \ T > T_u \ , \tag{6.98}$$

$$E = E(\rho_\ell, T_u) + C_{vh} (T - T_u) \ , \tag{6.99}$$

$$P = \frac{\rho}{\rho_\ell} P(\rho_\ell, T_u) + \frac{2}{3} C_{vh}\rho (T - T_u) \ , \tag{6.100}$$

$$S = S(\rho_\ell, T_\ell) - \frac{P(\rho_\ell, T_u)}{\rho_\ell T_u} \ell n \left(\frac{\rho}{\rho_\ell}\right) + C_{vh} \ell n \left(\frac{T}{T_u}\right) \ , \tag{6.101}$$

$$C_v = C_{vh} \ , \tag{6.102}$$

$$\frac{\partial P}{\partial T} = \frac{2}{3} C_{vh} \rho \ , \tag{6.103}$$

$$C_s = C_s(\rho_\ell, T_u) \sqrt{T/T_u} \ , \tag{6.104}$$

$$\mathbf{K}_r = \left\{\mathbf{K}_r(\rho_\ell, T_u) - 0.2\right\} \left\{\frac{T_u}{T}\right\}^3 + 0.2 \geq \mathrm{MIN}\left\{\mathbf{K}_r (\rho_\ell, T_u) \ , \ 0.2\right\} \ . \tag{6.105}$$

Region 7

$$\rho > \rho_u \, , \;\; T > T_u \;\; , \tag{6.106}$$

$$E = E(\rho_u, T_u) + C_{vh} \, (T - T_u) \;\; , \tag{6.107}$$

$$P = \frac{\rho}{\rho_u} \, P \, (\rho_u, T_u) + \frac{2}{3} \, C_{vh} \, \rho \, (T - T_u) \;\; , \tag{6.108}$$

$$S = S(\rho_u, T_u) - \frac{P(\rho_u, T_u)}{\rho_u \, T_u} \, \ell n \left(\frac{\rho}{\rho_u}\right) + C_{vh} \, \ell n \left(\frac{T}{T_u}\right) \;\; , \tag{6.109}$$

$$C_v = C_{vh} \;\; , \tag{6.110}$$

$$\frac{\partial P}{\partial T} = \frac{2}{3} \, C_v \, \rho \;\; , \tag{6.111}$$

$$C_s = C_s \, (\rho_u, T_u) \, \sqrt{T/T_u} \;\; , \tag{6.112}$$

$$\mathbf{K}_r = \left\{ \mathbf{K}_r (\rho_u, T_u) - 0.2 \right\} \left\{ \frac{T_u}{T} \right\}^3 + 0.2 \geq \mathrm{MIN} \left\{ \mathbf{K}_r (\rho_u, T_u), \; 0.2 \right\} \;\; . \tag{6.113}$$

Region 8

$$\rho > \rho_u \, , \;\; T < T_\ell \;\; , \tag{6.114}$$

$$E = \frac{T}{T_\ell} \, E(\rho_u, T_\ell) \;\; , \tag{6.115}$$

$$P = \frac{\rho \, T}{\rho_u T_\ell} \, P(\rho_u, T_\ell) \;\; , \tag{6.116}$$

$$S = S(\rho_u, T_\ell) - \frac{E(\rho_u, T_\ell)}{T_\ell} \, \ell n \left(\frac{T_\ell}{T}\right) - \frac{P(\rho_u, T_\ell)}{\rho_u \, T_\ell} \, \ell n \left(\frac{\rho}{\rho_u}\right) \;\; , \tag{6.117}$$

$$C_v = \frac{E(\rho_u, T_\ell)}{T_\ell} \;\; , \tag{6.118}$$

$$\frac{\partial P}{\partial T} = \frac{\rho}{\rho_u T_\ell} \, P(\rho_u, T_\ell) \;\; , \tag{6.119}$$

$$C_s = C_s (\rho_u, T_\ell) \;\; , \tag{6.120}$$

$$\mathbf{K}_r = \mathbf{K}_r (\rho_u, T_\ell) \;\; . \tag{6.121}$$

The formulas used in Regions 3, 7, and 8 are not too important since they are almost never used. On the other hand, the Region 1 expressions are frequently required in the mixed-phase calculation. For this reason, special coding is included in the mixed-phase calculation to treat this case rapidly.

VI-5. Radiation Field Terms

For problems in which the radiation calculation is included, the radiation field thermodynamic functions must be added to the material terms. Under the local thermodynamic equilibrium assumption, the field properties are determined solely by the temperature and density. The required expressions are

$$E_r = \frac{4\sigma T^4}{c\rho} , \tag{6.122}$$

$$C_{vr} = \frac{16\sigma T^3}{c\rho} \tag{6.123}$$

$$P_r = \frac{4\sigma T^4}{3c} , \tag{6.124}$$

$$\frac{\partial P_r}{\partial T} = \frac{16\sigma T^3}{3c} , \tag{6.125}$$

$$\frac{\partial P_r}{\partial \rho} = 0 , \tag{6.126}$$

and

$$S_r = \frac{16\sigma T^3}{3c\rho} , \tag{6.127}$$

where energy and entropy have units of per-unit mass in contrast to (2.5), which is per-unit volume. As before, $\sigma \left[= 1.0283 \times 10^{12} \text{ erg/cm}^2 \text{ sec eV}^4 \right]$ is the Stefan-Boltzmann constant and $c \left[= 2.997929 \times 10^{10} \text{ cm/sec} \right]$ is the velocity of light.

Calculation of the sound speed by (6.8) presents a problem since the $\left(\frac{\partial P_m}{\partial \rho}\right)_T$ is not easily available. Independent tabular values were retained in mesh for C_{sm}, the material sound speed. As a result, the approximate expression

$$C_s = \left\{ C_{sm}^2 + C_{sr}^2 \right\}^{1/2} \tag{6.128}$$

is employed, where

$$C_{sr}^2 = \frac{16\sigma T^4}{9c\rho} = \frac{4}{9} E_r \tag{6.129}$$

is determined by substitution of (6.123), (6.125), and (6.126) into (6.8). Because of the approximate nature of (6.128), a safety factor has been included by replacing the $\frac{4}{9} = 0.4444\ldots$ by 0.45 in (6.129).

VI-6. Coding and Storage

In the generation of the master data tape, each EOS is assigned a unique number. Request in CHART D for a given material must be made with this number. The code selects all of the required information from the tape automatically and stores it for future use in one of two ways. All tabular data can be stored in continuous arrays in machine fast core. This method has the disadvantage of requiring large storage blocks for the data tables. In the other method, only one table is retained in core. All tables required in the calculation are kept in the larger (and slower) memory systems, and only the one currently necessary is brought into fast core. On the CDC 6600, the extended core storage (ECS) system is used. However, provisions have been made for other systems which do not have ECS to use disk or tapes or whatever is available. For non-ECS machine modification, see Appendix C.

The listing in Appendix G contains the switch setting for ECS use. A single variable change in a data statement will force entire fast core storage. The instructions are included as comments. However, it is likely that dimensions will have to be increased.

VII. VOIDS, SPALL, AND JOIN

Voids or gaps between layers of material can appear in CHART D in one of two ways. They may be zoned into the initial configuration or be formed during the calculation as the result of material failure. Complete material separation is allowed, and provisions are included for a void to close and the material to join together. The means to treat these conditions form two completely unrelated computations. By far the largest part of the calculation involves the mechanism of determining the motion and related properties of the extra free surfaces in the interior of the material. The fracture models, on the other hand, form a small and isolated section of coding.

For storage reasons, material is only allowed to fracture and a void exist at a zone boundary. The situations before and after a fracture in zone i are shown in Fig. 7.1. Clearly, at least two new variables must be defined to describe the extra position and velocity. When a

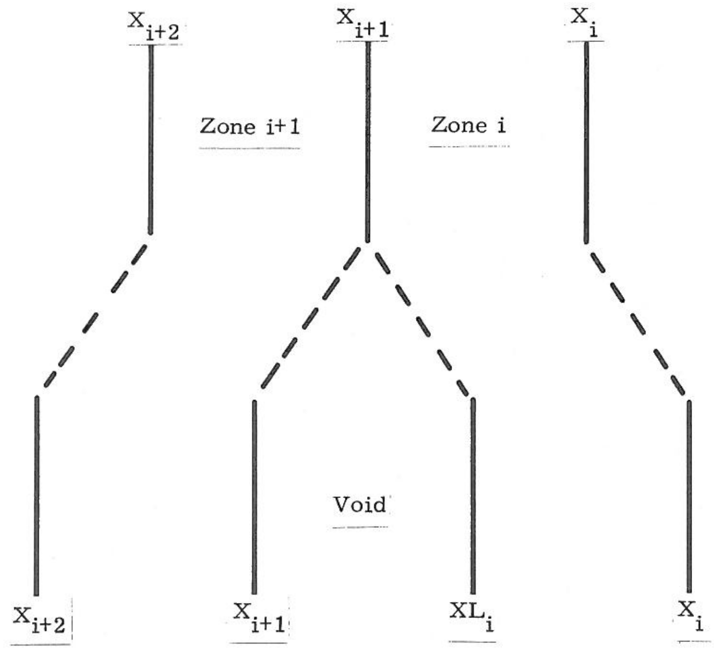

Fig. 7.1 Situation before and after fracture.

separation occurs between zones i and i+1 (position X_{i+1}), the right-hand side of zone i+1 is followed by the previously defined variables X_{i+1} and V_{i+1}. The information concerning the left-hand side of zone i is retained in XL_i and VL_i. It is now necessary to return to the calculations of Sections II through V and make provisions for this situation. In the momentum computation (2.20), each void boundary is treated as a free surface, with zero vapor pressure except for radiation pressure in the void area. Complete details are lengthy but obvious and will not be given here.

Voids appear in the standard edit as breaks in the normal printed order, with the appropriate XL and VL values inserted. A single-line gap is also inserted in the void position.

VII-1. Fracture Models

Three fracture models are available in CHART D. It is important that they be used and proper input parameters be defined. Unrealistically large spall thresholds can force the code into the regions with the thermodynamic discontinuities mentioned in Section VI-3 and in the authors' accompanying report[4] with catastrophic results.

All stress values in the following subsections are boundary-interpolated. When a fracture is located, the values of XL and VL are initialized to those of X and V.

Stress Gradient Model

The stress gradient criteria were developed by Thurston and Mudd.[14] Simple modifications are made for treating temperature effects. The reference temperature spall threshold is given by the function

$$\sigma_s = \sigma_o + A \left| \frac{\partial \sigma}{\partial X} \right|^B \leq \sigma_u \ , \tag{7.1}$$

where σ_o is the static tensile strength, σ_u is the ultimate or absolute maximum strength, A and B are material constants, and σ_s is the tensile stress at which spallation occurs. While only a very limited amount of temperature-dependent data is available, a simple multiplicative factor can be employed to approximate the effects:

$$\sigma_{sp} = - \sigma_s \left\{ \frac{T_s - T}{T_s - T_o} \right\}^C \leq 0 \ , \tag{7.2}$$

where σ_{sp} is the spallation stress, T_s is the temperature at which strength vanishes (usually the melt temperature), T_o is room temperature, and C is a constant. The value C = 1/2 seems to fit some of the available data. The minus sign in (7.2) is included so that the input of values of σ_o and σ_u are positive.

Cumulative Damage Model

In the cumulative damage criteria of Tuler and Butcher,[15] the quantity of interest is

$$K(t) = \int_o^t f(\sigma) \, d t \ , \tag{7.3}$$

where

$$\begin{aligned} f(\sigma) &= (-\sigma - \sigma_o)^\lambda , \quad \sigma < - \sigma_o \\ &= 0 , \quad \sigma \geq - \sigma_o \ , \end{aligned} \tag{7.4}$$

λ is a material constant and, as before, σ_o is the static tensile strength and a positive number. Failure is assumed to occur when K(t) exceeds a given value. A temperature dependence similar to that of (7.2) is given. If K_s is the reference temperature value, the spallation occurs when

$$K(t) > K_s \left\{ \frac{T_s - T}{T_s - T_o} \right\}^C \geq 0 \ . \tag{7.5}$$

In both of the above models, it is assumed that the numerical value of C is positive. The switch to distinguish between the two calculations is contained in the input value of C. If a positive or zero value is given, the stress gradient is employed. A negative value will result in the cumulative damage criteria with the negative of the input number assumed to be C. See Appendix H for complete input details.

Tensile Strength Model

In many practical problems, sufficient information to employ the above models is simply not available. By far the most widely used criterion is that of maximum tensile strength. Here, the material fails when the stress exceeds (in a negative sense) some given value. Unfortunately, this value is often treated arbitrarily. In this situation one should not be surprised if the code produces somewhat arbitrary results.

Observing the relations for the stress gradient model, it is clear that the present calculation is a special case of the former. If A is set to zero and $\sigma_o = \sigma_u$, the model is that of the tensile limit. The same type of reduction is possible with the cumulative damage criteria. Note the similarity in input form for this calculation and that for the stress gradient in Appendix H.

VII-2. Join

When two free surfaces collide, the material is said to rejoin. The condition is easily recognized when

$$X_{i+1} \geq XL_i \quad , \tag{7.6}$$

as related to Fig. 7.1. When this situation is found, a new velocity of the new single boundary is computed to conserve momentum:

$$V_{i+1} = (M_i \, VL_i + M_{i+1} \, V_{i+1}) / (M_i + M_{i+1}) \quad , \tag{7.7}$$

with the value of the rejoin velocity on the left-hand side and those on the right-hand side the free surface values. The new position is taken as the average of X_{i+1} and XL_i.

By forcing these relations to conserve momentum, kinetic energy will not be conserved. This is to be expected from physical arguments. The small amount of energy that would otherwise be lost to the calculation is introduced into the two colliding zones as internal energy.

The future behavior at this interface must also be considered. To prevent a welding effect, appropriate parameters in each of the above models are set so that no tensile wave can be supported at any interface where a void has previously existed. Clearly, this procedure will only relate to solid materials below the melt temperature. Hopefully, there exist no regions in the EOS with tensions above the melt temperature. If there is such an area on the thermodynamic surface, the EOS is improperly defined.

VIII. INITIAL AND BOUNDARY CONDITIONS

VIII-1. Zone and Material Numbering

In the initial definition of a problem, the position of each of the zone boundaries or spatial mesh points as referenced in Section II-4 must be specified. A material identification is also required. While most of this is done automatically by the code, the user must possess a clear knowledge of the numbering scheme and input order for satisfying results. All input starts with the largest position and consecutively works to smaller positions.

An example of a three-material problem is shown in Fig. 8.1. The zone and boundary numbers start with 1 at the largest position and increase with decreasing position. The material layers are defined by the material boundary positions. Material numbering is automatically produced and is internally related to the equation-of-state identification code. It is not necessary to zone an entire material layer with a single set of zoning input parameters. Each layer can be zoned in one or more regions. However, the material layer boundaries must lie on zoning region boundaries; i.e., the former must be a subset of the latter, and the entire layer must have the same EOS number, fracture, and elastic or porous properties. If this is not the desired result, the layer must be divided into two or more layers. In the standard versions of the code there is a maximum of 20 layers. There is no limit to the number of zoning regions except it cannot exceed the total number of zones in the problem and must at least be as large as the number of materials.

If several layers of the same material are found in a problem but these layers are separated by a different material, the various layers must be individually treated. The same EOS number can be used for all, however, and no extra EOS storage is required. For example, in Fig. 8.1, materials 1 and 3 could be the same substance with the same EOS but would be treated elsewhere in the code as different.

One of the zoning options can be used to produce voids in the initial configuration. These gaps can lie inside of a layer or between two layers. In the latter case, the material boundary is taken to be the left-hand side of the void. Another example similar to the first, except that it has two voids, is shown in Fig. 8.2. While still having three materials, this problem would require at least six zoning regions, in contrast to a minimum of three for Fig. 8.1.

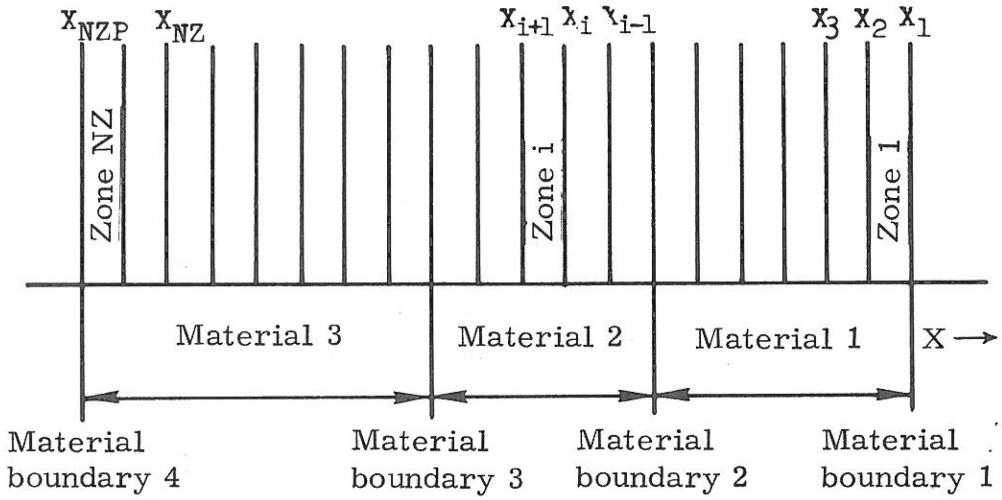

Fig. 8.1 Example of zone and material numbering. Note that $X_1 > X_2 > X_3 > X_i > X_{NZ} > X_{NZP}$.

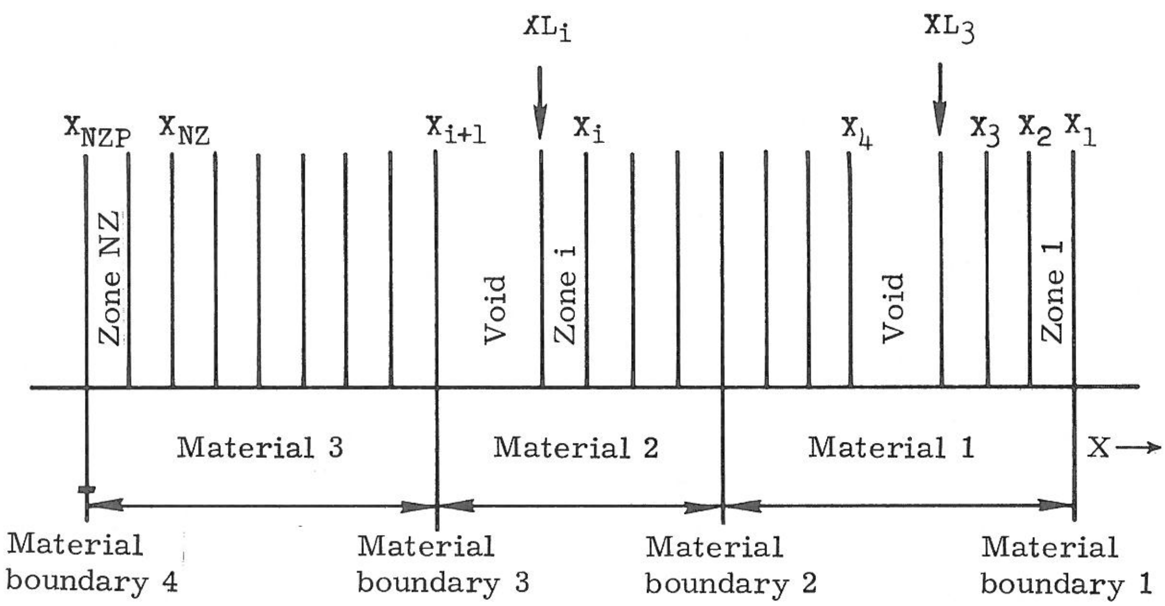

Fig. 8.2 Example of zone and material numbering with voids.

The principal part of the zoning is accomplished by use of card set 11 as related in Appendix H. The fine points of mass ratio zoning are discussed in Appendix B. Care must be taken to define any equations of state referenced in the zoning. A set of cards must be included for each analytic EOS. If tabular data are requested, the master data tape must be supplied.

VIII-2. Boundary Pressures and Temperatures

As mentioned in Sections II-4 and III-3, the user must supply external pressures and temperatures to couple the material under consideration to its environment.

The pressures can be provided in either of two ways. In the first, the exterior boundary can be fixed in space. This is equivalent to requiring the exterior pressure to equal the interior pressure (plus artificial viscosity). Under the second option, a time-dependent external pressure can be defined by giving the magnitude at specified times. For intermediate values, a linear interpolation is applied. An example is shown in Fig. 8.3. If no values are provided, the code assumes zero boundary pressures. Separate curves must be defined for both the inner and outer boundaries with the use of the same time values. Note, however, for cylindrical and spherical geometry problems without a central void that there is no inner surface; thus this input is ignored.

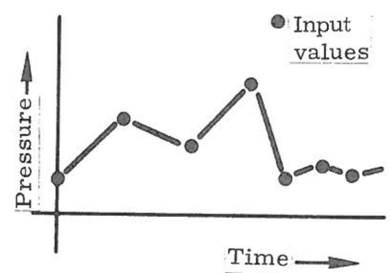

Fig. 8.3 A boundary pressure-time history.

Boundary temperatures are treated in much the same manner. Values linearly interpolated from input points are used to compute incident fluxes as related in Section III-3. The scale factors S_f and S_b can be set to yield reflecting boundaries.

VIII-3. Zone Activation

In many problems the motion is restricted to small parts of the entire problem for a significant portion of the calculation. In order to save computer time, an activity test is incorporated. Tests are made on both the material velocities and radiation fluxes. If either exceeds a specified value, the adjacent zones are activated.

Initially, any zone with a moving boundary or energy source is assumed to be active. Other zones may be activated by the card inputs. There are no restrictions on numerical order of active and inactive zones. Any zone, once activated, remains active until completion of the calculation.

It must be pointed out, however, that no zone in the problem is ever completely inactive. In some of the calculations, the inactive zones must at least be partially included, e.g., the matrix inversions in Section III. The reasoning behind this requires a detailed study of the structure of the relations and will not be given here. The important point is that problems should not be defined with large numbers of zones which will not be activated in the time period of interest, since the calculation will be unnecessarily slowed.

VIII-4. Energy Sources

CHART D contains provisions for several types of energy sources. All are used to define the $\dot{\mathscr{S}}$ function in Eq. (2.3). No matter which type of source is employed, the data are reduced to the following form for internal use. The coupling to externally produced deposition profiles is discussed in Section VIII-5. This calculation is also employed in the description of high-explosive materials as related in Section X.

Basically, the code requires a four-point deposition time history for each zone, as shown in Fig. 8.4. Each history can be independent of the rest. Storage is required for the four time values and two $\dot{\mathscr{S}}$ values. At the first and fourth value, $\dot{\mathscr{S}}$ is zero. A linear interpolation is used for intermediate times between

$$\begin{aligned} &\dot{\mathscr{S}}_{1i} = 0 \ , && t \le \tau_{1i} \ , \\ &\dot{\mathscr{S}}_{2i} \ , && t = \tau_{2i} \ , \\ &\dot{\mathscr{S}}_{3i} \ , && t = \tau_{3i} \ , \\ &\dot{\mathscr{S}}_{4i} = 0 \ , && t \ge \tau_{4i} \ , \end{aligned} \tag{8.1}$$

with

$$0 \le \tau_{1i} \le \tau_{2i} < \tau_{3i} \le \tau_{4i} \ . \tag{8.2}$$

For accuracy, any nonzero interval $\tau_{ji} - \tau_{j-1,i}$ should be large compared to Δt. As a result, during deposition the value of Δt is not allowed to exceed 1/200 of the largest value of τ_{4i}. In most problems this condition is sufficient to ensure resolution.

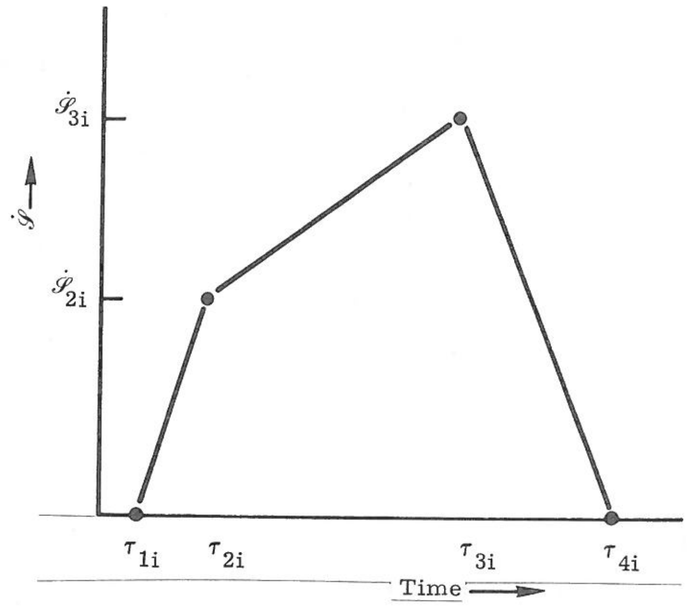

Fig. 8.4 Source strength-time history for zone i.

The total energy added to zone i through time t is

$$\mathscr{E}_{\text{dep } i}(t) = M_i \int_0^t \dot{\mathscr{S}}_i \, dt \;, \tag{8.3}$$

while the total source strength is

$$\mathscr{E}_{\text{source}}(t) = \sum_i \mathscr{E}_{\text{dep } i}(t) \;. \tag{8.4}$$

When $t > \tau_{4i}$, the deposition in zone i is complete with the result

$$\mathscr{E}_{\text{dep } i}(\infty) = \frac{M_i}{2} \left\{ \dot{\mathscr{S}}_{2i} \left[\tau_{3i} - \tau_{1i} \right] + \dot{\mathscr{S}}_{3i} \left[\tau_{4i} - \tau_{2i} \right] \right\} \;. \tag{8.5}$$

Clearly, this scheme requires six times the number of zone storage locations to retain the source histories. Except when required, these data are retained out of fast memory. As with excess tabular EOS data, the CDC 6600 extended core storage (ECS) system is employed. Modifications for machines without ECS are given in Appendix C.

This external storage of source histories would make it easy to include much more complex data. While it has not been done, a simple routine could be added to edit the data as time progresses to yield any desired form. One would only have to force the current values of τ_{2i} and τ_{3i} to encompass the correct time. No other code modifications would be necessary. The natural place for these changes would be at the beginning of subroutine SOURCE.

VIII-5. Coupling to Externally Generated Energy Profiles

One of the energy source options provides a mechanism for coupling to energy deposition profiles produced externally to CHART D. Possible sources of these profiles at Sandia include DTF[16] and BUCKL[17, 18] for electromagnetic radiation and ETRAN[19] for electron beam problems.

In general, most deposition codes fall in one of two classes. In the first, a zoning scheme similar to that employed in the hydro codes is used. The computed information consists of the total energy deposited in each zone. The result is a histogram as shown in Fig. 8.5. The codes DTF and ETRAN are of this type.

The other form of deposition profile is shown in Fig. 8.6. Here, the specific deposition at various points in the material is determined. BUCKL produces information using this system.

A calculation provided in the subroutine ZAPPER can accept either of the two forms and convert them into a form usable in CHART D. For historical reasons, the first form is referred to as DTF formatted data and the second as BUCKL formatted data. Both forms are converted to a histogram profile for CHART D by use of CHART D material zoning. There are no requirements that force similar zoning in the deposition code. Any zoning acceptable in the deposition is acceptable to ZAPPER. To eliminate requirements for common units, it is assumed that the given deposition profiles are for unit fluence, i.e., divided by the total incident flux. Provisions are in cluded for renormalization.

There are two restrictions to the acceptable data:

(1) Only plane geometry is allowed.

(2) There are no provisions for interior voids in the material on input.

This latter condition applies only to the input deposition format and, because of the former condition, this does not affect the energy profile. Voids may be zoned into the hydrodynamic calculation by a special rezoning after the ZAPPER computation has been completed.

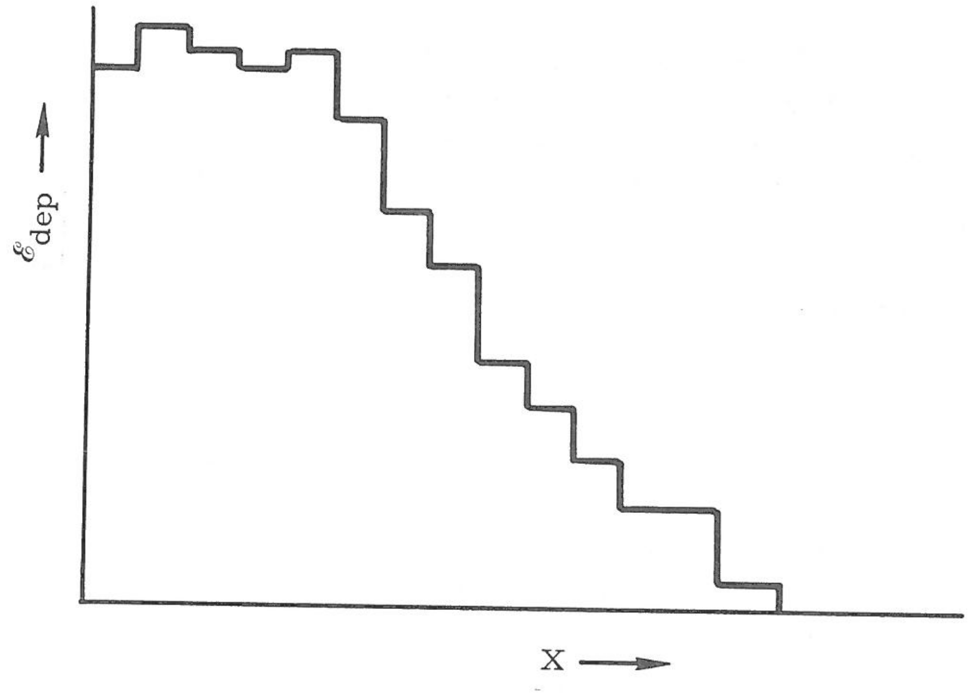

Fig. 8.5 A histogram energy deposition profile.

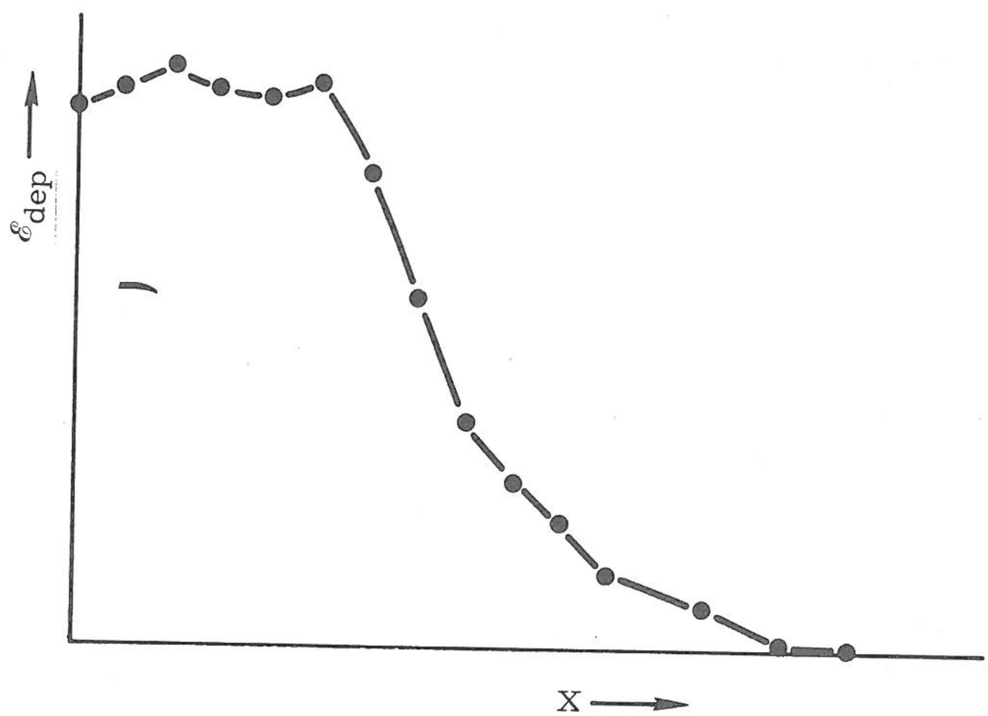

Fig. 8.6 A point energy deposition profile.

The above procedure determines the value of $\mathscr{E}_{\text{dep } i}(\infty)$ as defined in (8.5). Input parameters complete determination of the quantities in (8.1). Provisions have also been made to retard the deposition in each zone by the transit time of light from the front surface to the zone in question. It is assumed that the flux is incident from the right (on zone 1) as defined in Figs. 2.1 and 8.1.

Details of the input data formats are given in Appendix D.

IX. TIME STEP CONTROLS

Finite difference methods as employed here are frequently subject to mathematical limitations which place upper bounds on the integration time increment that can be used without unstable growth of spurious signals. A simple statement of the condition for integration of the hydrodynamic equations is that a sound wave should not be capable of propagating across any zone in the given interval of time; i.e.,

$$\Delta t < \frac{\Delta X}{C_s} , \tag{9.1}$$

where ΔX is the zone width and C_s the sound velocity.[6] This expression is obtained for the equations without artificial viscosity. A more exact criterion in the present situation is (see Appendix A of Reference 7)

$$\begin{aligned} \Delta t &< \frac{\Delta X}{C_s} , \quad \Delta V \geq 0 , \\ &< \frac{\Delta X}{\Phi + \sqrt{\Phi^2 + C_s^2}} , \quad \Delta V < 0 , \end{aligned} \tag{9.2}$$

where ΔV is the velocity differential across the zone, B_ℓ and B_q are the viscosity coefficients defined in Section II, and

$$\Phi = B_\ell C_s - B_q^2 \Delta V . \tag{9.3}$$

The hydrodynamic time step Δt_{cs} is taken to be the smallest value obtained from (9.2) for all active zones:

$$\Delta t_{cs} = f_1 \text{ MIN } \Delta t_i , \tag{9.4}$$

where the factor f_1 is included so that the time increment may be reduced from the strict stability limit. This factor is an input parameter and is normally chosen as 0.8. In no case should it be greater than 1.

Provisions have also been included to limit the rate of increase of Δt. With f_2 an input parameter, the time increment Δt_ℓ is defined as

$$\Delta t_\ell = f_2 \Delta t'' , \tag{9.5}$$

where $\Delta t''$ is the Δt of the last cycle, as in Section II-4. Normally, f_2 is taken as 1.05. If the temperature of a zone seems to be changing too rapidly or an excess of matrix inversions is required in the Section III calculation, Δt_ℓ is reduced slightly.

Input parameters are provided so that upper and lower bounds to the allowed increment may be given. The values are denoted as Δt_{max} and Δt_{min}. These are useful in forcing a given time step.

The final expression employed to determine the new time increment is given by

$$\Delta t = \mathrm{MIN}\left\{\Delta t_{source}, \mathrm{MAX}\left[\Delta t_{min}, \mathrm{MIN}\left(\Delta t_{cs}, \Delta t_\ell, \Delta t_{rad}, \Delta t_{max}\right)\right]\right\} , \tag{9.6}$$

where Δt_{rad} and Δt_{source} are given in Sections III and VIII. Obviously, if one of the Δt values in (9.6) does not apply to the problem under consideration, it is not included. For a safety factor, only 1/10 the value given by (9.6) is used on the first cycle of each problem. In some calculations this might not be sufficient, and the initial Δt should be controlled for a short time by Δt_{max}.

There are two sections of the code that may decrease the value of Δt after a cycle calculation has begun. Reasons for the radiation computation recycle are given in Section III. The other involves only the hydrodynamics. For reasons of accuracy, the density changes in a given time step are required to not exceed 10 percent. This calculation is sometimes forced by the rejoin procedure of Section VII. If too large a change is found, a recycle is performed with a reduced Δt value. In problems where an excess of recycles are encountered, the value of f_1 in (9.4) should be decreased.

X. HIGH EXPLOSIVES

The treatment of high explosives in CHART D is different from the methods employed in most hydrodynamic codes. In one sense they are considered just as is any other substance. All of the computations previously discussed, including the elastic calculation of Section IV, can be used. The only restriction to this is a result of storage arrangements. For reasons explained below the porous material computation cannot be employed with explosives. This has nothing to do with the models and, with slight recoding, can be treated.

Basically, the code only requires the detonation wave velocity D and either the chemical energy release per unit mass Q or the postdetonation pressure P_{cj} to function. There are, however, very strong requirements on the equation of state for proper burning behavior. These conditions are discussed in detail below. CHART D assumes that the given EOS data satisfy them. A section in the test program CKEOS is provided to test the data.[4] A simple self-detonation calculation is also provided.

X-1. Equations of State for High Explosives

It is assumed that explosives have an EOS similar in form to any other material. Generally, there are two interesting regions. The undetonated material is not greatly different from normal solid and plastics. Detonated material on the other hand is similar to gas. These two regions are sufficiently separated that the treatment by a single EOS is possible. There are, however, several relations that must be satisfied for proper burning behavior. These conditions follow. It is the code user's responsibility to ensure that they are satisfied. The actual mechanics of the burning are given in the next section.

The three conservation relations which describe a detonation front are

$$\rho(D - U) = \rho_o (D - U_o) \ , \tag{10.1}$$

$$P + \rho(D - U)^2 = P_o + \rho_o(D - U_o)^2 \ , \tag{10.2}$$

and

$$E - E_o - Q = \frac{1}{2}(P + P_o)\left(\frac{1}{\rho_o} - \frac{1}{\rho}\right) \ , \tag{10.3}$$

where quantities with subscript o refer to conditions before detonation and those without the subscript refer to conditions after detonation.[20] The symbols P, ρ, U, and E are pressure, density, material velocity, and internal energy. As previously mentioned, Q is the chemical energy released per unit mass and, unfortunately, a somewhat ill-defined quantity. To simplify the expressions it is assumed that both P_o and U_o vanish.

The above expressions do not consider the stability of the detonation wave. The question here is whether the front will propagate without increasing or decreasing in strength. The Chapman-Jouguet condition expresses the situation reached in stable propagation. This relation is

$$C_{cj} = D - U \ , \tag{10.4}$$

where C_{cj} is the sound velocity behind the detonation front.[20] The explosive can burn under conditions not satisfying (10.4) but will only stabilize when (10.4) is satisfied. To obtain the desired forms of the above expressions, substitute (10.4) into (10.1),

$$C_{cj} = \rho_o D/\rho \ , \tag{10.5}$$

and (10.1) into (10.2),

$$P = \rho_o D^2 \left\{1 - \frac{\rho_o}{\rho}\right\} \ . \tag{10.6}$$

These two relations impose rather strong conditions on the equation of state when an attempt is made to match the experimental data. Equation (10.3) serves more as a definition of Q which depends heavily on the form of the EOS.

Let us assume that experimental information concerning a given explosive is available. All normal properties of the undetonated material are given and, at a minimum, the values of C_{cj}, P_{cj}, and D. Information relating to the burn temperature is also helpful but not necessary.

The first step in testing a candidate EOS is to calculate, as a function of density, the solution of (10.6). Because of the form of the EOS, this involves determining a temperature which with the given density will yield a pressure satisfying (10.6). An example is presented in Fig. 10.1. The numerical values are appropriate for RDX with ρ_o = 1.82 gm/cc and D = 8.75 x 10^5 cm/sec. In general this curve will have a maximum at some density greater than ρ_o and decrease thereafter reaching T = 0 at $\rho = \rho_{max}$. Clearly the solution, if it exists, must lie somewhere between ρ_o and ρ_{max}. The sound speed at each point on the curve is determined from the EOS and is shown in Fig. 10.2. There is also the value given by Eq. (10.5). To avoid confusion, this relation is written as

$$\hat{C}_s = \rho_o D/\rho \tag{10.7}$$

and is also shown in Fig. 10.2. The point of intersection is the C-J point for this EOS.

It is possible that the two C_s curves will not intersect. This situation indicates that this material cannot form a stable detonation wave and usually results when the given detonation velocity D is grossly inconsistent with realistic values.

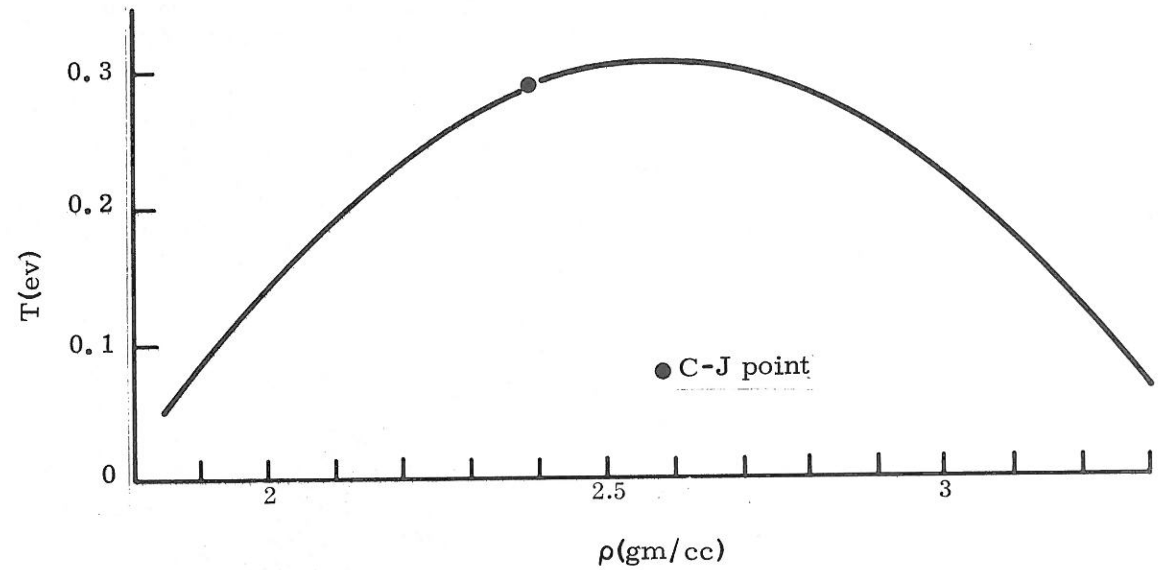

Fig. 10.1 Solution of Eq. (10.6) for RDX.

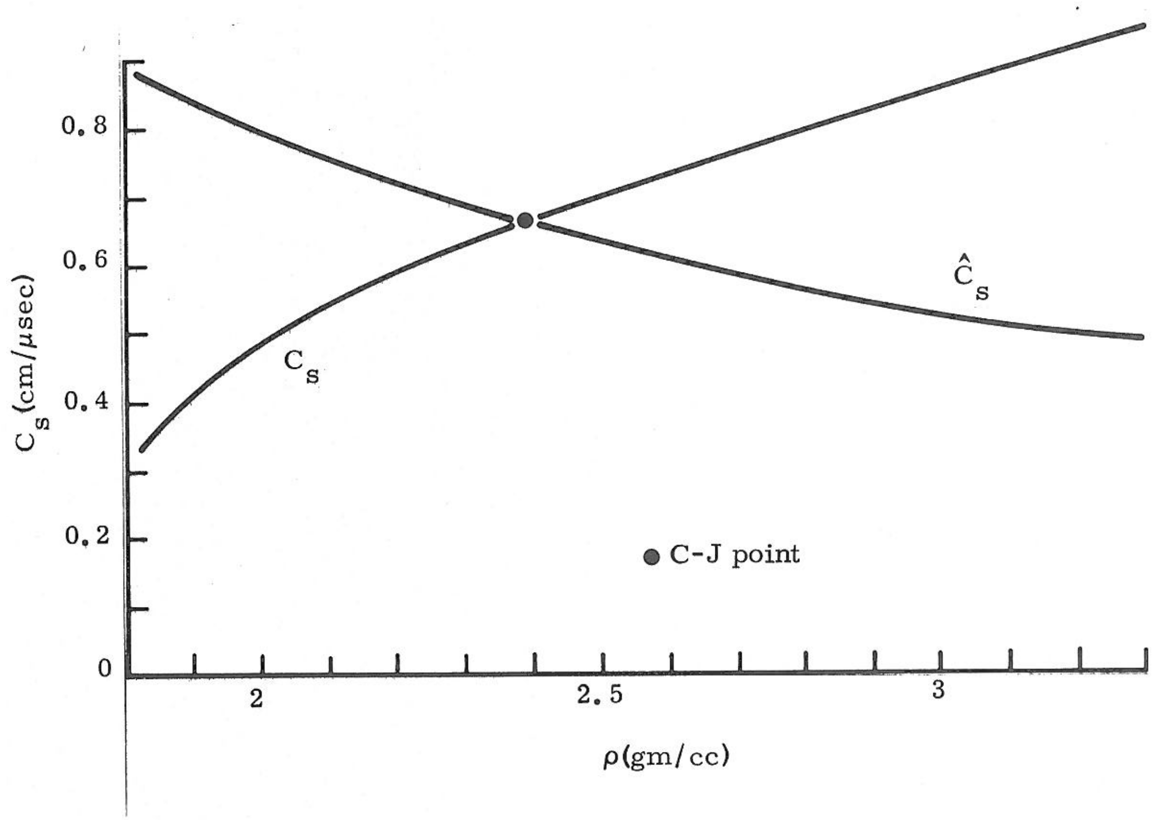

Fig. 10.2 Solutions of Eqs. (10.6) and (10.7) for RDX.

This intersection determines all of the detonation parameters which may be compared to the desired properties. If the agreement is not sufficient, the EOS parameters must be adjusted and the computation repeated. Normally, a favorable comparison is possible in a few iterations. The Q value can then be determined from (10.3) since the energy E is known. The results for RDX are shown in Fig. 10.3.

One of the obvious but sometimes overlooked requirements on the EOS is that the reference point sound speed must be less than the detonation velocity. If the condition is not satisfied, no amount of juggling of other parameters will produce a usable EOS.

In some problems other features of the EOS may be important. Release adiabats from the C-J point might require study. Unfortunately no general rules are available, and each problem must be considered independently.

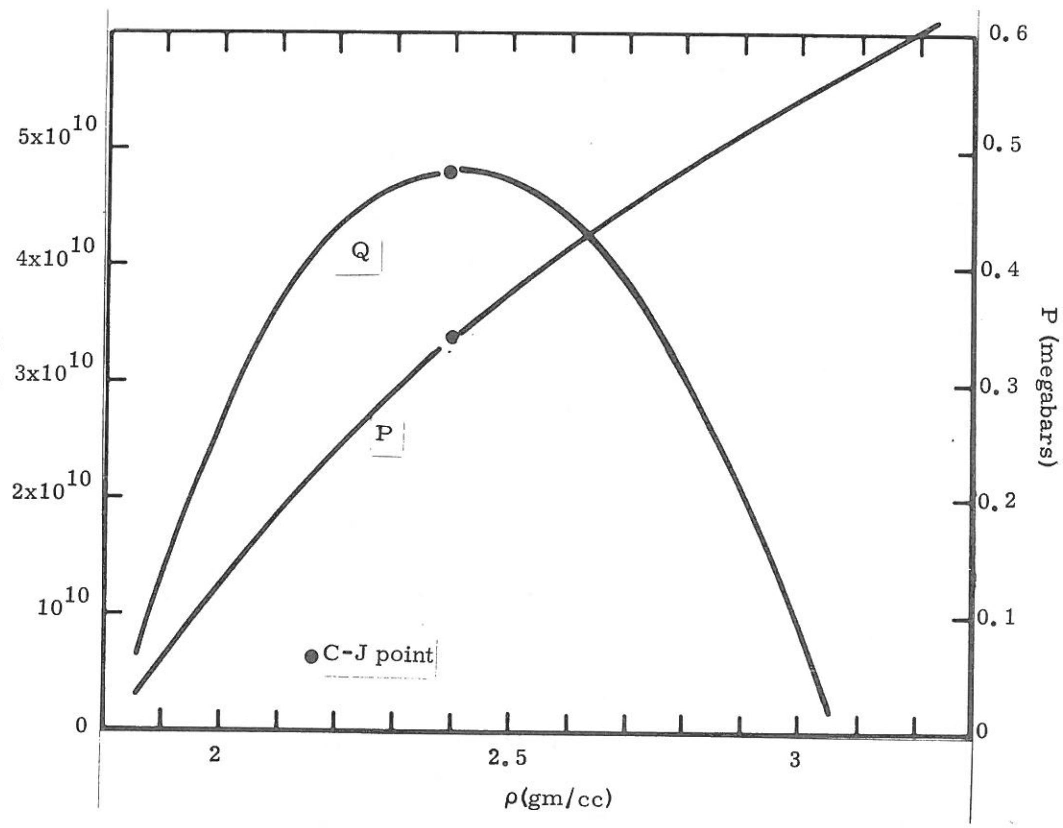

Fig. 10.3 Solutions of Eqs. (10.3) and (10.6) for RDX.

X-2. Inputs, Coding, and Storage

Seven input parameters are required to treat a burn of high-explosive material in addition to the EOS and are listed as source type 6. Two of these are the detonation velocity D and either the chemical energy release per unit mass Q or the Chapman-Jouguet pressure P_{cj}. If P_{cj} is given, a short computation is performed to determine a Q value. The C-J density is calculated from (10.6) in addition to a temperature appropriate to P_{cj}. Q is then determined by (10.3). Even if both are known, there is an advantage to giving P_{cj} instead of Q. If P_{cj} is defined, it is saved to serve as a switch for a self-detonation calculation. This is discussed further below.

In terms of the energy source calculation of Section VIII-4, Q can be considered as $\mathscr{E}_{dep\ i}(\infty)/M_i$, as given by (8.5). It is assumed in the present situation that

$$\tau_{1i} = \tau_{2i} \ , \tag{10.8}$$

$$\tau_{3i} = \tau_{4i} \ , \tag{10.9}$$

and

$$\dot{\mathscr{S}}_{2i} = \dot{\mathscr{S}}_{3i} \ , \tag{10.11}$$

so that

$$Q = 2\ \dot{\mathscr{S}}_{2i}\ (\tau_{3i} - \tau_{2i}) \ . \tag{10.11}$$

The τ values are determined by the other input parameters. Let X_o be the point of initiation of burn at time t_o. The start of burn in zone i is then taken as

$$\tau_{2i} = t_o + |X_o - \overline{X}_i|/D \ , \tag{10.12}$$

where $\overline{X}_i$ is the zone center. The other τ value is computed from the number of zones N desired in the front. The input parameter N is normally taken as about 3. The desired result is

$$\tau_{3i} = \tau_{2i} + N\,\Delta X_i/D \ , \tag{10.13}$$

where ΔX_i is the zone width. This determines all of the terms necessary for the source computation. The result is a narrow source region sweeping through the material with velocity D.

Because of the finite size of Δt, it was found that the above system would tend to put slightly more or less than average energy in each zone. Small waves in the burn profile were the result. For this reason, a special computation was added in subroutine SOURCE to keep track of exactly the energy generated in each zone. This quantity is compared to the correct total amount, and small adjustments are made as required. For zone i, the negative of the total generated energy is stored in an array called THESE(i). In order to save storage locations, this array is equivalenced to the array containing the distention ratios for the porous material calculation. As a result, the porous material and high-explosive calculations cannot be used for the same material at the same time. On the other hand, there is no reason that a given problem can not have both high-explosive and porous materials. In the subroutine FOAM, any zero or negative distention ratio is treated as unity. If it is really desired, this case can be treated by removing the equivalence statement, setting the proper dimension for THESE (in the main program and SOURCE), and modifying the eighth variable in the YIELD array as stated below. However, the restart calculation is not likely to operate correctly until after the burn is completed.

In cylindrical and spherical geometries, convergence of detonation waves can be encountered. In certain situations the wave will tend to propagate faster than D. To treat this case and possibly others, a self-detonation computation is provided. If P_{cj} is defined as an input parameter, it is stored in the location YIELD (J, 8), where J is the material layer number. Note that this variable is not used in the elastic computation in Section IV but is in the porous material storage as discussed in Section V. If the pressure in a zone exceeds the value of P_{cj} before the zone should start to burn, the τ values above are shifted to the current time. It is realized that this simple method does not cover all interesting situations of this type. However, the code can easily be modified to treat special cases as the need arises.

XI. INPUT, OUTPUT, AND ACCOUNTING

Complete details concerning the input parameters and their functions are given in Appendix H. Hopefully, no additional information is required other than the knowledge that each and every input does affect the function of the code and its computed results. The program can only be expected to solve the problem exactly as defined to it. Obviously, it is the users responsibility to make sure that this problem and the physical one in question have some correspondence.

XI-1. Standard Editing

The standard editing may be divided into two parts: information generated to initialize the calculation and cycle-by-cycle data produced during the running mode. The frequency of the cycle edits is controlled by several input parameters. All printed output is labeled with easily recognizable names, provided the appropriate sections of this report have been covered.

The format of the output changes to fit the problem at hand. When porous material is present, the distention ratios are listed. The linear momentum is printed in plane symmetry calculations and all three stress components in cylindrical geometry. These types of functions are completely automatic. The user has no control over such features.

In some problems it might be desirable to obtain more values of a given function than would be possible with the standard output because of the length of the printed information. For example, a finely detailed stress history at a given point in the material could be required. There are no provisions built into the code for this type of output. The bookkeeping and linkage would be extremely complex. On the other hand, it is quite simple to insert several cards into the deck to obtain any desired data. In most cases the natural point in the code for this insertion is after card number 1006 in the listing supplied in Appendix G.

XI-2. Binary Tape Output

Two binary output tapes are available. These are principally designed for plot and movie programs. The program MASPLT, described by the authors,[5] uses these tapes for input.

The standard cycle edit data may be written on output unit 2 at the same frequency as the printed data. A more dense set of data can be generated by special output onto unit 3. This feature is useful for movies. The frequency of these dumps should be quite frequent for movies, since MASPLT interpolates between dumps. The format of the information on both output units is the same and is detailed in Appendix E.

XI-3. Restart Input-Output

It is sometimes desirable to complete a long-running problem after evaluating the early part of the calculation. A binary tape dump containing sufficient information to restart the calculation can be generated. The frequency of these dumps is controlled by an input parameter relating to the internal computer clock. A dump is automatically produced and the code exits 5 seconds short of the job card time limit. Entire common blocks are written on the output tape during these dumps. For this reason, care must be used when changing the dimensions of subscripted variables.

The restart input tape is always unit 10. The restart output unit can be either 10 or 11. If unit 11 is used, information on tape 10 after the restart point is not destroyed. Multiple restarts are permitted by use of a single tape with new data added during each run.

It should be obvious that the power of this feature will be lost if the user does not request tapes on the appropriate drives. Failure to use this option has probably resulted in more lost computing time than is caused by any other feature in the code.

XI-4. Accounting

The features in this section do not affect the problem computation in any way. The following expressions relate only the method by which the code evaluates its results.

The total energy contained in a calculation is the sum of the kinetic and internal (including radiation field) energies. The internal energy is

$$\mathscr{E}_{int}(t_{j+1}) = \sum_{i=1}^{N} M_i E_i^{j+1} , \tag{11.1}$$

where E_i is given by (2.7) and N is the number of zones. The kinetic energy cannot be evaluated exactly at the same time because of the centering procedure explained in Section II. Within a half time step of (11.1), the result is

$$\mathscr{E}_k(t_{j+1}) = \frac{1}{8} \sum_{i=1}^{N} M_i (V_i^{j+1/2} + V_{i+1}^{j+1/2})^2 . \tag{11.2}$$

The appropriate modifications for fractures are obvious. The current total energy in the problem is then

$$\mathscr{E}_{totl}(t_{j+1}) = \mathscr{E}_k(t_{j+1}) + \mathscr{E}_{int}(t_{j+1}) . \tag{11.3}$$

In general, (11.3) will not yield a value which is independent of time. Energy may enter or leave the material under consideration by several methods. Those easily included are PdV work at both external boundaries, radiation leakage, and internal energy sources. For each of these, a current value is computed during each cycle and a running tab is retained. The work performed at the front surface is

$$W_f(t_{j+1}) = W_f(t_j) + \frac{1}{2} A_1 (P_1^j + P_1^{j+1}) (X_1^j - X_1^{j+1}) , \tag{11.4}$$

where the A_1 is given by (2.21). At the back surface the result is

$$W_b(t_{j+1}) = W_b(t_j) + \frac{1}{2} A_{n+1} (P_{N+1}^j + P_{N+1}^{j+1}) (X_{N+1}^{j+1} - X_{N+1}^j) . \tag{11.5}$$

The net radiation energy gains are

$$\mathscr{E}_{rf}(t_{j+1}) = \mathscr{E}_{rf}(t_j) - \frac{1}{2} A_1 (F_1^j + F_1^{j+1}) \Delta t \tag{11.6}$$

and

$$\mathscr{E}_{rb}(t_{j+1}) = \mathscr{E}_{rb}(t_j) + \frac{1}{2} A_{N+1} (F^j_{N+1} + F^{j+1}_{N+1}) \Delta t \quad . \tag{11.7}$$

The total source energy is

$$\mathscr{E}_s(t_{j+1}) = \mathscr{E}_s(t_j) + \sum_{i=1}^{N} M_i \dot{\mathscr{G}}_i^{j+1/2} \Delta t \quad . \tag{11.8}$$

The correct value of the total energy that should be in the problem is

$$\begin{aligned} \mathscr{E}_{tot2}(t_{j+1}) &= W_f(t_{j+1}) + W_b(t_{j+1}) + \mathscr{E}_s(t_{j+1}) \\ &\quad + \mathscr{E}_{rf}(t_{j+1}) + \mathscr{E}_{rb}(t_{j+1}) + \mathscr{E}_o \quad , \end{aligned} \tag{11.9}$$

where

$$\mathscr{E}_o = \mathscr{E}_{totl}(0) \tag{11.10}$$

is the initial energy. At each standard edit the current values of (11.1) through (11.3) are calculated. The total energy error is defined as

$$\Delta\mathscr{E} = \mathscr{E}_{totl} - \mathscr{E}_{tot2} \tag{11.11}$$

and the percent energy error as

$$\%\Delta\mathscr{E} = 100 \; \Delta\mathscr{E}/\mathscr{E}_{tot2} \quad . \tag{11.12}$$

The allowable error limits are not well defined in general. Even if the calculation were exactly conserving, (11.12) might be nonzero because of the centering error of (11.2). Normal calculations give typical errors of 0.001 to 0.1 percent. In problems where $\mathscr{E}_{rf}$ and $\mathscr{E}_{rb}$ are large and negative, larger errors are acceptable.

In plane geometry problems, a momentum calculation is provided. The equations are differenced in such a form as to exactly conserve momentum. All errors result from machine round-off. However, because of boundary pressures, the net momentum need not be constant.

For each zone the momentum is given by

$$\mathscr{M}_i = \frac{1}{2} M_i (V_i^{j+1/2} + V_{i+1}^{j+1/2}) \quad . \tag{11.13}$$

Necessary changes for a fracture are obvious. The total momentum summed to zone i from the front surface is

$$\mathrm{SMV}(i) = \sum_{j=1}^{i} \mathcal{M}_j \quad . \tag{11.14}$$

This quantity is contained in the standard edit data for each zone. Impulse delivered to a given layer is then easily determined.

The specific entropy of each zone is provided in the standard edit. The total entropy in the problem is also computed to provide an additional error check.

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Appendix A

STORAGE, SUBROUTINES, AND TAPE UNITS

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STORAGE, SUBROUTINES, AND TAPE UNITS

Storage Requirements

In the listing given in Appendix G, the dimensions are set for a maximum of 20 materials and 400 zones. These dimensions can be easily modified up to about 1700 zones by using the program ZCHART.[5] For the 400-zone code, the central memory storage required is 200000 octal on the CDC 6600 with the FUN compiler and somewhat less with the FTN compiler.

The extended core storage depends on both the number of zones and the number of tabular equations of state (NEOS) retained in the given problem. The following table applies to the 400-zone version. ZCHART produces a similar table for each new dimension set.

NEOS	ECS	
	DECIMAL	OCTAL
0	4805	000011305
1	4805	000011305
2	18507	000044113
3	25358	000061416
4	32209	000076721
5	39060	000114224
6	45911	000131527
7	52762	000147032
8	59613	000164335
9	66464	000201640
10	73315	000217143
11	80166	000234446
12	87017	000251751
13	93868	000267254
14	100719	000304557
15	107570	000322062
16	114421	000337365
17	121272	000354670
18	128123	000372173
19	134974	000407476
20	141825	000425001

List of Subroutines

These subroutines and entry points are defined:

CHART D	Main program
EDIT	Standard output
ELPL	Elastic-plastic calculation
FOAM	Porous material calculation
EDGE	Boundary pressures
TEDGE	Boundary temperatures (entry point in EDGE)
SOURCE	Energy sources
FRACT	Fracture calculations
EOS	Tabular equations of state and calls to ANEOS package
TPLINE	Determines triple line data
ANEOS	*
ANEOS1	*
ANEOS2	*
ANION1	*
ANION2	*
ANION3	*
EPINT3	* Evaluates the third exponential integral
ANTWOPH	*
ANPHASE	*
ANMAXW	*
ANLS	*
ANHUG	*
ANPHTR	*
ANDATA	*
ZAPPER	Conversion of DTF and BUCKL formatted input data
ZONE	Mass ratio zoning

*Part of ANEOS package. See Reference 4 for complete description. EPINT3 is also called from EOS.

The machine library functions for exponential (EXP), square root (SQRT), and natural logarithm (ALOG) are used. Calls to the CDC 6600 clocks SECOND and HOROLOG are also present.

<u>Logical Tape Units</u>

These logical tape units are defined on the program card:

1. Standard edit output tape. It is usually equivalenced to the printer.

2. Optional binary edit output tape for plot programs, etc. (see note below).

3. Optional binary movie output tape.

7. Standard DTF or BUCKL input tape.

10. Standard restart output and input tape.

11. Optional restart output tape.

12. EOS input tape.

17. Optional DTF or BUCKL input tape. It is usually equivalenced to the card reader.

NOTE: It is almost never desirable to produce both the binary dumps on units 2 and 3 at the same time. Accordingly, in the listing given in Appendix G, unit 2 has been equivalenced to unit 3 on the program card to save buffer storage. Any output on 2 will appear on unit 3 unless the program card is changed. When the program is used on machines without extended core storage, additional units must be defined (see Appendix C).

Appendix B

MASS RATIO ZONING

Appendix B

MASS RATIO ZONING

For a calculation of this type, it is advisable that the masses of adjacent zones be nearly equal. However, it is not always possible to use exactly the same mass for all zones in a given problem; in fact, it is sometimes necessary that they differ by many orders of magnitude in various parts of the material. This is accomplished by use of variable mass zoning that slowly increases or decreases the masses from one zone to the next. In CHART D this is done automatically, but the various inputs must be consistent with reality. It should be remembered that this discussion applies to a zoning region and not to a material layer as defined in Section VIII. There may be many zoning regions in a material layer.

Consider a material layer of mass $\mathcal{M}$. In this region there are ℓ zones, with M_i the mass of zone i and R the adjacent zone mass ratio:

$$R = M_i/M_{i-1} = M_{i+1}/M_i \ . \tag{B. 1}$$

The total mass $\mathcal{M}$ is then

$$\begin{aligned} \mathcal{M} &= \sum_{i=1}^{\ell} M_i = M_1 \sum_{i=1}^{\ell} R^{i-1} \ , \\ &= M_1 \left\{ \frac{1 - R^{\ell}}{1 - R} \right\} \text{ if } R \neq 1 \ , \\ &= \ell M_1 \text{ if } R = 1 \ . \end{aligned} \tag{B. 2}$$

From the above expressions, it is easily shown that the mass ratio R is given by

$$R = \frac{1 - M_1/\mathcal{M}}{1 - M_\ell/\mathcal{M}} = \left(\frac{M_\ell}{M_1} \right)^{\frac{1}{\ell - 1}} \tag{B. 3}$$

and the number of zones ℓ by

$$\begin{aligned} \ell &= \ln \left\{ 1 - (1 - R)\,\mathcal{M}/M_1 \right\} / \ln R \quad \text{if } R \neq 1 \\ &= \mathcal{M}/M_1 \quad \text{if } R = 1 \ . \end{aligned} \tag{B. 4}$$

Equations (B. 3) and (B. 4) may be combined to show that

$$\frac{M_\ell}{M_1} = \left\{(R - 1)\frac{\mathcal{M}}{M_1} + 1\right\} \Big/ R \tag{B. 5}$$

and

$$\frac{\mathcal{M}}{M_1} = \frac{\left(\frac{M_\ell}{M_1}\right)^{\frac{\ell}{\ell - 1}} - 1}{\left(\frac{M_\ell}{M_1}\right)^{\frac{1}{\ell - 1}} - 1} \; . \tag{B. 6}$$

As a zoning aid, plots of the functions are given in Figs. (B. 1) through (B. 6).

There are several impossible situations that can be generated by careless input. One of the more obscure may result when the values of $\mathcal{M}$, M_1, and $R < 1$ are being defined. The value of ℓ is required. However, consider (B. 2) in the limit as $\ell \to \infty$. This yields an upper bound on the allowed value of the total mass,

$$\mathcal{M} < \mathcal{M}_{max} = M_1/(1 - R) \; , \tag{B. 7}$$

that may be used with the given values of R and M_1. If a value of $\mathcal{M} > \mathcal{M}_{max}$ is given, an error message will be generated and the code will exit.

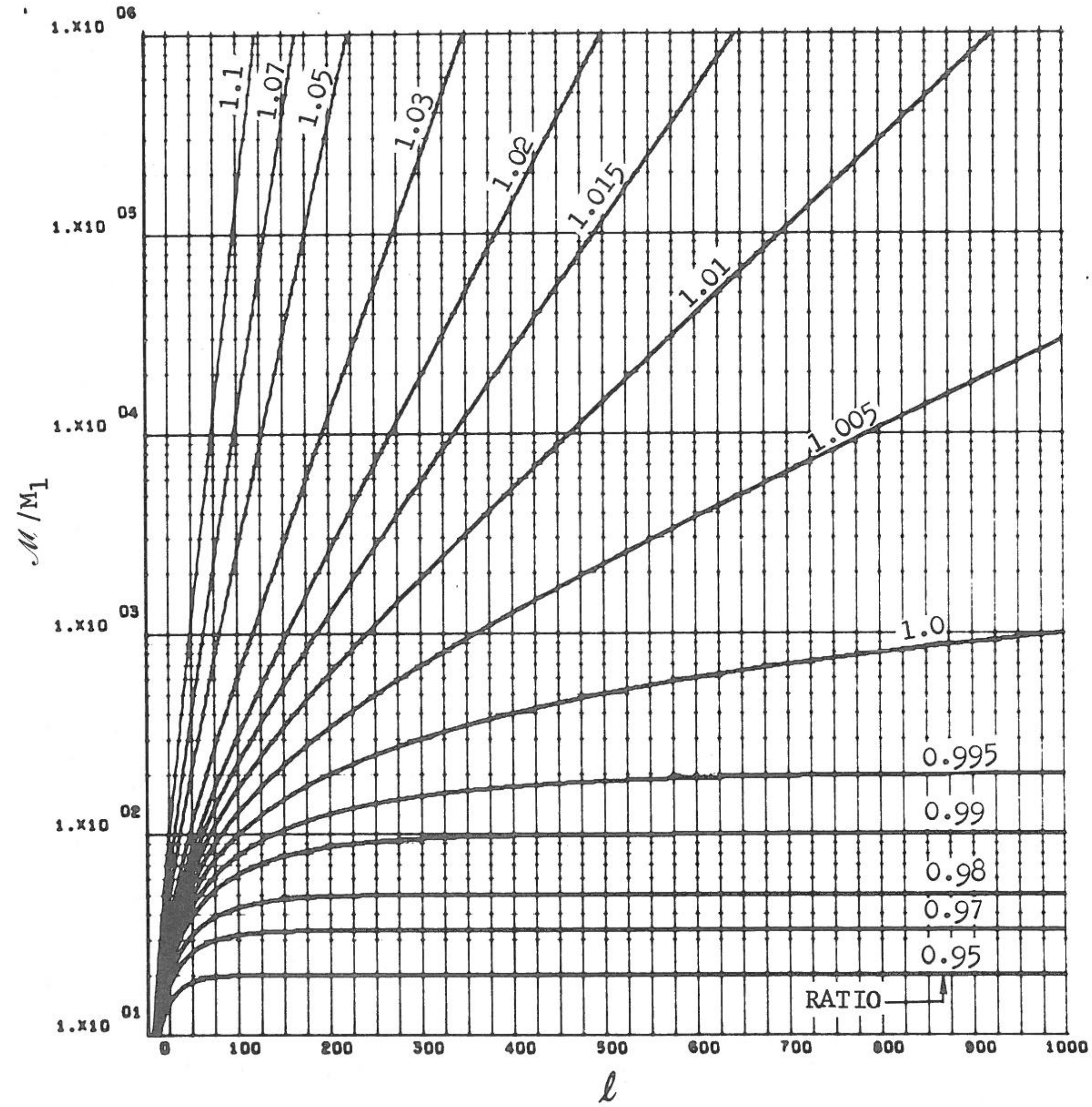


Fig. B.1 Ratio of total region mass to first zone mass versus number of zones ℓ for various mass ratios.

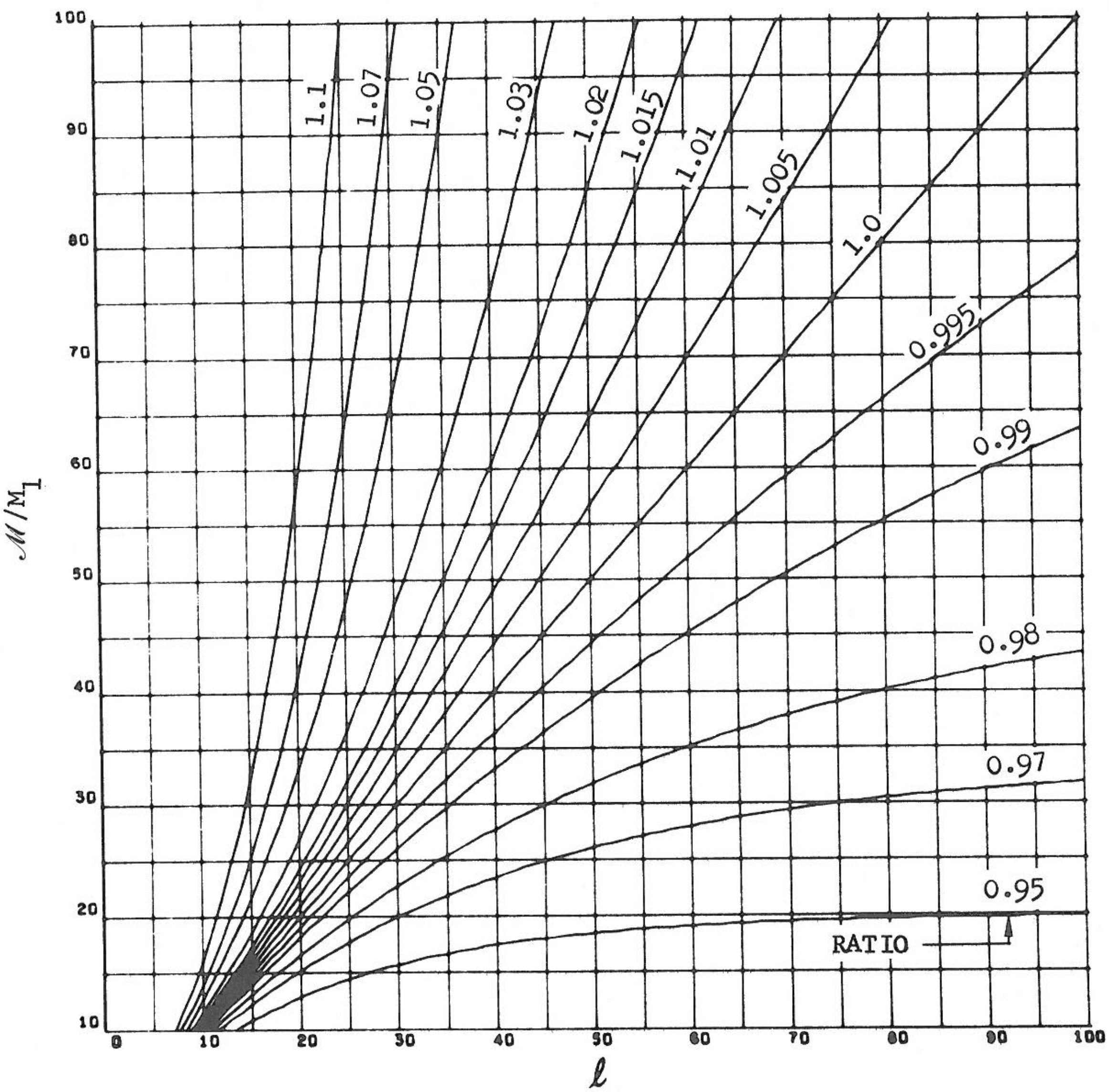


Fig. B. 2 Ratio of total region mass to first zone mass versus number of zones ℓ for various mass ratios.

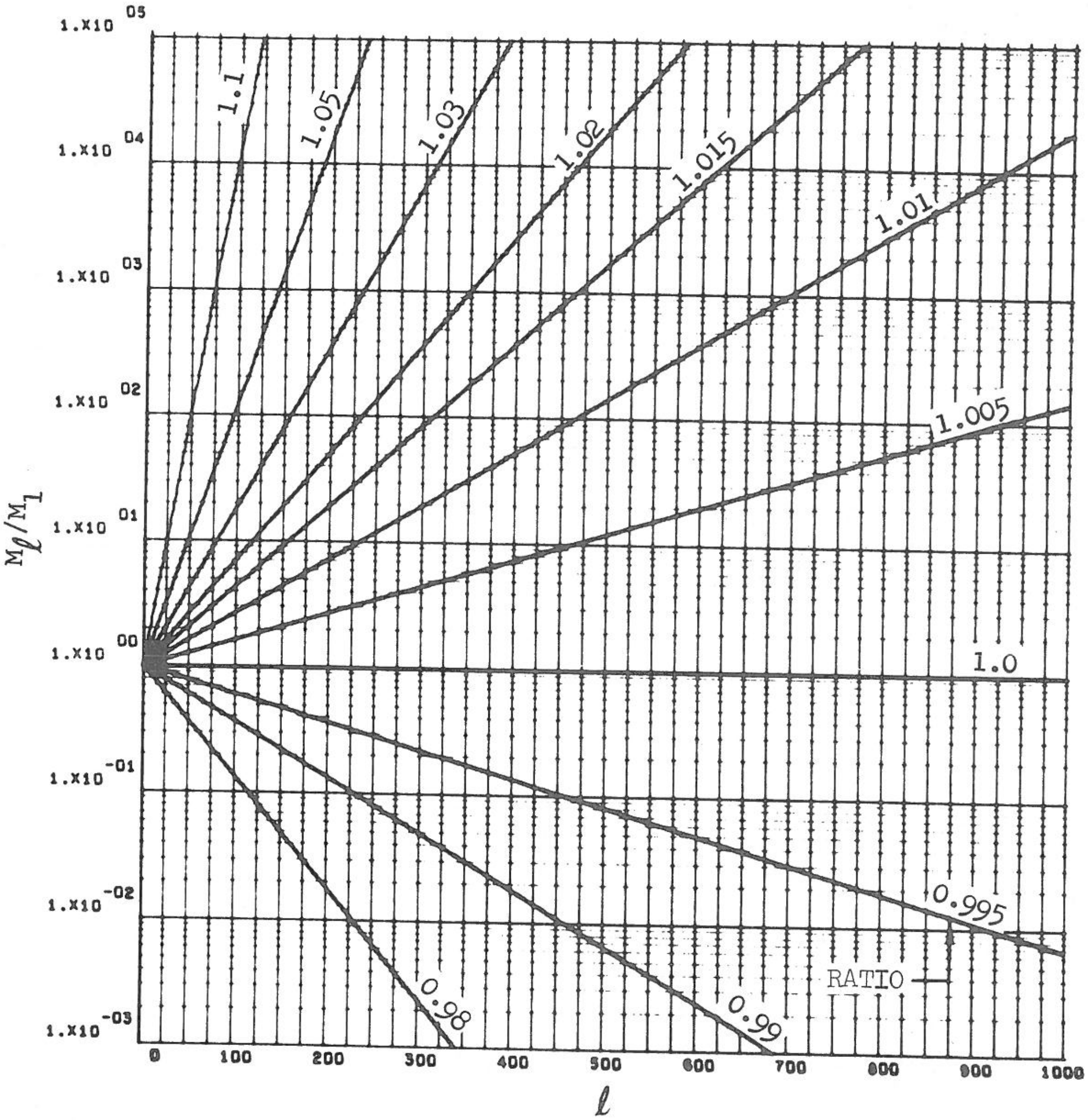


Fig. B.3 Ratio of ℓ^{th} zone mass to first zone mass versus ℓ for various mass ratios.

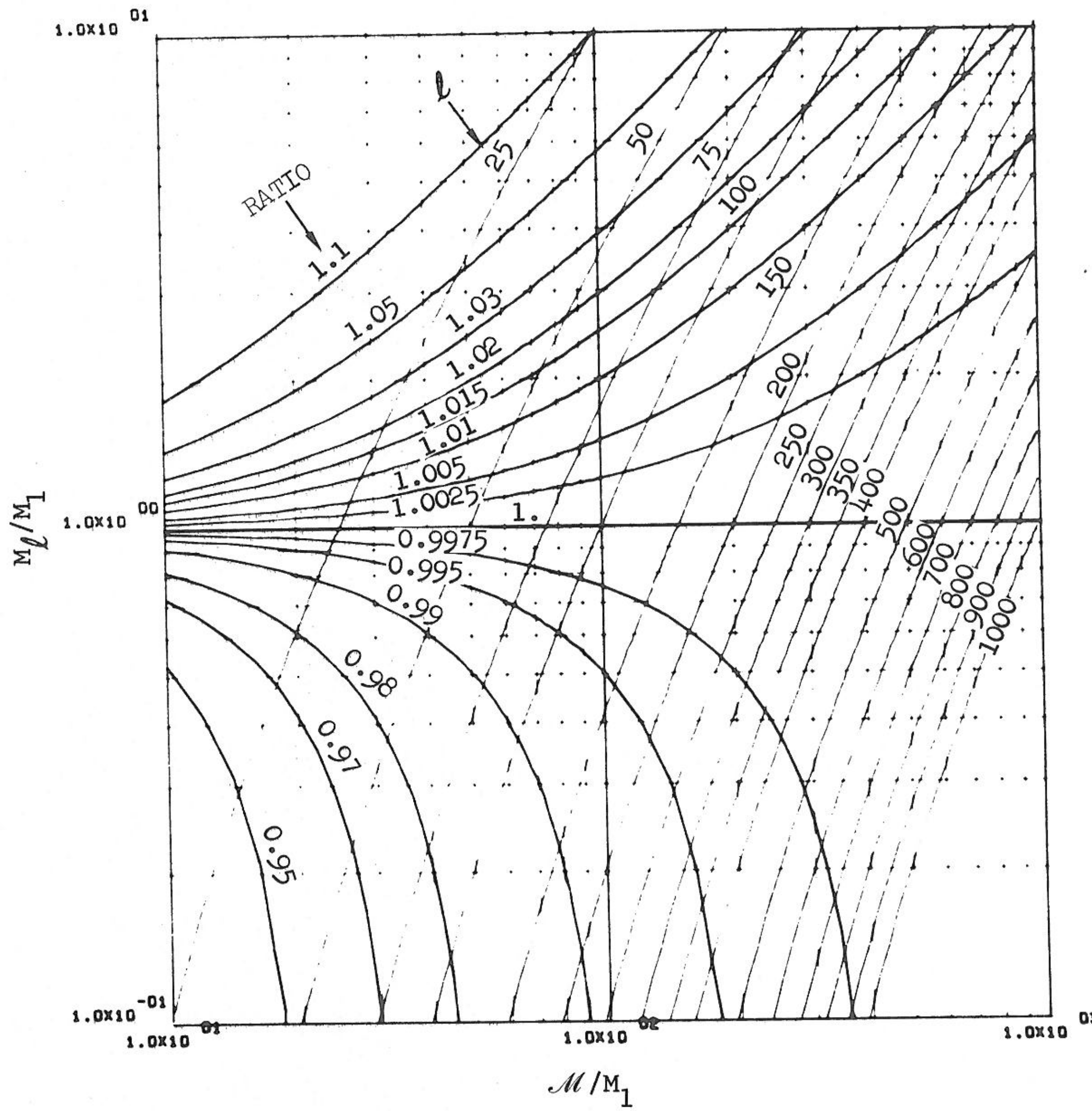


Fig. B.4 Ratio of ℓ^{th} zone mass to first zone mass versus ratio of total mass of ℓ zones to first zone mass for various mass ratios and ℓ .

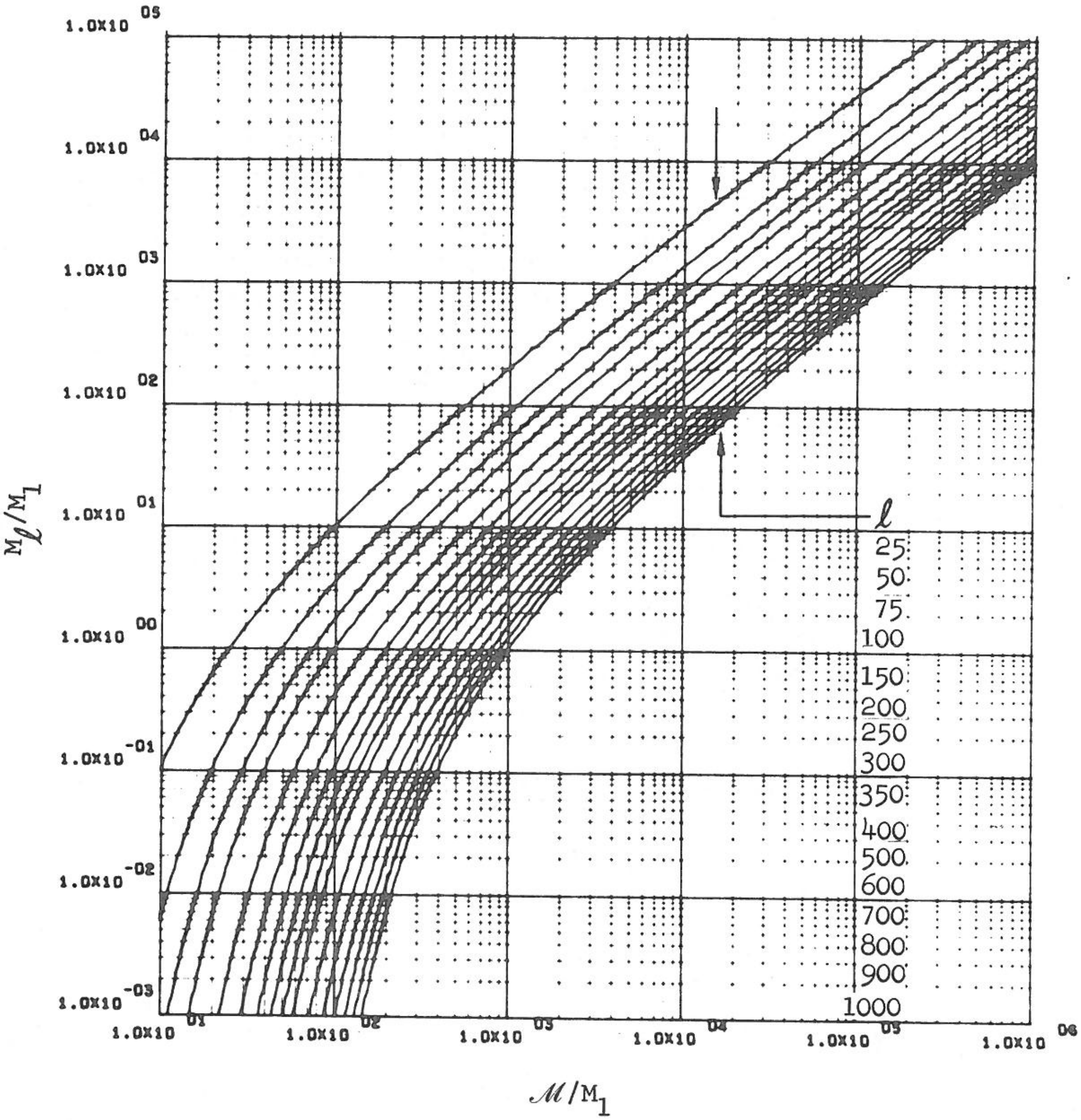


Fig. B.5 Ratio of ℓ^{th} zone mass to first zone mass versus ratio of total mass of ℓ zones to first zone mass for various ℓ.

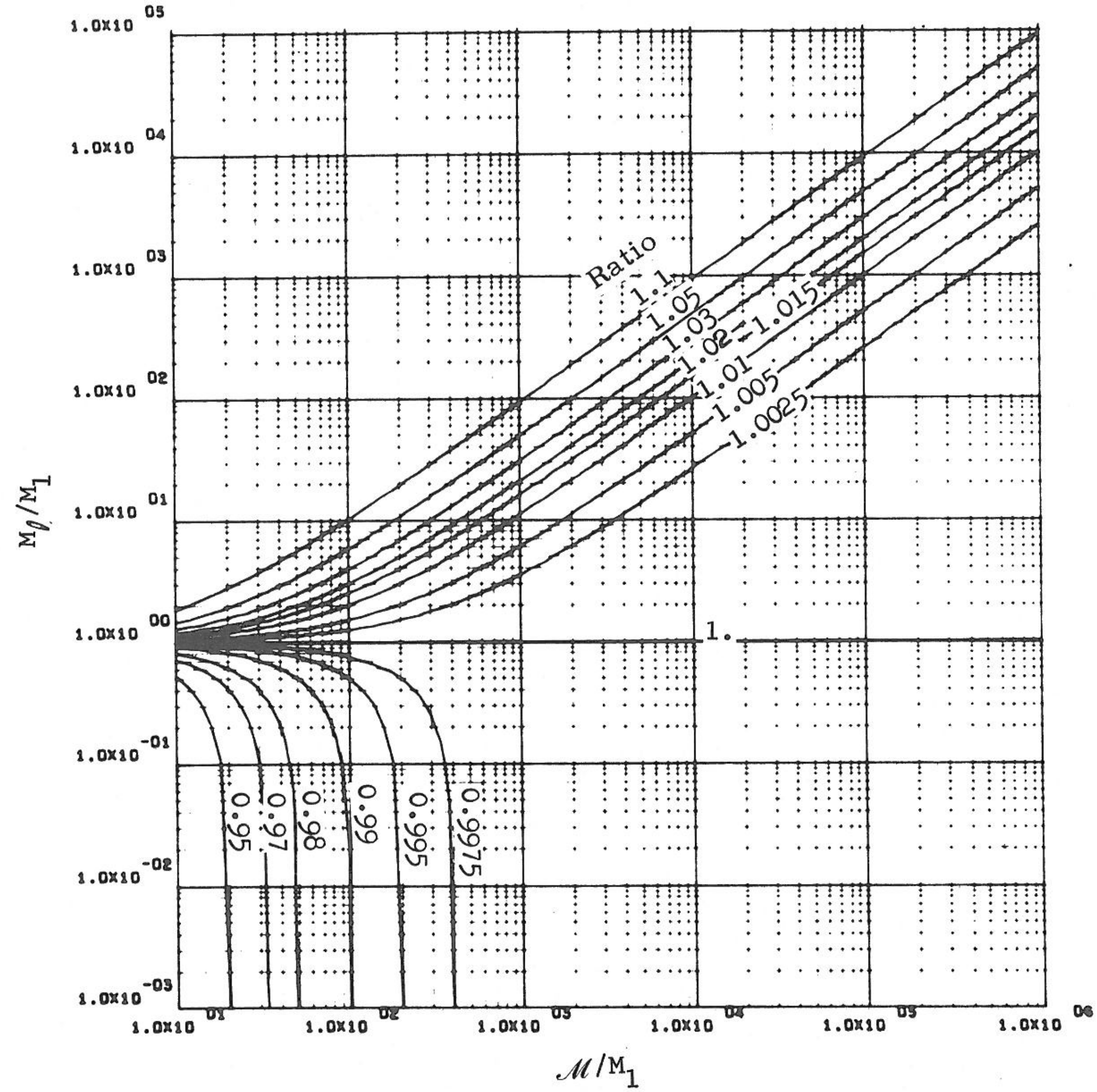


Fig. B. 6 Ratio of ℓ^{th} zone mass to first zone mass versus ratio of total mass of ℓ zones to first zone mass for various mass ratios.

Appendix C

MODIFICATIONS FOR MACHINES WITHOUT EXTENDED CORE STORAGE

Appendix C

MODIFICATIONS FOR MACHINES WITHOUT EXTENDED CORE STORAGE

In the program listed in Appendix G, the CDC 6600 extended core storage (ECS) is employed. This creates a problem on machines which do not have this feature. Disk or tape storage must be substituted. The following subroutine can be inserted in the program for this purpose. The method employed is not the most efficient that can be imagined, but no modifications in the main program except for the program card are necessary.

Each call to ECS is replaced by reference to a tape unit. The dimensions are set through COMMON/ECSD/ to those in subroutine EOS. The additional tape units must be defined on the program card. While the subroutine itself is small, provisions must be made in the central memory storage request to allow for the additional buffers. Computational speed will also suffer. If sufficient central memory is available, the subroutine can be reworked to use the faster storage.

In the example shown below, the code is limited to a maximum of five tabular equations of state.

```
******************  REPLACE CONTINUATION PART OF PROGRAM CARD
     1TAPE10,TAPE11,TAPE12,TAPE17=INPUT,TAPE18,TAPE19,TAPE20,TAPE21,
     2TAPE22,TAPE23,TAPE24,TAPE25,TAPE26)
```

```
******************  INSERT AFTER LAST CARD IN DECK
      SUBROUTINE WRITEC (ARRAY,L,N)
C     DUMMY CDC6600 EXTENDED CORE STORAGE ROUTINE FOR CHARTD
C     MEOST IS THE MAXIMUM NUMBER OF TABULAR EQUATIONS OF STATE
C     TO USE ADD KT ARRAY VALUES TO TAPE NUMBERS ON THE PROGRAM CARD
      COMMON /ECSD/ NECSA,NECSB
      DIMENSION ARRAY(1), KA(9), KT(9)
      DATA MEOST,J,KA/5,1,9*0/
      DATA KT/18,19,20,21,22,23,24,25,26/
      K=0
      GO TO 10
C
      ENTRY READEC
C
      K=1
10    IF (J) 20,50,20
20    J=0
      KK=(NECSB-4)/12
      KA(2)=6*KK
      KA(3)=10*KK
      KA(4)=11*KK+3
      DO 30 I=1,MEOST
30    KA(I+4)=NECSA*(I-1)+NECSB
      MEOST=MEOST+4
      DO 40 I=1,MEOST
      KK=KT(I)
40    REWIND KK
C
50    DO 70 I=1,MEOST
      IF (L-KA(I)) 70,60,70
60    KK=KT(I)
      GO TO 80
70    CONTINUE
      PRINT 120, L
      STOP
80    IF (K) 100,90,100
C     WRITE
90    WRITE (KK) (ARRAY(I),I=1,N)
      GO TO 110
C     READ
100   READ (KK) (ARRAY(I),I=1,N)
110   REWIND KK
      RETURN
C
120   FORMAT (17H1 DUMMY ECS ERROR,5X,8HLOCATION,I10)
      END
```

Appendix D

EXTERNAL ENERGY DEPOSITION TAPE FORMATS

Appendix D

EXTERNAL ENERGY DEPOSITION TAPE FORMATS

The coupling to externally generated energy deposition profiles is discussed in Section VIII. Two input formats are available. The input tape drive is 7. Either format can also be used with punch cards. In this case, the cards follow those of card set 13, type 5, as discussed in Appendix H.

DTF Formatted Data

Card 1 Format (9A8, I8)

Variables 1 to 9. An identification label - any BCD information.

Variable 10. The integer zero. This informs the code that a DTF formatted tape is to follow.

Card 2 Format (2I5)

Variable 1. NZDTF - The number of zones.

Variable 2. NMATDTF - The number of materials.

Card 3 Format (16I5)

Variable. NBDTF(I), I = 1, (NMATDTF+1) - The zone boundary numbers between the various material layers.

All Following Cards Format (2E20.10)

Variables. (DO(I), VO(I), I = 1, NZDTF) - The mass and energy deposited in zone I.

BUCKL Formatted Data

Card 1 Same as card 1 above (DTF Format) except Variable 10 is greater than zero. There is then one set of the following cards for each material or layer in the problem, starting from the right and proceeding to the left.

Card 2 Format (I4, E16.7, I4)

Variable 1. JL - The material layer numbers except for the last. JL is negative for the last to discontinue the reading of data.

Variable 2. TEMPH - The total mass of this layer. This must be the same as the CHART value.

Variable 3. JJ - The number of points in this layer. The first and last points coincide with the right and left layer boundaries.

All Following Cards Format (5E16.5)

Variables. (XO(I), VO(I), I = 1, JJ) - The mass depth in layer and specific deposition at point I.
XO(1) = 0.
XO(JJ) = TEMPH (above).

Return to card 2 for next layer if JL > 0.

Appendix E

BINARY OUTPUT TAPE FORMAT

Appendix E

BINARY OUTPUT TAPE FORMAT

The purpose and control of binary output tapes 2 and 3 are discussed in Section XI. The format of the information on both units is as follows:

Record 1:

(ANAME(I), I = 1, 13) - the problem identification

All following records:

NZ, NZP, ICYCLE, NCOUNT, TIME, X(NZP), V(NZP), (X(I), V(I), XL(I), VL(I), ISPALL(I), T(I), D(I), P(I), Q(I), E(I), ENTSV(I), SXD(I), SZD(I), DRATIO(I), I = 1, NZ),

where

NZ = number of zones

NZP = NZ+1 = number of zone boundaries

ICYCLE = cycle number

NCOUNT = tape record number

TIME = problem

X(I) = position of boundary I

V(I) = velocity of boundary I

XL(I) = position of left boundary of zone I if fractured

VL(I) = velocity of left boundary of zone I if fractured

ISPALL(I) = 0 if zone I is not fractured

= 1 if zone I is fractured

T(I) = temperature of zone I

D(I) = density of zone I

P(I) = pressure of zone I

Q(I) = artificial viscosity in zone I

E(I) = specific internal energy of zone I

ENTSV(I) = specific entropy of zone I

SXD(I) = X stress deviator of zone I

SZD(I) = Z stress deviator of zone I

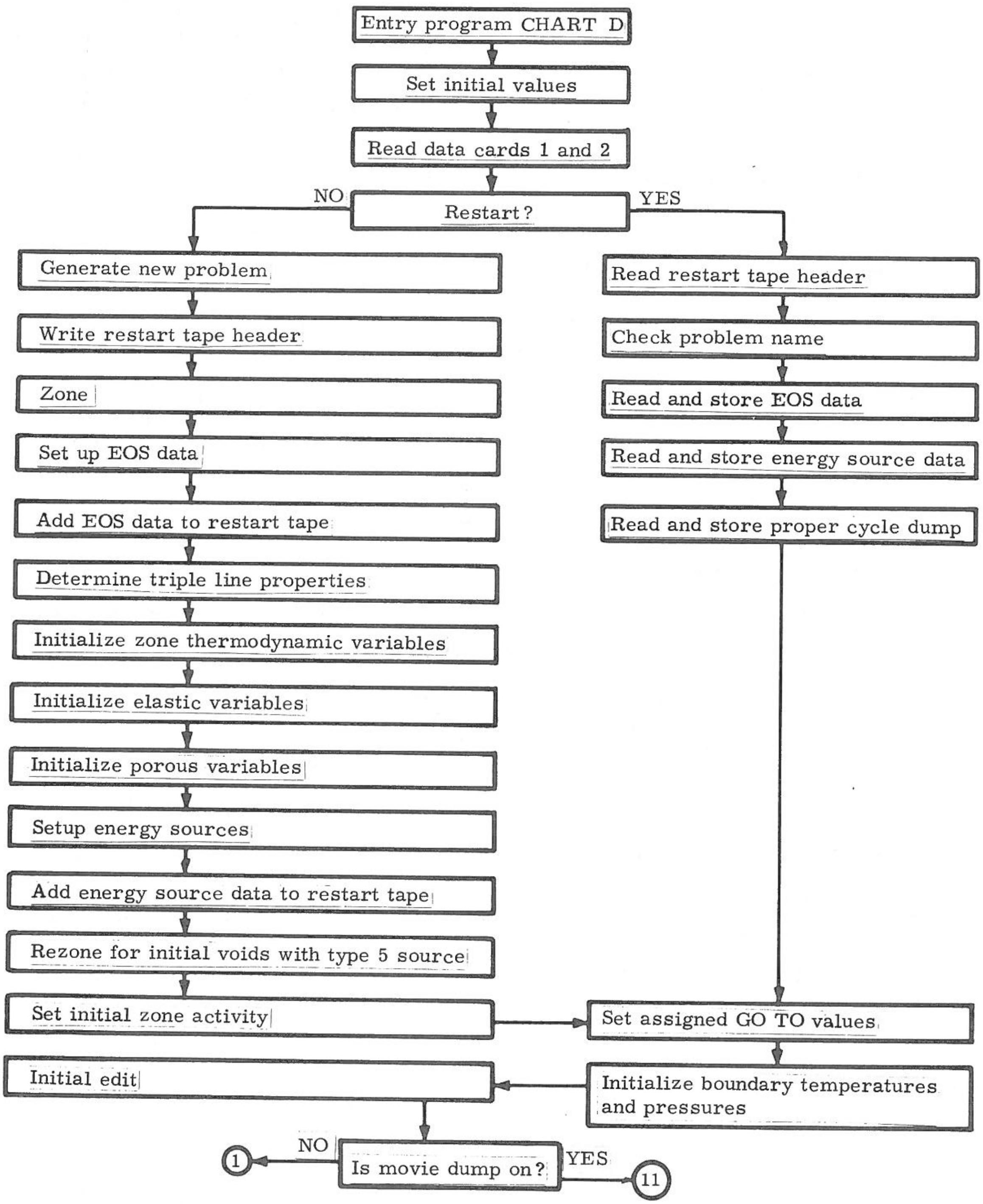
DRATIO(I) = distention ratio of zone I

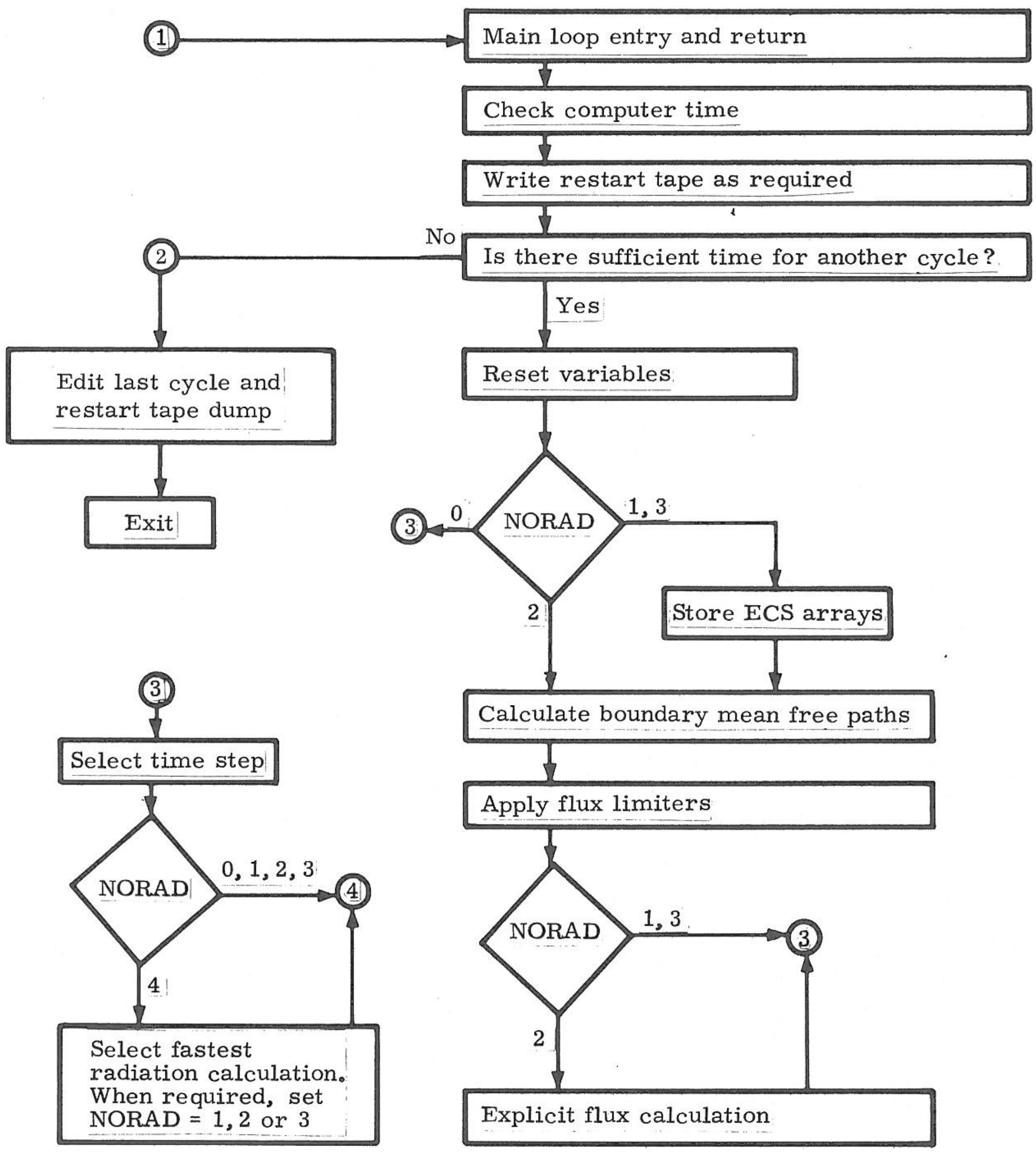
Appendix F

FLOW CHART OF MAIN PROGRAM

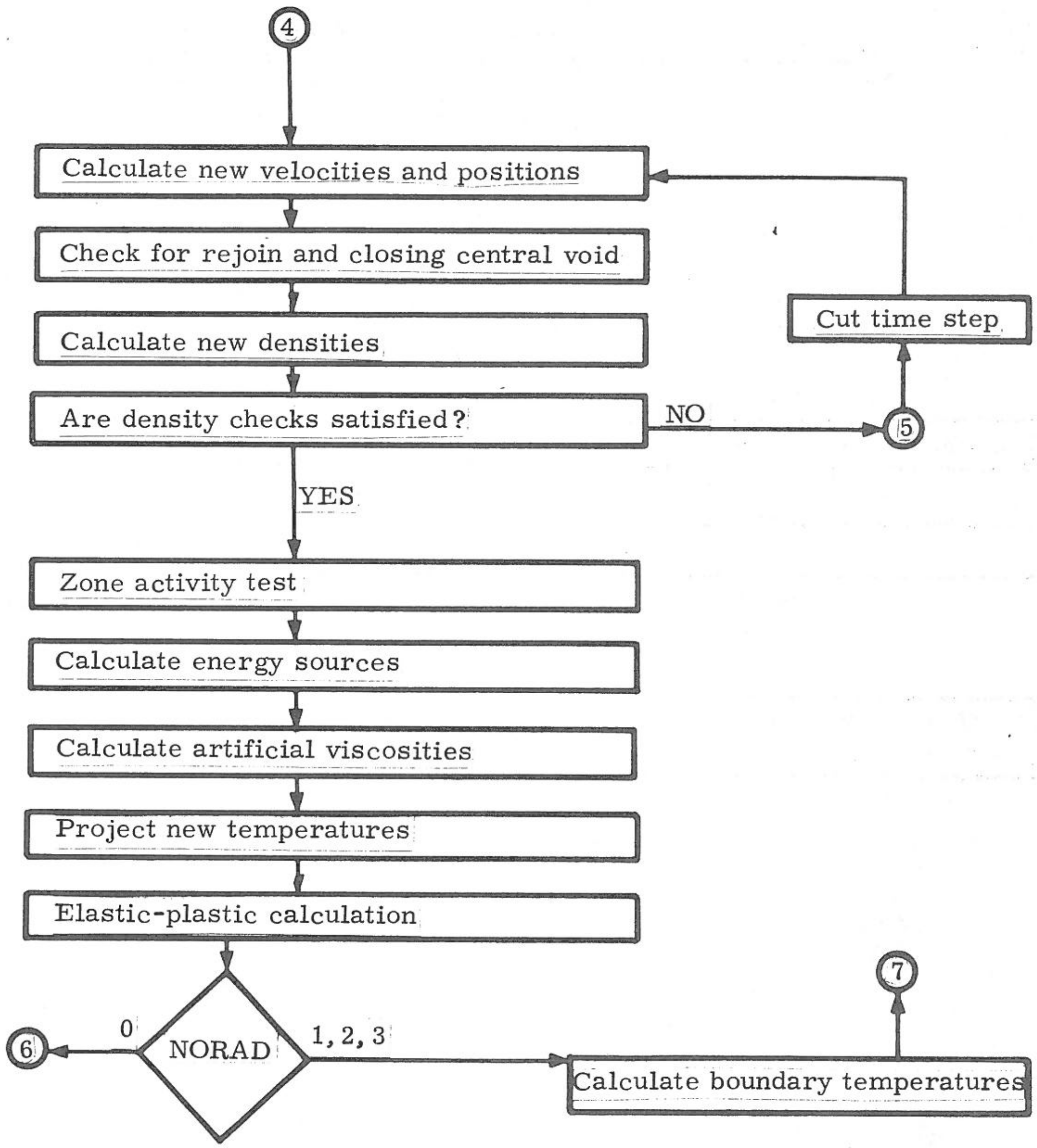
Appendix F

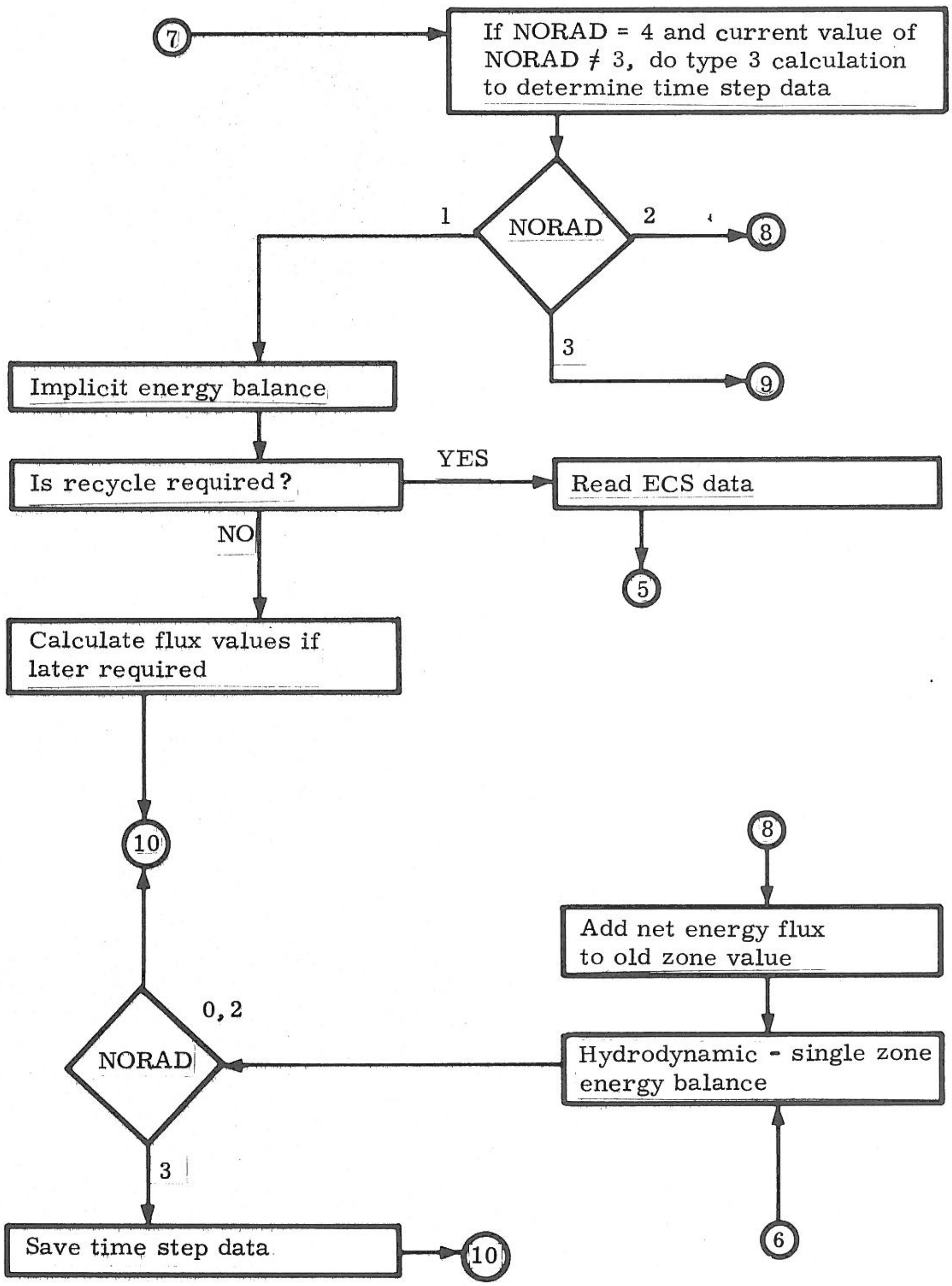
FLOW CHART OF MAIN PROGRAM



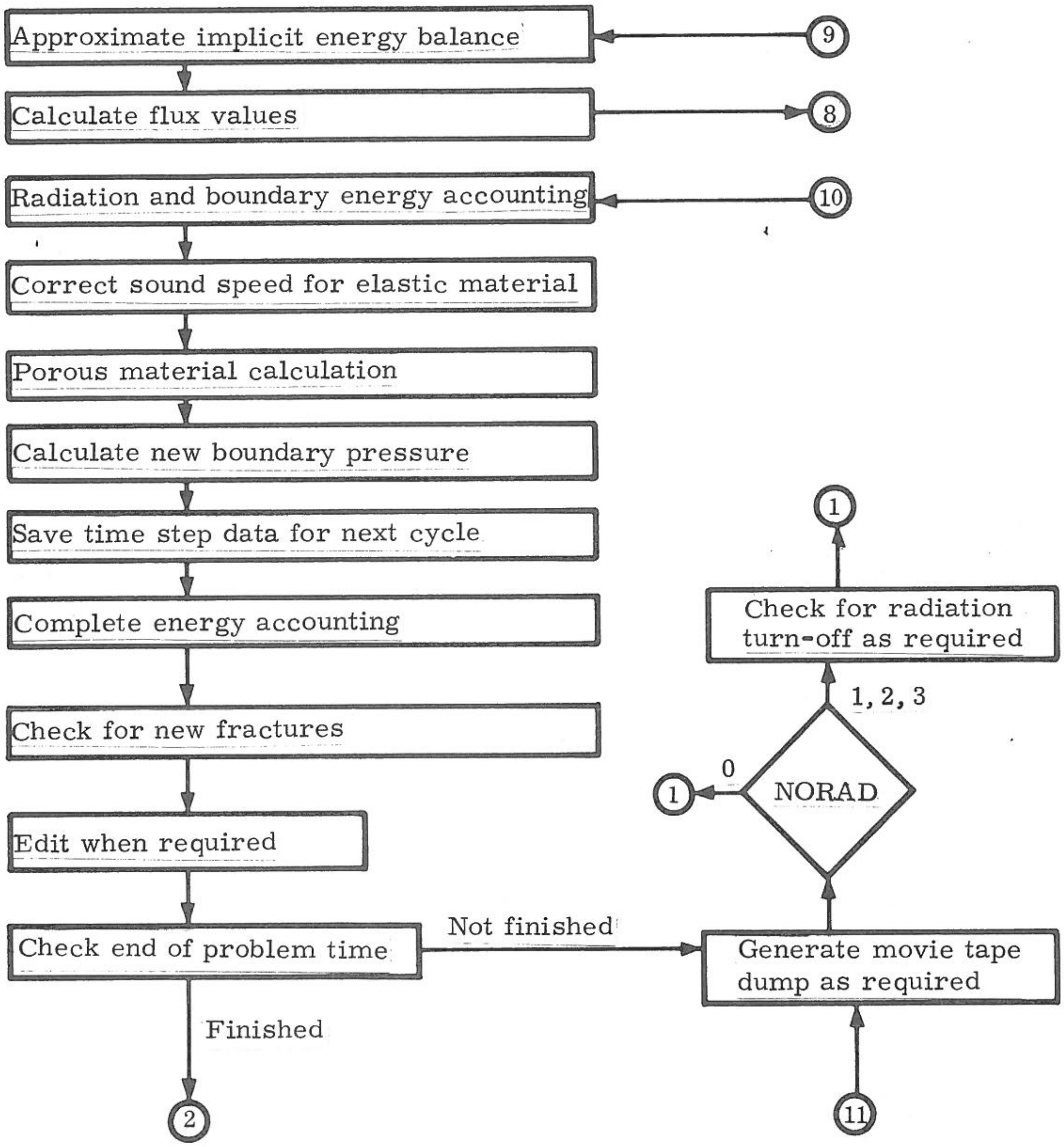


1
Main loop entry and return
Check computer time
Write restart tape as required
No
2
Is there sufficient time for another cycle?
Yes
Edit last cycle and restart tape dump
Exit
Reset variables
3
0
NORAD
1, 3
2
Store ECS arrays
Calculate boundary mean free paths
Apply flux limiters
NORAD
1, 3
3
2
Explicit flux calculation
3
Select time step
NORAD
0, 1, 2, 3
4
4
Select fastest radiation calculation. When required, set NORAD = 1, 2 or 3


4
Calculate new velocities and positions
Check for rejoin and closing central void
Calculate new densities
Are density checks satisfied?
NO
5
Cut time step
YES
Zone activity test
Calculate energy sources
Calculate artificial viscosities
Project new temperatures
Elastic-plastic calculation
NORAD
0
6
1, 2, 3
Calculate boundary temperatures
7



7
If NORAD = 4 and current value of NORAD ≠ 3, do type 3 calculation to determine time step data
NORAD
1
2
8
3
9
Implicit energy balance
Is recycle required?
YES
Read ECS data
5
NO
Calculate flux values if later required
10
8
Add net energy flux to old zone value
0, 2
NORAD
Hydrodynamic - single zone energy balance
3
Save time step data
10
6


Approximate implicit energy balance
9
Calculate flux values
8
Radiation and boundary energy accounting
10
Correct sound speed for elastic material
Porous material calculation
Calculate new boundary pressure
Save time step data for next cycle
Complete energy accounting
Check for new fractures
Edit when required
Check end of problem time
Not finished
Finished
2
Generate movie tape dump as required
11
NORAD
0
1
1, 2, 3
Check for radiation turn-off as required
1

Appendix G

FORTRAN LISTING

```
C   * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C   *                 ISSUED BY SANDIA CORPORATION.
C   *                   A PRIME CONTRACTOR TO THE
C   *              UNITED STATES ATOMIC ENERGY COMMISSION
C   * * * * * * * * * * * * * *   NOTICE   * * * * * * * * * * * * * * * *
C   * THIS REPORT WAS PREPARED AS AN ACCOUNT OF WORK SPONSORED BY THE
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C   * THE BASIC REFERENCE DOCUMENT FOR THIS CODE IS SC-RR-71 0713
C   * FEBRUARY, 1972.
C   * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
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C   * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
```

```
      PROGRAM CHARTD (INPUT,OUTPUT,TAPE1=OUTPUT,TAPE3,TAPE2=TAPE3,TAPE7,
     1TAPE10,TAPE11,TAPE12,TAPE17=INPUT)
C
C      SEPTEMBER,1971    THIS DECK LOADED 9/1/71
C      WARNING   - - -   ECS VERSION
C      FOR MACHINES WITHOUT EXTENDED CORE STORAGE MORE TAPES ARE REQUIRED
C      AND THE DUMMY ECS SUBROUTINE MUST BE ADDED
C
C      S.L.THOMPSON   SANDIA   ALBUQUERQUE,N.M.   5162
C      SC-RR-710713,  SC-RR-710714 AND SC-TM-710715
C      RADIATION DIFFUSION HYDRO CODE
C      PLANE,CYLINDERICAL,OR SPHERICAL GEOMETRY
C      ELASTIC-PLASTIC AND DISTENDED MATERIAL ROUTINES
C      TEMPERATURE AND DENSITY ARE INDEPENDENT VARIABLES
C      TAPE 1 IS STANDARD EDIT OUTPUT TAPE
C      TAPE 2 IS OPTIONAL EDIT OUTPUT TAPE
C      TAPE 3 IS MOVIE TAPE
C      TAPE 10 IS STANDARD RESTART OUTPUT AND INPUT TAPE
C      TAPE 11 IS OPTIONAL RESTART OUTPUT TAPE
C      TAPE 12 IS EOS INPUT TAPE - READ ONLY
C      TAPE 7 IS STANDARD DEPOSITION INPUT TAPE - READ ONLY
C      TAPE 17 IS OPTIONAL DEPOSITION INPUT TAPE
      COMMON /A/ JBND(21),ITRIED(400),IZPTL(400),IZPRL(400),KPHASE(400),
     1KACT(401),ISPALL(400),NSPALL,OBS,IBS,ICYCLE,IDTMAX,IDTMIN,JPRIN,NC
     2OUNT,NMTRLS,NZN,NZ,NZP,NDUMP,NBPRES,NOSOUR,NACTION,NORAD,IGM,NRADC
     3K,MOVIE,IMPEXP,IMPA,KRD4,NOHYD
      COMMON D(400),DO(400),T(400),TO(400),P(400),XM(400),XM2(401),X(401
     1),XO(401),V(401),VO(401),XL(400),XLO(400),VL(400),VLO(401),CSOD(40
     20),Q(400),SXD(400),SZD(400),FPATH(400),FLUX(401),E(400),PPPT(400),
     3PEPTIN(400),PSPALL(400),SD(400),TEMP(400),TSAVE(400),PSAVE(400),ES
     4AVE(400),TEMPR(401),TMSPALL(20),DT,DTMAX,DTMIN,DTTEMP,DTRAD,TIME,T
     5PN,TEND,DTRADT,BL,BQ,DTIMEP(25),DLTTMX(25),DTMINN(25),TIMEP(25),TD
     6TMINN(25),TIMES(25),WORKF,WORKB,ENO,ESOURS,TBPRES(25),PINNER(25),P
     7OUTER(25),XMATUP(21),DTCS,DTP,TITH(25),TEINTH(25),TEOUTH(25),FLINF
     8,FLINFO,FLINB,FLINBO,FLOUF,FLOUFO,FLOUB,FLOUBO,RADEB,RADEF,SCRADF,
     9SCRADB,SPLA(20),SPLB(20),SPLC(20),SPLD(20),ENTSV(400),TMOV(10),DTM
     $OV(10),TRADOFF,SWEP,YIELD(20,8),DRATIO(400),SWPOR
      COMMON /C/ TEMPA,TEMPB,TEMPC,TEMPD,TEMPE,TEMPF,TEMPG,TEMPH,TEMPI,T
     1EMPJ,TEMPK,TEMPL,TEMPM,TEMPN,TEMPAB,TBPU,PBDRYO,PBDRYI,TRADMIN,RAD
     2K1,RADK2,RADK3,RADK4,RADK5,RADK6,TEBOUT,TEBIN,TTHIU
      COMMON /D/ IS,IS1,ICALL,ITLOW,JTLOW,INES
      COMMON /E/ IZETL(21),IZERL(21),ITL(21),IRL(21),IEOS(400),IEOSS(20)
     1,KTP(21),NRDS(21),NUMTEM(20),IGAS(20),NOANEOS,NISEOS
      COMMON /NAME/ ANAME(13),MAXZONE,NTS1,NTS2,NTS3,ITTMP,CYMESH
      COMMON /TAPES/ I,IIN,IOUT,IEOSTP,ITWO
      DIMENSION SD2(1), SD3(1), TSOUR1(1), TSOUR2(1), TSOUR3(1), TSOUR4(
     11), THESE(1)
      EQUIVALENCE (SD2(1),SD(1)), (SD3(1),TEMP(1)), (TSOUR1(1),TSAVE(1))
     1, (TSOUR2(1),PSAVE(1)), (TSOUR3(1),ESAVE(1)), (TSOUR4(1),TEMPR(1))
     2, (THESE(1),DRATIO(1))
      DIMENSION GG(1), GGA(1), GGB(1), GGC(1), GGE(1), GGF(1)
      EQUIVALENCE (GG(1),TEMP(1)), (GGA(1),GGF(1),FLUX(1))
      EQUIVALENCE (GGB(1),TSAVE(1)), (GGC(1),GGE(1),PSAVE(1))
      INTEGER OBS
C     THESE VARIABLES ARE DIMENSION OF ABOVE COMMONS AND VARIABLES
```

```
      DATA KOMMONA,KOMMONB,MAXZONE,MAXNMT/2446,13841,400,20/
      DATA MAXTHI,MAXNPRI,MAXDTMA,MAXDTMI,MAXBPR/5*24/
C     TAPE NUMBERS
      DATA IIN,IOUT,IEOSTP,ITWO/10,10,12,0/
      CALL SECOND (TEMPA)
C     SAVE JOB CARD TIME LIMIT
      CALL HOROLOG (TEMPB,JJ,JJJ)
      NDX=TEMPA+TEMPB+.5
      PRINT 5590, TEMPA,JJJ,JJ
C     ZERO THE VARIABLES
      DO 10 I=1,KOMMONA
   10 JBND(I)=0
      DO 20 I=1,KOMMONB
   20 D(I)=0.
      DO 30 I=1,MAXZONE
   30 DRATIO(I)=1.
C     MISCELLANEOUS CONSTANTS
      PIE=3.1415926536
      FOURPIE=4.*PIE
      PIE43=FOURPIE/3.
      TWOPIE=2.*PIE
      RADK6=5.669E-5*(1.60207E4/1.38046)**4
      CLIGHT=2.997929E10
      RADK5=RADK6/CLIGHT
      RADK2=16.*RADK5
      RADK1=RADK2/3.
      RADK4=4.*RADK5
      RADK3=RADK4/3.
      RADK5=4.*RADK6/3.
      RADK7=2.*RADK5
      NDUMPC=JPRIN=JMOV=1
      ISTOPN=ICYCLE=NCOUNT=MOVFRM=TTOMOV=TIME=TSOURM=0.
      NCKA=35
      TEMINT=.001
      CK=1.E-6
      CKA=.1
      CKB=.5
      CKC=1.E-4
      CKR=.001
      TCONR=10.
      TRADMIN=.026
      MITTMP=40
      KTTMP1=10
      FLUXMIN=RADK6*TRADMIN**4
      DTRADT=1.
      NCKRD4=250
      NCKR=0
C
      READ 5600, (ANAME(I),I=1,13)
      DO 40 J=1,50
   40 PRINT 5620, (ANAME(I),I=1,13)
      PRINT 5610
      READ 5630, ITIMEL,NG,NDUMP,IS,IS1,NEDREJ,FRACOT,DTINCR,TEND
      IF (TEND.LE.0.) TEND=1.E10
      IF (IS.GT.0) IOUT=11
```

```
      IF (IS1.GT.0) ITWO=1
      IF (FRACDT.LE.0.) FRACDT=.8
      IF (DTINCR.LE.0.) DTINCR=1.05
      DTINCI=1./DTINCR
      DTTEMT=DTINCR
      IF (ITIMEL.EQ.0.OR.ITIMEL.GT.NDX) ITIMEL=NDX
      PRINT 5650, ITIMEL,NG,NDUMP,IIN,IOUT,IEOSTP,ITWO,NEDREJ,FRACDT,DTI
     1NCR,TEND
      IF (ITWO.EQ.1) WRITE (2) (ANAME(I),I=1,13)
      IF (NDUMP.EQ.0) NDUMP=9999
      IDTDMP=NDUMP
      IF (NG.GE.0) GO TO 120
C     READ RESTART TAPE
      NG=-NG
      ZAV=TEND
      READ (IIN) (X(I),I=1,13)
      DO 50 I=1,13
      IF (X(I).EQ.ANAME(I)) GO TO 50
      PRINT 5660
      PRINT 5620, (ANAME(J),J=1,13),(X(J),J=1,13)
      STOP 76
   50 CONTINUE
C     CALL EOS RESTART SET UP
      ICALL=3
      CALL EOS
      JJ=6*MAXZONE
      READ (IIN) (SD(I),I=1,JJ)
      CALL WRITEC (SD,0,JJ)
      IF (IIN.EQ.IOUT) GO TO 60
      WRITE (IOUT) (ANAME(I),I=1,13)
      ICALL=4
      CALL EOS
      WRITE (IOUT) (SD(I),I=1,JJ)
   60 DO 110 I=1,NG
      READ (IIN) (JBND(J),J=1,KOMMONA)
      IF (EOF,IIN) 70,80
   70 PRINT 5670, I,NG
      STOP 5007
   80 READ (IIN) (D(J),J=1,KOMMONB)
      IF (EOF,IIN) 90,100
   90 PRINT 5670, I,NG
      STOP 5006
  100 PRINT 5680, I,NG,ICYCLE
  110 CONTINUE
      NCOUNT=NCOUNT-1
      IF (IIN.NE.IOUT) NG=0
      NDUMP=IDTDMP
      TEND=ZAV
      GO TO 1780
C     END OF RESTART READ
C
C     READ NEW PROBLEM INPUT CARDS
  120 CONTINUE
      NG=0
      WRITE (IOUT) (ANAME(I),I=1,13)
```

```
      READ 5690, IGM,NRZC,NMTRLS,NPRIN,NDTMAX,NDTMINN,NBPRES,NOSOUR,IBS,
     1OBS,NSPALL,NACTION,NORAD,NTHIST,NRADCK,MOVIE
      PRINT 5700, IGM,NORAD
      IF (NORAD.LT.0) NOHYD=1
      IF (NORAD.LT.0) NORAD=-NORAD
      IF (NORAD.GE.4) KRD4=1
      IF (NORAD.GE.4) NORAD=1
      IF (NORAD.GE.3) IMPA=1
      IF (NORAD.GE.3) NORAD=1
      IMPEXP=NORAD-1
      IF (NORAD.NE.0) NORAD=1
      PRINT 5710, NRZC,NMTRLS,NPRIN,NDTMAX,NDTMINN,NBPRES,NOSOUR,IBS,OBS
     1,NSPALL,NACTION,NTHIST,NRADCK,MOVIE
      IF ((IGM+2)/3.EQ.1) GO TO 130
      PRINT 5750, IGM
      STOP 2002
  130 KSQSP=NSPALL
      NSPALL=0
      IF (MOVIE.GE.10) GO TO 140
      IF (NMTRLS.GT.MAXNMT) GO TO 140
      IF (NPRIN.GT.MAXNPRI) GO TO 140
      IF (NDTMAX.GT.MAXDTMA) GO TO 140
      IF (NTHIST.GT.MAXTHI) GO TO 140
      IF (NDTMINN.GT.MAXDTMI) GO TO 140
      IF (NBPRES.LE.MAXBPR) GO TO 150
  140 PRINT 5760
      STOP 5744
  150 CONTINUE
      READ 5770, BL,BQ,XM2(1),XM2(2),SCRADF,SCRADB,TRADOFF,SWEP
      IF (BL+BQ) 170,160,170
  160 BL=.1
      BQ=2.
  170 CONTINUE
      PRINT 5780, BL,BQ,XM2(1),XM2(2),SCRADF,SCRADB,TRADOFF,SWEP
      IF (TRADOFF.LT.0.) TRADOFF=1.E100
      IF (SCRADB.EQ.0.) SCRADB=1.
      IF (SCRADF.EQ.0.) SCRADF=1.
      READ 5770, (TIMEP(I),DTIMEP(I),I=1,NPRIN)
      PRINT 5790, (I,TIMEP(I),DTIMEP(I),I=1,NPRIN)
      IF (NDTMAX.LE.0) GO TO 180
      READ 5770, (TIMES(I),DLTTMX(I),I=1,NDTMAX)
      PRINT 5800, (I,TIMES(I),DLTTMX(I),I=1,NDTMAX)
      GO TO 190
  180 NDTMAX=1
      DLTTMX(1)=1.E10
  190 IF (NDTMINN.LE.0) GO TO 200
      READ 5770, (TDTMINN(I),DTMINN(I),I=1,NDTMINN)
      PRINT 5810, (I,TDTMINN(I),DTMINN(I),I=1,NDTMINN)
      GO TO 210
  200 NDTMINN=1
  210 IF (MOVIE.LE.0) GO TO 220
      READ 5770, (TMOV(I),DTMOV(I),I=1,MOVIE)
      TMOV(MOVIE+1)=DTMOV(MOVIE)=1.E100
      PRINT 5720, (I,TMOV(I),DTMOV(I),I=1,MOVIE)
  220 IF (NBPRES.LE.0) GO TO 230
```

```
      READ 5820, (TBPRES(I),PINNER(I),POUTER(I),I=1,NBPRES)             CHD  221
      TBPRES(1)=0.                                                      CHD  222
      TBPRES(NBPRES+1)=1.E100                                           CHD  223
      PINNER(NBPRES+1)=PINNER(NBPRES)                                   CHD  224
      POUTER(NBPRES+1)=POUTER(NBPRES)                                   CHD  225
      J=NBPRES+1                                                        CHD  226
      PRINT 5830, (I,TBPRES(I),PINNER(I),POUTER(I),I=1,J)               CHD  227
  230 CONTINUE                                                          CHD  228
      IF (NORAD.EQ.0) GO TO 250                                         CHD  229
      IF (NTHIST.LE.0) GO TO 240                                        CHD  230
      READ 5820, (TITH(I),TEINTH(I),TEOUTH(I),I=1,NTHIST)               CHD  231
      TITH(1)=0.                                                        CHD  232
      J=NTHIST+1                                                        CHD  233
      TITH(J)=1.E100                                                    CHD  234
      TEINTH(J)=TEINTH(J-1)                                             CHD  235
      TEOUTH(J)=TEOUTH(J-1)                                             CHD  236
      PRINT 5840, (I,TITH(I),TEINTH(I),TEOUTH(I),I=1,J)                 CHD  237
      GO TO 250                                                         CHD  238
  240 TITH(2)=1.E100                                                    CHD  239
      TEINTH(1)=TEINTH(2)=TEOUTH(1)=TEOUTH(2)=TITH(1)=0.                CHD  240
  250 CONTINUE                                                          CHD  241
      BL=0.5*BL                                                         CHD  242
      BQ=.5*BQ**2                                                       CHD  243
      DTMAX=DLTTMX(1)                                                   CHD  244
      DTMIN=DTMINN(1)                                                   CHD  245
      TPN=DTIMEP(1)                                                     CHD  246
      TIMEP(NPRIN+1)=TIMES(NDTMAX+1)=TDTMINN(NDTMINN+1)=1.E300          CHD  247
      DTIMEP(NPRIN+1)=DTIMEP(NPRIN)                                     CHD  248
      DTMINN(NDTMINN+1)=DTMINN(NDTMINN)                                 CHD  249
      DLTTMX(NDTMAX+1)=DLTTMX(NDTMAX)                                   CHD  250
      IDTMIN=IDTMAX=1                                                   CHD  251
      DT=DLTTMX(1)                                                      CHD  252
      IM1=MAXZONE+1                                                     CHD  253
      DO 260 I=1,IM1                                                    CHD  254
  260 KACT(I)=1                                                         CHD  255
C                                                                       CHD  256
C     ZONING AND PROBLEM SET UP                                         CHD  257
      JBAD=0                                                            CHD  258
      PRINT 5850, NMTRLS                                                CHD  259
      IA=NMTRLS+1                                                       CHD  260
      READ 5770, (XMATUP(I),I=1,IA)                                     CHD  261
      PRINT 5860, (I,XMATUP(I),I=1,IA)                                  CHD  262
      J=1                                                               CHD  263
      JJ=2                                                              CHD  264
      DO 880 I=1,NRZC                                                   CHD  265
      IS=10H * * * * *                                                  CHD  266
      PRINT 5880, I,(IS,L=1,8)                                          CHD  267
      READ 5870, ITYPE,TEMPD,TEMPE,TEMPA,TEMPB,TEMPC,IES                CHD  268
      IF (TEMPB.LE.0.) TEMPB=.02567785                                  CHD  269
      PRINT 5890, ITYPE,TEMPD,TEMPE,TEMPA,TEMPB,TEMPC,IES               CHD  270
      READ 5770, (TEMP(L),L=1,8)                                        CHD  271
      IF (TEMP(6).LE.0..AND.TEMP(3).GE.0.) TEMP(6)=.8                   CHD  272
      IF (TEMP(4).LE.0..AND.TEMP(3).GE.0.) TEMP(4)=TEMPA                CHD  273
      PRINT 5910, (L,TEMP(L),L=1,8)                                     CHD  274
      READ 5770, (TEMP(L),L=9,16)                                       CHD  275
```

```
      PRINT 5920, (L,TEMP(L+8),L=1,8)
      IF (ITYPE.EQ.97) GO TO 310
      IS=9H MATERIAL
      IF (TEMP(3)) 280,270,270
  270 TEMP(4)=1./TEMP(4)
      IF (TEMP(1).EQ.0.) PRINT 5530, IS
      IF (TEMP(1).NE.0.) PRINT 5540, IS
      GO TO 290
  280 TEMP(1)=TEMP(1)/TEMPA
      IF (TEMP(2).EQ.0.) TEMP(2)=-2.
      IF (TEMP(5).GE.0..AND.TEMP(5).LT.TEMP(4)) TEMP(5)=TEMP(4)
      IF (TEMP(5).LT.0.) TEMP(5)=1./TEMP(5)
      PRINT 5550, IS
      SWPOR=1.
  290 CONTINUE
      DO 300 L=1,8
  300 YIELD(JJ-1,L)=TEMP(L)
      IF (TEMP(10).LE.0.) TEMP(10)=1000.
      IF (TEMP(13).EQ.0.) TEMP(13)=1.
      IF (TEMP(13).GT.0..AND.TEMP(14).EQ.0.) TEMP(14)=TEMP(9)
      TMSPALL(JJ-1)=TEMP(10)
      SPLA(JJ-1)=TEMP(11)
      SPLB(JJ-1)=TEMP(12)
      SPLC(JJ-1)=TEMP(13)
      SPLD(JJ-1)=TEMP(14)
      ZAV=TEMP(9)
      IEOSS(JJ-1)=IES
  310 CONTINUE
      IF (IGM.EQ.1.OR.TEMPE.GE.0.) GO TO 320
      PRINT 5930
      STOP 2374
  320 CONTINUE
      IF (I.EQ.1) X(1)=TEMPD
      IF (I.EQ.1) GO TO 330
      IF (REGL.EQ.TEMPD) GO TO 330
      JBAD=1
      PRINT 5940, TEMPD,REGL
      X(J)=REGL
  330 REGL=TEMPE
      IF (ITYPE.LT.90) STOP 47
      ITYPE=ITYPE-90
      INES=0
      GO TO (340,400,550,610,630,710,870,900), ITYPE
C
C     TYPE 1 ZONING
  340 READ 5870, NDXC
      PRINT 5950, NDXC
      DO 350 II=1,NDXC
      READ 5870, NDX,TEMPD,TEMPE,TEMPF,TEMPG
      PRINT 5960, NDX,TEMPD,TEMPE,TEMPF,TEMPG,II
      IF (TEMPE.LE.0.) TEMPE=TEMPA
      IF (TEMPF.LE.0.) TEMPF=TEMPB
      IF (TEMPG.EQ.0.) TEMPG=TEMPC
      TEMPH=X(J)
      DO 350 K=1,NDX
```

```
      D(J)=TEMPE
      T(J)=TEMPF
      PSPALL(J)=ZAV
      V(J)=TEMPG
      J=J+1
      X(J)=TEMPH-K*TEMPD
  350 CONTINUE
  360 CONTINUE
      IF (ABS(X(J)-REGL).LE.1.E-6*ABS(REGL)) GO TO 380
      IF (REGL.NE.0.) GO TO 370
      IF (ABS(X(J)).GT.1.E-6) GO TO 370
      X(J)=0.
      GO TO 380
  370 PRINT 5970, REGL
      PRINT 5980, X(J),REGL
      JBAD=1
  380 IF (ABS(XMATUP(JJ)-REGL).GT.1.E-6) GO TO 390
      JBND(JJ)=J
      JJ=JJ+1
      GO TO 880
  390 IF (REGL.GE.XMATUP(JJ)) GO TO 880
      PRINT 5990, REGL,XMATUP(JJ)
      JBAD=1
      GO TO 880
C
C     TYPE 2 ZONING
  400 READ 5770, TEMPJ,TEMPH,TEMPG
      PRINT 6000, TEMPJ,TEMPH,TEMPG
      IF (TEMPJ) 410,900,430
  410 IF (I.GT.1) GO TO 420
      PRINT 6050
      STOP 2377
  420 PSP=X(J)
      IF (ISPALL(J-1).EQ.1) PSP=XL(J-1)
      TEMPJ=-TEMPJ*(X(J-1)-PSP)*D(J-1)/TEMPA
  430 RATIO=-1.
      INES=1
      KCUTM=JBAD
      ZEBOUT=TEMPJ
      ZEBIN=TEMPH
      IF (TEMPG.GT.0.) GO TO 480
  440 INES=0
      AMAX=TEMPD-TEMPE
      TEMPM=TEMPJ
      TEMPN=TEMPH
      TEMPJ=TEMPD-TEMPJ
      TEMPH=TEMPE+TEMPH
      IF (IGM-2) 470,450,460
  450 AMAX=AMAX*(TEMPD+TEMPE)
      TEMPM=TEMPM*(TEMPD+TEMPJ)
      TEMPN=TEMPN*(TEMPE+TEMPH)
      GO TO 470
  460 AMAX=AMAX*(TEMPD**2+TEMPD*TEMPE+TEMPE**2)
      TEMPM=TEMPM*(TEMPD**2+TEMPD*TEMPJ+TEMPJ**2)
      TEMPN=TEMPN*(TEMPE**2+TEMPE*TEMPH+TEMPH**2)
```

```
  470 RATIO=(AMAX-TEMPN)/(AMAX-TEMPM)
      IF (RATIO.NE.1.) TEMPM=ALOG(1.-(1.-RATIO)*AMAX/TEMPN)/ALOG(RATIO)
      IF (RATIO.EQ.1.) TEMPM=AMAX/TEMPN
      IS=TEMPM+.5
      GO TO 640
  480 CALL ZONE (IGM,J,IS,MAXZONE,JBAD,TEMPD,TEMPE,TEMPJ,TEMPH,RATIO,TEM
     1PG,X,XO,VO)
      IF (INES) 490,510,490
  490 IF (JBAD-KCUTM) 500,510,500
  500 PRINT 5900
      TEMPJ=ZEBOUT
      TEMPH=ZEBIN
      JBAD=KCUTM
      GO TO 440
  510 IF (JBAD.LT.3) GO TO 520
      JBAD=JBAD-3
      ITIMEL=0
  520 K=J
      J=IS
  530 JJJ=J-1
      DO 540 L=K,JJJ
      D(L)=TEMPA
      T(L)=TEMPB
      PSPALL(L)=ZAV
  540 V(L)=TEMPC
      L=J-K
      PRINT 6010, L
      GO TO 360
C
C     TYPE 3 ZONING
  550 READ 5770, AMAX,RATIO
      PRINT 6020, AMAX,RATIO
      IF (AMAX) 560,900,580
  560 IF (J.GT.1) GO TO 570
      PRINT 6030
      GO TO 910
  570 AMAX=AMAX*(X(J)-X(J-1))
  580 TEMPD=X(J)-REGL
      TEMPE=.5*TEMPD
      TEMPF=ALOG(TEMPE*(RATIO-1.)/AMAX+1.)/ALOG(RATIO)
      JJJ=J
      K=TEMPF
      TEMPG=K
      NUM=K+1
      IF (TEMPG.EQ.TEMPF) NUM=NUM-1
      TEMPD=TEMPE*(RATIO-1.)/(RATIO**NUM-1.)
      DO 590 K=1,NUM
  590 X(J+K)=X(J+K-1)-TEMPD*RATIO**(K-1)
      J=J+NUM
      DO 600 K=1,NUM
  600 X(J+K)=X(J+K-1)-TEMPD*RATIO**(NUM-K)
      J=J+NUM
      K=JJJ
      GO TO 530
C
```

```
C       TYPE 4 ZONING
  610 READ 5770, TEMPJ,TEMPH,RATIO,TEMPG
      PRINT 6040, TEMPJ,TEMPH,RATIO,TEMPG
      IF (TEMPJ.GE.0.) GO TO 480
      IF (I.GT.1) GO TO 620
      PRINT 6050
      STOP 2017
  620 PSP=X(J)
      IF (ISPALL(J-1).EQ.1) PSP=XL(J-1)
      TEMPJ=RATIO*(X(J-1)-PSP)*D(J-1)/TEMPA
      GO TO 480
C
C       TYPE 5 ZONING
  630 READ 5870, IS,RATIO
  640 PRINT 6070, IS,RATIO
      IF (IGM-2) 650,660,670
  650 TEMPH=TEMPD-TEMPE
      GO TO 680
  660 TEMPH=(TEMPD-TEMPE)*(TEMPD+TEMPE)
      GO TO 680
  670 TEMPH=(TEMPD-TEMPE)*(TEMPD**2+TEMPD*TEMPE+TEMPE**2)
  680 TEMPJ=IS
      IF (RATIO.NE.1) TEMPH=TEMPH*(1.-RATIO)/(1.-EXP(TEMPJ*ALOG(RATIO)))
      IF (RATIO.EQ.1) TEMPH=TEMPH/TEMPJ
      TEMPJ=0
      TEMPG=.001
      IF (IGM-2) 480,690,700
  690 TEMPH=SQRT(TEMPH+TEMPE**2)-TEMPE
      GO TO 480
  700 TEMPH=(TEMPH+TEMPE**3)**(1./3.)-TEMPE
      GO TO 480
C
C       TYPE 6 ZONING
  710 IF (I.EQ.1.OR.I.EQ.NRZC) GO TO 720
      PRINT 6060
      STOP 2023
  720 READ 5870, IS,RATIO,TEMPG,TEMPH
      PRINT 6070, IS,RATIO
      PRINT 6080, TEMPG,TEMPH
      IF (IS.GT.0) GO TO 730
      IS=MAXZONE-J
  730 IF (TEMPG.NE.0.) GO TO 740
      IF (I.EQ.1) TEMPG=1.E100
      IF (I.EQ.NRZC) TEMPG=-1.E100
  740 TEMPN=1./3.
      IF (I.EQ.NRZC) GO TO 830
      X(MAXZONE)=TEMPE
      X(MAXZONE-1)=TEMPE+TEMPH
      KL=MAXZONE-1
  750 KKK=KL
      KK=KL+1
      KL=KL-1
      TEMPAB=X(KK)/X(KKK)
  760 IF (IGM-2) 770,780,790
  770 X(KL)=X(KKK)*(1.+RATIO*(1.-TEMPAB))
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      GO TO 800
  780 X(KL)=X(KKK)*SQRT(1.+RATIO*(1.-TEMPAB)*(1.+TEMPAB))
      GO TO 800
  790 X(KL)=X(KKK)*(1.+RATIO*(1.-TEMPAB)*(1.+TEMPAB+TEMPAB**2))**TEMPN
  800 IF (I.EQ.NRZC) GO TO 850
      IF (MAXZONE-KKK.GE.IS) GO TO 810
      IF (X(KL).GE.TEMPG) GO TO 810
      GO TO 750
  810 DO 820 KK=KL,MAXZONE
      KKK=KK-KL+1
  820 X(KKK)=X(KK)
      J=KKK
      K=1
      XMATUP(1)=X(1)
      GO TO 530
  830 X(J+1)=TEMPD-TEMPH
      KL=J+1
  840 KKK=KL
      KK=KL-1
      KL=KL+1
      TEMPAB=X(KK)/X(KKK)
      GO TO 760
  850 IF (KKK-J.GE.IS) GO TO 860
      IF (X(KL).LE.TEMPG) GO TO 860
      GO TO 840
  860 K=J
      J=KL
      XMATUP(NMTRLS+1)=REGL=X(KL)
      GO TO 530
C
C     TYPE 7 ZONING
  870 IF (I.LE.1.OR.I.GE.NRZC) STOP 2007
      ISPALL(J-1)=1
      PSPALL(J-1)=0.
      XL(J-1)=X(J)
      VL(J-1)=V(J-1)
      X(J)=TEMPE
      PRINT 6090, X(J),XL(J-1)
      KACT(J-1)=KACT(J)=KACT(J+1)=KACT(J-2)=0
      NSPALL=NSPALL+1
      GO TO 360
  880 CONTINUE
      NZP=J
      IF (JJ-2.EQ.NMTRLS.AND.X(1).EQ.XMATUP(1).AND.JBND(JJ-1).EQ.NZP) GO
     1 TO 890
      PRINT 6100
      JBAD=1
  890 IF (JBAD.LE.0) GO TO 920
  900 CONTINUE
  910 PRINT 6110
      PRINT 6120, J,JJ,JBAD, (X(IS),IS=1,J)
      STOP 67
  920 CONTINUE
      NZ=NZP-1
      V(NZP)=V(NZ)
```

```
      IF (IBS.EQ.1) V(NZP)=0.
      IF (OBS.EQ.1) V(1)=0.
      IF (IGM.EQ.1) GO TO 930
      IF (X(NZP).GT.0.) GO TO 930
      IBS=1
      V(NZP)=0.
      X(NZP)=0.
  930 NZN=NZ-1
      IF (NZ.LE.MAXZONE) GO TO 940
      PRINT 6130, NZ,MAXZONE
      STOP 744
  940 CONTINUE
C     END OF ZONING
C
      JJJ=1
      JBND(1)=1
      DO 950 JJ=1,NZ
      IF (JJ.EQ.JBND(JJJ+1)) JJJ=JJJ+1
      IF (YIELD(JJJ,3).LT.0.) DRATIO(JJ)=YIELD(JJJ,1)
  950 IEOS(JJ)=IEOSS(JJJ)
      TEMPB=XM2(2)
      DO 1010 I=1,NZ
      TEMPM=X(I+1)
      IF (ISPALL(I).EQ.1) TEMPM=XL(I)
      IF (IGM-2) 960,970,980
  960 XM(I)=D(I)*(X(I)-TEMPM)
      GO TO 990
  970 XM(I)=D(I)*PIE*(X(I)-TEMPM)*(X(I)+TEMPM)
      GO TO 990
  980 XM(I)=D(I)*PIE43*(X(I)-TEMPM)*(X(I)**2+X(I)*TEMPM+TEMPM**2)
  990 IF (I.GT.1) GO TO 1000
      XM2(I)=2./(XM(1)+XM2(1))
      GO TO 1010
 1000 XM2(I)=2./(XM(I)+XM(I-1))
 1010 CONTINUE
      XM2(NZP)=2./(XM(NZ)+TEMPB)
C     SETUP EOS TABLES
      ICALL=2
      CALL EOS
      IF (NSPALL) 1020,1040,1040
 1020 IF (SWEP) 1040,1030,1040
 1030 IF (SWPOR) 1040,1090,1040
C     CALCULATE TRIPLE LINE PROPERTIES
 1040 JJJ=0
      DO 1080 JJ=1,NZ
      IF (JJ.NE.JBND(JJJ+1)) GO TO 1080
      JJJ=JJJ+1
      IF (YIELD(JJJ,3)) 1050,1060,1070
 1050 YIELD(JJJ,3)=-YIELD(JJJ,6)
      IF (YIELD(JJJ,3).EQ.0.) YIELD(JJJ,3)=-7.777E-7
      CALL TPLINE (IEOS(JJ),YIELD(JJJ,6),YIELD(JJJ,7),YIELD(JJJ,8))
      GO TO 1080
 1060 CALL TPLINE (IEOS(JJ),TEMPA,YIELD(JJJ,7),YIELD(JJJ,3))
      GO TO 1080
 1070 CALL TPLINE (IEOS(JJ),TEMPA,YIELD(JJJ,7),TEMPB)
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```
 1080 CONTINUE
 1090 CONTINUE
C     INITIALIZE THERMODYNAMIC FUNCTIONS
      ICALL=1
      FLUX(NZP)=0.
      JJ=1
      PRINT 6150
      DO 1120 I=1,NZ
      TEMPA=D(I)
      DO(I)=TEMPA
      TEMPJ=T(I)
      CALL EOS
      P(I)=TEMPD
      E(I)=TEMPC
      PPPT(I)=TEMPH
      PEPTIN(I)=1./TEMPG
      ITRIED(I)=0
      FLUX(I)=0.
      IF (I.NE.JBND(JJ+1)) GO TO 1100
      IF (ISPALL(I-1).EQ.1) PRINT 6180, XL(I-1)
      JJJ=JJ+1
      PRINT 6160, JJ,JJJ
      JJ=JJJ
 1100 IF (I.GT.1) GO TO 1110
      PRINT 6170, X(I),I,XM(I),PPPT(I),TEMPG,IEOSS(JJ),IEOS(I),IZPTL(I),
     1IZPRL(I)
      GO TO 1120
 1110 TEMPI=XM(I)/XM(I-1)
      PRINT 6180, X(I),TEMPI,I,XM(I),PPPT(I),TEMPG,IEOSS(JJ),IEOS(I),IZP
     1TL(I),IZPRL(I)
 1120 CONTINUE
      PRINT 6170, X(NZP),NZP
C     CORRECT SOUND SPEED ELASTIC-PLASTIC CASE
      IF (SWEP.EQ.0.) GO TO 1150
      DO 1130 JJ=1,NZ
      XLO(JJ)=KACT(JJ)
 1130 KACT(JJ)=0
      IS=1
      CALL ELPL
      DO 1140 JJ=1,NZ
 1140 KACT(JJ)=XLO(JJ)
 1150 CONTINUE
C     FOR POROUS MATERIALS ONLY
      IF (SWPOR) 1160,1210,1160
 1160 JJJ=0
      DO 1180 JJ=1,NZ
      IF (JJ.NE.JBND(JJJ+1)) GO TO 1180
      JJJ=JJJ+1
      IF (YIELD(JJJ,3)) 1170,1180,1180
 1170 TEMPA=YIELD(JJJ,3)
      IF (TEMPA.EQ.-7.777E-7) TEMPA=-CSOD(JJ)
      TSAVE(JJJ)=-TEMPA
      YIELD(JJJ,3)=TEMPA/CSOD(JJ)
      IF (YIELD(JJJ,3).GE.0.) STOP 7405
      TEMPB=YIELD(JJJ,1)+YIELD(JJJ,4)*(YIELD(JJJ,3)**2-YIELD(JJJ,1))/(D(
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     1JJ)*TEMPA**2)
      IF (TEMPB.LE.1.) GO TO 1180
      TEMPC=YIELD(JJJ,4)+(YIELD(JJJ,4)-YIELD(JJJ,5))*(SQRT((YIELD(JJJ,1)
     1-1.)/(TEMPB-1.))-1.)
      IF (YIELD(JJJ,5).LT.0.) TEMPC=YIELD(JJJ,4)-YIELD(JJJ,5)*ALOG((TEMPC
     1B-1.)/(YIELD(JJJ,1)-1.))
      YIELD(JJJ,4)=TEMPC
 1180 CONTINUE
      JJJ=0
      DO 1200 JJ=1,NZ
      IF (JJ.NE.JBND(JJJ+1)) GO TO 1190
      JJJ=JJJ+1
 1190 IF (DRATIO(JJ).LE.1.) GO TO 1200
      CSOD(JJ)=TSAVE(JJJ)
 1200 CONTINUE
 1210 CONTINUE
C
C     SETUP ANY INTERNAL SOURCES.
      DO 1220 I=1,NZ
 1220 SD2(I)=SD3(I)=TSOUR1(I)=TSOUR2(I)=TSOUR3(I)=TSOUR4(I)=0.
      IF (NOSOUR.LE.0) GO TO 1680
      JJJ=NOSOUR
      PRINT 6190, JJJ
      GO TO (1240,1320,1320,1380,1510,1520,1230), JJJ
 1230 STOP 5221
 1240 READ 5640, NOSOUR
C     TYPE 1   INTERNAL SOURCE
      JJ=1
 1250 READ 6200, I,(VO(K),K=1,6)
      TSOUR1(I)=VO(1)
      TSOUR2(I)=VO(2)
      TSOUR3(I)=VO(3)
      TSOUR4(I)=VO(4)
      SD2(I)=VO(5)
      SD3(I)=VO(6)
      IF (I.GE.JJ) GO TO 1270
 1260 PRINT 6210, I,JJ,NOSOUR,(VO(K),K=1,6)
      STOP 5237
 1270 JJ=I+1
      IF (I-NOSOUR) 1250,1280,1260
 1280 TEMPB=0.
      PRINT 6220
      DO 1300 I=1,NOSOUR
      IF (TSOUR4(I).LE.0) GO TO 1290
      KACT(I)=0
      TEMPA=.5*XM(I)*(SD2(I)*(TSOUR3(I)-TSOUR1(I))+SD3(I)*(TSOUR4(I)-TSO
     1UR2(I)))
      TEMPB=TEMPB+TEMPA
      PRINT 6230, TSOUR1(I),TSOUR2(I),TSOUR3(I),TSOUR4(I),SD2(I),SD3(I),
     1I,TEMPA,TEMPB
 1290 CONTINUE
      IF (TSOUR1(I).GT.TSOUR2(I)) GO TO 1310
      IF (TSOUR2(I).GT.TSOUR3(I)) GO TO 1310
      IF (TSOUR3(I).GT.TSOUR4(I)) GO TO 1310
      IF (TSOUR4(I).GT.0.) GO TO 1300
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      TSOUR3(I)=TSOUR4(I)=-1.
 1300 CONTINUE
      KACT(NOSOUR+1)=0
      GO TO 1680
 1310 PRINT 6240, I,(TSOUR1(I),TSOUR2(I),TSOUR3(I),TSOUR4(I))
      STOP 5211
 1320 READ 5640, NOSOUR
C     TYPES 2 AND 3 INTERNAL SOURCE
      JJ=1
 1330 READ 6200, I,(VO(K),K=1,3)
      TSOUR1(I)=VO(1)
      TSOUR4(I)=VO(2)
      SD2(I)=VO(3)/(VO(2)-VO(1))
      IF (JJJ.EQ.2) SD2(I)=SD2(I)/XM(I)
      IF (I.GE.JJ) GO TO 1350
 1340 PRINT 6210, I,JJ,NOSOUR,(VO(K),K=1,3)
      STOP 5254
 1350 JJ=I+1
      IF (I-NOSOUR) 1330,1360,1340
 1360 DO 1370 I=1,NOSOUR
      TSOUR2(I)=TSOUR1(I)
      TSOUR3(I)=TSOUR4(I)
 1370 SD3(I)=SD2(I)
      GO TO 1280
 1380 READ 5640, KK
C     TYPE 4  INTERNAL SOURCE
C     KK IS THE NUMBER OF SOURCE REGIONS
      DO 1480 I=1,KK
      READ 5770, (VO(K),K=1,5)
      IF (VO(1).GT.VO(2)) GO TO 1400
      PRINT 6250, I
 1390 PRINT 6260, I,(VO(K),K=1,5)
      STOP 5353
 1400 DO 1410 K=1,NZ
      JJ=NZP-K
      IF (VO(1).LE.X(JJ)) GO TO 1420
 1410 CONTINUE
      PRINT 6260, JJ,X(JJ)
      GO TO 1390
 1420 KKK=JJ
C     KKK IS FIRST ZONE IN REGION
      JJ=JJ+1
      DO 1430 K=JJ,NZP
      ILOW=K-1
      IF (VO(2).GE.X(K)) GO TO 1440
 1430 CONTINUE
      PRINT 6260, K,X(K)
      GO TO 1390
 1440 IF (ILOW.GE.KKK) GO TO 1450
      PRINT 6270, ILOW,KKK
      STOP 5364
 1450 TEMPA=0.
      DO 1460 K=KKK,ILOW
 1460 TEMPA=TEMPA+XM(K)
      TEMPB=(VO(5)-VO(4))*TEMPA
```

```
      DO 1470 K=KKK,ILOW
      TSOUR1(K)=VO(4)
      TSOUR4(K)=VO(5)
      IF (SD2(K).NE.0.) PRINT 6280, K
 1470 SD2(K)=VO(3)/TEMPB
 1480 PRINT 6290, I,KKK,ILOW,VO(3)
      DO 1490 I=1,NZ
      JJ=NZP-I
      IF (SD2(JJ).NE.0.) GO TO 1500
 1490 CONTINUE
 1500 NOSOUR=JJ
      GO TO 1360
C     TYPE 5    INTERNAL SOURCE
 1510 IF (IGM.NE.1) STOP 5400
      CALL ZAPPER
      GO TO 1280
C     TYPE 6    INTERNAL SOURCE
 1520 NOSOUR=0
 1530 READ 5770, (TO(I),I=1,8)
      TEMPN=0.
      IF (TO(6).LT.0.) TEMPN=-TO(6)
      IF (TO(7).LT.2.5) TO(7)=2.5
      INES=IS=0
      DO 1540 I=1,NZP
      IF (X(I).GE.TO(3)) IS=I
      IF (X(I).GT.TO(4)) GO TO 1540
      INES=I
      GO TO 1550
 1540 CONTINUE
 1550 IF (IS) 1560,1560,1570
 1560 PRINT 6270, IS,INES
      STOP
 1570 IF (INES) 1560,1560,1580
 1580 IS1=INES-1
      IF (TEMPN.EQ.0.) GO TO 1630
      I=IS
      ICALL=1
      TEMPA=D(I)/(1.-TEMPN/(D(I)*TO(5)**2))
      ZLOW=.001
      ZUP=1000.
      TO(9)=ENTSV(I)
      TO(10)=FPATH(I)
      TO(11)=CSOD(I)
      TO(12)=KPHASE(I)
 1590 TEMPJ=.5*(ZLOW+ZUP)
      CALL EOS
      IF (ZUP-ZLOW.LE.1.E-4*TEMPJ) GO TO 1620
      IF (TEMPD-TEMPN) 1600,1620,1610
 1600 ZLOW=TEMPJ
      GO TO 1590
 1610 ZUP=TEMPJ
      GO TO 1590
 1620 TO(6)=TEMPC-E(I)-.5*(TO(5)*(1.-D(I)/TEMPA))**2
      TEMPAB=CSOD(I)
      ENTSV(I)=TO(9)
```

```
      FPATH(I)=TO(10)
      CSOD(I)=TO(11)
      KPHASE(I)=TO(12)
 1630 PRINT 6300, (TO(I),I=1,8),IS,IS1
      IF (TEMPN.EQ.0.) GO TO 1650
      PRINT 6310, TEMPA,TEMPJ,TEMPD,TEMPAB
      IF (TO(6).LT.0.) STOP
C     SET  PREDETONATION PRESSURE
      DO 1640 JJ=2,21
      IF (IS.GE.JBND(JJ)) GO TO 1640
      YIELD(JJ-1,8)=TEMPN
      GO TO 1650
 1640 CONTINUE
      GO TO 1560
 1650 IF (IS1-IS) 1560,1660,1660
 1660 IF (NOSOUR.LT.IS1) NOSOUR=IS1
      DO 1670 I=IS,IS1
      IF (THESE(I).LE.1.) THESE(I)=0.
      TSOUR1(I)=TSOUR2(I)=TO(2)+ABS(.5*(X(I+1)+X(I))-TO(1))/TO(5)
      TSOUR3(I)=TSOUR4(I)=TSOUR1(I)+TO(7)*(X(I)-X(I+1))/TO(5)
 1670 SD2(I)=SD3(I)=TO(6)/(TSOUR3(I)-TSOUR1(I))
      IF (TO(8)) 1530,1280,1530
 1680 CONTINUE
      JJ=6*MAXZONE
      CALL WRITEC (SD,0,JJ)
      WRITE (IOUT) (SD(I),I=1,JJ)
C     INITIAL ZONE ACTIVATION OF INACTIVE ZONES
      IF (V(1).NE.0.) KACT(1)=0
      IF (V(NZP).NE.0.) KACT(NZ)=0
      DO 1690 I=2,NZ
      IF (V(I).EQ.0.) GO TO 1690
      KACT(I-1)=KACT(I)=0
 1690 CONTINUE
      IF (NACTION.LE.0) GO TO 1700
      IM1=2*NACTION
      READ 5770, (XO(I),I=1,IM1)
      PRINT 6330, NACTION,(I,XO(2*I-1),XO(2*I),I=1,NACTION)
      GO TO 1710
 1700 NACTION=1
      XO(1)=0.
      XO(2)=-1.
 1710 IM1=0
      DO 1730 I=1,NZP
      TEMPAB=X(I)
      DO 1720 KK=1,NACTION
      KKK=2*KK
      IF (TEMPAB.LT.XO(KKK-1).OR.TEMPAB.GT.XO(KKK)) GO TO 1720
      KACT(I)=0
 1720 CONTINUE
      IF (KACT(I).EQ.0) IM1=IM1+1
 1730 CONTINUE
      IF (IM1.EQ.NZP) NACTION=0
      PRINT 6340, IM1
C
C     SLIGHT REZONE FOR INITIAL VOID OR FRACTURE
```

```
      IF (KSQSP.LE.0) GO TO 1770
      IF (IGM.EQ.1) GO TO 1740
      PRINT 6350
      STOP 2050
 1740 READ 6360, JJJ
      NSPALL=NSPALL+JJJ
      DO 1760 K=1,JJJ
      READ 6360, JJ,TEMPA
      TEMPA=ABS(TEMPA)
      IF (JJ.LE.1) STOP 6203
      IF (JJ.GT.NMTRLS) STOP 6204
      IA=JBND(JJ)-1
      ISPALL(IA)=1
      PSPALL(IA)=0.
      KKK=JBND(JJ)
      XL(IA)=X(KKK)
      VL(IA)=V(IA)
      KACT(IA)=KACT(IA+1)=KACT(IA+2)=0
      IF (IA.GT.1) KACT(IA-1)=0
      DO 1750 I=1,IA
      XL(I)=XL(I)+TEMPA
 1750 X(I)=X(I)+TEMPA
 1760 PRINT 6370, JBND(JJ),TEMPA
 1770 IF (KSQSP.LT.0.AND.NSPALL.EQ.0) NSPALL=-1
C
 1780 IF (IGM-2) 1790,1800,1810
 1790 ASSIGN 2910 TO NGM1
      ASSIGN 2910 TO NGM2
      ASSIGN 2940 TO NGM3
      ASSIGN 3080 TO NGM4
      ASSIGN 31(0 TO NGM5
      ASSIGN 3150 TO NGM6
      ASSIGN 3200 TO NGM7
      ASSIGN 3240 TO NGM8
      ASSIGN 3300 TO NGM9
      GO TO 1820
 1800 ASSIGN 2820 TO NGM1
      ASSIGN 2870 TO NGM2
      ASSIGN 2950 TO NGM3
      ASSIGN 3040 TO NGM4
      ASSIGN 3110 TO NGM5
      ASSIGN 3160 TO NGM6
      ASSIGN 3210 TO NGM7
      ASSIGN 3250 TO NGM8
      ASSIGN 3310 TO NGM9
      GO TO 1820
 1810 ASSIGN 2840 TO NGM1
      ASSIGN 2890 TO NGM2
      ASSIGN 2960 TO NGM3
      ASSIGN 3060 TO NGM4
      ASSIGN 3120 TO NGM5
      ASSIGN 3170 TO NGM6
      ASSIGN 3220 TO NGM7
      ASSIGN 3260 TO NGM8
      ASSIGN 3320 TO NGM9
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 1820 ASSIGN 2780 TO KSWA
      IF (SWEP.EQ.0..OR.IGM.EQ.1) ASSIGN 2790 TO KSWA
      IF (SWEP) 1840,1830,1840
 1830 ASSIGN 2910 TO KSWB
      ASSIGN 2910 TO KSWC
      ASSIGN 2910 TO KSWD
      ASSIGN 2910 TO KSWE
      ASSIGN 3080 TO KSWF
      ASSIGN 3080 TO KSWG
      GO TO 1850
 1840 ASSIGN 2830 TO KSWB
      ASSIGN 2850 TO KSWC
      ASSIGN 2880 TO KSWD
      ASSIGN 2900 TO KSWE
      ASSIGN 3050 TO KSWF
      ASSIGN 3070 TO KSWG
 1850 IF (NORAD) 1860,1860,1870
 1860 ASSIGN 3550 TO NRAD2
      ASSIGN 3760 TO NRAD3
      IF (NORAD.NE.-666) GO TO 1880
      NORAD=0
      GO TO 2040
 1870 ASSIGN 3540 TO NRAD2
      ASSIGN 3610 TO NRAD3
      JTLOW=0
      TTHIU=0.
      TEMPJ=TIME
      CALL TEDGE
 1880 ASSIGN 3520 TO NOB1
      IF (BL.GT.0.) GO TO 1890
      ASSIGN 3510 TO NOB1
 1890 IF (NBPRES.LE.0) GO TO 1900
      ITLOW=0
      TBPU=0.
      ASSIGN 5120 TO NOBP
      TEMPJ=TIME
      CALL EDGE
      GO TO 1910
 1900 ASSIGN 5130 TO NOBP
      PBDRYI=PBDRYO=0.
 1910 IF (NORAD) 1920,1980,1920
 1920 IF (SCRADF) 1930,1940,1940
 1930 PBDRYO=PBDRYO+RADK3*T(1)**4
      GO TO 1950
 1940 PBDRYO=PBDRYO+.5*RADK3*(SCRADF*TEBOUT**4+T(1)**4)
 1950 IF (SCRADB) 1960,1970,1970
 1960 PBDRYI=PBDRYI+RADK3*T(NZ)**4
 1970 PBDRYI=PBDRYI+.5*RADK3*(SCRADB*TEBIN**4+T(NZ)**4)
 1980 IF (NOSOUR.LE.0) GO TO 2000
      ASSIGN 3480 TO ISOUR
      TEMPJ=TIME
      CALL SOURCE
      TSOURM=TSOUR4(1)
      DO 1990 I=2,NOSOUR
 1990 TSOURM=AMAX1(TSOURM,TSOUR4(I))
```

```
      TSOURM=1.0001*TSOURM
      GO TO 2010
 2000 ASSIGN 3490 TO ISOUR
 2010 DO 2020 I=1,NZP
      IF (NOHYD.NE.0) V(I)=0.
      IF (NOHYD.NE.0.AND.I.LT.NZP) VL(I)=0.
      XO(I)=KACT(I)
 2020 KACT(I)=0
      CALL EDIT
      DO 2030 I=1,NZP
 2030 KACT(I)=XO(I)
      IF (MOVIE.GT.0) GO TO 5420
C
C     MAIN LOOP RETURN
 2040 CONTINUE
C
      CALL SECOND (TSEC)
      NDUMPC=TSEC
      IF (NDUMPC.GE.ITIMEL-5) GO TO 2050
      IF (NDUMPC.LT.NDUMP) GO TO 2070
      GO TO 2060
 2050 ISTOPN=1
      IF (ICALL.NE.44) CALL EDIT
 2060 NDUMP=NDUMP+IDTDMP
      NG=NG+1
C     WRITE RESTART TAPE
      WRITE (IOUT) (JBND(J),J=1,KOMMONA)
      WRITE (IOUT) (D(J),J=1,KOMMONB)
      PRINT 6380, NG,TIME,ICYCLE
      IF (ISTOPN.NE.1) GO TO 2070
      END FILE IOUT
C     NORMAL EXIT FOR TIME LIMIT
      RETURN
C
 2070 CONTINUE
C     RESET
      DO 2080 I=1,NZ
      DO(I)=D(I)
      TO(I)=T(I)
      XO(I)=X(I)
      VO(I)=V(I)
 2080 CONTINUE
      XO(NZP)=X(NZP)
      VO(NZP)=V(NZP)
      ZEBOUT=TEBOUT
      ZEBIN=TEBIN
      IF (NCKR.EQ.1) GO TO 2090
      IF (IMPEXP) 2100,2090,2100
 2090 CALL WRITEC (CSOD,6*MAXZONE,4*MAXZONE)
      CALL WRITEC (ISPALL,10*MAXZONE,MAXZONE+3)
 2100 IF (NCKR.NE.1) GO TO 2110
      IMPEXP=1
      IMPA=0
 2110 KCUTM=0
      IF (IMPEXP) 2280,2130,2120
```

```
 2120 IP1=-1
      GO TO 2140
 2130 IP1=0
C     CALCULATE BOUNDARY AVERAGE MEAN FREE PATH
 2140 IF (ISPALL(1)) 2160,2150,2160
 2150 TEMPA=(X(1)-X(2))/FPATH(1)
      GO TO 2170
 2160 TEMPA=(X(1)-XL(1))/FPATH(1)
 2170 DO 2230 I=2,NZ
      TEMPB=TEMPA
      IF (ISPALL(I)) 2190,2180,2190
 2180 TEMPA=(X(I)-X(I+1))/FPATH(I)
      GO TO 2200
 2190 TEMPA=(X(I)-XL(I))/FPATH(I)
 2200 IF (ISPALL(I-1)) 2210,2220,2210
 2210 TEMPR(I)=RADK6
      GO TO 2230
 2220 TEMPR(I)=RADK7/(TEMPA+TEMPB)
C     FLUX LIMITER
      IF (NRADCK.NE.0) GO TO 2230
      TEMPC=ABS(1.-(TO(I-1)/TO(I))**4)
      IF (TEMPC.LT.1.E-9) GO TO 2230
      TEMPC=CLIGHT*(DO(I)*E(I)+DO(I-1)*E(I-1))/(2.*TEMPC*TO(I)**4)
      IF (TEMPR(I).GT.TEMPC) TEMPR(I)=TEMPC
 2230 CONTINUE
      TEMPR(1)=TEMPR(NZP)=RADK6
      IF (SCRADF.LT.0.) TEMPR(1)=0.
      IF (SCRADB.LT.0.) TEMPR(NZP)=0.
      DO 2250 I=1,NZ
      IF (KACT(I)) 2240,2250,2240
 2240 TEMPR(I)=TEMPR(I+1)=0.
 2250 CONTINUE
      IF (IP1) 2260,2280,3910
C     EXPLICIT DIFFUSION FLUX CALCULATION
 2260 TEMPA=ZEBOUT**4*SCRADF
      FLINF=TEMPR(1)*TEMPA
      FLOUF=TEMPR(1)*TO(1)**4
      DO 2270 I=1,NZ
      TEMPB=TEMPA
      TEMPA=TO(I)**4
 2270 FLUX(I)=TEMPR(I)*(TEMPA-TEMPB)
      FLINB=TEMPR(NZP)*SCRADB*ZEBIN**4
      FLOUB=TEMPR(NZP)*TEMPA
      FLUX(NZP)=FLINB-FLOUB
 2280 ICYCLE=ICYCLE+1
      NTS1=NTS2=NTS3=0
C     SELECT TIME STEP
      DTPP=DTP
      DTP=DT
      DTTEMP=DT*DTTEMT
      IF (TIME.LT.TIMES(IDTMAX+1)) GO TO 2290
      IDTMAX=IDTMAX+1
      DTMAX=DLTTMX(IDTMAX)
 2290 CONTINUE
      IF (TIME.LT.TDTMINN(IDTMIN+1)) GO TO 2300
```

```
      IDTMIN=IDTMIN+1
      DTMIN=DTMINN(IDTMIN)
 2300 CONTINUE
C     COURANT CONDITION
      DTCS=1.E100
      TEMPA=XO(1)
      TEMPI=VO(1)
      DO 2340 I=1,NZ
      TEMPB=TEMPA
      TEMPA=XO(I+1)
      TEMPJ=TEMPI
      TEMPI=VO(I+1)
      IF (KACT(I).EQ.1) GO TO 2340
      IF (ISPALL(I).EQ.1) GO TO 2340
      TEMPK=TEMPI-TEMPJ
      IF (TEMPK) 2310,2310,2320
 2310 TEMPC=(TEMPB-TEMPA)/CSOD(I)
      GO TO 2330
 2320 TEMPC=2.*(BL*CSOD(I)+BQ*TEMPK)
      TEMPC=(TEMPB-TEMPA)/(TEMPC+SQRT(TEMPC**2+CSOD(I)**2))
 2330 IF (TEMPC.GE.DTCS) GO TO 2340
      DTCS=TEMPC
      NTS1=I
 2340 CONTINUE
      IF (NSPALL.LE.0) GO TO 2360
      DO 2350 I=1,NZN
      IF (ISPALL(I).EQ.0) GO TO 2350
      XLO(I)=XL(I)
      VLO(I)=VL(I)
      TEMPC=(XO(I)-XLO(I))/CSOD(I)
      IF (TEMPC.LT.DTCS) DTCS=TEMPC
 2350 CONTINUE
 2360 CONTINUE
      DTCS=FRACDT*DTCS
      IF (ICYCLE.EQ.1) DTCS=0.1*DTCS
      IF (NOHYD.NE.0) DTCS=1.E10
C     RADIATION CONDITION
      IF (NCKR.EQ.0) GO TO 2450
C     SELECT FASTEST METHOD
C     CHECK TYPE 2
      GO TO 2590
 2370 IF (DTRAD.GT.10.*DT) GO TO 2400
      TEMPI=DTRAD
      ZUP=NTS2
C     CHECK TYPE 3
      GO TO 2580
 2380 TEMPJ=DTRAD
      ZLOW=NTS2
C     CHECK TYPE 1
      GO TO 2480
 2390 TEMPA=0.75*TEMPJ
      TEMPB=0.65*DTRAD
      IF (TEMPI.LT.TEMPA) GO TO 2440
      IF (TEMPI.LT.TEMPB) GO TO 2430
C     EXPLICIT SELECTED
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```
      DTRAD=TEMPI                                                       CHD 1156
      NTS2=ZUP                                                          CHD 1157
 2400 TEMPA=2.                                                          CHD 1158
      IMPEXP=1                                                          CHD 1159
 2410 IMPA=0                                                            CHD 1160
 2420 PRINT 6140, ICYCLE,TIME,TEMPA                                     CHD 1161
      GO TO 2730                                                        CHD 1162
C     IMPLICIT SELECTED                                                 CHD 1163
 2430 IMPEXP=0                                                          CHD 1164
      TEMPA=1.                                                          CHD 1165
      GO TO 2410                                                        CHD 1166
 2440 IF (TEMPA.LT.TEMPB) GO TO 2430                                    CHD 1167
C     APPROXIMATE IMPLICIT SELECTED                                     CHD 1168
      IMPEXP=0                                                          CHD 1169
      IMPA=1                                                            CHD 1170
      TEMPA=3.                                                          CHD 1171
      DTRAD=TEMPJ                                                       CHD 1172
      NTS2=ZLOW                                                         CHD 1173
      GO TO 2420                                                        CHD 1174
 2450 IF (IMPEXP) 2460,2470,2590                                        CHD 1175
 2460 DTRAD=1.E50                                                       CHD 1176
      GO TO 2730                                                        CHD 1177
 2470 IF (IMPA) 2480,2480,2580                                          CHD 1178
C     IMPLICIT DIFFUSION                                                CHD 1179
 2480 DTRAD=1.E-50                                                      CHD 1180
      TEMPG=6.                                                          CHD 1181
      TEMPC=TO(1)**3                                                    CHD 1182
      IF (IGM-2) 2490,2500,2510                                         CHD 1183
 2490 TEMPA=1.                                                          CHD 1184
      GO TO 2520                                                        CHD 1185
 2500 TEMPA=XO(1)                                                       CHD 1186
      TEMPG=TWOPIE*TEMPG                                                CHD 1187
      GO TO 2520                                                        CHD 1188
 2510 TEMPA=XO(1)**2                                                    CHD 1189
      TEMPG=FOURPIE*TEMPG                                               CHD 1190
 2520 TEMPD=-TEMPG*TEMPA*TEMPR(1)*TEMPC                                 CHD 1191
      DO 2570 I=1,NZN                                                   CHD 1192
      IP1=I+1                                                           CHD 1193
      TEMPB=TEMPC                                                       CHD 1194
      TEMPC=TO(IP1)**3                                                  CHD 1195
      TEMPE=TEMPD                                                       CHD 1196
      IF (IGM-2) 2550,2530,2540                                         CHD 1197
 2530 TEMPA=XO(IP1)                                                     CHD 1198
      GO TO 2550                                                        CHD 1199
 2540 TEMPA=XO(IP1)**2                                                  CHD 1200
 2550 TEMPD=TEMPG*TEMPA*TEMPR(IP1)*(TEMPB-TEMPC)                        CHD 1201
      IF (KACT(I)) 2570,2560,2570                                       CHD 1202
 2560 TEMPF=PEPTIN(I)*(TEMPE-TEMPD)/XM(I)                               CHD 1203
      IF (TEMPF.LE.DTRAD) GO TO 2570                                    CHD 1204
      NTS2=I                                                            CHD 1205
      DTRAD=TEMPF                                                       CHD 1206
 2570 CONTINUE                                                          CHD 1207
      DTRAD=1./DTRAD                                                    CHD 1208
      IF (NCKR) 2730,2730,2390                                          CHD 1209
C     APPROXIMATE IMPLICIT DIFFUSION                                    CHD 1210
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 2580 DTRAD=DTRADT*DTP
      NTS2=IMPA
      IF (NCKR) 2730,2730,2380
C     EXPLICIT DIFFUSION
 2590 TEMPB=100.
      TEMPA=0.
      DO 2720 I=1,NZ
      IF (KACT(I)) 2720,2600,2720
 2600 IF (IGM-2) 2630,2610,2620
 2610 TEMPC=TWOPIE*(XO(I+1)*FLUX(I+1)-XO(I)*FLUX(I))
      GO TO 2640
 2620 TEMPC=FOURPIE*(FLUX(I+1)*XO(I+1)**2-FLUX(I)*XO(I)**2)
      GO TO 2640
 2630 TEMPC=FLUX(I+1)-FLUX(I)
 2640 IF (TEMPC) 2650,2720,2660
 2650 TEMPC=ABS(TEMPC)*TEMPB/(XM(I)*E(I))
      GO TO 2710
 2660 IF (I.EQ.1) GO TO 2670
      IF (I.EQ.NZ) GO TO 2680
      TEMPM=TO(I-1)+TO(I+1)
      GO TO 2690
 2670 TEMPM=TO(2)+ZEBOUT
      GO TO 2690
 2680 TEMPM=TO(NZ)+ZEBIN
 2690 IF (10.*TO(I)-TEMPM) 2700,2650,2650
C     THIS PATH FOR RAPID HEATING OF COLD ZONES
 2700 TEMPC=ABS(TEMPC)*2./(XM(I)*(E(I)+1.E10))
 2710 IF (TEMPC.LE.TEMPA) GO TO 2720
      TEMPA=TEMPC
      NTS2=I
 2720 CONTINUE
      DTRAD=1./(TEMPA+1.E-50)
      IF (NCKR) 2730,2730,2370
 2730 DT=AMAX1(DTMIN,AMIN1(DTMAX,DTCS,DTRAD,DTTEMP))
      IF (ICYCLE.GT.1) GO TO 2740
      DTP=1.E-25
      DTPP=DT
 2740 TEMPA=0.095*DTPP
      IF (DT.GE.TEMPA) GO TO 2750
      IF (DT.NE.DTTEMP) GO TO 2750
      PRINT 6320, ICYCLE,TIME,DT,DTP,DTPP,DTTEMP,DTCS,DTRAD,DTMAX,DTMIN,
     1TEMPA
      DTTEMP=TEMPA
      GO TO 2730
 2750 IF (NOSOUR.LE.0) GO TO 2760
      IF (TIME.GE.TSOURM) GO TO 2760
      IF (DT.LE.TSOURM/200.) GO TO 2760
      DT=TSOURM/200.
C     NEW DT DETERMINED
 2760 IEDREJ=0
      IFLPR=0
      IF (TIME*1.E-9.LE.DT) GO TO 2770
      PRINT 6390, ICYCLE,TIME,DT,KCUTM,DTMIN,DTMAX,DTCS,DTTEMP
      IF (TIME*1.E-11.GT.DT) IFLPR=1
      IF (TIME*1.E-12.GT.DT) STOP 77
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 2770 DTH=.5*(DT+DTP)
C     CALCULATE NEW VELOCITIES AND POSITIONS
      IF (NOHYD.NE.0) GO TO 3360
      DO 2990 I=1,NZ
      TEMPA=TEMPB
      TEMPB=XO(I)
      TEMPG=TEMPE
      TEMPF=TEMPD
      TEMPD=P(I)+Q(I)-SXD(I)
      IM1=I-1
      IF (KACT(I).EQ.1) GO TO 2980
      GO TO KSWA, (2790,2780)
 2780 TEMPM=XO(I+1)
      IF (ISPALL(I).EQ.1) TEMPM=XLO(I)
 2790 IF (I.GT.1) GO TO 2860
      IF (OBS) 2810,2810,2800
 2800 V(1)=TEMPC=0.
      GO TO 2920
 2810 TEMPC=XM2(1)*(TEMPD-PBCRYO)
      GO TO NGM1, (2910,2820,2840)
 2820 TEMPC=TEMPC*TWOPIE*TEMPB
      GO TO KSWB, (2910,2830)
 2830 TEMPC=TEMPC+2.*(2.*SXD(1)+SZD(1))/((XO(1)+TEMPM)*DO(1))
      GO TO 2910
 2840 TEMPC=TEMPC*FOURPIE*TEMPB**2
      GO TO KSWC, (2910,2850)
 2850 TEMPC=TEMPC+6.*SXD(1)/((XO(1)+TEMPM)*DO(1))
      GO TO 2910
 2860 TEMPC=XM2(I)*(TEMPD-TEMPF)
      GO TO NGM2, (2910,2870,2890)
 2870 TEMPC=TEMPC*TWOPIE*TEMPB
      GO TO KSWD, (2910,2880)
 2880 TEMPC=TEMPC+2.*(2.*(SXD(I)+SXD(I-1))+SZD(I)+SZD(I-1))/(DO(I)*(XO(I
     1)+TEMPM)+DO(I-1)*(XO(I)+XO(I-1)))
      GO TO 2910
 2890 TEMPC=TEMPC*FOURPIE*TEMPB**2
      GO TO KSWE, (2910,2900)
 2900 TEMPC=TEMPC+6.*(SXD(I)+SXD(I-1))/(DO(I)*(XO(I)+TEMPM)+DO(I-1)*(XO(
     1I)+XO(I-1)))
 2910 TEMPC=VO(I)+TEMPC*DTH
      IF (ABS(TEMPC).LT.CKC) TEMPC=0.
      V(I)=TEMPC
 2920 X(I)=TEMPE=TEMPB+TEMPC*DT
      IF (I.EQ.1) GO TO 2990
 2930 GO TO NGM3, (2940,2950,2960)
 2940 D(IM1)=XM(IM1)/(TEMPG-TEMPE)
      GO TO 2970
 2950 D(IM1)=XM(IM1)/((TEMPG-TEMPE)*(TEMPG+TEMPE)*PIE)
      GO TO 2970
 2960 D(IM1)=XM(IM1)/((TEMPG-TEMPE)*(TEMPG**2+TEMPG*TEMPE+TEMPE**2)*PIE4
     13)
 2970 IF (ABS(D(IM1)-DO(IM1)).LE.CKA*DO(IM1)) GO TO 2990
      IF (ISPALL(IM1).EQ.1) GO TO 2990
      IF (I.EQ.2) GO TO 2990
      IF (ISPALL(I-2)) 3020,3020,2990
```

```
 2980 TEMPE=X(I)                                                        CHD 1321
      IF (I.EQ.1) GO TO 2990                                            CHD 1322
      IF (KACT(IM1).EQ.0) GO TO 2930                                    CHD 1323
 2990 CONTINUE                                                          CHD 1324
      IF (KACT(NZP).EQ.0) GO TO 3000                                    CHD 1325
      IF (KACT(NZ)) 3090,3090,3140                                      CHD 1326
 3000 IF (IBS) 3030,3030,3010                                           CHD 1327
 3010 V(NZP)=TEMPC=0.                                                   CHD 1328
      GO TO 3090                                                        CHD 1329
 3020 DT=DT*DTINCI                                                      CHD 1330
      PRINT 6400, DT,ICYCLE,TIME,IM1,D(IM1),DO(IM1)                     CHD 1331
      GO TO 2760                                                        CHD 1332
 3030 TEMPC=XM2(NZP)*(TEMPD-PBDRYI)                                     CHD 1333
      GO TO NGM4, (3080,3040,3060)                                      CHD 1334
 3040 TEMPC=TEMPC*TWOPIE*XO(NZP)                                        CHD 1335
      GO TO KSWF, (3080,3050)                                           CHD 1336
 3050 TEMPC=TEMFC-2.*(2.*SXD(NZ)+SZD(NZ))/((XO(NZ)+XO(NZP))*DO(NZ))     CHD 1337
      GO TO 3080                                                        CHD 1338
 3060 TEMPC=TEMPC*FOURPIE*XO(NZP)**2                                    CHD 1339
      GO TO KSWG, (3080,3070)                                           CHD 1340
 3070 TEMPC=TEMPC-6.*SXD(NZ)/((XO(NZ)+XO(NZP))*DO(NZ))                  CHD 1341
 3080 TEMPC=VO(NZP)-TEMPC*DTH                                           CHD 1342
      IF (ABS(TEMPC).LT.CKC) TEMPC=0.                                   CHD 1343
      V(NZP)=TEMPC                                                      CHD 1344
      X(NZP)=XO(NZP)+TEMPC*DT                                           CHD 1345
      IF (IGM.EQ.1) GO TO 3090                                          CHD 1346
C     CHECK FOR CLOSING CENTRAL VOID                                    CHD 1347
      IF (X(NZP).GT.0.) GO TO 3090                                      CHD 1348
      SD(NZ)=.5*TEMPC**2/(XM2(NZP)*XM(NZ)*DT)                           CHD 1349
      X(NZP)=V(NZP)=0.                                                  CHD 1350
      IBS=1                                                             CHD 1351
      IEDREJ=1                                                          CHD 1352
      I=-1                                                              CHD 1353
      PRINT 6410, ICYCLE,TIME                                           CHD 1354
 3090 GO TO NGM5, (3100,3110,3120)                                      CHD 1355
 3100 D(NZ)=XM(NZ)/(X(NZ)-X(NZP))                                       CHD 1356
      GO TO 3130                                                        CHD 1357
 3110 D(NZ)=XM(NZ)/((X(NZ)-X(NZP))*(X(NZ)+X(NZP))*PIE)                  CHD 1358
      GO TO 3130                                                        CHD 1359
 3120 D(NZ)=XM(NZ)/((X(NZ)-X(NZP))*(X(NZ)**2+X(NZ)*X(NZP)+X(NZP)**2)*PIECHD 1360
     143)                                                               CHD 1361
 3130 IF (ISPALL(NZN).EQ.1) GO TO 3140                                  CHD 1362
      IF (ABS(D(NZ)-DO(NZ)).LT.CKA*DO(NZ)) GO TO 3140                   CHD 1363
      IF (I.EQ.-1) GO TO 3140                                           CHD 1364
      DT=DT*DTINCI                                                      CHD 1365
      IM1=NZ                                                            CHD 1366
      GO TO 3020                                                        CHD 1367
 3140 CONTINUE                                                          CHD 1368
C     SPALL SURFACE VELOCITY AND POSITION                               CHD 1369
      IF (NSPALL.LE.0) GO TO 3360                                       CHD 1370
      DO 3190 I=1,NZN                                                   CHD 1371
      IF (ISPALL(I).EQ.0) GO TO 3190                                    CHD 1372
      IM1=I+1                                                           CHD 1373
      TEMPB=P(I)+Q(I)-SXD(I)                                            CHD 1374
      TEMPC=P(IM1)+Q(IM1)-SXD(IM1)                                      CHD 1375
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```
      IF (NORAD.EQ.0) GO TO 3150
      TEMPD=.0625*RADK3*(TO(I)+TO(IM1))**4
      TEMPB=TEMPB-TEMPD
      TEMPC=TEMPC-TEMPD
 3150 TEMPB=TEMPB/XM(I)
      TEMPC=TEMPC/XM(IM1)
      IF (IGM.EQ.1) GO TO 3180
      TEMPA=XO(I+2)
      IF (ISPALL(I+1).EQ.1) TEMPA=XLO(I+1)
      GO TO NGM6, (3150,3160,3170)
 3160 TEMPB=TWOPIE*TEMPB*XLO(I)-(2.*SXD(I)+SZD(I))/((XO(I)+XLO(I))*DO(I)
     1)
      TEMPC=TWOPIE*TEMPC*XO(IM1)+(2.*SXD(IM1)+SZD(IM1))/((XO(IM1)+TEMPA)
     1*DO(IM1))
      GO TO 3180
 3170 TEMPB=FOURPIE*TEMPB*XLC(I)**2-3.*SXD(I)/((XO(I)+XLO(I))*DO(I))
      TEMPC=FOURPIE*TEMPC*XO(IM1)**2+3.*SXD(IM1)/((XO(IM1)+TEMPA)*DO(IM1
     1))
 3180 TEMPB=VLO(I)-2.*DTH*TEMPB
      TEMPC=VO(IM1)+2.*DTH*TEMPC
      IF (ABS(TEMPB).LT.CKC) TEMPB=0.
      IF (ABS(TEMPC).LT.CKC) TEMPC=0.
      VL(I)=TEMPB
      V(IM1)=TEMPC
      XL(I)=XLO(I)+VL(I)*DT
      X(IM1)=XO(IM1)+V(IM1)*DT
 3190 CONTINUE
      DO 3290 I=1,NZN
      IF (ISPALL(I).EQ.0) GO TO 3290
      GO TO NGM7, (3200,3210,3220)
 3200 D(I)=XM(I)/(X(I)-XL(I))
      GO TO 3230
 3210 D(I)=XM(I)/((X(I)-XL(I))*(X(I)+XL(I))*PIE)
      GO TO 3230
 3220 D(I)=XM(I)/((X(I)-XL(I))*(X(I)**2+X(I)*XL(I)+XL(I)**2)*PIE43)
 3230 IF (ABS(D(I)-DO(I)).GT.CKA*DO(I)) GO TO 3280
      IM1=I+1
      IF (ISPALL(IM1).EQ.1) GO TO 3290
      GO TO NGM8, (3240,3250,3260)
 3240 D(IM1)=XM(IM1)/(X(IM1)-X(IM1+1))
      GO TO 3270
 3250 D(IM1)=XM(IM1)/((X(IM1)-X(IM1+1))*(X(IM1)+X(IM1+1))*PIE)
      GO TO 3270
 3260 D(IM1)=XM(IM1)/((X(IM1)-X(IM1+1))*(X(IM1)**2+X(IM1)*X(IM1+1)+X(IM1
     1+1)**2)*PIE43)
 3270 IF (ABS(D(IM1)-DO(IM1)).LE.CKA*DO(IM1)) GO TO 3290
      PRINT 6420, IM1,I,D(IM1),DO(IM1),X(IM1),XO(IM1),X(IM1+1),XO(IM1+1)
     1,V(IM1),VO(IM1),V(IM1+1),VO(IM1+1)
      GO TO 3020
 3280 PRINT 6430, I,I,D(I),DO(I),X(I),XO(I),XL(I),XLO(I),V(I),VO(I),VL(I
     1),VLO(I)
      IM1=I
      GO TO 3020
 3290 CONTINUE
C     CHECK FOR REJOIN
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      DO 3350 I=1,NZN
      IF (ISPALL(I).EQ.0) GO TO 3350
      IF (XL(I).GT.X(I+1)) GO TO 3350
      IF (X(I+1).GT.(.9*XL(I)+.1*X(I))) GO TO 3330
      TEMPAB=X(I+2)
      IF (ISPALL(I+1).EQ.1) TEMPAB=XL(I+1)
      IF (XL(I).LT.(.9*X(I+1)+.1*TEMPAB)) GO TO 3330
      TEMPE=TIME+DT
      IEDREJ=I+1
      IF (NEDREJ.NE.0) PRINT 6440, IEDREJ,ICYCLE,TEMPE
      IEDREJ=1
      ISPALL(I)=0
      NSPALL=NSPALL-1
      TEMPE=V(I+1)
      V(I+1)=(XM(I)*VL(I)+XM(I+1)*V(I+1))/(XM(I)+XM(I+1))
      TEMPJ=.25*(XM(I)*VL(I)**2+XM(I+1)*TEMPE**2-(XM(I)+XM(I+1))*V(I+1)*
     1*2)
      X(I+1)=.5*(XL(I)+X(I+1))
      SD(I)=.5*TEMPJ/(XM(I)*DT)
      SD(I+1)=.5*TEMPJ/(XM(I+1)*DT)
      GO TO NGM9, (3300,3310,3320)
 3300 D(I)=XM(I)/(X(I)-X(I+1))
      D(I+1)=XM(I+1)/(X(I+1)-TEMPAB)
      GO TO 3350
 3310 D(I)=XM(I)/((X(I)-X(I+1))*(X(I)+X(I+1))*PIE)
      D(I+1)=XM(I+1)/((X(I+1)-TEMPAB)*(X(I+1)+TEMPAB)*PIE)
      GO TO 3350
 3320 D(I)=XM(I)/((X(I)-X(I+1))*(X(I)**2+X(I)*X(I+1)+X(I+1)**2)*PIE43)
      D(I+1)=XM(I+1)/((X(I+1)-TEMPAB)*(X(I+1)**2+X(I+1)*TEMPAB+TEMPAB**2
     1)*PIE43)
      GO TO 3350
 3330 PRINT 6450
      DO 3340 KKK=1,NZ
 3340 SD(KKK)=0.
      GO TO 3020
 3350 CONTINUE
 3360 CONTINUE
C     CHECK FOR ZONE ACTIVATION
      IF (NACTION.EQ.0) GO TO 3470
      IF (KCUTM.GT.0) GO TO 3470
      IF (V(1)) 3390,3370,3390
 3370 IF (NORAD) 3400,3400,3380
 3380 IF (ABS(FLUX(1))-FLUXMIN) 3400,3400,3390
 3390 KACT(1)=KACT(2)=0
 3400 NACTION=IM1=0
      IP1=2
      DO 3460 I=2,NZ
      IM1=IM1+1
      IP1=IP1+1
      IF (V(I)) 3440,3410,3440
 3410 IF (NORAD) 3450,3450,3420
 3420 IF (ABS(FLUX(I))-FLUXMIN) 3450,3450,3430
 3430 IF (I.GT.2) KACT(I-2)=0
 3440 KACT(IM1)=KACT(I)=KACT(IP1)=0
 3450 IF (KACT(IM1).EQ.0) NACTION=NACTION+1
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 3460 CONTINUE
      IF (KACT(NZ).EQ.0) NACTION=NACTION+1
      IF (KACT(NZP).EQ.0) NACTION=NACTION+1
      IF (NACTION.EQ.0) STOP 3333
      IF (NACTION.NE.NZP) GO TO 3470
      NACTION=0
      PRINT 6460, TIME,ICYCLE
 3470 CONTINUE
C     CALCULATE ENERGY SOURCES
      GO TO ISOUR, (3490,3480)
 3480 TEMPJ=TIME+0.5*DT
      CALL SOURCE
      IF (TEMPJ.LE.TSOURM) GO TO 3490
      ASSIGN 3490 TO ISOUR
      NOSOUR=0
C     CALCULATE NEW VISCOSITIES AND PROJECT NEW TEMPERATURES
 3490 TEMPA=V(1)
      DO 3560 I=1,NZ
      TEMPB=TEMPA
      TEMPA=V(I+1)
      IF (KACT(I).EQ.1) GO TO 3560
      IF (ISPALL(I).EQ.1) GO TO 3560
      TEMPE=D(I)
      TEMPF=DO(I)
      IF (TEMPA.GT.TEMPB) GO TO 3500
      Q(I)=0.
      GO TO 3530
 3500 TEMPC=TEMPB-TEMPA
      GO TO NOB1, (3520,3510)
 3510 Q(I)=(TEMPE+TEMPF)*BQ*TEMPC**2
      GO TO 3530
 3520 Q(I)=(TEMPE+TEMPF)*TEMPC*(BQ*TEMPC-BL*CSOD(I))
 3530 TEMP(I)=TEMPE=(TEMPF-TEMPE)/(TEMPF*TEMPE)
      T(I)=TO(I)*(1.-PPPT(I)*PEPTIN(I)*TEMPE)+(SD(I)*DT-Q(I)*TEMPE)*PEPT
     1IN(I)
      GO TO NRAD2, (3550,3540)
 3540 IF (T(I).GT.3.*(TO(I)+5.)) T(I)=3.*(TO(I)+5.)
 3550 IF (T(I).GT.0.) GO TO 3560
      T(I)=TO(I)
 3560 CONTINUE
C     CALCULATE VISCOSITIES AND PROJECT NEW TEMPERATURES NEAR SPALLS
      IF (NSPALL.LE.0) GO TO 3600
      DO 3590 I=1,NZN
      IF (ISPALL(I).EQ.0) GO TO 3590
      IF (V(I).GE.VL(I)) GO TO 3570
      Q(I)=(D(I)+DO(I))*(VL(I)-V(I))*(BQ*(VL(I)-V(I))+BL*CSOD(I))
      GO TO 3580
 3570 Q(I)=0.
 3580 TEMP(I)=TEMPE=(DO(I)-D(I))/(DO(I)*D(I))
      T(I)=TO(I)*(1.-PPPT(I)*PEPTIN(I)*TEMPE)-Q(I)*TEMPE*PEPTIN(I)
      IF (T(I).GT.0.) GO TO 3590
      T(I)=TO(I)
 3590 CONTINUE
 3600 CONTINUE
C     UPDATE STRESS DEVIATORS AND CALCULATE CORRECTION TO ENERGY
```

```
      IS=0
C     DEVIATOR STRESS WORK ADDED TO E ARRAY
      IF (SWEP.NE.0.) CALL ELPL
      DTTEMT=DTINCR
      ICALL=1
      NCKR=0
      GO TO NRAD3, (3760,3610)
C     CALCULATE NEW BOUNDARY TEMPERATURES
 3610 TEMPJ=TIME+DT
      CALL TEDGE
      IF (KRD4.NE.1) GO TO 3670
C     TYPE 4 RADIATION CHECK PATH
      IF (ICYCLE.NE.NCKRD4*(ICYCLE/NCKRD4)) GO TO 3670
      IF (IMPEXP.EQ.1.AND.DTRAD.GT.10.*DT) GO TO 3670
      IF (IMPA.EQ.1) GO TO 3660
      NCKR=20+IMPEXP
      IMPA=1
      IMPEXP=0
      IF (NCKR.EQ.20) GO TO 3620
      CALL WRITEC (FLUX,11*MAXZONE+3,MAXZONE+1)
      GO TO 3680
 3620 CALL WRITEC (FPATH,11*MAXZONE+3,MAXZONE)
      GO TO 3680
 3630 IMPA=0
      IF (NCKR.EQ.20) GO TO 3640
      CALL READEC (FLUX,11*MAXZONE+3,MAXZONE+1)
      IMPEXP=1
      GO TO 3650
 3640 CALL READEC (FPATH,11*MAXZONE+3,MAXZONE)
      IMPEXP=0
 3650 CALL WRITEC (TSAVE,11*MAXZONE+3,MAXZONE)
      GO TO 3670
 3660 NCKR=1
 3670 ITTMP=0
      IF (IMPEXP) 3760,3680,3690
 3680 IP1=1
      GO TO 2140
C     EXPLICIT DIFFUSION  ADD ENERGY FLUX TO E ARRAY
 3690 IF (IGM-2) 3700,3720,3740
 3700 DO 3710 I=1,NZ
 3710 E(I)=E(I)+DT*(FLUX(I+1)-FLUX(I))/XM(I)
      GO TO 3760
 3720 TEMPA=TWOPIE*DT
      DO 3730 I=1,NZ
      IP1=I+1
 3730 E(I)=E(I)+TEMPA*(FLUX(IP1)*XO(IP1)-FLUX(I)*XO(I))/XM(I)
      GO TO 3760
 3740 TEMPA=FOURPIE*DT
      DO 3750 I=1,NZ
      IP1=I+1
 3750 E(I)=E(I)+TEMPA*(FLUX(IP1)*XO(IP1)**2-FLUX(I)*XO(I)**2)/XM(I)
C     $ $ $ $ $ $ $ $ $ $ $ $ $ $ $ $ $ $ $ $ $ $ $ $ $ $ $ $ $ $ $ $
C     HYDRO ONLY AND EXPLICIT DIFFUSION ENERGY BALANCE
 3760 DO 3900 I=1,NZ
      IF (KACT(I)) 3900,3770,3900
```

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 3770 ITRY=0
      TEMPA=D(I)
      TEMPL=-.5*TEMP(I)
      TEMPB=E(I)+(P(I)+2.*Q(I))*TEMPL+SD(I)*DT
      TEMPJ=T(I)
 3780 CALL EOS
      TEMPI=TEMPG-TEMPL*TEMPH
      IF (TEMPI.LE.0.) GO TO 3820
      TEMPI=(TEMPC-TEMPB-TEMPL*TEMPD)/TEMPI
      IF (ABS(TEMPI).LE.CK*TEMPJ) GO TO 3810
      TEMPK=TEMPJ
      TEMPJ=TEMPJ-TEMPI
      IF (TEMPJ.LT.10.*TEMPK) GO TO 3790
      TEMPJ=10.*TEMPK
 3790 IF (TEMPJ.GE.TEMINT) GO TO 3800
      TEMPJ=.9*TEMPK+.1*TEMINT
 3800 ITRY=ITRY+1
      IF (ITRY-NCKA) 3780,3780,3820
 3810 T(I)=TEMPJ
      E(I)=TEMPC
      P(I)=TEMPD
      PPPT(I)=TEMPH
      PEPTIN(I)=1./TEMPG
      ITRIED(I)=ITRY
      GO TO 3900
C     TROUBLE SECTION
 3820 ZLOW=TEMINT
      ZUP=10.*TO(I)
 3830 TEMPJ=.5*(ZLOW+ZUP)
      CALL EOS
      ITRY=ITRY+1
      ZAV=TEMPC-TEMPB-TEMPL*TEMPD
      IF (ABS(ZAV).LE.CK*TEMPC) GO TO 3810
      IF (ITRY.LT.500) GO TO 3840
      IF (ITRY.GT.997) GO TO 3840
      IF (ZUP-ZLOW.LE.1.E-7*TEMPJ) GO TO 3810
 3840 IF (ZAV) 3860,3810,3850
 3850 ZUP=TEMPJ
      GO TO 3870
 3860 ZLOW=TEMPJ
 3870 IF (ITRY-998) 3830,3880,3890
 3880 ZLOW=ZUP=TO(I)
      GO TO 3830
 3890 PRINT 5560, I,ICYCLE,TIME,TO(I),ZAV,TEMPC
      GO TO 3810
 3900 CONTINUE
      IF (NCKR.GT.1) GO TO 4900
      IF (IMPA) 5000,5000,4840
 3910 IF (IMPA) 3920,3920,4480
C     IMPLICIT DIFFUSION ENERGY BALANCE
 3920 TEMPA=DT/16.
      TEMPR(NZP)=TEMPR(NZP)*TEMPA
      IF (IGM-2) 3950,3930,3940
 3930 TEMPA=TWOPIE*TEMPA
      TEMPR(NZP)=TEMPR(NZP)*TWOPIE*XO(NZP)
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      GO TO 3950
 3940 TEMPA=FOURPIE*TEMPA
      TEMPR(NZP)=TEMPR(NZP)*FOURPIE*XO(NZP)*X(NZP)
 3950 DO 4010 I=1,NZ
      IF (KACT(I)) 3960,3970,3960
 3960 TSAVE(I)=ITRIED(I)=0
      GO TO 4010
 3970 ESAVE(I)=E(I)-(P(I)+2.*Q(I))*.5*TEMP(I)+SD(I)*DT
      TSAVE(I)=ITRIED(I)=-1
      IF (IGM-2) 3980,3990,4000
 3980 TEMPR(I)=TEMPR(I)*TEMPA
      GO TO 4010
 3990 TEMPR(I)=TEMPR(I)*TEMPA*XO(I)
      GO TO 4010
 4000 TEMPR(I)=TEMPR(I)*TEMPA*XO(I)*X(I)
 4010 CONTINUE
      TEMPM=SCRADF*(TEBOUT+ZEBOUT)**4
      TEMPN=SCRADB*(TEBIN+ZEBIN)**4
 4020 DO 4050 I=1,NZ
      IF (TSAVE(I)) 4030,4050,4030
 4030 TEMPA=D(I)
      TEMPJ=T(I)
      CALL EOS
      ITRIED(I)=ITRIED(I)+1
      E(I)=TEMPC
      P(I)=TEMPD
      PPPT(I)=TEMPH
      IF (TEMPG) 4250,4250,4040
 4040 PEPTIN(I)=TEMPG
 4050 CONTINUE
      TEMPE=0.
      TEMPB=TEMPM
      TEMPG=T(1)+TO(1)
      TEMPF=TEMPG**3
      TEMPC=TEMPF*TEMPG
      TEMPF=4.*TEMPF
      DO 4100 I=1,NZ
      TEMPA=TEMFB
      TEMPB=TEMPC
      TEMPD=TEMPE
      TEMPE=TEMPF
      IP1=I+1
      IF (I.EQ.NZ) GO TO 4060
      TEMPG=T(IP1)+TO(IP1)
      TEMPF=TEMPG**3
      TEMPC=TEMPF*TEMPG
      TEMPF=4.*TEMPF
      GO TO 4070
 4060 TEMPF=0.
      TEMPC=TEMPN
 4070 IF (KACT(I)) 4080,4090,4080
 4080 GGA(I)=GGC(I)=GG(I)=0.
      GGB(I)=1.
      GO TO 4100
 4090 GGA(I)=TEMPR(I)*TEMPD/XM(I)
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      GGC(I)=TEMPR(IP1)*TEMPF/XM(I)
      TEMPG=.5*(D(I)-DO(I))/(D(I)*DO(I))
      GGB(I)=PEPTIN(I)-TEMPG*PPPT(I)+(TEMPR(IP1)+TEMPR(I))*TEMPE/XM(I)
      GG(I)=E(I)-ESAVE(I)-TEMPG*P(I)-(TEMPR(IP1)*TEMPC-(TEMPR(I)+TEMPR(I
     1P1))*TEMPB+TEMPR(I)*TEMPA)/XM(I)
 4100 CONTINUE
C     BACKWARD-FORWARD SOLUTION
      GGE(1)=GGC(1)/GGB(1)
      GGF(1)=-GG(1)/GGB(1)
      DO 4120 I=2,NZN
      IP1=I-1
      TEMPG=GGB(I)-GGA(I)*GGE(IP1)
      IF (TEMPG) 4110,4270,4110
 4110 GGE(I)=GGC(I)/TEMPG
      IF (ABS(GGE(I)).GT.1.E4) GO TO 4260
 4120 GGF(I)=(GGA(I)*GGF(IP1)-GG(I))/TEMPG
      TEMPG=GGB(NZ)-GGA(NZ)*GGE(NZN)
      IF (TEMPG) 4130,4280,4130
 4130 TSAVE(NZ)=TEMPG=(GGA(NZ)*GGF(NZN)-GG(NZ))/TEMPG
      TEMPAB=CK
      NDX=1
      IF (ITTMP-MITTMP+2) 4160,4150,4140
 4140 TEMPAB=100.*TEMPAB
 4150 TEMPAB=10.*TEMPAB
C     LAST TWO STATEMENTS RELAX CONVERGENCE CONDITION
      NDX=0
 4160 IF (ABS(TEMPG).LE.TEMPAB*T(NZ)) TSAVE(NZ)=0.
      DO 4170 IP1=1,NZN
      I=NZ-IP1
      TSAVE(I)=TEMPG=GGE(I)*TEMPG+GGF(I)
      IF (ABS(TEMPG).LE.TEMPAB*T(I)) TSAVE(I)=0.
 4170 CONTINUE
      DO 4200 I=1,NZ
      IF (TSAVE(I)) 4180,4200,4180
 4180 IF (NDX) 4190,4190,4210
 4190 NDX=NDX+1
      IF (ABS(TSAVE(I)).GT.0.01*T(I)) GO TO 4210
 4200 CONTINUE
C     ALL TEMPERATURES CONVERGED
      GO TO 4340
 4210 DO 4240 I=1,NZ
      IF (TSAVE(I)) 4220,4240,4230
 4220 TEMPG=T(I)
      T(I)=T(I)+TSAVE(I)
      IF (T(I).GE..8*TEMPG) GO TO 4240
      T(I)=.8*TEMPG
      GO TO 4240
 4230 TEMPG=T(I)
      T(I)=T(I)+TSAVE(I)
      IF (T(I).LE.3.*TEMPG) GO TO 4240
      T(I)=3.*TEMPG
 4240 CONTINUE
      ITTMP=ITTMP+1
      IF (ITTMP-MITTMP) 4020,4020,4290
C     TROUBLE HERE
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 4250 IP1=5290                                                          CHD 1761
      GO TO 4300                                                        CHD 1762
 4260 IP1=5291                                                          CHD 1763
      GO TO 4300                                                        CHD 1764
 4270 IP1=5292                                                          CHD 1765
      GO TO 4300                                                        CHD 1766
 4280 IP1=5293                                                          CHD 1767
      GO TO 4300                                                        CHD 1768
 4290 IP1=5294                                                          CHD 1769
C     FOR RECYCLE PRINT CHANGE NEXT CARD                                CHD 1770
 4300 JJ=0                                                              CHD 1771
      IF (NCKR.GT.1.AND.IMPA.EQ.1) GO TO 4770                           CHD 1772
      IF (JJ) 4310,4320,4310                                            CHD 1773
 4310 PRINT 5570, ICYCLE,TIME,DT,I,IP1,TEMPG,TEMPA,TEMPJ,TEMPC,TEMPD,TEMCHD 1774
     1PH,TEMPB,TEMFL,ITTMP                                              CHD 1775
      PRINT 5580, (I,TEMP(I),FLUX(I),TSAVE(I),PSAVE(I),T(I),TO(I),D(I),DCHD 1776
     1O(I),SD(I),E(I),I=1,NZ)                                           CHD 1777
 4320 KCUTM=KCUTM+1                                                     CHD 1778
      IF (KCUTM.GT.5) STOP 5210                                         CHD 1779
      DT=0.5*DT                                                         CHD 1780
      DO 4330 I=1,NZ                                                    CHD 1781
      D(I)=TEMPA=DO(I)                                                  CHD 1782
      T(I)=TEMP.=TO(I)                                                  CHD 1783
      CALL EOS                                                          CHD 1784
      E(I)=TEMPC                                                        CHD 1785
      P(I)=TEMPD                                                        CHD 1786
      PPPT(I)=TEMPH                                                     CHD 1787
 4330 PEPTIN(I)=1./TEMPG                                                CHD 1788
      CALL READEC (CSOD,6*MAXZONE,4*MAXZONE)                            CHD 1789
      CALL READEC (ISPALL,10*MAXZONE,MAXZONE+3)                         CHD 1790
      GO TO 2760                                                        CHD 1791
 4340 DO 4360 I=1,NZ                                                    CHD 1792
      IF (KACT(I)) 4360,4350,4360                                       CHD 1793
 4350 PEPTIN(I)=1./PEPTIN(I)                                            CHD 1794
 4360 CONTINUE                                                          CHD 1795
C     CALCULATE FLUX IF LATER REQUIRED                                  CHD 1796
      IF (ICYCLE.EQ.50*(ICYCLE/50)) GO TO 4370                          CHD 1797
      IF (NCOUNT+1.NE.10*((NCOUNT+1)/10)) GO TO 4470                    CHD 1798
 4370 TEMPB=1.                                                          CHD 1799
      DO 4460 I=1,NZP                                                   CHD 1800
      TEMPL=TEMPM                                                       CHD 1801
      IF (NZP-I) 4380,4390,4380                                         CHD 1802
 4380 TEMPM=(T(I)+TO(I))**4                                             CHD 1803
      GO TO 4400                                                        CHD 1804
 4390 TEMPM=TEMPN                                                       CHD 1805
 4400 IF (TEMPR(I)) 4420,4410,4420                                      CHD 1806
 4410 FLUX(I)=0.                                                        CHD 1807
      GO TO 4460                                                        CHD 1808
 4420 IF (IGM-2) 4450,4430,4440                                         CHD 1809
 4430 TEMPB=TWOPIE*XO(I)                                                CHD 1810
      GO TO 4450                                                        CHD 1811
 4440 TEMPB=FOURPIE*XO(I)*X(I)                                          CHD 1812
 4450 FLUX(I)=TEMPR(I)*(TEMPM-TEMPL)/(DT*TEMPB)                         CHD 1813
 4460 CONTINUE                                                          CHD 1814
 4470 CONTINUE                                                          CHD 1815
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      IF (NCKR-1) 4920,4920,4900                                        CHD 1816
C     APPROXIMATE IMPLICIT DIFFUSION FIRST PASS TEMPERATURES            CHD 1817
 4480 IF (IGM-2) 4490,4500,4510                                         CHD 1818
 4490 TEMPB=DT                                                          CHD 1819
      GO TO 4520                                                        CHD 1820
 4500 TEMPA=TWOPIE*DT                                                   CHD 1821
      GO TO 4520                                                        CHD 1822
 4510 TEMPA=FOURPIE*DT                                                  CHD 1823
 4520 DO 4580 I=2,NZ                                                    CHD 1824
      IF (TEMPR(I)) 4540,4530,4540                                      CHD 1825
 4530 PSAVE(I)=0.                                                       CHD 1826
      GO TO 4580                                                        CHD 1827
 4540 TEMPR(I)=.25*TEMPR(I)*(TO(I)+TO(I-1))**3                          CHD 1828
      IF (IGM-2) 4570,4550,4560                                         CHD 1829
 4550 TEMPB=TEMPA*XO(I)                                                 CHD 1830
      GO TO 4570                                                        CHD 1831
 4560 TEMPB=TEMPA*XO(I)*X(I)                                            CHD 1832
 4570 PSAVE(I)=TEMPB*TEMPR(I)                                           CHD 1833
 4580 CONTINUE                                                          CHD 1834
      DO 4700 I=1,NZ                                                    CHD 1835
      IF (KACT(I)) 4590,4600,4590                                       CHD 1836
 4590 ESAVE(I)=-TO(I)                                                   CHD 1837
      GGB(I)=1.                                                         CHD 1838
      GGA(I)=GGC(I)=0.                                                  CHD 1839
      GO TO 4700                                                        CHD 1840
 4600 TEMPJ=T(I)                                                        CHD 1841
      TEMPA=D(I)                                                        CHD 1842
      CALL EOS                                                          CHD 1843
      TEMPB=.5*TEMP(I)*TEMPH                                            CHD 1844
      ESAVE(I)=TEMPC-E(I)-TEMPG*TEMPJ-SD(I)*DT+TEMP(I)*(Q(I)+.5*(TEMPD+PCHD 1845
     1(I)-TEMPH*TEMPJ))                                                 CHD 1846
      GGB(I)=TEMPG+TEMPB                                                CHD 1847
      IF (I.EQ.1) GO TO 4620                                            CHD 1848
      IF (I.EQ.NZ) GO TO 4630                                           CHD 1849
      GGA(I)=PSAVE(I)/XM(I)                                             CHD 1850
      GGC(I)=PSAVE(I+1)/XM(I)                                           CHD 1851
      ESAVE(I)=ESAVE(I)+(GGA(I)*(TO(I)-TO(I-1))-GGC(I)*(TO(I+1)-TO(I))) CHD 1852
 4610 GGB(I)=GGB(I)+GGA(I)+GGC(I)                                       CHD 1853
      GO TO 4700                                                        CHD 1854
 4620 IP1=1                                                             CHD 1855
      GO TO 4640                                                        CHD 1856
 4630 IP1=NZP                                                           CHD 1857
 4640 IF (IGM-2) 4650,4660,4670                                         CHD 1858
 4650 TEMPB=1.                                                          CHD 1859
      GO TO 4680                                                        CHD 1860
 4660 TEMPB=TWOPIE*XO(IP1)                                              CHD 1861
      GO TO 4680                                                        CHD 1862
 4670 TEMPB=FOURPIE*XO(IP1)*X(IP1)                                      CHD 1863
 4680 TEMPB=TEMPB*TEMPR(IP1)*DT                                         CHD 1864
      IF (I.EQ.NZ) GO TO 4690                                           CHD 1865
      GGA(1)=0.                                                         CHD 1866
      GGC(1)=PSAVE(2)/XM(1)                                             CHD 1867
      GGB(1)=GGB(1)+.5*TEMPB*TO(1)**3/XM(1)                             CHD 1868
      ESAVE(1)=ESAVE(1)+(.5*TO(1)**4-SCRADF*(ZEBOUT+TEBOUT)**4/16.)*TEMPCHD 1869
     1B/XM(1)-GGC(1)*(TO(2)-TO(1))                                      CHD 1870
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      GO TO 4610
 4690 GGA(NZ)=PSAVE(NZ)/XM(NZ)
      GGC(NZ)=0.
      GGB(NZ)=GGB(NZ)+.5*TEMPB*TO(NZ)**3/XM(NZ)
      ESAVE(NZ)=ESAVE(NZ)+GGA(NZ)*(TO(NZ)-TO(NZN))-(.5*TO(NZ)**4-SCRADB*
     1(ZEBIN+TEBIN)**4/16.)*TEMPB/XM(NZ)
      GO TO 4610
 4700 CONTINUE
C     BACKWARD-FORWARD SOLUTION
      GGE(1)=GGC(1)/GGB(1)
      GGF(1)=-ESAVE(1)/GGB(1)
      DO 4730 I=2,NZ
      IP1=I-1
      TEMPG=GGB(I)-GGA(I)*GGE(IP1)
      IF (TEMPG) 4720,4710,4720
 4710 IP1=5386
      GO TO 4300
 4720 GGE(I)=GGC(I)/TEMPG
      IF (ABS(GGE(I)).LT.1.E5) GO TO 4730
      IP1=5387
      GO TO 4300
 4730 GGF(I)=(GGA(I)*GGF(IP1)-ESAVE(I))/TEMPG
      TSAVE(NZ)=GGF(NZ)
      DO 4740 IP1=1,NZN
      I=NZ-IP1
 4740 TSAVE(I)=GGE(I)*TSAVE(I+1)+GGF(I)
      IF (NCKR.LE.1) GO TO 4790
C     TYPE 4 RADIATION RETURN
      DO 4760 I=1,NZ
      IF (KACT(I)) 4750,4760,4750
 4750 TSAVE(I)=TO(I)
 4760 CONTINUE
      GO TO 3630
 4770 TSAVE(1)=1.E100
      DO 4780 I=2,NZ
 4780 TSAVE(I)=1.
      GO TO 3630
 4790 DO 4820 I=1,NZ
      IF (KACT(I)) 4800,4810,4800
 4800 TSAVE(I)=TO(I)
      GO TO 4820
 4810 T(I)=TSAVE(I)
      IF (T(I).GT.0.) GO TO 4820
      IP1=5394
      GO TO 4300
 4820 CONTINUE
C     FLUX
      TEMPA=TO(1)+T(1)
      FLOUF=TEMPR(1)*.5*TEMPA*TO(1)**3
      FLINF=SCRADF*TEMPR(1)*(ZEBOUT+TEBOUT)**4/16.
      FLUX(1)=FLOUF-FLINF
      DO 4830 I=2,NZ
      TEMPB=TEMPA
      TEMPA=TO(I)+T(I)
 4830 FLUX(I)=TEMPR(I)*(TEMPA-TEMPB)
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      FLOUB=TEMPR(NZP)*.5*TEMPA*TO(NZ)**3
      FLINB=TEMPR(NZP)*SCRADB*(ZEBIN+TEBIN)**4/16.
      FLUX(NZP)=FLINB-FLOUB
C     END FIRST PASS GO TO EXPLICIT CALCULATION FOR FINAL ENERGY BALANCE
      GO TO 3690
C     APPROXIMATE IMPLICIT DIFFUSION TIME STEP CONTROL
 4840 TEMPA=1.
      IMPA=NZP
      DO 4880 I=1,NZ
      IF (T(I)-TSAVE(I)) 4850,4880,4860
 4850 TEMPB=TSAVE(I)/T(I)
      GO TO 4870
 4860 TEMPB=T(I)/TSAVE(I)
 4870 IF (TEMPB.LE.TEMPA) GO TO 4880
      IMPA=I
      TEMPA=TEMPB
 4880 CONTINUE
      IF (TEMPA.LT.10.) GO TO 4890
      IF (NCKR.GT.1) GO TO 4890
C     ERROR TOO BIG TRY AGAIN
      IP1=5402
      GO TO 4300
 4890 DTRADT=2.2-TEMPA
      IF (DTRADT.LT..1) DTRADT=.1
      IF (NCKR-1) 5000,5000,4910
 4900 CALL READEC (TSAVE,11*MAXZONE+3,MAXZONE)
      GO TO 4840
 4910 IMPA=0
      NCKR=1
      IF (IMPEXP) 4920,4920,5000
C     END ENERGY BALANCE SECTION
C     $ $ $ $ $ $ $ $ $ $ $ $ $ $ $ $ $ $ $ $ $ $ $ $ $ $ $ $ $ $ $ $ $ $ $
C     ENERGY ACCOUNTING
 4920 IF (KACT(1)) 4940,4930,4940
 4930 IF (SCRADF) 4940,4950,4950
 4940 FLINF=FLOUF=0.
      GO TO 4960
 4950 FLINF=RADK6*SCRADF*(.5*(TEBOUT+ZEBOUT))**4
      FLOUF=RADK6*(.5*(T(1)+TO(1)))**4
 4960 IF (KACT(NZ)) 4980,4970,4980
 4970 IF (SCRADB) 4980,4990,4990
 4980 FLINB=FLOUB=0.
      GO TO 5000
 4990 FLINB=RADK6*SCRADB*(.5*(TEBIN+ZEBIN))**4
      FLOUB=RADK6*(.5*(T(NZ)+TO(NZ)))**4
 5000 IF (IMPEXP) 5080,5010,5010
 5010 IF (IGM-2) 5020,5030,5040
 5020 TEMPC=TEMPD=1.
      GO TO 5070
 5030 TEMPC=TWOPIE*XO(1)
      TEMPD=TWOPIE*XO(NZP)
      GO TO 5070
 5040 IF (IMPEXP.GT.0) GO TO 5050
      TEMPC=X(1)
      TEMPD=X(NZP)
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      GO TO 5060
 5050 TEMPC=XO(1)
      TEMPD=XO(NZP)
 5060 TEMPC=FOURPIE*XO(1)*TEMPC
      TEMPD=FOURPIE*XO(NZP)*TEMPD
 5070 RADEF=RADEF+DT*(FLINF-FLOUF)*TEMPC
      RADEB=RADEB+DT*(FLINB-FLOUB)*TEMPD
 5080 IF (IGM-2) 5090,5100,5100
 5090 TEMPC=TEMPD=1.
      GO TO 5110
 5100 TEMPC=PIE*(XO(1)+X(1))**(IGM-1)
      TEMPD=PIE*(XO(NZP)+X(NZP))**(IGM-1)
 5110 WORKF=WORKF+(XO(1)-X(1))*PBDRYO*TEMPC
      WORKB=WORKB+(X(NZP)-XO(NZP))*PBDRYI*TEMPD
C     CORRECT SOUND SPEED
      IS=1
      IF (SWEP.NE.0) CALL ELPL
C     CALCULATE DISTENTION RATIO FOR POROUS MATERIALS
      IF (SWPOR.EQ.1.) CALL FOAM
      TIME=TIME+DT
C     CALCULATE BOUNDARY PRESSURES
      GO TO NOBP, (5130,5120)
 5120 TEMPJ=TIME
      CALL EDGE
      GO TO 5140
 5130 PBDRYO=PB[RYI=0.
 5140 IF (NORAD) 5150,5210,5150
 5150 IF (SCRADF) 5160,5170,5170
 5160 PBDRYO=PBDRYO+RADK3*T(1)**4
      GO TO 5180
 5170 PBDRYO=PBDRYO+.5*RADK3*(SCRADF*TEBOUT**4+T(1)**4)
 5180 IF (SCRADB) 5190,5200,5200
 5190 PBDRYI=PBDRYI+RADK3*T(NZ)**4
      GO TO 5210
 5200 PBDRYI=PBDRYI+.5*RADK3*(SCRADB*TEBIN**4+T(NZ)**4)
 5210 CONTINUE
C     TIME STEP DATA
      IF (DTTEMT.GT.1..AND.ITTMP.GT.5) DTTEMT=1.
      DO 5250 I=1,NZ
      IF (T(I)-TO(I)) 5220,5250,5240
 5220 IF (T(I).GT.CKB*TO(I)) GO TO 5250
 5230 DTTEMT=DTINCI
      NTS3=I
      GO TO 5260
 5240 IF (T(I).GT.2.*TO(I)+.1) GO TO 5230
 5250 CONTINUE
C     SOURCE ENERGY
 5260 TEMPJ=0.
      IF (NOSOUR.LE.0) GO TO 5280
      DO 5270 I=1,NOSOUR
      IF (THESE(I).LE.0.) THESE(I)=THESE(I)-SD(I)*DT
 5270 TEMPJ=SD(I)*XM(I)+TEMPJ
      ESOURS=ESOURS+TEMPJ*DT
 5280 DO 5300 I=1,NZP
      IF (KACT(I)) 5300,5290,5300
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 5290 CYMESH=CYMESH+1.
 5300 CONTINUE
C      CHECK FOR FRACTURE
       IF (NSPALL.LT.0) GO TO 5360
       TEMPM=IEDREJ
       TEMPN=NEDREJ
       IF (SWEP) 5310,5330,5310
 5310 DO 5320 I=1,NZ
       TEMPR(I)=P(I)
 5320 P(I)=P(I)-SXD(I)
 5330 CALL FRACT
       IEDREJ=TEMPM
       IF (SWEP) 5340,5360,5340
 5340 DO 5350 I=1,NZ
 5350 P(I)=TEMPR(I)
 5360 IF (NEDREJ.LE.0) GO TO 5370
       IF (IEDREJ.EQ.1) GO TO 5400
 5370 IF (TIME.LT.TEND) GO TO 5380
C      END OF PROBLEM
       ITIMEL=0
 5380 IF (IFLPR.EQ.1) GO TO 5400
       TEMP=TIME+DT*.5
C      CHECK EDIT TIME
       IF (TEMP.LT.TIMEP(JPRIN+1)) GO TO 5390
       JPRIN=JPRIN+1
       CALL EDIT
       TPN=TIMEP(JPRIN)+DTIMEP(JPRIN)
       GO TO 5410
 5390 CONTINUE
       IF (TEMP.LT.TPN) GO TO 5410
       TPN=TPN+DTIMEP(JPRIN)
 5400 CALL EDIT
 5410 IF (MOVIE.LE.0) GO TO 5450
C      GENERATE MOVIE TAPE
       TEMPA=TIME+.5*DT
       IF (TEMPA-TTOMOV) 5440,5430,5430
 5420 WRITE (3) (ANAME(I),I=1,13)
 5430 MOVFRM=MOVFRM+1
       TTOMOV=TIME+DTMOV(JMOV)
       PRINT 5730, MOVFRM,ICYCLE,TIME
       WRITE (3) NZ,NZP,ICYCLE,MOVFRM,TIME,X(NZP),V(NZP),(X(I),V(I),XL(I)
     1,VL(I),ISPALL(I),T(I),D(I),P(I),Q(I),E(I),ENTSV(I),SXD(I),SZD(I),D
     2RATIO(I),I=1,NZ)
 5440 IF (TIME.LT.TMOV(JMOV+1)) GO TO 5450
       JMOV=JMOV+1
       TTOMOV=TM(V(JMOV)+DTMOV(JMOV)
       GO TO 5440
 5450 CONTINUE
       IF (IEDREJ.NE.1) GO TO 5470
       DO 5460 KKK=1,NZ
 5460 SD(KKK)=0.
C      CHECK RADIATION FOR POSSIBLE TURN OFF
 5470 IF (NORAD.EQ.0) GO TO 2040
       IF (TIME.LT.TRADOFF) GO TO 2040
       IF (ICYCLE.NE.50*(ICYCLE/50)) GO TO 2040
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      IF (ICYCLE.LT.200) GO TO 2040                                     CHD 2091
      IF (TIME.LT.1.05*TSOURM) GO TO 2040                               CHD 2092
      TEMPA=1.                                                          CHD 2093
      DO 5510 I=1,NZ                                                    CHD 2094
      IF (IGM-2) 5500,5480,5490                                         CHD 2095
 5480 TEMPA=TWOFIE*X(I)                                                 CHD 2096
      GO TO 5500                                                        CHD 2097
 5490 TEMPA=FOURPIE*X(I)**2                                             CHD 2098
 5500 IF (DT*(ABS(FLUX(I))+ABS(FLUX(I+1)))*TEMPA.GT.1.E-5*XM(I)*E(I)) GOCHD 2099
     1 TO 2040                                                          CHD 2100
      IF (RADK4*T(I)**4.GT.1.E-4*E(I)*D(I)) GO TO 2040                  CHD 2101
 5510 CONTINUE                                                          CHD 2102
C     APPEARS THAT RADIATION MAY BE TURNED OFF                          CHD 2103
      NORAD=-666                                                        CHD 2104
      DO 5520 I=1,NZP                                                   CHD 2105
 5520 FLUX(I)=FPATH(I)=0.                                               CHD 2106
      FLINF=FLOUF=FLINFO=FLOUFO=FLINB=FLOUB=FLINBO=FLOUBO=0.            CHD 2107
      KRD4=NCKR=0                                                       CHD 2108
      IF (NOHYD.NE.0) ITIMEL=0                                          CHD 2109
      IMPEXP=-1                                                         CHD 2110
      IMPA=0                                                            CHD 2111
      PRINT 5740, ICYCLE,TIME                                           CHD 2112
      GO TO 1780                                                        CHD 2113
C                                                                       CHD 2114
 5530 FORMAT (13H0HYDRODYNAMIC,A9)                                      CHD 2115
 5540 FORMAT (16H0ELASTIC-PLASTIC,A9)                                   CHD 2116
 5550 FORMAT (7H0POROUS,A9)                                             CHD 2117
 5560 FORMAT (22H0 ENERGY BALANCE ERROR,2I6,4E13.5)                     CHD 2118
 5570 FORMAT (23H0ENERGY BALANCE RECYCLE,I8,2E13.5,2I10,/,8E13.5,I8)    CHD 2119
 5580 FORMAT (I5,10E12.4)                                               CHD 2120
 5590 FORMAT (9H1 CHART D,75X,14HSEPTEMBER,1971,//,20H  EXECUTION BEGAN CHD 2121
     1AT,E10.3,8H SECONDS,8X,5HDATE ,A10,5X,5HTIME ,A10,//)             CHD 2122
 5600 FORMAT (13A6)                                                     CHD 2123
 5610 FORMAT (1H1)                                                      CHD 2124
 5620 FORMAT (5X,13A6)                                                  CHD 2125
 5630 FORMAT (6I5,5E10.3)                                               CHD 2126
 5640 FORMAT (8I10)                                                     CHD 2127
 5650 FORMAT (8H0ITIMEL=,I6,36X,3HNG=,I6/,7H NDUMP=,I6,37X,4HIIN=,I6/,6HCHD 2128
     1 IOUT=,I6,38X,7HIEOSTP=,I6,/,6H ITWO=,I6,38X,7HNEDREJ=,I6,/,8H FRACHD 2129
     2CDT=,E15.7,27X,7HDTINCR=,E15.7,/,6H TEND=,E15.7)                  CHD 2130
 5660 FORMAT (28H RESTARTED THE WRONG PROBLEM)                          CHD 2131
 5670 FORMAT (19H EOF FOUND ON INPUT,I10,3H OF,I5,8H RESTART)           CHD 2132
 5680 FORMAT (8H RESTART,I4,4H OF ,I4,14H HAS BEEN READ,I6)             CHD 2133
 5690 FORMAT (16I5)                                                     CHD 2134
 5700 FORMAT (5H0IGM=,I4,41X,6HNORAD=,I4)                               CHD 2135
 5710 FORMAT (6H0NRZC=,I4,40X,7HNMTRLS=,I4,/,7H NPRIN=,I4,39X,7HNDTMAX=,CHD 2136
     1I4,/,9H NDTMINN=,I4,37X,7HNBPRES=,I4,/,8H NOSOUR=,I4,38X,4HIBS=,I4CHD 2137
     2,/,5H OBS=,I4,41X,7HNSPALL=,I5,/,9H NACTION=,I4,37X,7HNTHIST=,I5,/CHD 2138
     3,8H NRADCK=,I5,37X,6HMOVIE=,I5)                                   CHD 2139
 5720 FORMAT (6H0    I,4X,7HTMOV(I),14X,8HDTMOV(I),//,(I6,E17.7,E16.7)) CHD 2140
 5730 FORMAT (13H0 MOVIE FRAME,I8,19H WRITTEN     CYCLE=,I8,9H    TIME=,CHD 2141
     1E12.4)                                                            CHD 2142
 5740 FORMAT (31H1 RADIATION HAS BEEN TURNED OFF,3X,7HICYCLE=,I7,5X,5HTICHD 2143
     1ME=,E12.5)                                                        CHD 2144
 5750 FORMAT (17H0THERE IS NO TYPE,I6,9H GEOMETRY)                      CHD 2145
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5760 FORMAT (36H0SOMETHING IS TOO BIG FOR DIMENSIONS)                   CHD 2146
5770 FORMAT (8E10.3)                                                     CHD 2147
5780 FORMAT (4H0BL=,E15.7,31X,3HBQ=,E15.7/,8H XM2(1)=,E15.7,27X,7HXM2(2CHD 2148
    1)=,E15.7,/,8H SCRADF=,E15.7,27X,7HSCRADB=,E15.7,/,9H TRADOFF=,E15.CHD 2149
    27,26X,5HSWEP=,E15.7)                                               CHD 2150
5790 FORMAT (//,5X,1HI,4X,8HTIMEP(I),12X,9HDTIMEP(I),//,(I6,2X,E15.7,1XCHD 2151
    1,E15.7))                                                           CHD 2152
5800 FORMAT (1H0,4X,1HI,4X,8HTIMES(I),12X,9HDLTTMX(I),//(I6,2X,E15.7,1XCHD 2153
    1,E15.7))                                                           CHD 2154
5810 FORMAT (1H0,4X,1HI,4X,10HTDTMINN(I),10X,9HDTMINN(I),//(I6,2X,E15.7CHD 2155
    1,1X,E15.7))                                                        CHD 2156
5820 FORMAT (3E10.3)                                                     CHD 2157
5830 FORMAT (1H0,3X,1HI,6X,9HTBPRES(I),6X,9HPINNER(I),6X,9HPOUTER(I),/,CHD 2158
    1(I5,3E15.4))                                                       CHD 2159
5840 FORMAT (1H0,3X,1HI,7X,7HTITH(I),7X,9HTEINTH(I),6X,9HTEOUTH(I),/,(ICHD 2160
    15,3E15.4))                                                         CHD 2161
5850 FORMAT (20H1 ZONING INFORMATION,//,10H  NMTRLS =,I4)                CHD 2162
5860 FORMAT (1H0,4X,1HI,4X,9HXMATUP(I),//(I6,2X,E15.7))                  CHD 2163
5870 FORMAT (I5,5E10.3,I5,2E10.3)                                        CHD 2164
5880 FORMAT (//,14H0ZONING REGION,I5,4X,8A10)                            CHD 2165
5890 FORMAT (8H0ITYPE =,I4,38X,16HUPPER BOUNDARY =,E14.7,/,17H LOWER BOCHD 2166
    1UNDARY =,E14.7,19X,9HDENSITY =,E14.7,/,14H TEMPERATURE =,E14.7,22XCHD 2167
    2,10HVELOCITY =,E15.7,/,13H EOS NUMBER =,I6)                        CHD 2168
5900 FORMAT (//,56H WILL ATTEMPT DIFFERENT ZONING METHOD ON THE LAST RECHD 2169
    1GION,/,16H CHECK CAREFULLY)                                        CHD 2170
5910 FORMAT (/,(2(,7H YIELD(,I1,3H) =,E14.7,24X)))                       CHD 2171
5920 FORMAT (2(7H FRACT(,I1,3H) =,E14.7,24X))                            CHD 2172
5930 FORMAT (54H0A NEGATIVE RADIUS HAS BEEN ENCOUNTERED IN INPUT CARDS)CHD 2173
5940 FORMAT (15H UPPER BOUNDARY,E20.10,19H AND LOWER BOUNDARY,E20.10,13CHD 2174
    1H DO NOT MATCH)                                                    CHD 2175
5950 FORMAT (26H0NUMBER OF DELTA X CARDS =,I5)                           CHD 2176
5960 FORMAT (18H0NUMBER OF ZONES =,I5,27X,9HDELTA X =,E14.7,/,19H OVERRCHD 2177
    1IDE DENSITY =,E14.7,17X,22HOVERRIDE TEMPERATURE =,E14.7,/,20H OVERCHD 2178
    2RIDE VELOCITY =,E14.7,16X,18HSUBREGION NUMBER =,I5)                CHD 2179
5970 FORMAT (17H REGION ENDING AT,E10.3,22H IS NOT ZONED PROPERLY)       CHD 2180
5980 FORMAT (19H CALCULATED VALUE =,E20.10,14H GIVEN VALUE =,E20.10)     CHD 2181
5990 FORMAT (20H REGION BOUNDARY AT ,E17.10,40H PASSED THE MATERIAL      CHD 2182
    1       BOUNDARY AT,E20.10)                                         CHD 2183
6000 FORMAT (21H0WIDTH OF FIRST ZONE=,E13.5,16X,19HWIDTH OF LAST ZONE=,CHD 2184
    1E13.5,/,34H MAXIMUM FRACTIONAL ERROR ALLOWED=,E13.5)               CHD 2185
6010 FORMAT (23H0NUMBER OF ZONES USED =,I5)                              CHD 2186
6020 FORMAT (24H0WIDTH OF BOUNDARY ZONE=,E13.5,13X,6HRATIO=,E13.5)       CHD 2187
6030 FORMAT (52H AMAX CAN NOT BE NEGATIVE IN THE FIRST REGION,TYPE 3)    CHD 2188
6040 FORMAT (21H0WIDTH OF FIRST ZONE=,E13.5,16X,19HWIDTH OF LAST ZONE=,CHD 2189
    1E13.5,/,7H RATIO=,E13.5,30X,33HMAXIMUM FRACTIONAL ERROR ALLOWED=,ECHD 2190
    213.5)                                                              CHD 2191
6050 FORMAT (38H0TEMPJ CANNOT BE NEGATIVE FOR REGION 1)                  CHD 2192
6060 FORMAT (56H0TYPE 6 ZONING CAN ONLY BE USED FOR FIRST OR LAST REGIOCHD 2193
    1N)                                                                 CHD 2194
6070 FORMAT (17H0NUMBER OF ZONES=,I6,27X,6HRATIO=,E13.5)                 CHD 2195
6080 FORMAT (17H CUTOFF POSITION=,E13.5,20X,16HEDGE ZONE WIDTH=,E13.5)   CHD 2196
6090 FORMAT (30H0A VOID HAS BEEN ZONED BETWEEN,E13.5,4H AND,E13.5)       CHD 2197
6100 FORMAT (30H CHECK THE NUMBER OF MATERIALS)                          CHD 2198
6110 FORMAT (42H SOMETHING APPEARS TO BE WRONG WITH ZONING)              CHD 2199
6120 FORMAT (3I10,/,(8E15.7))                                            CHD 2200
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 6130 FORMAT (31H0THERE ARE TOO MANY ZONES   NZ=,I7,10H  MAXZONE=,I7)
 6140 FORMAT (///,16H  STARTING CYCLE,I7,7H  TIME=,E12.5,18H  RADIATION
     1OPTION,F3.0,14H  WILL BE USED)
 6150 FORMAT (90H1      X(I)       M(I)/M(I-1)   I        M(I)        PPPT(I)
     1  CV(I)      NUMEOS  IEOS IZPTL IZPRL,/)
 6160 FORMAT (17H0 END OF MATERIAL,I3,19H  START OF MATERIAL,I3,/)
 6170 FORMAT (E12.4,12X,I4,3E12.4,4I6)
 6180 FORMAT (2E12.4,I4,3E12.4,4I6)
 6190 FORMAT (6H1 TYPE,I3,16H INTERNAL SOURCE)
 6200 FORMAT (I5,6E10.3)
 6210 FORMAT (26H INCORRECT INPUT IN SOURCE,3I6,/,6E17.8)
 6220 FORMAT (113H1    TSOUR1(I)       TSOUR2(I)       TSOUR3(I)       TSOUR4(I
     1)       SDOT2(I)        SDOT3(I) ZONE(I)  E ZONE(I)       SUM E)
 6230 FORMAT (6E14.6,I5,2E14.6)
 6240 FORMAT (16H ERROR IN SOURCE,I4,4E18.7)
 6250 FORMAT (14H SOURCE REGION,I3,40H HAS UPPER AND LOWER BOUNDARIES RE
     1VERSED)
 6260 FORMAT (19H SOURCE INPUT ERROR,/,I5,5E15.7)
 6270 FORMAT (13H SOURCE ERROR,2I10)
 6280 FORMAT (47H0 THERE IS AN OVERLAPPING SOURCE REGION IN ZONE,I5,27H
     1 SOME ENERGY HAS BEEN LOST,/)
 6290 FORMAT (27H0 SOURCE STRENGTH IN REGION,I3,17H,CONTAINING ZONES,I5,
     18H THROUGH,I5,3H IS,E15.7,5H ERGS)
 6300 FORMAT (11H1 HE SOURCE,//,21H POINT OF INITIATION=,E15.7,14X,16HDE
     1TONATION TIME=,E15.7,/,16H RIGHT BOUNDARY=,E15.7,19X,14HLEFT BOUND
     2ARY=,E15.7,/,21H DETONATION VELOCITY=,E15.7,14X,24HCHEMICAL ENERGY
     3 RELEASE=,E15.7,/,29H ZONE DETONATION FRONT WIDTH=,E15.7,6X,19HLAS
     4T REGION SWITCH=,E15.7,/,19H FIRST REGION ZONE=,I5,26X,17HLAST REG
     5ION ZONE=,I5)
 6310 FORMAT (/,9H DENSITY=,E15.7,26X,12HTEMPERATURE=,E15.7,/,10H PRESSU
     1RE=,E15.7,25X,12HSOUND SPEED=,E15.7)
 6320 FORMAT (//,37H0LARGE TIME STEP CUT ATTEMPTED CYCLE=,I7,8X,5HTIME=,
     1E12.5,/,4H0DT=,E12.5,9X,4HDTP=,E12.5,9X,5HDTPP=,E12.5,8X,7HDTTEMP=
     2,E12.5,/,6H0DTCS=,E12.5,7X,6HDTRAD=,E12.5,7X,6HDTMAX=,E12.5,7X,6HD
     3TMIN=,E12.5,/,19H0DTTEMP(CORRECTED)=,E12.5)
 6330 FORMAT (10H0THERE ARE,I4,26H REGIONS OF INITIAL ACTION,(/,7H REGIO
     1N,I4,22H HAS LOWER BOUNDARY AT,E12.4,22H AND UPPER BOUNDARY AT,E12
     2.4))
 6340 FORMAT (10H0INITIALLY,I5,17H ZONES ARE ACTIVE)
 6350 FORMAT (51H0REZONE FOR VOID CAN ONLY BE USED IN PLANE GEOMETRY)
 6360 FORMAT (I5,E15.7)
 6370 FORMAT (34H0A VOID HAS BEEN ZONED AT BOUNDARY,I4,9H  SPACE =,E15.7
     1,3H CM)
 6380 FORMAT (16H0 RESTART NUMBER,I5,21H IS WRITTEN     TIME =,E14.7,11H
     1  ICYCLE =,I6)
 6390 FORMAT (47H0 THE TIME STEP IS BECOMING VERY SMALL.  CYCLE=,I7,6H T
     1IME=,E17.9,/,5H  DT=,E12.5,7H KCUTM=,I4,7H DTMIN=,E12.5,7H DTMAX=,
     2E12.5,6H DTCS=,E12.5,8H DTTEMP=,E12.5)
 6400 FORMAT (31H TIME STEP CUT FOR DENSITY, DT=,E13.6,7H CYCLE=,I6,6H T
     1IME=,E13.6,13H ZONE NUMBER=,I5,9H NEW DEN=,E12.5,9H OLD DEN=,E12.5
     2)
 6410 FORMAT (30H0CENTRAL VOID CLOSED ON CYCLE=,I6,7H  TIME=,E13.5)
 6420 FORMAT (24H0 RIGHT BOUNDARY OF ZONE,I5,18H  FRACTURE OF ZONE,I5,/,
     110X,2HD=,E15.7,7X,3HD0=,E15.7,/,4H  X=,E15.7,6X,3HX0=,E15.7,7X,3HX
     2L=,E15.7,7X,4HXL0=,E15.7,/,4H  V=,E15.7,6X,3HV0=,E15.7,7X,3HVL=,E1
     35.7,7X,4HVL0=,E15.7)
 6430 FORMAT (23H0 LEFT BOUNDARY OF ZONE,I5,18H  FRACTURE OF ZONE,I5,/,4
     1X,2HD=,E15.7,15X,3HD0=,E15.7,/,4H  X=,E15.7,6X,3HX0=,E15.7,7X,3HXL
     2=,E15.7,7X,4HXL0=,E15.7,/,4H  V=,E15.7,6X,3HV0=,E15.7,7X,3HVL=,E15
     3.7,7X,4HVL0=,E15.7)
 6440 FORMAT (19H0REJOIN AT BOUNDARY,I6,8H  CYCLE=,I6,7H  TIME=,E14.7)
 6450 FORMAT (25H0TIME STEP CUT FOR REJOIN)
 6460 FORMAT (28H1 ALL ZONES ACTIVATED  TIME=,E14.7,8H  CYCLE=,I6)
      END
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      SUBROUTINE EDIT                                                   CHD 2265
C     REVISED STANDARD EDIT                                             CHD 2266
      COMMON /A/ JBND(21),ITRIED(400),IZPTL(400),IZPRL(400),KPHASE(400),CHD 2267
     1KACT(401),ISPALL(400),NSPALL,OBS,IBS,ICYCLE,IDTMAX,IDTMIN,JPRIN,NCCHD 2268
     2OUNT,NMTRLS,NZN,NZ,NZP,NDUMP,NBPRES,NOSOUR,NACTION,NORAD,IGM,NRADCCHD 2269
     3K,MOVIE,IMPEXP,IMPA,KRD4,NOHYD                                    CHD 2270
      COMMON D(400),DO(400),T(400),TO(400),P(400),XM(400),XM2(401),X(401CHD 2271
     1),XO(401),V(401),VO(401),XL(400),XLO(400),VL(400),VLO(401),CSOD(40CHD 2272
     20),Q(400),SXD(400),SZD(400),FPATH(400),FLUX(401),E(400),PPPT(400),CHD 2273
     3PEPTIN(400),PSPALL(400),SD(400),TEMP(400),TSAVE(400),PSAVE(400),ESCHD 2274
     4AVE(400),TEMPR(401),TMSPALL(20),DT,DTMAX,DTMIN,DTTEMP,DTRAD,TIME,TCHD 2275
     5PN,TEND,DTRADT,BL,BQ,DTIMEP(25),DLTTMX(25),DTMINN(25),TIMEP(25),TDCHD 2276
     6TMINN(25),TIMES(25),WORKF,WORKB,ENO,ESOURS,TBPRES(25),PINNER(25),PCHD 2277
     7OUTER(25),XMATUP(21),DTCS,DTP,TITH(25),TEINTH(25),TEOUTH(25),FLINFCHD 2278
     8,FLINFO,FLINB,FLINBC,FLOUF,FLOUFO,FLOUB,FLOUBO,RADEB,RADEF,SCRADF,CHD 2279
     9SCRADB,SPLA(20),SPLB(20),SPLC(20),SPLD(20),ENTSV(400),TMOV(10),DTMCHD 2280
     $OV(10),TRADOFF,SWEP,YIELD(20,8),DRATIO(400),SWPOR                 CHD 2281
      COMMON /C/ TEMPA,TEMPB,TEMPC,TEMPD,TEMPE,TEMPF,TEMPG,TEMPH,TEMPI,TCHD 2282
     1EMPJ,TEMPK,TEMPL,TEMPM,TEMPN,TEMPAB,TBPU,PBDRYO,PBDRYI,TRADMIN,RADCHD 2283
     2K1,RADK2,RADK3,RADK4,RADK5,RADK6,TEBOUT,TEBIN,TTHIU               CHD 2284
      COMMON /D/ IS,IS1,ICALL,ITLOW,JTLOW,INES                          CHD 2285
      COMMON /E/ IZETL(21),IZERL(21),ITL(21),IRL(21),IEOS(400),IEOSS(20)CHD 2286
     1,KTP(21),NROS(21),NUMTEM(20),IGAS(20),NOANEOS,NISEOS              CHD 2287
      COMMON /NAME/ ANAME(13),MAXZONE,NTS1,NTS2,NTS3,ITTMP,CYMESH       CHD 2288
      COMMON /TAPES/ I,IIN,IOUT,IEOSTP,ITWO                             CHD 2289
      COMMON /ISE/ ISEND,ENTCR(20),ENTTPL(20)                           CHD 2290
      DATA NTS1,NTS2,NTS3,ITTMP/4*0/                                    CHD 2291
      DATA CYMESH,START/0.,-1./                                         CHD 2292
      DATA LSVST/8H SUM MV /                                            CHD 2293
      IF (ISEND) 310,10,310                                             CHD 2294
   10 NCOUNT=NCOUNT+1                                                   CHD 2295
C     PRINTS TIME IN SECONDS                                            CHD 2296
      CALL SECOND (TEMPA)                                               CHD 2297
      IF (START) 20,30,30                                               CHD 2298
   20 START=TEMPA                                                       CHD 2299
      TEMPN=0.                                                          CHD 2300
      GO TO 40                                                          CHD 2301
   30 TEMPN=3600.*CYMESH/(TEMPA-START)                                  CHD 2302
   40 WRITE (1,420) ANAME,NTS1,NTS2,NTS3,ITTMP                          CHD 2303
      WRITE (1,430) TIME,DT,NCOUNT,ICYCLE,TEMPA,DTCS,DTP,DTTEMP,DTMAX,DTCHD 2304
     1MIN                                                               CHD 2305
      II=1                                                              CHD 2306
      TEMPA=TEMPB=TEMPD=0.                                              CHD 2307
      DO 160 I=1,NZ                                                     CHD 2308
      TEMPD=TEMPD+ENTSV(I)*XM(I)                                        CHD 2309
      TEMPB=TEMPB+E(I)*XM(I)                                            CHD 2310
      TEMPJ=V(I+1)                                                      CHD 2311
      IF (ISPALL(I).EQ.1) TEMPJ=VL(I)                                   CHD 2312
      TEMPA=TEMPA+XM(I)*(V(I)+TEMPJ)**2                                 CHD 2313
      IF (ITRIED(I).GT.99) ITRIED(I)=99                                 CHD 2314
      IF (I.LT.JBND(II)) GO TO 50                                       CHD 2315
C     MATERIAL BOUNDARY                                                 CHD 2316
      IF (II.GT.1) ITRIED(I)=-ITRIED(I)                                 CHD 2317
      IS=II                                                             CHD 2318
      II=II+1                                                           CHD 2319
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   50 IF (KPHASE(I)-1) 90,60,90
   60 IF (ENTSV(I)-ENTTPL(IS)) 70,70,80
   70 IF (DRATIO(I)-1.) 100,100,110
   80 IF (ENTSV(I)-ENTCR(IS)) 120,130,130
   90 IF (ENTSV(I)-ENTTPL(IS)) 150,140,140
C     SOLID
  100 PSAVE(I)=2H S
      GO TO 160
C     DISTENDED SOLID
  110 PSAVE(I)=2HDS
      GO TO 160
C     LIQUID
  120 PSAVE(I)=2H L
      GO TO 160
C     VAPOR
  130 PSAVE(I)=2H V
      GO TO 160
C     LIQUID-VAPOR
  140 PSAVE(I)=2HLV
      GO TO 160
C     SOLID-VAPOR
  150 PSAVE(I)=2HSV
  160 CONTINUE
      TEMPA=TEMPA/8.
      TEMPC=TEMPA+TEMPB
      IF (ICYCLE.EQ.0) EN0=TEMPC
      WRITE (1,440) TEMPD,PBDRYI,WORKB,PBDRYO,WORKF
      WRITE (1,450) TEMPC,TEMPA,TEMPB,EN0,ESOURS
      TEMPA=WORKF+WORKB+EN0+ESOURS
      IF (NORAD.EQ.0..AND.RADEB+RADEF.EQ.0.) GO TO 170
      WRITE (1,460) RADEB,TEBIN,RADEF,TEBOUT,DTRAD
      TEMPA=TEMPA+RADEB+RADEF
  170 TEMPB=TEMPC-TEMPA
      TEMPC=0.
      IF (TEMPA.NE.0.) TEMPC=100.*TEMPB/TEMPA
      WRITE (1,470) TEMPA,TEMPB,TEMPC
      IF (IGM.GT.1) LSVST=8HSTRESS Y
      I=10H STRESS Z
      IF (SWPOR.EQ.1.) I=10HDISTENTION
      WRITE (1,480) I,LSVST
      TEMPA=TEMPAB=0.
      DO 240 I=1,NZ
      IF (KACT(I)) 180,190,180
  180 IF (TEMPAB.EQ.1.) GO TO 240
      WRITE (1,490)
      TEMPAB=1.
      GO TO 240
  190 TEMPC=P(I)-SXD(I)
      IF (SWPOR.EQ.1.) GO TO 200
      TEMPD=P(I)-SZD(I)
      GO TO 210
  200 TEMPD=DRATIO(I)
      IF (TEMPD.LT.1.) TEMPD=1.
  210 IF (IGM.EQ.1) GO TO 220
      TEMPA=P(I)+SXD(I)+SZD(I)
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      GO TO 230
  220 TEMPI=V(I+1)
      IF (ISPALL(I).EQ.1) TEMPI=VL(I)
      TEMPA=TEMPA+.5*XM(I)*(V(I)+TEMPI)
  230 TEMPAB=0.
      WRITE (1,510) X(I),V(I),I,T(I),D(I),P(I),TEMPC,TEMPD,Q(I),E(I),FPA
     1TH(I),ENTSV(I),ITRIED(I),TEMPA,CSOD(I),PSAVE(I)
      IF (ISPALL(I).EQ.0) GO TO 240
      WRITE (1,510) XL(I),VL(I),I
      WRITE (1,500)
  240 CONTINUE
      IF (KACT(NZP).EQ.0) WRITE (1,510) X(NZP),V(NZP),NZP
      IF (NOSOUR.LE.0) GO TO 260
      IS=0
      DO 250 I=1,NOSOUR
      IF (SD(I).LE.0.) GO TO 250
      IS=IS+1
      PSAVE(IS)=I
      TSAVE(IS)=SD(I)
  250 CONTINUE
      IF (IS.LE.0) GO TO 260
      WRITE (1,520)
      WRITE (1,530) (PSAVE(I),TSAVE(I),I=1,IS)
  260 IF (ITWO.NE.1) GO TO 270
      WRITE (2) NZ,NZP,ICYCLE,NCOUNT,TIME,X(NZP),V(NZP),(X(I),V(I),XL(I)
     1,VL(I),ISPALL(I),T(I),D(I),P(I),Q(I),E(I),ENTSV(I),SXD(I),SZD(I),D
     2RATIO(I),I=1,NZ)
  270 IF (NORAD.EQ.0) GO TO 300
      IF (NCOUNT.NE.10*(NCOUNT/10)) GO TO 300
      IS=NZP
      IS1=1
      DO 290 I=1,NZP
      IF (FLUX(I)) 280,290,280
  280 IF (I.LE.IS) IS=I
      IS1=I
  290 CONTINUE
      IF (IS.GT.IS1) GO TO 300
      WRITE (1,410) (I,FLUX(I),I=IS,IS1)
  300 ICALL=44
      WRITE (1,400) ICYCLE,CYMESH,TEMPN
      RETURN
C
  310 II=1
      DO 390 I=1,NZ
      IF (I.LT.JBND(II)) GO TO 390
      PSAVE(1)=DRATIO(I)
      PSAVE(2)=ENTSV(I)
      PSAVE(3)=FPATH(I)
      PSAVE(4)=CSOD(I)
      PSAVE(5)=KPHASE(I)
      ISEND=-1
      DRATIO(I)=1.
      CALL TPLINE (IEOS(I),TEMPA,TEMPJ,TEMPB)
      IF (TEMPA) 330,330,320
  320 IF (TEMPJ) 330,330,350
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 330 ENTTPL(II)=-1.E50
 340 ENTCR(II)=-1.E50
     GO TO 380
 350 ICALL=1
     CALL EOS
     ENTTPL(II)=ENTSV(I)
     ISEND=-2
     CALL TPLINE (IEOS(I),TEMPA,TEMPJ,TEMPB)
     IF (TEMPA) 340,340,360
 360 IF (TEMPJ) 340,340,370
 370 CALL EOS
     ENTCR(II)=ENTSV(I)
 380 DRATIO(I)=PSAVE(1)
     ENTSV(I)=PSAVE(2)
     FPATH(I)=PSAVE(3)
     CSOD(I)=PSAVE(4)
     KPHASE(I)=PSAVE(5)
     II=II+1
 390 CONTINUE
     ISEND=0
     GO TO 10
C
 400 FORMAT (///,38H  THE NO. OF MESH-CYCLES THROUGH CYCLE,I6,3H IS,F10
    1.0,20X,E10.2,15H MESH-CYCLES/HR)
 410 FORMAT (///,14H BOUNDARY-FLUX,//,(7(I6,E12.4)))
 420 FORMAT (1H1,2X,13A6,20X,4I6)
 430 FORMAT (8H0 TIME =,E12.5,7X,4HDT =,E12.5,9X,8HNCOUNT =,I5,12X,7HCY
    1CLE =,I6,9X,14HMACHINE TIME =,E12.5,/,8H  DTCS =,E12.5,6X,5HDTP =,
    2E12.5,9X,8HDTTEMP =,E12.5,5X,7HDTMAX =,E12.5,3X,7HDTMIN =,E12.5)
 440 FORMAT (9H  TOT S =,E12.4,6X,7HPB IN =,E12.4,6X,9HWORK IN =,E12.4,
    14X,8HPB OUT =,E12.4,2X,10HWORK OUT =,E12.4)
 450 FORMAT (9H  TOT E =,E12.4,6X,7HKIN E =,E12.4,6X,7HINT E =,E12.4,6X
    1,10HINITIAL E=,E11.4,11H E SOURCE =,E12.4)
 460 FORMAT (12H  RAD E IN =,E12.4,3X,11HT IN EDGE =,E12.4,2X,11HRAD E
    1OUT =,E12.4,2X,12HT OUT EDGE =,E12.4,2X,6HDTRAD=,E12.4)
 470 FORMAT (17H  CORRECT TOT E =,E12.4,23X,9HDELTA E =,E12.4,4X,29HPER
    1CENT ENERGY CONSERVATICN =,E12.4,/)
 480 FORMAT (7X,1HX,10X,1HV,7X,1HI,5X,1HT,8X,3HRHO,8X,1HP,6X,8HSTRESS X
    1,1X,A10,3X,1HQ,8X,1HE,7X,4HRMFP,3X,7HENTROPY,1X,2HIT,2X,A8,4X,2HCS
    2,3X,2HPH)
 490 FORMAT (1H0,40X,37H/ / / / /  INACTIVE REGION  / / / / /,/)
 500 FORMAT (1X)
 510 FORMAT (E12.4,E11.3,I4,2E10.3,3E10.2,2E9.2,E8.1,E9.2,I3,E10.2,E9.2
    1,A2)
 520 FORMAT (25H0 ENERGY SOURCE STRENGTHS,/)
 530 FORMAT (9(F4.0,E10.3))
     END
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      SUBROUTINE ELPL                                                   CHD 2477
C     ELASTIC-PLASTIC CALCULATION                                       CHD 2478
      COMMON /A/ JBND(21),ITRIED(400),IZPTL(400),IZPRL(400),KPHASE(400),CHD 2479
     1KACT(401),ISPALL(400),NSPALL,OBS,IBS,ICYCLE,IDTMAX,IDTMIN,JPRIN,NCCHD 2480
     2OUNT,NMTRLS,NZN,NZ,NZP,NDUMP,NBPRES,NOSOUR,NACTION,NORAD,IGM,NRADCCHD 2481
     3K,MOVIE,IMPEXP,IMPA,KRD4,NOHYD                                    CHD 2482
      COMMON D(400),DO(400),T(400),TO(400),P(400),XM(400),XM2(401),X(401CHD 2483
     1),XO(401),V(401),VO(401),XL(400),XLO(400),VL(400),VLO(401),CSOD(40CHD 2484
     20),Q(400),SXD(400),SZD(400),FPATH(400),FLUX(401),E(400),PPPT(400),CHD 2485
     3PEPTIN(400),PSPALL(400),SD(400),TEMP(400),TSAVE(400),PSAVE(400),ESCHD 2486
     4AVE(400),TEMPR(401),TMSPALL(20),DT,DTMAX,DTMIN,DTTEMP,DTRAD,TIME,TCHD 2487
     5PN,TEND,DTRADT,BL,BQ,DTIMEP(25),DLTTMX(25),DTMINN(25),TIMEP(25),TDCHD 2488
     6TMINN(25),TIMES(25),WORKF,WORKB,ENO,ESOURS,TBPRES(25),PINNER(25),PCHD 2489
     7OUTER(25),XMATUP(21),DTCS,DTP,TITH(25),TEINTH(25),TEOUTH(25),FLINFCHD 2490
     8,FLINFO,FLINB,FLINBO,FLOUF,FLOUFO,FLOUB,FLOUBO,RADEB,RADEF,SCRADF,CHD 2491
     9SCRADB,SPLA(20),SPLB(20),SPLC(20),SPLD(20),ENTSV(400),TMOV(10),DTMCHD 2492
     $OV(10),TRADOFF,SWEP,YIELD(20,8),DRATIO(400),SWPOR                 CHD 2493
      COMMON /C/ TEMPA,TEMPB,TEMPC,TEMPD,TEMPE,TEMPF,TEMPG,TEMPH,TEMPI,TCHD 2494
     1EMPJ,TEMPK,TEMPL,TEMPM,TEMPN,TEMPAB,TBPU,PBDRYO,PBDRYI,TRADMIN,RADCHD 2495
     2K1,RADK2,RADK3,RADK4,RADK5,RADK6,TEBOUT,TEBIN,TTHIU               CHD 2496
      COMMON /D/ IS,IS1,ICALL,ITLOW,JTLOW,INES                          CHD 2497
C     IF IS.EQ.0     UPDATE STRESS DEVIATORS AND ENERGY                 CHD 2498
C     IF IS.NE.0     CORRECT SOUND SPEED                                CHD 2499
      JJJ=1                                                             CHD 2500
      IF (IS) 10,100,10                                                 CHD 2501
C     SOUND SPEED SECTION                                               CHD 2502
   10 DO 90 I=1,NZ                                                      CHD 2503
      IF (I.LT.JBND(JJJ)) GO TO 20                                      CHD 2504
      TEMPA=YIELD(JJJ,5)                                                CHD 2505
      TEMPB=YIELD(JJJ,6)                                                CHD 2506
      TEMPC=YIELD(JJJ,3)                                                CHD 2507
      IF (TEMPA.EQ.0..AND.TEMPC.GT.0.) TEMPC=0.                         CHD 2508
      TEMPD=TEMPB*TEMPC                                                 CHD 2509
      TEMPE=1.-TEMPB                                                    CHD 2510
      JJJ=JJJ+1                                                         CHD 2511
   20 IF (KACT(I)) 90,30,90                                             CHD 2512
   30 IF (E(I)-TEMPC) 40,90,90                                          CHD 2513
   40 IF (KPHASE(I)-1) 90,50,90                                         CHD 2514
   50 IF (E(I)-TEMPD) 60,60,70                                          CHD 2515
C     TEMPF IS POISSON RATIO                                            CHD 2516
   60 TEMPF=TEMPA                                                       CHD 2517
      GO TO 80                                                          CHD 2518
   70 TEMPF=E(I)/TEMPC                                                  CHD 2519
      TEMPF=(TEMPA*(1.-TEMPF)+0.5*(TEMPF-TEMPB))/TEMPE                  CHD 2520
   80 CSOD(I)=CSOD(I)*SQRT(3.*(1.-TEMPF)/(1.+TEMPF))                    CHD 2521
   90 CONTINUE                                                          CHD 2522
      RETURN                                                            CHD 2523
C     STRESS DEVIATORS AND ENERGY                                       CHD 2524
  100 DO 290 I=1,NZ                                                     CHD 2525
      IF (I.LT.JBND(JJJ)) GO TO 110                                     CHD 2526
      TEMPA=YIELD(JJJ,1)                                                CHD 2527
      TEMPB=YIELD(JJJ,2)                                                CHD 2528
      TEMPC=YIELD(JJJ,3)                                                CHD 2529
      TEMPD=YIELD(JJJ,4)                                                CHD 2530
      TEMPE=YIELD(JJJ,5)                                                CHD 2531
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```
      TEMPF=YIELD(JJJ,6)
      TEMPG=TEMPC*TEMPF
      TEMPH=1.-TEMPF
      TEMPI=TEMPA*(1.-TEMPB)
      TEMPB=TEMPA*TEMPB*TEMPD
      JJJ=JJJ+1
C     Y=TEMPA AND POISSON RATIO=TEMPD
  110 IF (KACT(I)) 290,120,290
  120 IF (E(I)-TEMPC) 130,280,280
  130 IF (KPHASE(I)-1) 280,140,280
  140 TEMPA=TEMPI+TEMPB*D(I)
      IF (E(I)-TEMPG) 150,150,160
  150 TEMPD=TEMPE
      GO TO 170
  160 TEMPD=E(I)/TEMPC
      TEMPA=TEMPA*(1.-TEMPD)/TEMPH
      TEMPD=(TEMPE*(1.-TEMPD)+0.5*(TEMPD-TEMPF))/TEMPH
C     G=TEMPN
  170 TEMPN=0.25*(DO(I)+D(I))*CSOD(I)**2*(1.-2.*TEMPD)/(1.-TEMPD)
C     COMPUTE DEVIATORS
      SXDO=SXD(I)
      TEMPJ=(D(I)-DO(I))/(1.5*DT*(D(I)+DO(I)))
C     TEMPK IS X STRETCH DEVIATOR
C     TEMPJ IS Z STRETCH DEVIATOR
      IF (ISPALL(I)) 190,180,190
  180 IS=I+1
      TEMPK=2.*(V(I)-V(IS))/(X(I)+XO(I)-X(IS)-XO(IS))+TEMPJ
      GO TO 200
  190 TEMPK=2.*(V(I)-VL(I))/(X(I)+XO(I)-XL(I)-XLO(I))+TEMPJ
  200 SXD(I)=SXDO+2.*DT*TEMPN*TEMPK
      TEMPL=.6666666666*TEMPA**2
      IF (IGM-2) 210,240,210
C     PLANE AND SPHERICAL
  210 TEMPD=1.5*SXD(I)**2
      IF (TEMPD-TEMPL) 230,230,220
  220 SXD(I)=TEMPA*(SXD(I)/(1.5*ABS(SXD(I))))
C     TEMPD IS DEVIATOR STRESS WORK
  230 TEMPD=1.5*DT*TEMPK*(SXD(I)-SXDO)/(D(I)+DO(I))
      SZD(I)=-0.5*SXD(I)
      GO TO 270
C     CYLINDRICAL
  240 SZDO=SZD(I)
      SZD(I)=SZDO+2.*DT*TEMPN*TEMPJ
      TEMPD=2.*(SXD(I)*(SXD(I)+SZD(I))+SZD(I)**2)
      IF (TEMPD-TEMPL) 260,260,250
  250 TEMPD=SQRT(TEMPL/TEMPD)
      SXD(I)=TEMPD*SXD(I)
      SZD(I)=TEMPD*SZD(I)
  260 TEMPD=DT*((SXD(I)+SXDO)*(2.*TEMPK+TEMPJ)+(SZD(I)-SZDO)*(2.*TEMPJ+T
     1EMPK))/(D(I)+DO(I))
  270 E(I)=E(I)+TEMPD
      GO TO 290
C     CAME HERE BECAUSE MATERIAL HAS NO STRENGTH
  280 SXD(I)=SZD(I)=0.
  290 CONTINUE

      RETURN
      END
```

```
      SUBROUTINE FOAM                                                   CHD 2589
C     POROUS MATERIAL CALCULATION                                       CHD 2590
      COMMON /A/ JBND(21),ITRIED(400),IZPTL(400),IZPRL(400),KPHASE(400),CHD 2591
     1KACT(401),ISPALL(400),NSPALL,OBS,IBS,ICYCLE,IDTMAX,IDTMIN,JPRIN,NCCHD 2592
     2OUNT,NMTRLS,NZN,NZ,NZP,NDUMP,NBPRES,NOSOUR,NACTION,NORAD,IGM,NRADCCHD 2593
     3K,MOVIE,IMPEXP,IMPA,KRD4,NOHYD                                    CHD 2594
      COMMON D(400),DO(400),T(400),TO(400),P(400),XM(400),XM2(401),X(401CHD 2595
     1),XO(401),V(401),VO(401),XL(400),XLO(400),VL(400),VLO(401),CSOD(40CHD 2596
     20),Q(400),SXD(400),SZD(400),FPATH(400),FLUX(401),E(400),PPPT(400),CHD 2597
     3PEPTIN(400),PSPALL(400),SD(400),TEMP(400),TSAVE(400),PSAVE(400),ESCHD 2598
     4AVE(400),TEMPR(401),TMSPALL(20),DT,DTMAX,DTMIN,DTTEMP,DTRAD,TIME,TCHD 2599
     5PN,TEND,DTRADT,BL,BQ,DTIMEP(25),DLTTMX(25),DTMINN(25),TIMEP(25),TDCHD 2600
     6TMINN(25),TIMES(25),WORKF,WORKB,ENO,ESOURS,TBPRES(25),PINNER(25),PCHD 2601
     7OUTER(25),XMATUP(21),DTCS,DTP,TITH(25),TEINTH(25),TEOUTH(25),FLINFCHD 2602
     8,FLINFO,FLINB,FLINBO,FLOUF,FLOUFO,FLOUB,FLOUBO,RADEB,RADEF,SCRADF,CHD 2603
     9SCRADB,SPLA(20),SPLB(20),SPLC(20),SPLD(20),ENTSV(400),TMOV(10),DTMCHD 2604
     $OV(10),TRADOFF,SWEP,YIELD(20,8),DRATIO(400),SWPOR                 CHD 2605
      COMMON /C/ TEMPA,TEMPB,TEMPC,TEMPD,TEMPE,TEMPF,TEMPG,TEMPH,TEMPI,TCHD 2606
     1EMPJ,TEMPK,TEMPL,TEMPM,TEMPN,TEMPAB,TBPU,PBDRYO,PBDRYI,TRADMIN,RADCHD 2607
     2K1,RADK2,RADK3,RADK4,RADK5,RADK6,TEBOUT,TEBIN,TTHIU               CHD 2608
      COMMON /D/ IS,IS1,ICALL,ITLOW,JTLOW,INES                          CHD 2609
      COMMON /E/ IZETL(21),IZERL(21),ITL(21),IRL(21),IEOS(400),IEOSS(20)CHD 2610
     1,KTP(21),NROS(21),NUMTEM(20),IGAS(20),NOANEOS,NISEOS              CHD 2611
      COMMON /TAPES/ I,IIN,IOUT,IEOSTP,ITWO                             CHD 2612
      COMMON /ANDPDR/ C82                                               CHD 2613
      DATA EMNR,EMMR/1.00001,1.0001/                                    CHD 2614
      DATA ABET,AKO,BKO/25.,.5,0./                                      CHD 2615
      JJJ=ICALL=I=1                                                     CHD 2616
   10 IF (I.LT.JBND(JJJ)) GO TO 70                                      CHD 2617
      Z3=YIELD(JJJ,3)                                                   CHD 2618
      IF (Z3) 30,20,20                                                  CHD 2619
   20 JJJ=JJJ+1                                                         CHD 2620
      I=JBND(JJJ)                                                       CHD 2621
      GO TO 670                                                         CHD 2622
   30 Z1=YIELD(JJJ,1)                                                   CHD 2623
      Z2=YIELD(JJJ,2)                                                   CHD 2624
      Z4=YIELD(JJJ,4)                                                   CHD 2625
      Z5=YIELD(JJJ,5)                                                   CHD 2626
      Z6=YIELD(JJJ,6)                                                   CHD 2627
      Z7=YIELD(JJJ,7)                                                   CHD 2628
      Z8=YIELD(JJJ,8)                                                   CHD 2629
      JJJ=JJJ+1                                                         CHD 2630
      GEMEU=Z8*EMNR                                                     CHD 2631
      GEMEL=Z8/EMNR                                                     CHD 2632
      GEMTU=Z7*EMNR                                                     CHD 2633
      GEMTL=Z7/EMNR                                                     CHD 2634
      IF (BKO) 50,40,50                                                 CHD 2635
   40 BKO=1./(1.-AKO)                                                   CHD 2636
      ABETD=1./SQRT(ABET)                                               CHD 2637
      ABETL=ALOG(ABET)                                                  CHD 2638
   50 DISN1=Z1-1.                                                       CHD 2639
      ALPL=(ABET-1.+Z1)/ABET                                            CHD 2640
      ALPN=ALPL-1.                                                      CHD 2641
      IF (Z5.LT.0.) GO TO 60                                            CHD 2642
      PALPL=Z5-(Z5-Z4)*ABETD                                            CHD 26
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```
      GO TO 70
   60 PALPL=Z4-Z5*ABETL
   70 IF (KACT(I)) 660,80,660
   80 IF (DRATIO(I)-1.) 660,660,90
   90 DISTR=DRATIO(I)
      DRATIO(I)=1.
      DV2=.5*(D(I)-DO(I))/(D(I)*DO(I))
      IF (E(I).LT.Z8) GO TO 310
C     ABOVE MELT
  100 IS1=0
      GEM=GEMEU
      GO TO 120
C     ABOVE OR BELOW MELT
  110 IS1=-1
  120 TEMPA=D(I)
      TLOW=Z7
      IF (TEMPA.LT.Z6) GO TO 140
  130 TLOW=.001
  140 IS=0
      TEMPJ=T(I)
      IF (IS1) 170,150,160
  150 IF (TEMPJ.LT.GEMTU) TEMPJ=GEMTU
      GO TO 170
  160 IF (TEMPJ.GT.GEMTL) TEMPJ=GEMTL
  170 CALL EOS
C     TEMPN IS THE CORRECTED ENERGY
      TEMPN=E(I)-DV2*(P(I)-TEMPD)
      IF (IS1) 200,180,190
  180 IF (TEMPN-GEM) 210,200,200
  190 IF (TEMPN-GEM) 200,200,210
  200 TEMPAB=(TEMPN-TEMPC)/(TEMPG-DV2*TEMPH)
      GO TO 220
  210 TEMPAB=(GEM-TEMPC)/TEMPG
  220 TEMPN=ABS(TEMPAB)
      TEMPK=1.E-6
      IF (IS.GT.190) TEMPK=1.E-3
      IF (TEMPN.LE.TEMPK*TEMPJ) GO TO 280
      IF (TEMPN.GT..05*TEMPJ) TEMPAB=.05*TEMPJ*TEMPAB/TEMPN
      TEMPK=TEMPJ+TEMPAB
      IF (TEMPK.LE.TLOW) TEMPK=.5*(TLOW+TEMPJ)
      IF (IS1-1) 240,230,240
  230 IF (TEMPK.GE.Z7) TEMPK=.5*(Z7+TEMPJ)
  240 IS=IS+1
      IF (IS-200) 270,250,260
  250 PRINT 700, IS1,ICYCLE,T(I),E(I),P(I),GEM,DV2,TEMPA,DISTR,TLOW,IS1,
     1ICYCLE,D(I),TEMPE
  260 PRINT 700, I,IS,TEMPJ,TEMPK,TEMPAB,TEMPC,TEMPD,TEMPG,TEMPH
      IF (IS.GE.400) STOP 12
  270 TEMPJ=TEMPK
      GO TO 170
  280 P(I)=TEMPD
      IF (IS1) 290,290,340
  290 T(I)=TEMPJ
  300 E(I)=TEMPC
      PPPT(I)=TEMPH
```

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      PEPTIN(I)=1./TEMPG
      GO TO 640
C     CALCULATE TRIAL DISTENTION
  310 TEMPE=(Z1-DISTR-Z3*(DISTR-1.))/DISN1
      TLOW=2.*(TEMPE**2-DISTR)*(D(I)-DO(I))/(D(I)+DO(I))
      TEMPE=ABS(TLOW)
      IF (TEMPE.GT.0.05*DISTR) TLOW=.05*DISTR*TEMPE/TLOW
      TEMPE=DISTR+TLOW
      IF (TEMPE.LT.1.) TEMPE=1.
      TEMPA=TEMPE*D(I)
      PHAT=P(I)
      GEM=GEMEL
      IF (TEMPA-Z6) 320,320,330
  320 IS1=1
      GO TO 130
  330 IS1=2
      GO TO 130
C     CALCULATE CRUSH STRENGTH
  340 IF (Z2) 350,350,360
  350 TLOW=E(I)/Z8
      IF (TLOW.LE.AKO) GO TO 360
      TLOW=BKO*(TLOW-AKO)
      FKOFE=1.+TLOW*(TLCW*(Z2+1.)-Z2-2.)
      IF (FKOFE.LE.1.) GO TO 370
  360 FKOFE=1.
      IF (T(I).GT.Z7) FKOFE=0.
  370 CRUSH=TEMPE-1.
      IF (Z5.LT.0.) GO TO 390
      IF (TEMPE.LT.ALPL) GO TO 380
      CRUSH=Z5-(Z5-Z4)*SQRT(CRUSH/DISN1)
      GO TO 410
  380 CRUSH=(PALPL*CRUSH+Z5*(ALPL-TEMPE))/ALPN
      GO TO 410
  390 IF (TEMPE.LT.ALPL) GO TO 400
      CRUSH=Z4+Z5*ALOG(CRUSH/DISN1)
      GO TO 410
  400 CRUSH=PALPL-Z5*(ALPL-TEMPE)/ALPN
  410 CRUSH=CRUSH*FKOFE
      IF (CRUSH.LT.1.E6) CRUSH=1.E6
      IF (P(I).GT.CRUSH) GO TO 430
      IF (TEMPC.GE.Z8) GO TO 420
      DRATIO(I)=TEMPE
      GO TO 290
  420 P(I)=PHAT
      GO TO 100
C     CORRECT ENERGY FOR CRUSH
  430 P(I)=PHAT
      TEMPK=E(I)
      E(I)=TEMPK-DV2*(PHAT-CRUSH)
      IF (E(I)-GEM) 450,450,440
C     CORRECTED ENERGY ABOVE MELT
  440 GEM=Z8*EMMR
      IF (E(I).LT.GEM) E(I)=GEM
      DV2=0.
      T(I)=Z7*EMMR
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      GO TO 100                                                    CHD 2754
C     CALCULATE NEW SOLID DENSITY AND TEMPERATURE                  CHD 2755
  450 TEMPJ=T(I)                                                   CHD 2756
      TEMPA=D(I)*DISTR                                             CHD 2757
      IS=0                                                         CHD 2758
      PNC=PHAT                                                     CHD 2759
      DIS=DISTR                                                    CHD 2760
  460 CRUSHP=DIS-1.                                                CHD 2761
      IF (Z5.LT.0.) GO TO 480                                      CHD 2762
      IF (DIS.LT.ALPL) GO TO 470                                   CHD 2763
      CRUSH=(Z4-Z5)*SQRT(CRUSHP/DISN1)                             CHD 2764
      CRUSHP=CRUSH/(2.*CRUSHP)                                     CHD 2765
      CRUSH=Z5+CRUSH                                               CHD 2766
      GO TO 500                                                    CHD 2767
  470 CRUSH=(PALPL*CRUSHP+Z5*(ALPL-DIS))/ALPN                      CHD 2768
      CRUSHP=(PALPL-Z5)/ALPN                                       CHD 2769
      GO TO 500                                                    CHD 2770
  480 IF (DIS.LT.ALPL) GO TO 490                                   CHD 2771
      CRUSH=Z4+Z5*ALOG(CRUSHP/DISN1)                               CHD 2772
      CRUSHP=Z5/CRUSHP                                             CHD 2773
      GO TO 500                                                    CHD 2774
  490 CRUSH=PALPL-Z5*(ALPL-DIS)/ALPN                               CHD 2775
      CRUSHP=Z5/ALPN                                               CHD 2776
  500 CRUSH=CRUSH*FKOFE                                            CHD 2777
      IF (CRUSH.GT.1.E6) GO TO 510                                 CHD 2778
      CRUSH=1.E6                                                   CHD 2779
      CRUSHP=0.                                                    CHD 2780
      GO TO 520                                                    CHD 2781
  510 CRUSHP=CRUSHP*FKOFE                                          CHD 2782
  520 E(I)=TEMPK-DV2*(PNC-CRUSH)                                   CHD 2783
      IF (E(I).GT.GEM) GO TO 440                                   CHD 2784
      IF (IEOS(I)) 530,530,540                                     CHD 2785
C     ANALYTIC                                                     CHD 2786
  530 CALL EOS                                                     CHD 2787
      PHAT=C82                                                     CHD 2788
      EHAT=(TEMPD-TEMPJ*TEMPH)/TEMPA**2                            CHD 2789
      GO TO 550                                                    CHD 2790
C     TABLE                                                        CHD 2791
  540 TEMPM=TEMPA                                                  CHD 2792
      TEMPA=1.0001*TEMPA                                           CHD 2793
      CALL EOS                                                     CHD 2794
      PHAT=TEMPD                                                   CHD 2795
      EHAT=TEMPC                                                   CHD 2796
      TEMPA=TEMPM                                                  CHD 2797
      CALL EOS                                                     CHD 2798
      PHAT=(PHAT-TEMPD)/(.0001*TEMPA)                              CHD 2799
      EHAT=(EHAT-TEMPC)/(.0001*TEMPA)                              CHD 2800
  550 TEMPI=CRUSHP/D(I)                                            CHD 2801
      TEMPAB=PHAT-TEMPI                                            CHD 2802
      TEMPI=EHAT-DV2*TEMPI                                         CHD 2803
      TLOW=TEMPAB*TEMPG-TEMPH*TEMPI                                CHD 2804
      IF (TLOW.EQ.0.) GO TO 600                                    CHD 2805
      TEMPN=((TEMPC-E(I))*TEMPH-(TEMPD-CRUSH)*TEMPG)/TLOW          CHD 2806
      TEMPM=((TEMPD-CRUSH)*TEMPI-(TEMPC-E(I))*TEMPAB)/TLOW         CHD 2807
      TEMPAB=ABS(TEMPN)                                            CHD 2808
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```
      TEMPI=ABS(TEMPM)
      IF (TEMPAB.GT.1.E-6*TEMPA) GO TO 560
      IF (TEMPI.LE.1.E-6*TEMPJ) GO TO 610
  560 IF (TEMPAB.GT..05*TEMPA) TEMPN=.05*TEMPA*TEMPN/TEMPAB
      IF (TEMPI.GT..05*TEMPJ) TEMPM=.05*TEMPJ*TEMPM/TEMPI
      IF (IS-200) 590,570,580
  570 IF (ABS(TEMPJ-Z7).GT.1.E-2*Z7) GO TO 580
      E(I)=Z8*EMMR
      T(I)=Z7*EMMR
      DV2=0.
      GO TO 100
  580 PRINT 700, IS,I,TEMPJ,TEMPM,TEMPA,TEMPN,E(I),TEMPC,CRUSH,TEMPD,ICY
     1CLE
  590 TEMPM=TEMPJ+TEMPM
      TEMPN=TEMPA+TEMPN
      IF (TEMPN.LT.Z6) TEMPN=.5*(Z6+TEMPA)
      IS=IS+1
      TEMPA=TEMPN
      TEMPJ=TEMPM
      DIS=TEMPA/D(I)
      IF (IS.LE.400) GO TO 460
      STOP 41
  600 IS=500
      GO TO 580
  610 T(I)=TEMPJ
C     CALCULATE DISTENTION RATIO
      IF (TEMPA-D(I)) 620,620,630
  620 E(I)=TEMPK
      GO TO 110
  630 DRATIO(I)=TEMPA/D(I)
      P(I)=TEMPD
      GO TO 300
  640 TEMPAB=DRATIO(I)-1.
      IF (TEMPAB) 560,660,650
C     CORRECT SOUND SPEED
  650 CSOD(I)=CSOD(I)*(Z1-DRATIO(I)-Z3*TEMPAB)/DISN1
  660 I=I+1
  670 IF (I.LE.NZ) GO TO 10
C     CHECK TO SEE IF ALL VOIDS ARE CLOSED
      SWPOR=0.
      DO 680 I=1,NZ
      IF (DRATIO(I).LE.1.) GO TO 680
      SWPOR=1.
      GO TO 690
  680 CONTINUE
      PRINT 710, ICYCLE,TIME
  690 CONTINUE
      RETURN
C
  700 FORMAT (2I10,8E13.6)
  710 FORMAT (25H1ALL VOIDS CLOSED  CYCLE=,I8,5X,5HTIME=,E12.5)
      END
```

```
      SUBROUTINE EDGE
C     CALCULATES BOUNDARY PRESSURES AND TEMPERATURES
      COMMON /A/ JBND(21),ITRIED(400),IZPTL(400),IZPRL(400),KPHASE(400),
     1KACT(401),ISPALL(400),NSPALL,OBS,IBS,ICYCLE,IDTMAX,IDTMIN,JPRIN,NC
     2OUNT,NMTRLS,NZN,NZ,NZP,NDUMP,NBPRES,NOSOUR,NACTION,NORAD,IGM,NRADC
     3K,MOVIE,IMPEXP,IMPA,KRD4,NOHYD
      COMMON D(400),DO(400),T(400),TO(400),P(400),XM(400),XM2(401),X(401
     1),XO(401),V(401),VO(401),XL(400),XLO(400),VL(400),VLO(401),CSOD(40
     20),Q(400),SXD(400),SZD(400),FPATH(400),FLUX(401),E(400),PPPT(400),
     3PEPTIN(400),PSPALL(400),SD(400),TEMP(400),TSAVE(400),PSAVE(400),ES
     4AVE(400),TEMPR(401),TMSPALL(20),DT,DTMAX,DTMIN,DTTEMP,DTRAD,TIME,T
     5PN,TEND,DTRADT,BL,BQ,DTIMEP(25),DLTTMX(25),DTMINN(25),TIMEP(25),TD
     6TMINN(25),TIMES(25),WORKF,WORKB,ENO,ESOURS,TBPRES(25),PINNER(25),P
     7OUTER(25),XMATUP(21),DTCS,DTP,TITH(25),TEINTH(25),TEOUTH(25),FLINF
     8,FLINFO,FLINB,FLINBO,FLOUF,FLOUFO,FLOUB,FLOUBO,RADEB,RADEF,SCRADF,
     9SCRADB,SPLA(20),SPLB(20),SPLC(20),SPLD(20),ENTSV(400),TMOV(10),DTM
     $OV(10),TRADOFF,SWEP,YIELD(20,8),DRATIO(400),SWPOR
      COMMON /C/ TEMPA,TEMPB,TEMPC,TEMPD,TEMPE,TEMPF,TEMPG,TEMPH,TEMPI,T
     1EMPJ,TEMPK,TEMPL,TEMPM,TEMPN,TEMPAB,TBPU,PBDRYO,PBDRYI,TRADMIN,RAD
     2K1,RADK2,RADK3,RADK4,RADK5,RADK6,TEBOUT,TEBIN,TTHIU
      COMMON /D/ IS,IS1,ICALL,ITLOW,JTLOW,INES
   10 IF (TEMPJ-TBPU) 30,20,20
   20 ITLOW=ITLOW+1
      TBPL=TBPRES(ITLOW)
      TBPU=TBPRES(ITLOW+1)
      IF (TBPU.EQ.TBPL) GO TO 20
      DTTT=1./(TBPU-TBPL)
      TBIN1=PINNER(ITLOW)
      TBIN2=PINNER(ITLOW+1)-TBIN1
      TBOUT1=POUTER(ITLOW)
      TBOUT2=POUTER(ITLOW+1)-TBOUT1
      GO TO 10
   30 PBDRYO=(TEMPJ-TBPL)*DTTT
      PBDRYI=TBIN1+TBIN2*PBDRYO
      PBDRYO=TBOUT1+TBOUT2*PBDRYO
      RETURN
      ENTRY TEDGE
   40 IF (TEMPJ-TTHIU) 60,50,50
   50 JTLOW=JTLOW+1
      TTHIL=TITH(JTLOW)
      TTHIU=TITH(JTLOW+1)
      IF (TTHIU.EQ.TTHIL) GO TO 50
      QTTT=1./(TTHIU-TTHIL)
      QBIN1=TEINTH(JTLOW)
      QBIN2=TEINTH(JTLOW+1)-QBIN1
      QBOUT1=TEOUTH(JTLOW)
      QBOUT2=TEOUTH(JTLOW+1)-QBOUT1
      GO TO 40
   60 TEBOUT=(TEMPJ-TTHIL)*QTTT
      TEBIN=QBIN1+QBIN2*TEBOUT
      TEBOUT=QBOUT1+QBOUT2*TEBOUT
      RETURN
      END
```

```
      SUBROUTINE SOURCE
C     CALCULATES INTERNAL ENERGY SOURCE STRENGTHS
      COMMON /A/ JBND(21),ITRIED(400),IZPTL(400),IZPRL(400),KPHASE(400),
     1KACT(401),ISFALL(400),NSPALL,OBS,IBS,ICYCLE,IDTMAX,IDTMIN,JPRIN,NC
     2OUNT,NMTRLS,NZN,NZ,NZP,NDUMP,NBPRES,NOSOUR,NACTION,NORAD,IGM,NRADC
     3K,MOVIE,IMPEXP,IMPA,KRD4,NOHYD
      COMMON D(400),DO(400),T(400),TO(400),P(400),XM(400),XM2(401),X(401
     1),XO(401),V(401),VO(401),XL(400),XLO(400),VL(400),VLO(401),CSOD(40
     20),Q(400),SXD(400),SZD(400),FPATH(400),FLUX(401),E(400),PPPT(400),
     3PEPTIN(400),PSPALL(400),SD(400),TEMP(400),TSAVE(400),PSAVE(400),ES
     4AVE(400),TEMPR(401),TMSPALL(20),DT,DTMAX,DTMIN,DTTEMP,DTRAD,TIME,T
     5PN,TEND,DTRADT,BL,BQ,DTIMEP(25),DLTTMX(25),DTMINN(25),TIMEP(25),TD
     6TMINN(25),TIMES(25),WORKF,WORKB,ENO,ESOURS,TBPRES(25),PINNER(25),P
     7OUTER(25),XMATUP(21),DTCS,DTP,TITH(25),TEINTH(25),TEOUTH(25),FLINF
     8,FLINFO,FLINB,FLINBO,FLOUF,FLOUFO,FLOUB,FLOUBO,RADEB,RADEF,SCRADF,
     9SCRADB,SPLA(20),SPLB(20),SPLC(20),SPLD(20),ENTSV(400),TMOV(10),DTM
     $OV(10),TRADOFF,SWEP,YIELD(20,8),DRATIO(400),SWPOR
      COMMON /C/ TEMPA,TEMPB,TEMPC,TEMPD,TEMPE,TEMPF,TEMPG,TEMPH,TEMPI,T
     1EMPJ,TEMPK,TEMPL,TEMPM,TEMPN,TEMPAB,TBPU,PBDRYO,PBDRYI,TRADMIN,RAD
     2K1,RADK2,RADK3,RADK4,RADK5,RADK6,TEBOUT,TEBIN,TTHIU
      COMMON /NAME/ ANAME(13),MAXZONE,NTS1,NTS2,NTS3,ITTMP,CYMESH
      DIMENSION SD2(1), SD3(1), TSOUR1(1), TSOUR2(1), TSOUR3(1), TSOUR4(
     11), THESE(1)
      EQUIVALENCE (SD2(1),SD(1)), (SD3(1),TEMP(1)), (TSOUR1(1),TSAVE(1))
     1, (TSOUR2(1),PSAVE(1)), (TSOUR3(1),ESAVE(1)), (TSOUR4(1),TEMPR(1))
     2, (THESE(1),DRATIO(1))
      IS=6*MAXZONE
      CALL READEC (SD,0,IS)
      DO 170 I=1,NOSOUR
      IF (THESE(I).LE.0.) TEMPA=0.5*(SD2(I)*(TSOUR3(I)-TSOUR1(I))+SD3(I)
     1*(TSOUR4(I)-TSOUR2(I)))
      IF (TSOUR3(I)-TEMPJ) 10,10,40
   10 IF (TSOUR4(I)-TEMPJ) 20,20,30
   20 SD(I)=0.
      GO TO 140
   30 SD(I)=SD3(I)*(TSOUR4(I)-TEMPJ)/(TSOUR4(I)-TSOUR3(I))
      GO TO 140
   40 IF (TSOUR1(I)-TEMPJ) 60,50,50
   50 IF (THESE(I)) 130,90,20
   60 IF (TSOUR2(I)-TEMPJ) 70,70,80
   70 SD(I)=SD2(I)+(SD3(I)-SD2(I))*(TEMPJ-TSOUR2(I))/(TSOUR3(I)-TSOUR2(I
     1))
      GO TO 140
   80 SD(I)=SD2(I)*(TEMPJ-TSOUR1(I))/(TSOUR2(I)-TSOUR1(I))
      GO TO 140
C     CHECK FOR HE PREDETONATION
   90 DO 100 JJJ=2,21
      IF (I.GE.JBND(JJJ)) GO TO 100
      JJ=JJJ-1
      GO TO 110
  100 CONTINUE
      STOP 213
  110 IF (YIELD(JJ,8)) 20,20,120
  120 IF (P(I).LT.YIELD(JJ,8)) GO TO 20
      PRINT 180, I,TEMPJ,ICYCLE
C     HE PREDETONATION
  130 SD(I)=SD2(I)
  140 IF (THESE(I).GT.0.) GO TO 170
      TEMPB=SD(I)*DT-THESE(I)
      IF (TEMPB-TEMPA) 150,170,160
  150 IF (TEMPJ-TSOUR4(I)) 170,160,160
  160 SD(I)=(TEMPA+THESE(I))/DT
      IF (ABS(THESE(I)).GT.0.999999*TEMPA.AND.TEMPJ.GE.TSOUR4(I)) THESE(
     1I)=1.
  170 CONTINUE
      RETURN
C
  180 FORMAT (/,21H  PREDETONATION  ZONE,I5,5X,5HTIME=,E12.4,5X,6HCYCLE=
     1,I8)
      END
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      SUBROUTINE FRACT                                                  CHD 2984
C     SPALL CALCULATION BASED ON EITHER THE                             CHD 2985
C     MAXIMUM TENSILE STRENGTH                                          CHD 2986
C     STRESS GRADIENT METHOD OF THURSTON AND MUDD                       CHD 2987
C     OR                                                                CHD 2988
C     THE CUMULATIVE DAMAGE METHOD OF TULER AND BUTCHER                 CHD 2989
C                                                                       CHD 2990
      COMMON /A/ JBND(21),ITRIED(400),IZPTL(400),IZPRL(400),KPHASE(400),CHD 2991
     1KACT(401),ISFALL(400),NSPALL,OBS,IBS,ICYCLE,IDTMAX,IDTMIN,JPRIN,NCCHD 2992
     2OUNT,NMTRLS,NZN,NZ,NZP,NDUMP,NBPRES,NOSOUR,NACTION,NORAD,IGM,NRADCCHD 2993
     3K,MOVIE,IMPEXP,IMPA,KRD4,NOHYD                                    CHD 2994
      COMMON D(400),DO(400),T(400),TO(400),P(400),XM(400),XM2(401),X(401CHD 2995
     1),XO(401),V(401),VO(401),XL(400),XLO(400),VL(400),VLO(401),CSOD(40CHD 2996
     20),Q(400),SXD(400),SZD(400),FPATH(400),FLUX(401),E(400),PPPT(400),CHD 2997
     3PEPTIN(400),PSPALL(400),SD(400),TEMP(400),TSAVE(400),PSAVE(400),ESCHD 2998
     4AVE(400),TEMPR(401),TMSPALL(20),DT,DTMAX,DTMIN,DTTEMP,DTRAD,TIME,TCHD 2999
     5PN,TEND,DTRADT,BL,BQ,DTIMEP(25),DLTTMX(25),DTMINN(25),TIMEP(25),TDCHD 3000
     6TMINN(25),TIMES(25),WORKF,WORKB,ENO,ESOURS,TBPRES(25),PINNER(25),PCHD 3001
     7OUTER(25),XMATUP(21),DTCS,DTP,TITH(25),TEINTH(25),TEOUTH(25),FLINFCHD 3002
     8,FLINFO,FLINB,FLINBO,FLOUF,FLOUFO,FLOUB,FLOUBO,RADEB,RADEF,SCRADF,CHD 3003
     9SCRADB,SPLA(20),SPLB(20),SPLC(20),SPLD(20),ENTSV(400),TMOV(10),DTMCHD 3004
     $OV(10),TRADOFF,SWEP,YIELD(20,8),DRATIO(400),SWPOR                 CHD 3005
      COMMON /C/ TEMPA,TEMPB,TEMPC,TEMPD,TEMPE,TEMPF,TEMPG,TEMPH,TEMPI,TCHD 3006
     1EMPJ,TEMPK,TEMPL,TEMPM,TEMPN,TEMPAB,TBPU,PBDRYO,PBDRYI,TRADMIN,RADCHD 3007
     2K1,RADK2,RADK3,RADK4,RADK5,RADK6,TEBOUT,TEBIN,TTHIU                CHD 3008
C     ENTER WITH STRESS IN P ARRAY                                      CHD 3009
      IF (ICYCLE.EQ.1) GO TO 100                                        CHD 3010
   10 JJJ=1                                                             CHD 3011
      DO 90 I=1,NZN                                                     CHD 3012
      TEMPI=P(I)                                                        CHD 3013
      IP1=I+1                                                           CHD 3014
      P(I)=.5*(TEMPI+P(IP1))                                            CHD 3015
      IF (I.LT.JBND(JJJ)) GO TO 20                                      CHD 3016
      JJ=JJJ                                                            CHD 3017
      JJJ=JJJ+1                                                         CHD 3018
      TEMPA=SPLA(JJ)                                                    CHD 3019
      TEMPB=SPLB(JJ)                                                    CHD 3020
      TEMPC=SPLC(JJ)                                                    CHD 3021
      TEMPD=SPLD(JJ)                                                    CHD 3022
      TEMPE=TMSPALL(JJ)                                                 CHD 3023
      TEMPF=1./(TEMPE-.025678)                                          CHD 3024
      TEMPAB=YIELD(JJ,7)                                                CHD 3025
   20 IF (P(I).GT.-1.E6) GO TO 90                                       CHD 3026
      IF (T(I).GT.TEMPAB) GO TO 90                                      CHD 3027
      IF (ISPALL(I).EQ.1) GO TO 90                                      CHD 3028
      IF (TEMPC.LT.0.) GO TO 70                                         CHD 3029
C     STRESS GRADIENT                                                   CHD 3030
      IF (T(I).GE.TEMPE) GO TO 50                                       CHD 3031
      IF (TEMPA.GT.0.) GO TO 30                                         CHD 3032
      TEMPG=PSPALL(I)                                                   CHD 3033
      GO TO 40                                                          CHD 3034
   30 TEMPK=2.*ABS(TEMPI-P(IP1))/(XM(I)/D(I)+XM(IP1)/D(IP1))            CHD 3035
      IF (IGM.GT.1) TEMPK=3.1415926536*TEMPK*(2.*X(IP1))**(IGM-1)       CHD 3036
      TEMPG=TEMPD+TEMPA*TEMPK**TEMPB                                    CHD 3037
      IF (TEMPG.GT.PSPALL(I)) TEMPG=PSPALL(I)                           CHD 3038
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   40 TEMPG=-TEMPG*((TEMPE-T(I))*TEMPF)**TEMPC                          CHD 3039
      IF (TEMPG.GT.-1.E6) TEMPG=-1.E6                                   CHD 3040
      IF (P(I).GT.TEMPG) GO TO 90                                       CHD 3041
   50 PSPALL(I)=0.                                                      CHD 3042
   60 ISPALL(I)=1                                                       CHD 3043
      NSPALL=NSPALL+1                                                   CHD 3044
      XL(I)=X(IP1)                                                      CHD 3045
      VL(I)=V(IP1)                                                      CHD 3046
      TEMPM=1.                                                          CHD 3047
      IF (TEMPN.NE.0.) PRINT 140, I,IP1,ICYCLE,TIME                     CHD 3048
      GO TO 90                                                          CHD 3049
C     CUMULATIVE DAMAGE                                                 CHD 3050
   70 IF (P(I).GE.-TEMPA) GO TO 90                                      CHD 3051
      PSPALL(I)=PSPALL(I)+DT*(-TEMPA-P(I))**TEMPB                       CHD 3052
      IF (T(I).(E.TEMPE) GO TO 80                                       CHD 3053
      TEMPH=TEMPD*((TEMPE-T(I))*TEMPF)**(-TEMPC)                        CHD 3054
      IF (PSPALL(I).LE.TEMPH) GO TO 90                                  CHD 3055
   80 PSPALL(I)=1.E100                                                  CHD 3056
      GO TO 60                                                          CHD 3057
   90 P(I)=TEMPI                                                        CHD 3058
      RETURN                                                            CHD 3059
  100 JJJ=1                                                             CHD 3060
      DO 130 I=1,NZN                                                    CHD 3061
      IF (I.LT.JBND(JJJ)) GO TO 110                                     CHD 3062
      JJ=JJJ                                                            CHD 3063
      JJJ=JJJ+1                                                         CHD 3064
      IF (TMSPALL(JJ).LE..025679) TMSPALL(JJ)=.025679                   CHD 3065
  110 IF (SPLC(JJ).GE.0.) GO TO 120                                     CHD 3066
      IF (ISPALL(I).NE.1) GO TO 130                                     CHD 3067
      PSPALL(I)=1.E100                                                  CHD 3068
      GO TO 130                                                         CHD 3069
  120 IF (SPLB(JJ).EQ.0.) SPLB(JJ)=1.                                   CHD 3070
  130 CONTINUE                                                          CHD 3071
      GO TO 10                                                          CHD 3072
C                                                                       CHD 3073
  140 FORMAT (17H0FRACTURE OF ZONE,I5,12H AT BOUNDARY,I5,8H  CYCLE=,I6,8CHD 3074
     1H   TIME=,E14.7)                                                  CHD 3075
      END                                                               CHD 3076
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      SUBROUTINE EOS
C     EQUATION OF STATE ROUTINE WITH ECS
      COMMON /A/ JBND(21),ITRIED(400),IZPTL(400),IZPRL(400),KPHASE(400),
     1KACT(401),ISPALL(400),NSPALL,OBS,IBS,ICYCLE,IDTMAX,IDTMIN,JPRIN,NC
     2OUNT,NMTRLS,NZN,NZ,NZP,NDUMP,NBPRES,NOSOUR,NACTION,NORAD,IGM,NRADC
     3K,MOVIE,IMPEXP,IMPA,KRD4,NOHYD
      COMMON D(400),DO(400),T(400),TO(400),P(400),XM(400),XM2(401),X(401
     1),XO(401),V(401),VO(401),XL(400),XLO(400),VL(400),VLO(401),CSOD(40
     20),Q(400),SXD(400),SZD(400),FPATH(400),FLUX(401),E(400),PPPT(400),
     3PEPTIN(400),PSPALL(400),SD(400),TEMP(400),TSAVE(400),PSAVE(400),ES
     4AVE(400),TEMPR(401),TMSPALL(20),DT,DTMAX,DTMIN,DTTEMP,DTRAD,TIME,TC
     5PN,TEND,DTRADT,BL,BQ,DTIMEP(25),DLTTMX(25),DTMINN(25),TIMEP(25),TDC
     6TMINN(25),TIMES(25),WORKF,WORKB,ENO,ESOURS,TBPRES(25),PINNER(25),PC
     7OUTER(25),XMATUP(21),DTCS,DTP,TITH(25),TEINTH(25),TEOUTH(25),FLINFC
     8,FLINFO,FLINB,FLINBO,FLOUF,FLOUFO,FLOUB,FLOUBO,RADEB,RADEF,SCRADF,
     9SCRADB,SPLA(20),SPLB(20),SPLC(20),SPLD(20),ENTSV(400),TMOV(10),DTM
     $OV(10),TRADOFF,SWEP,YIELD(20,8),DRATIO(400),SWPOR
      COMMON /C/ TEMPA,TEMPB,TEMPC,TEMPD,TEMPE,TEMPF,TEMPG,TEMPH,TEMPI,T
     1EMPJ,TEMPK,TEMPL,TEMPM,TEMPN,TEMPAB,TBPU,PBDRYO,PBDRYI,TRADMIN,RAD
     2K1,RADK2,RADK3,RADK4,RADK5,RADK6,TEBOUT,TEBIN,TTHIU
      COMMON /D/ IS,IS1,ICALL,ITLOW,JTLOW,INES
      COMMON /E/ IZETL(21),IZERL(21),ITL(21),IRL(21),IEOS(400),IEOSS(20)
     1,KTP(21),NROS(21),NUMTEM(20),IGAS(20),NOANEOS,NISEOS
      COMMON /NAME/ ANAME(13),MAXZONE,NTS1,NTS2,NTS3,ITTMP,CYMESH
      COMMON /TAPES/ I,IIN,ICUT,IEOSTP,ITWO
      COMMON /BIG/ TTBL(37),RTBL(35),XTTBL(37),YRTBL(35),PTBL(1295),ETBL
     1(1295),STBL(1295),SOUNSP(1295),ROSTAB(1295),BETA1(29),BETA2(29),BE
     2TA3(29),BETA4(29),BETA5(29),BETA6(29),BETA7(29),BETA8(29),CVHIGH(2
     30),RCRIT(20),TCRIT(20),RHOOO(20),RSMIN(20),RTRIP(20),TTRIP(20),BET
     4A9(20),BETA10(20),BETA11(20),BETA12(20),AAAT(440),AMISS(240)
      COMMON /ECSD/ NECSA,NECSB
      COMMON /ANDPDR/ C82
      DATA ATHIRD,ROWAO,LTIES,LASTES/.333333333333,0.,0,0/
      DATA MAXNOT,MAXNOD,MAXTPH,MAXSIZE/37,35,29,1295/
      DATA NNNIZE,NNNTTB,NISEOS,NECSA,IEOS/588,7751,1,6851,400*0./
C     MAXIMUM TABLE SIZE IS 37 TEMPERATURES BY 35 DENSITIES
C     WITH 29 TWO-PHASE TEMPERATURES INTERVALS
C     ECS IS NOT USED WHEN NISEOS=0
C     ECS IS USED WHEN NISEOS=1 IF REQUIRED
C
      GO TO (10,970,1530,1570,1660), ICALL
C
C     ICALL=1 ENTER WITH
C     TEMPJ=TEMPERATURE
C     TEMPA=DENSITY
C     I=ZONE NUMBER
C     RETURN WITH
C     TEMPC=ENERGY
C     TEMPD=PRESSURE
C     TEMPG=CV=HEAT CAPACITY
C     TEMPH=PARTP/PART T
C     ENTSV(I)=ENTROPY
C     FPATH(I)=ROSSELAND MEAN FREE PATH
C     CSOD(I)=SOUND SPEED
C
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   10 IES=IEOS(I)                                                      CHD 3132
      IF (DRATIO(I).LE.1.) GO TO 20                                    CHD 3133
      TEMPAS=TEMPA                                                     CHD 3134
      TEMPA=DRATIO(I)*TEMPA                                            CHD 3135
   20 CONTINUE                                                         CHD 3136
      IF (IES.LT.0) GO TO 900                                          CHD 3137
      IES2=IES+1                                                       CHD 3138
      IF (NISEOS) 30,30,40                                             CHD 3139
   30 ITLO=ITL(IES)                                                    CHD 3140
      ITHI=ITL(IES2)-1                                                 CHD 3141
      IRLO=IRL(IES)                                                    CHD 3142
      IRHI=IRL(IES2)-1                                                 CHD 3143
      KTPIES=KTP(IES)                                                  CHD 3144
      KTPIET=KTP(IES2)                                                 CHD 3145
      NRSIES=NROS(IES)                                                 CHD 3146
      GO TO 50                                                         CHD 3147
C     ECS PATH                                                         CHD 3148
   40 ITLO=IRLO=KTPIES=NRSIES=1                                        CHD 3149
      ITHI=ITL(IES2)-ITL(IES)                                          CHD 3150
      IRHI=IRL(IES2)-IRL(IES)                                          CHD 3151
      KTPIET=KTP(IES2)-KTP(IES)+1                                      CHD 3152
      IF (IES.EQ.LASTES) GO TO 50                                      CHD 3153
      IA=NECSA*(IES-1)+NECSB                                           CHD 3154
      CALL READEC (TTBL,IA,NECSA)                                      CHD 3155
      LASTES=IES                                                       CHD 3156
C     SEARCH T MESH                                                    CHD 3157
   50 ITOFF=0                                                          CHD 3158
      IT=IZPTL(I)                                                      CHD 3159
      IF (TTBL(IT)-TEMPJ) 90,110,60                                    CHD 3160
   60 IT=IT-1                                                          CHD 3161
      IF (IT.GE.ITLO) GO TO 80                                         CHD 3162
      ITOFF=-1                                                         CHD 3163
      IF (TEMPJ.GT.0.) GO TO 70                                        CHD 3164
      IBACK=5                                                          CHD 3165
      PRINT 1690, I,ICYCLE,TEMPJ,TEMPA,IBACK                           CHD 3166
      STOP                                                             CHD 3167
   70 IT=IT+1                                                          CHD 3168
      XT=XTTBL(ITLC)                                                   CHD 3169
      TPOINT=TTBL(ITLO)                                                CHD 3170
      GO TO 120                                                        CHD 3171
   80 IF (TTBL(IT)-TEMPJ) 110,110,60                                   CHD 3172
   90 IT=IT+1                                                          CHD 3173
      IF (IT.LE.ITHI) GO TO 100                                        CHD 3174
      IT=IT-2                                                          CHD 3175
      ITOFF=1                                                          CHD 3176
      XT=XTTBL(ITHI)                                                   CHD 3177
      TPOINT=TTBL(ITHI)                                                CHD 3178
      GO TO 120                                                        CHD 3179
  100 IF (TTBL(IT).LE.TEMPJ) GO TO 90                                  CHD 3180
      IT=IT-1                                                          CHD 3181
  110 XT=ALOG(TEMPJ)                                                   CHD 3182
      TPOINT=TEMPJ                                                     CHD 3183
  120 XT1=XTTBL(IT)                                                    CHD 3184
      XT2=XTTBL(IT+1)                                                  CHD 3185
C     DETERMINE  NUMBER OF PHASES                                      CHD 3186
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      IF (TEMPA.GE.RTRIP(IES)) GO TO 210                                CHD 3187
      IF (TEMPJ.GT..999*TCRIT(IES)) GO TO 210                           CHD 3188
      IF (TEMPJ.GT.TTRIP(IES)) GO TO 130                                CHD 3189
      IF (TEMPA.GT.RSMIN(IES)) GO TO 210                                CHD 3190
  130 KT=IT-ITLO+KTPIES                                                 CHD 3191
      IF (KT.GE.KTPIET) GO TO 200                                       CHD 3192
      IF (ITOFF.GE.0) GO TO 140                                         CHD 3193
      RHLIQ=RHOOO(IES)+BETA9(IES)*TEMPJ                                 CHD 3194
      IF (TEMPA.GE.RHLIQ) GO TO 210                                     CHD 3195
      RHVAP=BETA11(IES)*TEMPJ                                           CHD 3196
      IF (TEMPA.LE.RHVAP) GO TO 210                                     CHD 3197
      RHLIQP=BETA9(IES)                                                 CHD 3198
      RHVAPP=BETA11(IES)                                                CHD 3199
      GO TO 230                                                         CHD 3200
  140 C85=XTTBL(IT)                                                     CHD 3201
      C86=XTTBL(IT+1)                                                   CHD 3202
      C82=.5*(C85+C86)                                                  CHD 3203
      IF (XT.GT.C82) GO TO 170                                          CHD 3204
      C81=.75*C85+.25*C86                                               CHD 3205
      IF (XT.GT.C81) GO TO 160                                          CHD 3206
      C82=C81                                                           CHD 3207
      C81=C85                                                           CHD 3208
      C86=BETA5(KT)                                                     CHD 3209
      C84=BETA1(KT)                                                     CHD 3210
      IF (IT.EQ.ITLO) GO TO 150                                         CHD 3211
      C85=BETA8(KT-1)                                                   CHD 3212
      C83=BETA4(KT-1)                                                   CHD 3213
      GO TO 190                                                         CHD 3214
  150 C83=ALOG(TTBL(ITLO)*BETA9(IES)+RHOOO(IES))                        CHD 3215
      C85=ALOG(TTBL(ITLO)*BETA11(IES))                                  CHD 3216
      GO TO 190                                                         CHD 3217
  160 C83=BETA1(KT)                                                     CHD 3218
      C84=BETA2(KT)                                                     CHD 3219
      C85=BETA5(KT)                                                     CHD 3220
      C86=BETA6(KT)                                                     CHD 3221
      GO TO 190                                                         CHD 3222
  170 C85=.75*C86+.25*C85                                               CHD 3223
      IF (XT.GT.C85) GO TO 180                                          CHD 3224
      C81=C82                                                           CHD 3225
      C82=C85                                                           CHD 3226
      C83=BETA2(KT)                                                     CHD 3227
      C84=BETA3(KT)                                                     CHD 3228
      C85=BETA6(KT)                                                     CHD 3229
      C86=BETA7(KT)                                                     CHD 3230
      GO TO 190                                                         CHD 3231
  180 C81=C85                                                           CHD 3232
      C82=C86                                                           CHD 3233
      C83=BETA3(KT)                                                     CHD 3234
      C84=BETA4(KT)                                                     CHD 3235
      C85=BETA7(KT)                                                     CHD 3236
      C86=BETA8(KT)                                                     CHD 3237
  190 C84=(C84-C83)/(C82-C81)                                           CHD 3238
      RHLIQ=EXP(C83+C84*(XT-C81))                                       CHD 3239
      IF (TEMPA.GE.RHLIQ) GO TO 210                                     CHD 3240
      C86=(C86-C85)/(C82-C81)                                           CHD 3241
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      RHVAP=EXP(C85+C86*(XT-C81))                                       CHD 3242
      IF (TEMPA.LE.RHVAP) GO TO 210                                     CHD 3243
      RHLIQP=RHLIQ*C84/TEMPJ                                            CHD 3244
      RHVAPP=RHVAP*C86/TEMPJ                                            CHD 3245
      GO TO 230                                                         CHD 3246
  200 C81=(TCRIT(IES)-TEMPJ)                                            CHD 3247
      C82=C81**ATHIRD                                                   CHD 3248
      RHLIQ=RCRIT(IES)+BETA10(IES)*C82                                  CHD 3249
      IF (TEMPA.GE.RHLIQ) GO TO 210                                     CHD 3250
      RHVAP=RCRIT(IES)-BETA12(IES)*C82                                  CHD 3251
      IF (TEMPA.LE.RHVAP) GO TO 210                                     CHD 3252
      C81=C82/(3.*C81)                                                  CHD 3253
      RHLIQP=-BETA10(IES)*C81                                           CHD 3254
      RHVAPP=BETA12(IES)*C81                                            CHD 3255
      GO TO 230                                                         CHD 3256
C                                                                       CHD 3257
C     ONE-PHASE REGION                                                  CHD 3258
  210 KPHASE(I)=1                                                       CHD 3259
      IR=IZPRL(I)                                                       CHD 3260
      ROWA=TEMPA                                                        CHD 3261
      IBACK=0                                                           CHD 3262
      GO TO 370                                                         CHD 3263
  220 TEMPC=EEVAL                                                       CHD 3264
      TEMPD=PPVAL                                                       CHD 3265
      TEMPG=CVVAL                                                       CHD 3266
      TEMPH=DPVAL                                                       CHD 3267
      ENTSV(I)=SSVAL                                                    CHD 3268
      CSOD(I)=CSDVAL                                                    CHD 3269
      IZPTL(I)=IT                                                       CHD 3270
      IZPRL(I)=IR                                                       CHD 3271
      GO TO 930                                                         CHD 3272
C                                                                       CHD 3273
C     TWO-PHASE REGION                                                  CHD 3274
  230 KPHASE(I)=2                                                       CHD 3275
C     LIQUID SIDE OF REGION                                             CHD 3276
      IR=IZPRL(I)                                                       CHD 3277
      ROWA=RHLIQ                                                        CHD 3278
      IBACK=1                                                           CHD 3279
      GO TO 370                                                         CHD 3280
  240 EELIQ=EEVAL                                                       CHD 3281
      PPLIQ=PPVAL                                                       CHD 3282
      CVLIQ=CVVAL                                                       CHD 3283
      DPLIQ=DPVAL                                                       CHD 3284
      ROSLIQ=ROSLAN                                                     CHD 3285
      SSLIQ=SSVAL                                                       CHD 3286
      IZPRL(I)=IR                                                       CHD 3287
C     VAPOR SIDE OF REGION                                              CHD 3288
      ROWA=RHVAP                                                        CHD 3289
      IF (RHVAP.GE.RTBL(IRLO)) GO TO 250                                CHD 3290
      IF (ITOFF) 250,330,250                                            CHD 3291
  250 IR=IRLO                                                           CHD 3292
      IBACK=-1                                                          CHD 3293
      GO TO 370                                                         CHD 3294
C     CALCULATE MIXED FUNCTIONS                                         CHD 3295
  260 C81=RHLIQ-RHVAP                                                   CHD 3296
```

```
      C82=RHLIQ-TEMPA
      C83=TEMPA-RHVAP
      C84=RHVAP*C82/(TEMPA*C81)
      C85=RHLIQ*C83/(TEMPA*C81)
      TEMPC=C84*EEVAL+C85*EELIQ
      IF (PPLIQ-1.E8) 290,270,270
  270 TEMPD=.99*RHLIQ+.01*RHVAP
      IF (TEMPA-TEMPD) 290,290,280
  280 TEMPD=((TEMPA-TEMPD)*PPLIQ+(RHLIQ-TEMPA)*PPVAL)/(RHLIQ-TEMPD)
      GO TO 300
  290 TEMPD=PPLIQ=PPVAL
  300 TEMPH=(SSVAL-SSLIQ)*((RHLIQ*RHVAP)/(RHLIQ-RHVAP))
      ENTSV(I)=C84*SSVAL+C85*SSLIQ
      ROSLAN=(C82*ROSLAN+C83*ROSLIQ)/C81
      TEMPG=C84*CVVAL+C85*CVLIQ-C84*(TEMPJ*DPVAL-PPVAL)*RHVAPP/RHVAP**2-
     1C85*(TEMPJ*DPLIQ-PPLIQ)*RHLIQP/RHLIQ**2-(EELIQ-EEVAL)*(RHVAP*C83*R
     2HLIQP+RHLIQ*C82*RHVAPP)/(TEMPA*C81**2)
      CSDVAL=TEMPJ*TEMPH**2/(TEMPG*TEMPA**2)
      IF (CSDVAL.LT.1.E-8) GO TO 310
      CSOD(I)=SQRT(CSDVAL)
      GO TO 320
  310 CSOD(I)=1.E-4
  320 IZPTL(I)=IT
      GO TO 930
C     CAME HERE BECAUSE VAPOR DENSITY IS OFF TABLE BUT TEMPERATURE IS OK
  330 MPT1=NRSIES+IT-ITLO
      MPT2=MPT1+1
      EEVAL=EXP((ETBL(MPT1)*DXX2+ETBL(MPT2)*DXX1)/DELX)
      CVVAL=(ETBL(MPT2)-ETBL(MPT1))*EEVAL/(DELX*TEMPJ)
      PPVAL=EXP((PTBL(MPT1)*DXX2+PTBL(MPT2)*DXX1)/DELX)
      DPVAL=(PTBL(MPT2)-PTBL(MPT1))*PPVAL/(DELX*TEMPJ)
      SSVAL=(STBL(MPT1)*DXX2+STBL(MPT2)*DXX1)/DELX
      C81=ROWA/RTBL(IRLO)
      PPVAL=PPVAL*C81
      DPVAL=DPVAL*C81
      SSVAL=SSVAL-PPVAL*ALOG(C81)/(ROWA*TEMPJ)
      GO TO LEMOVA, (350,340)
  340 EEVAL=EEVAL-AMISS(12*IES-8)
  350 ICOME=1
      GO TO 670
  360 PPVAL=PPVAL+COLDP
      EEVAL=EEVAL+COLDE
      IF (NORAD.EQ.0) GO TO 260
      ROSLAN=EXP((DXX1*ROSTAB(MPT2)+DXX2*ROSTAB(MPT1))/DELX)
      GO TO 260
C
C     SEARCH RHO MESH      HERE ROWA IS THE DENSITY
  370 IROFF=0
      IF (RTBL(IR)-ROWA) 410,430,380
  380 IR=IR-1
      IF (IR.GE.IRLO) GO TO 400
      IROFF=-1
      IF (ROWA.GT.0.) GO TO 390
      PRINT 1690, I,ICYCLE,TEMPJ,ROWA,IBACK
      STOP
```

```
  390 IR=IR+1
      GO TO 430
  400 IF (RTBL(IR)-ROWA) 430,430,380
  410 IR=IR+1
      IF (IR.LE.IRHI) GO TO 420
      IROFF=1
      IR=IR-2
      GO TO 430
  420 IF (RTBL(IR).LE.ROWA) GO TO 410
      IR=IR-1
  430 CONTINUE
C     DETERMINE IF IN MESH         IF NOT   WHERE
      YR1=YRTBL(IR)
      YR2=YRTBL(IR+1)
      NPT11=NRSIES+IT-ITLO+(IR-IRLO)*NUMTEM(IES)
      NPT21=NPT11+1
      NPT12=NPT11+NUMTEM(IES)
      NPT22=NPT12+1
      IF (ITOFF) 510,440,550
  440 IF (IROFF) 450,470,490
  450 NOFRG=1
  460 YR=YR1
      GO TO 590
  470 NOFRG=0
  480 YR=ALOG(ROWA)
      GO TO 590
  490 NOFRG=3
  500 YR=YR2
      GO TO 590
  510 IF (IROFF) 520,530,540
  520 NOFRG=5
      GO TO 460
  530 NOFRG=4
      GO TO 480
  540 NOFRG=8
      GO TO 500
  550 IF (IROFF) 560,570,580
  560 NOFRG=6
      GO TO 460
  570 NOFRG=2
      GO TO 480
  580 NOFRG=7
      GO TO 500
C     INTERPOLATE IN MESH FOR TEMPERATURE DEPENDENT PARTS
C     OF THERMODYNAMIC FUNCTIONS
  590 DELX=XT2-XT1
      DXX1=XT-XT1
      DXX2=XT2-XT
      DELY=YR2-YR1
      DYY1=YR-YR1
      DYY2=YR2-YR
      DXDY=DELX*DELY
      DXY11=DXX1*DYY1
      DXY12=DXX1*DYY2
      DXY21=DXX2*DYY1
```

```
      DXY22=DXX2*DYY2
C     ENERGY ANC CV                                                     CHD 3407
      EEVAL=EXP((DXY11*ETBL(NPT22)+DXY21*ETBL(NPT12)+DXY12*ETBL(NPT21)+DCHD 3408
     1XY22*ETBL(NPT11))/DXDY)                                           CHD 3409
      CVVAL=(((ETBL(NPT21)-ETBL(NPT11))*DYY2+(ETBL(NPT22)-ETBL(NPT12))*DCHD 3410
     1YY1)/DXDY)*EEVAL/TPOINT                                           CHD 3411
C     PRESSURE AND DERIVATIVES                                          CHD 3412
      PPVAL=EXP((DXY11*PTBL(NPT22)+DXY21*PTBL(NPT12)+DXY12*PTBL(NPT21)+DCHD 3413
     1XY22*PTBL(NPT11))/DXDY)                                           CHD 3414
      DPVAL=(((PTBL(NPT21)-PTBL(NPT11))*DYY2+(PTBL(NPT22)-PTBL(NPT12))*DCHD 3415
     1YY1)/DXDY)*PFVAL/TPOINT                                           CHD 3416
      DPRAL=(((PTBL(NPT12)-PTBL(NPT11))*DXX2+(PTBL(NPT22)-PTBL(NPT21))*DCHD 3417
     1XX1)/DXDY)*PPVAL/ROWA                                             CHD 3418
C     ENTROPY                                                           CHD 3419
      SSVAL=(DXY11*STBL(NPT22)+DXY21*STBL(NPT12)+DXY12*STBL(NPT21)+DXY22CHD 3420
     1*STBL(NPT11))/DXDY                                                CHD 3421
      GO TO LEMOVB, (610,600)                                           CHD 3422
  600 EEVAL=EEVAL-AMISS(12*IES-8)                                       CHD 3423
  610 IF (IBACK) 630,620,630                                            CHD 3424
C     SOUNC SPEED                                                       CHD 3425
  620 CSDVAL=EXP((DXY11*SOUNSP(NPT22)+DXY21*SOUNSP(NPT12)+DXY12*SOUNSP(NCHD 3426
     1PT21)+DXY22*SOUNSP(NPT11))/DXDY)                                  CHD 3427
C     ROSSELAND MEAN                                                    CHD 3428
  630 IF (NORAD.EQ.0) GO TO 640                                         CHD 3429
      ROSLAN=EXP((CXY11*ROSTAB(NPT22)+DXY21*ROSTAB(NPT12)+DXY12*ROSTAB(NCHD 3430
     1PT21)+DXY22*ROSTAB(NPT11))/DXDY)                                  CHD 3431
  640 CONTINUE                                                          CHD 3432
C     ZERO-TEMPERATURE PART OF THERMODYNAMICS                           CHD 3433
      IF (IGAS(IES)) 650,660,650                                        CHD 3434
C     GAS PATH                                                          CHD 3435
  650 COLDE=COLDP=0.                                                    CHD 3436
      GO TO 730                                                         CHD 3437
C     SOLID PATH                                                        CHD 3438
  660 ICOME=0                                                           CHD 3439
      IF (IES.NE.LTIES) GO TO 670                                       CHD 3440
      IF (ROWA.EQ.ROWAO) GO TO 720                                      CHD 3441
  670 KA=22*(IES-1)                                                     CHD 3442
      ETA=ROWA/RHOOO(IES)                                               CHD 3443
      IF (ETA.GT.1.E-20) GO TO 680                                      CHD 3444
C     VERY LOW DENSITY                                                  CHD 3445
      COLDP=0.                                                          CHD 3446
      COLDE=AAAT(KA+17)*AAAT(KA+15)-AAAT(KA+16)*AAAT(KA+14)             CHD 3447
      GO TO 710                                                         CHD 3448
  680 ETA13=ETA**ATHIRD                                                 CHD 3449
      ETA23=ETA/ETA13                                                   CHD 3450
      ETA2=AAAT(KA+13)                                                  CHD 3451
      IF (ETA.LE.ETA2) GO TO 690                                        CHD 3452
      C81=AAAT(KA+2)/ETA13                                              CHD 3453
      C82=EXP(-C81)                                                     CHD 3454
      C83=AAAT(KA+1)*ETA23                                              CHD 3455
      C84=AAAT(KA+4)*ETA13                                              CHD 3456
      C85=AAAT(KA+5)*ETA23                                              CHD 3457
      COLDF=ETA*C83*C82-(AAAT(KA+3)+C84+C85+AAAT(KA+19)*ETA)            CHD 3458
      CALL EPINT3 (C81,C82,C86)                                         CHD 3459
      COLDE=AAAT(KA+6)+(3.*C83*C86+(AAAT(KA+3)+1.5*C84+3.*C85)/ETA-AAAT(CHD 3460
```

```
     1KA+19)*ALOG(ETA))/RHOOO(IES)
      GO TO 710
  690 ETA1=AAAT(KA+12)
      C81=EXP(-AAAT(KA+8)/ETA13)
      C82=EXP(-AAAT(KA+10)/ETA13)
      COLDP=ETA23*(AAAT(KA+7)*C81-AAAT(KA+9)*C82)
      COLDE=AAAT(KA+16)*(C81-AAAT(KA+14))-AAAT(KA+17)*(C82-AAAT(KA+15))
      IF (ETA.GE.ETA1) GO TO 710
      IF (AAAT(KA+11)) 700,710,700
  700 C81=ETA/ETA1
      C82=(1.-C81)
      C83=C82**3
      COLDP=COLDP+AAAT(KA+11)*C83*(C81-0.2)*ETA**2
      COLDE=COLDE-AAAT(KA+18)*ETA*C82*C83
  710 LTIES=IES
      ROWAO=ROWA
  720 IF (ICOME) 360,730,360
  730 IF (NOFRG.GT.0) GO TO 750
C     IN TABLE
  740 EEVAL=EEVAL+COLDE
      PPVAL=PPVAL+COLDP
      IF (IBACK) 260,220,240
C     OFF TABLE
  750 GO TO (760,770,780,790,800,810,820,830), NOFRG
  760 C81=ROWA/RTBL(IRLO)
      PPVAL=PPVAL*C81
      DPVAL=DPVAL*C81
      SSVAL=SSVAL-FPVAL*ALOG(C81)/(TEMPJ*ROWA)
      GO TO 890
  770 C81=TEMPJ-TTBL(ITHI)
      CVVAL=CVHIGH(IES)
      EEVAL=EEVAL+CVVAL*C81
      DPVAL=2.*CVVAL*ROWA/3.
      PPVAL=PPVAL+DPVAL*C81
      SSVAL=SSVAL+CVVAL*ALOG(TEMPJ/TTBL(ITHI))
      GO TO 840
  780 C81=ROWA/RTBL(IRHI)
      PPVAL=PPVAL*C81
      DPVAL=DPVAL*C81
      SSVAL=SSVAL-FPVAL*ALOG(C81)/(TEMPJ*ROWA)
      GO TO 890
  790 C81=TEMPJ/TTBL(ITLO)
      EEVAL=EEVAL*C81
      CVVAL=EEVAL/TEMPJ
      PPVAL=PPVAL*C81
      DPVAL=PPVAL/TEMPJ
      SSVAL=SSVAL+CVVAL*ALOG(C81)
      GO TO 890
  800 C81=TEMPJ/TTBL(ITLO)
      C82=ROWA/RTBL(IRLO)
      EEVAL=EEVAL*C81
      CVVAL=EEVAL/TEMPJ
      PPVAL=PPVAL*C81*C82
      DPVAL=PPVAL/TEMPJ
      SSVAL=SSVAL-DPVAL*ALOG(C82)/ROWA+CVVAL*ALOG(C81)
```

```
      GO TO 890
  810 C81=TEMPJ-TTBL(ITHI)
      C82=ROWA/RTBL(IRLO)
      CVVAL=CVHIGH(IES)
      EEVAL=EEVAL+CVVAL*C81
      SSVAL=SSVAL-PPVAL*ALOG(C82)/(RTBL(IRLO)*TTBL(ITHI))+CVVAL*ALOG(TEM
     1PJ/TTBL(ITHI))
      DPVAL=2.*CVVAL*ROWA/3.
      PPVAL=PPVAL*C82+DPVAL*C81
      GO TO 840
  820 C81=TEMPJ-TTBL(ITHI)
      C82=ROWA/RTBL(IRHI)
      CVVAL=CVHIGH(IES)
      EEVAL=EEVAL+CVVAL*C81
      SSVAL=SSVAL-PPVAL*ALOG(C82)/(RTBL(IRHI)*TTBL(ITHI))+CVVAL*ALOG(TEM
     1PJ/TTBL(ITHI))
      DPVAL=2.*CVVAL*ROWA/3.
      PPVAL=PPVAL*C82+DPVAL*C81
      GO TO 840
  830 C81=TEMPJ/TTBL(ITLO)
      C82=ROWA/RTBL(IRHI)
      EEVAL=EEVAL*C81
      CVVAL=EEVAL/TEMPJ
      PPVAL=PPVAL*C81*C82
      DPVAL=PPVAL/TEMPJ
      SSVAL=SSVAL+CVVAL*ALOG(C81)-PPVAL*ALOG(C82)/(ROWA*TEMPJ)
      GO TO 890
  840 IF (NORAD) 850,870,850
  850 C81=ROSLAN-.2
      IF (C81) 870,870,860
  860 ROSLAN=C81*(TTBL(ITHI)/TEMPJ)**3+.2
  870 IF (IBACK) 890,880,890
  880 CSDVAL=CSDVAL*SQRT(TEMPJ/TTBL(ITHI))
  890 CONTINUE
      GO TO 740
C
C     ANALYTIC EOS CALCULATICN
  900 IES2=-IES
      IF (TEMPJ.GT.0.) GO TO 920
  910 IBACK=6
      PRINT 1690, I,ICYCLE,TEMPJ,TEMPA,IBACK
      STOP
  920 IF (TEMPA.LE.0.) GO TO 910
      CALL ANEOS (TEMPJ,TEMPA,TEMPD,TEMPC,ENTSV(I),TEMPG,TEMPH,C82,ROSLA
     1N,CSOD(I),KPHASE(I),IES2)
      IF (KPHASE(I).GT.3) KPHASE(I)=1
C     SAVE C82=DPDRHO FOR FOAM CALCULATION
  930 IF (DRATIO(I).LE.1.) GO TO 940
      TEMPA=TEMPAS
  940 IF (NORAD.NE.0) GO TO 950
      FPATH(I)=0.
      RETURN
  950 FPATH(I)=1./(TEMPA*ROSLAN)
      IF (TEMPJ.LE.TRADMIN) RETURN
C     ADD RADIATION TERMS TO MATERIAL TERMS
```

```
      C81=TEMPJ**3                                                        CHD 3572
      TEMPH=TEMPH+RADK1*C81                                               CHD 3573
      TEMPG=TEMPG+RADK2*C81/TEMPA                                         CHD 3574
      ENTSV(I)=ENTSV(I)+RADK1*C81/TEMPA                                   CHD 3575
      C81=RADK3*C81*TEMPJ                                                 CHD 3576
      TEMPD=TEMPD+C81                                                     CHD 3577
      C81=3.*C81/TEMPA                                                    CHD 3578
      IF (1.E-5*TEMPC.GT.C81) GO TO 960                                   CHD 3579
      CSOD(I)=SQRT(CSOD(I)**2+.45*C81)                                    CHD 3580
  960 TEMPC=TEMPC+C81                                                     CHD 3581
      RETURN                                                              CHD 3582
C                                                                         CHD 3583
C     SET UP EQUATION OF STATE                                            CHD 3584
C     READ EOS INPUT TAPE                                                 CHD 3585
  970 CONTINUE                                                            CHD 3586
C     NECSB IS FIRST ECS LOCATION FOR EOS                                 CHD 3587
      NECSB=12*MAXZONE+4                                                  CHD 3588
      IINN=IIN                                                            CHD 3589
      IIN=IEOSTP                                                          CHD 3590
      DO 980 IJ=1,NMTRLS                                                  CHD 3591
      IF (IEOSS(IJ).GT.0.) GO TO 990                                      CHD 3592
  980 CONTINUE                                                            CHD 3593
      GO TO 1000                                                          CHD 3594
  990 READ (IIN,1860) (IZETL(IJ),IJ=1,10)                                 CHD 3595
      PRINT 1840, (IZETL(IJ),IJ=1,10)                                     CHD 3596
C     PUTS EOS IN NUMERICAL ASCENDING ORDER, IZERL STORES THE SEQUENCE    CHD 3597
 1000 DO 1010 JJ=1,NMTRLS                                                 CHD 3598
 1010 IZETL(JJ)=IEOSS(JJ)                                                 CHD 3599
      DO 1030 JJ=1,NMTRLS                                                 CHD 3600
      IS=99999                                                            CHD 3601
      DO 1020 JK=1,NMTRLS                                                 CHD 3602
      IF (IS.LE.IZETL(JK)) GO TO 1020                                     CHD 3603
      IS=IZETL(JK)                                                        CHD 3604
      JL=JK                                                               CHD 3605
 1020 CONTINUE                                                            CHD 3606
      IZERL(JJ)=IS                                                        CHD 3607
      IZETL(JL)=99999                                                     CHD 3608
 1030 CONTINUE                                                            CHD 3609
      IS=1                                                                CHD 3610
      ISS=1                                                               CHD 3611
      IZETL(1)=IZERL(1)                                                   CHD 3612
 1040 CONTINUE                                                            CHD 3613
      IF (IS.GE.NMTRLS) GO TO 1060                                        CHD 3614
      IF (IZERL(IS).LT.IZERL(IS+1)) GO TO 1050                            CHD 3615
      IS=IS+1                                                             CHD 3616
      GO TO 1040                                                          CHD 3617
 1050 CONTINUE                                                            CHD 3618
      IS=IS+1                                                             CHD 3619
      ISS=ISS+1                                                           CHD 3620
      IZETL(ISS)=IZERL(IS)                                                CHD 3621
      GO TO 1040                                                          CHD 3622
 1060 CONTINUE                                                            CHD 3623
C     ISS = NUMBER OF DIFFERENT EOS                                       CHD 3624
C     IZETL STORES DIFFERENT EOS NUMBERS IN ASCENDING ORDER               CHD 3625
C     PUT ANALYTICAL EOS NUMBERS LAST                                     CHD 3626
```

```
      IF (ISS.EQ.1) GO TO 1090
      IF (IZETL(ISS).LT.0) GO TO 1090
 1070 IF (IZETL(1).GT.0) GO TO 1090
      IS=ISS-1
      JJ=IZETL(1)
      DO 1080 J=1,IS
 1080 IZETL(J)=IZETL(J+1)
      IZETL(ISS)=JJ
      GO TO 1070
 1090 PRINT 1850, ISS,(IZETL(IS),IS=1,ISS)
C     READ ANALYTICAL EOS DATA CARDS
      NOANEOS=0
      DO 1100 IS=1,ISS
      IF (IZETL(IS).GT.0) GO TO 1100
      NOANEOS=1
      CALL ANEOS2 (1,ISS,IIN,IZETL)
      GO TO 1110
 1100 CONTINUE
 1110 CONTINUE
C     TABULAR FORM
      DO 1120 IJ=1,ISS
      IF (IZETL(IJ)) 1120,1120,1130
 1120 CONTINUE
      GO TO 1140
 1130 PRINT 1770
 1140 IS=0
      IF (NISEOS) 1170,1170,1150
C     TURN OFF ECS SWITCH IF NOT REQUIRED
 1150 IA=0
      DO 1160 J=1,ISS
      IF (IZETL(J).GT.0) IA=IA+1
 1160 CONTINUE
      IF (IA.GE.2) GO TO 1170
      NISEOS=0
      PRINT 1670
 1170 ITL(1)=IRL(1)=KTP(1)=NROS(1)=1
C     READ TABULAR EOS DATA
      DO 1390 J=1,ISS
      IES=IZETL(J)
      IF (IES.LT.0) GO TO 1390
 1180 IS=IS+1
      READ (IIN,1700) IES2,(TSAVE(I),I=1,8)
      IF (IES2.NE.-12345) GO TO 1190
      PRINT 1780, IS,IES
      STOP
 1190 IF (IES-IES2) 1200,1220,1210
 1200 PRINT 1790, IES2,IES
      STOP
C     SKIP OVER UNNECESSARY DATA
 1210 READ (IIN,1710) LQR,MQR,IBACK
      READ (IIN,1740) (TSAVE(I),I=1,11)
      READ (IIN,1720) (TSAVE(I),I=1,MQR)
      READ (IIN,1720) (TSAVE(I),I=1,LQR)
      JJ=LQR*MQR
      READ (IIN,1750) (C81,I=1,JJ)
```

```
      JJ=2*IBACK                                                          CHD 3682
      READ (IIN,1740) (TSAVE(I),I=1,JJ)                                   CHD 3683
      READ (IIN,1720) (TSAVE(I),I=1,MQR)                                  CHD 3684
      GO TO 1180                                                          CHD 3685
C     READ AND SAVE TABLE DATA                                            CHD 3686
 1220 READ (IIN,1710) LQR,MQR,IBACK,IGAS(J),DXX1,DXX2,CVHIGH(J)           CHD 3687
      PRINT 1800, IES,(TSAVE(I),I=1,8),DXX1,DXX2                          CHD 3688
      IG=22*J                                                             CHD 3689
      IA=IG-21                                                            CHD 3690
      READ (IIN,1720) RCRIT(J),TCRIT(J),RHOOO(J),RSMIN(J),RTRIP(J),TTRIPCHD 3691
     1(J),(AAAT(I),I=IA,IG),BETA9(J),BETA10(J),BETA11(J),BETA12(J)        CHD 3692
      IA=12*(J-1)+1                                                       CHD 3693
      IG=IA+11                                                            CHD 3694
      READ (IIN,1720) (AMISS(I),I=IA,IG)                                  CHD 3695
      IRL(J+1)=IRL(J)+MQR                                                 CHD 3696
      ITL(J+1)=IRL(J)+LQR                                                 CHD 3697
      KTP(J+1)=KTP(J)+IBACK                                               CHD 3698
      NROS(J+1)=NROS(J)+LQR*MQR                                           CHD 3699
      NUMTEM(J)=LQR                                                       CHD 3700
      IA=IRL(J)                                                           CHD 3701
      IG=IRL(J+1)-1                                                       CHD 3702
      IF (IG.GT.MAXNOD) GO TO 1340                                        CHD 3703
      READ (IIN,1720) (RTBL(I),I=IA,IG)                                   CHD 3704
      NPT11=NPT22=0                                                       CHD 3705
      DO 1230 I=IA,IG                                                     CHD 3706
      IF (RTBL(I).EQ.DXX1) NPT11=I-IA+1                                   CHD 3707
 1230 YRTBL(I)=ALOG(RTBL(I))                                              CHD 3708
      IA=ITL(J)                                                           CHD 3709
      IG=ITL(J+1)-1                                                       CHD 3710
      IF (IG.GT.MAXNOT) GO TO 1350                                        CHD 3711
      READ (IIN,1720) (TTBL(I),I=IA,IG)                                   CHD 3712
      DO 1240 I=IA,IG                                                     CHD 3713
      IF (TTBL(I).EQ.DXX2) NPT22=I-IA+1                                   CHD 3714
 1240 XTTBL(I)=ALOG(TTBL(I))                                              CHD 3715
      JK=NROS(J)                                                          CHD 3716
      JL=NROS(J+1)-1                                                      CHD 3717
      READ (IIN,1730) (PTBL(I),ETBL(I),STBL(I),SOUNSP(I),ROSTAB(I),I=JK,CHD 3718
     1JL)                                                                 CHD 3719
      IF (IGAS(J)) 1260,1250,1260                                         CHD 3720
C     ZERO REFERENCE PRESSURE                                             CHD 3721
 1250 IF (NPT11*NPT22.LE.0) GO TO 1260                                    CHD 3722
      JL=JK+NPT22+LQR*(NPT11-1)-1                                         CHD 3723
      KA=22*(J-1)                                                         CHD 3724
      C84=DXX1/RHOOO(J)                                                   CHD 3725
      IF (C84.GT.AAAT(KA+13)) GO TO 1260                                  CHD 3726
      IF (C84.LT.AAAT(KA+12)) GO TO 1260                                  CHD 3727
      C83=C84**ATHIRD                                                     CHD 3728
      C82=C84/C83                                                         CHD 3729
      DXY11=C82*(AAAT(KA+7)*EXP(-AAAT(KA+8)/C83)-AAAT(KA+9)*EXP(-AAAT(KACHD 3730
     1+10)/C83))                                                          CHD 3731
      DXY22=DXY11+PTBL(JL)                                                CHD 3732
      IF (ABS(DXY22).GT.100.) GO TO 1260                                  CHD 3733
      PTBL(JL)=PTBL(JL)-DXY22+1.E-2                                       CHD 3734
 1260 JK=JK-1                                                             CHD 3735
      JL=MQR*LQR                                                          CHD 3736
```

```
      DO 1290 I=1,JL
      JK=JK+1
      PTBL(JK)=ALOG(PTBL(JK))
      ETBL(JK)=ALOG(ETBL(JK))
      IF (SOUNSP(JK).GE.0.0001) GO TO 1270
      SOUNSP(JK)=0.0001
 1270 SOUNSP(JK)=ALOG(SOUNSP(JK))
      IF (ROSTAB(JK).GT.0.) GO TO 1280
      ROSTAB(JK)=.2
 1280 ROSTAB(JK)=ALOG(ROSTAB(JK))
 1290 CONTINUE
      IF (JK.GT.MAXSIZE) GO TO 1360
      IA=KTP(J)
      IG=KTP(J+1)-1
      IF (IG.GT.MAXTPH) GO TO 1370
      DO 1300 I=IA,IG
 1300 READ (IIN,1720) BETA1(I),BETA2(I),BETA3(I),BETA4(I),BETA5(I),BETA6
     1(I),BETA7(I),BETA8(I)
      IF (IGAS(J).NE.0) GO TO 1320
      DO 1310 JK=1,8
      JI=MAXTPH*(JK-1)
      DO 1310 I=IA,IG
 1310 BETA1(I+JI)=ALOG(BETA1(I+JI))
C     NEXT RECORD SET IS MELTING TEMPERATURES AT MESH DENSITIES
 1320 READ (IIN,1720) (TSAVE(I),I=1,MQR)
      IF (NISEOS) 1390,1390,1330
C     ECS PATH
 1330 IA=NECSA*(J-1)+NECSB
      CALL WRITEC (TTBL,IA,NECSA)
      PSAVE(J+1)=ITL(J+1)
      PSAVE(J+26)=IRL(J+1)
      PSAVE(J+51)=KTP(J+1)
      PSAVE(J+76)=NROS(J+1)
      ITL(J+1)=IRL(J+1)=KTP(J+1)=NROS(J+1)=1
      GO TO 1390
C     SET FLAG FOR TABLE OVERFLOW
 1340 I=1
      GO TO 1380
 1350 I=2
      GO TO 1380
 1360 I=3
      IG=JK
      GO TO 1380
 1370 I=4
 1380 PRINT 1760, I,IG,IES,J,ISS,MAXNOD,MAXNOT,MAXSIZE,MAXTPH
      STOP
 1390 CONTINUE
      IES=ISS+1
      IF (NISEOS) 1420,1420,1400
C     ECS PATH
 1400 DO 1410 J=2,IES
      IF (IZETL(J-1).LT.0) GO TO 1420
      NISEOS=J-1
      ITL(J)=PSAVE(J)
      IRL(J)=PSAVE(J+25)
```

```
      KTP(J)=PSAVE(J+50)
      NROS(J)=PSAVE(J+75)
      ITL(J)=ITL(J)+ITL(J-1)-1
      IRL(J)=IRL(J)+IRL(J-1)-1
      KTP(J)=KTP(J)+KTP(J-1)-1
 1410 NROS(J)=NROS(J)+NROS(J-1)-1
 1420 DO 1450 J=1,IES
      IF (J.EQ.IES) GO TO 1430
      IF (IZETL(J).GT.0) GO TO 1440
      IF (J.EQ.1) GO TO 1460
 1430 PRINT 1820, J,NROS(J),MAXSIZE,J,ITL(J),MAXNOT,J,IRL(J),MAXNOD,J,KT
     1P(J),MAXTPH
      GO TO 1460
 1440 IF (J.EQ.1) PRINT 1810
      PRINT 1830, J,NROS(J),J,ITL(J),J,IRL(J),J,KTP(J),J,NUMTEM(J)
 1450 CONTINUE
 1460 CONTINUE
      DO 1480 I=1,NZ
      IES=IEOS(I)
      DO 1470 J=1,ISS
      IF (IES.NE.IZETL(J)) GO TO 1470
      IF (IES.LT.0) GO TO 1480
      IEOS(I)=J
      GO TO 1480
 1470 CONTINUE
      PRINT 1870
      STOP 26
 1480 CONTINUE
C     IEOS(I) IS THE SEQUENCE NUMBER OF THE EOS FOR ZONE I
C     INITIALIZE THE LAST PLACE IN TABLE SAVERS
      DO 1520 I=1,NZ
      J1=IEOS(I)
      IF (J1.LT.0) GO TO 1510
      IF (NISEOS) 1490,1490,1500
 1490 IZPTL(I)=ITL(J1)
      IZPRL(I)=IRL(J1)
      GO TO 1520
C     ECS PATH
 1500 IZPTL(I)=IZPRL(I)=1
      GO TO 1520
 1510 IZPTL(I)=IZPRL(I)=0
 1520 CONTINUE
      IIN=IINN
C     END OF EOS SET UP
      GO TO 1570
C
C     EOS RESTART SET UP
 1530 READ (IIN) (IZETL(I),I=1,NNNIZE)
      READ (IIN) (TTBL(I),I=1,NNNTTB)
      NECSB=12*MAXZONE+4
      IA=NECSB
      IF (NISEOS) 1560,1560,1540
C     ECS PATH
 1540 DO 1550 I=1,NISEOS
      READ (IIN) (TTBL(J),J=1,NECSA)
```

```
      IA=NECSA*(I-1)+NECSB
 1550 CALL WRITEC (TTBL,IA,NECSA)
      IA=IA+NECSA
 1560 IF (NOANECS.EQ.1) CALL ANEOS2 (3,ISS,IIN,IZETL)
      GO TO 1610
C
C     WRITE EOS DATA FOR RESTART
 1570 WRITE (IOUT) (IZETL(I),I=1,NNNIZE)
      WRITE (IOUT) (TTBL(I),I=1,NNNTTB)
      IA=NECSB
      IF (NISEOS) 1600,1600,1580
C     ECS PATH
 1580 DO 1590 I=1,NISEOS
      IA=NECSA*(I-1)+NECSB
      CALL READEC (TTBL,IA,NECSA)
 1590 WRITE (IOUT) (TTBL(J),J=1,NECSA)
      IA=IA+NECSA
 1600 IF (NOANECS.EQ.1) CALL ANEOS2 (2,ISS,IOUT,IZETL)
 1610 PRINT 1680, IA,NISEOS
      ASSIGN 350 TO LEMOVA
      ASSIGN 610 TO LEMOVB
      DO 1640 I=1,MAXZONE
      IF (IEOS(I)) 1640,1650,1620
 1620 IES=IEOS(I)
      IF (AMISS(12*IES-8)) 1630,1640,1630
 1630 ASSIGN 340 TO LEMOVA
      ASSIGN 600 TO LEMOVB
      GO TO 1650
 1640 CONTINUE
 1650 RETURN
 1660 STOP 305
C
 1670 FORMAT (26H0 ECS SWITCH IS OFF IN EOS)
 1680 FORMAT (29H1 LAST ECS LOCATION IN USE IS,I10,//,I5,22H EOS TABLES
     1ARE STORED)
 1690 FORMAT (48H1 ZERO OR NEGATIVE DENSITY OR TEMPERATURE   ZONE,I5,5HC
     1YCLE,I8,/,4H  T=,E13.6,20X,4HRHO=,E13.6,15X,6HIBACK=,I7)
 1700 FORMAT (I6,7A10,A4)
 1710 FORMAT (4I5,3E20.10)
 1720 FORMAT (4E20.10)
 1730 FORMAT (5E16.8)
 1740 FORMAT (E20.10)
 1750 FORMAT (E16.8)
 1760 FORMAT (25H EOS TABLES ARE TOO LARGE,5I7)
 1770 FORMAT (17H1 TABULAR EOS ARE)
 1780 FORMAT (34H0 END OF EOS TAPE HAS BEEN REACHED,2I7)
 1790 FORMAT (18H0 FOUND EOS NUMBER,I7,18H  WHEN LOOKING FOR,I7)
 1800 FORMAT (8H0 NUMBER,I7,5X,7A10,A4,/,21H  REFERENCE  DENSITY=,E14.7,
     115H   TEMPERATURE=,E14.7)
 1810 FORMAT (//,20H   TABLE STORAGE DATA)
 1820 FORMAT (7H0 NROS(,I2,2H)=,I6,1H/,I6,1X,4HITL(,I2,2H)=,I4,1H/,I4,6X
     1,4HIRL(,I2,2H)=,I4,1H/,I4,6X,4HKPT(,I2,2H)=,I5,1H/,I5)
 1830 FORMAT (7H0 NROS(,I2,2H)=,I6,8X,4HITL(,I2,2H)=,I4,11X,4HIRL(,I2,2H
     1)=,I4,11X,4HKTP(,I2,2H)=,I5,8X,7HNUMTEM(,I2,2H)=,I4)
 1840 FORMAT (25H1 HEADING ON EOS TAPE IS ,10A8)

 1850 FORMAT (//,I5,25H EOS TABLES ARE REQUESTED,/,(17I7))
 1860 FORMAT (10A8)
 1870 FORMAT (13H1ERROR IN EOS)
      END
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```
      SUBROUTINE TPLINE (NES,RM,TM,EM)                                  CHD 3906
C     DETERMINES TRIPLE LINE AND CRITICAL POINT PROPERTIES              CHD 3907
      COMMON /BIG/ TTBL(37),RTBL(35),XTTBL(37),YRTBL(35),PTBL(1295),ETBLCHD 3908
     1(1295),STBL(1295),SOUNSP(1295),ROSTAB(1295),BETA1(29),BETA2(29),BECHD 3909
     2TA3(29),BETA4(29),BETA5(29),BETA6(29),BETA7(29),BETA8(29),CVHIGH(2CHD 3910
     30),RCRIT(20),TCRIT(20),RHOOO(20),RSMIN(20),RTRIP(20),TTRIP(20),BETCHD 3911
     4A9(20),BETA10(20),BETA11(20),BETA12(20),AAAT(440),AMISS(240)      CHD 3912
      COMMON /ANES/ ACK(1080),ZZS(100),COT(100),FNI(100),RCT(21),TCT(21)CHD 3913
     1,RSOL(1000),RVAP(1000),TTWO(1000),SAVER(92),CMLT(8),ZB(92),DZB(40)CHD 3914
     2,BOLTS,EIP(4370),LOCSV(21),LOCKP(21),LOCKPL(21)                   CHD 3915
      COMMON /ISE/ ISEND,ENTCR(20),ENTTPL(20)                           CHD 3916
      DATA ISEND/1/                                                     CHD 3917
      DATA II/0/                                                        CHD 3918
      DATA RSOL,TTWO/2000*0./                                           CHD 3919
      IF (ISEND) 10,20,20                                               CHD 3920
   10 IF (ISEND+1) 200,40,40                                            CHD 3921
   20 IF (II) 40,30,40                                                  CHD 3922
   30 PRINT 260                                                         CHD 3923
   40 IF (NES) 60,60,50                                                 CHD 3924
   50 RM=RTRIP(NES)                                                     CHD 3925
      TM=TTRIP(NES)                                                     CHD 3926
      II=12*(NES-1)+1                                                   CHD 3927
      EM=AMISS(II)                                                      CHD 3928
      GO TO 190                                                         CHD 3929
   60 II=-NES                                                           CHD 3930
      JJ=LOCSV(II)+18                                                   CHD 3931
      TM=ACK(JJ)                                                        CHD 3932
      IF (TM) 70,70,80                                                  CHD 3933
   70 RM=EM=0.                                                          CHD 3934
      GO TO 190                                                         CHD 3935
   80 K1=LOCKP(II)                                                      CHD 3936
      K2=LOCKPL(II)                                                     CHD 3937
      IF (K1-K2) 150,90,90                                              CHD 3938
   90 JJ=JJ+12                                                          CHD 3939
      IF (ACK(JJ).LE.1.) GO TO 100                                      CHD 3940
      TM=0.                                                             CHD 3941
      GO TO 70                                                          CHD 3942
  100 D8=.999999*TM                                                     CHD 3943
      GU=ACK(JJ-19)                                                     CHD 3944
      GL=ACK(JJ-7)                                                      CHD 3945
  110 RM=.5*(GU+GL)                                                     CHD 3946
      CALL ANEOS (D8,RM,D1,EM,D2,D3,D4,D5,D6,D7,K2,II)                  CHD 3947
      IF (GU-GL.LE.1.E-9*RM) GO TO 140                                  CHD 3948
      IF (D1) 120,130,130                                               CHD 3949
  120 GL=RM                                                             CHD 3950
      GO TO 110                                                         CHD 3951
  130 GU=RM                                                             CHD 3952
      GO TO 110                                                         CHD 3953
  140 IF (ABS(D1).LE.100.) GO TO 180                                    CHD 3954
      IF (ISEND.GE.0) PRINT 230, ACK(JJ),NES                            CHD 3955
      RM=ACK(JJ-19)                                                     CHD 3956
      GO TO 180                                                         CHD 3957
  150 DO 170 I=K1,K2                                                    CHD 3958
      IF (TM-TTWO(I)) 170,160,170                                       CHD 3959
  160 RM=RSOL(I)                                                        CHD 3960
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      GO TO 180
  170 CONTINUE                                                          CHD 3961
      PRINT 250, NES,TM                                                 CHD 3962
      GO TO 90                                                          CHD 3963
  180 CALL ANEOS (TM,RM,D1,EM,D2,D3,D4,D5,D6,D7,JJ,II)                  CHD 3964
  190 IF (ISEND.GE.0) PRINT 240, NES,TM,RM,EM                           CHD 3965
      RETURN                                                            CHD 3966
  200 IF (NES) 210,210,220                                              CHD 3967
  210 II=-NES                                                           CHD 3968
      RM=RCT(II)                                                        CHD 3969
      TM=TCT(II)                                                        CHD 3970
      RETURN                                                            CHD 3971
  220 RM=RCRIT(NES)                                                     CHD 3972
      TM=TCRIT(NES)                                                     CHD 3973
      RETURN                                                            CHD 3974
C                                                                       CHD 3975
  230 FORMAT (16H0 WARNING - TYPE,F3.0,22H EOS USED FOR MATERIAL,I4,45H CHD 3976
     1DOES NOT HAVE CORRECT TRIPLE LINE PROPERTIES,/)                   CHD 3977
  240 FORMAT (/,5H0EOS=,I6,5X,3HTM=,E12.5,5X,5HRHOM=,E12.5,5X,3HEM=,E12.CHD 3978
     15)                                                                CHD 3979
  250 FORMAT (//,13H0TPLINE ERROR,I10,E14.5)                            CHD 3980
  260 FORMAT (17H1TRIPLE LINE DATA)                                     CHD 3981
      END                                                               CHD 3982
                                                                        CHD 3983
```

```
      SUBROUTINE ANEOS (T,RHO,P,E,S,CV,DPDT,DPDR,FKROS,CS,KPA,MAT)
C     ANEOS PACKAGE
C     RUNNING ENTRY POINT
      COMMON /ANES/ ACK(1080),ZZS(100),COT(100),FNI(100),RCT(21),TCT(21)
     1,RSOL(1000),RVAP(1000),TTWO(1000),SAVER(92),CMLT(8),ZB(92),DZB(40)
     2,BOLTS,EIP(4370),LOCSV(21),LOCKP(21),LOCKPL(21)
      COMMON /BNES/ PM,EM,SM,CVM,DPDTM,DPDRM
      LOC=LOCSV(MAT)
      NMATS=ACK(LOC+30)
      IF (NMATS-2) 30,80,10
C     CHECK FOR LIQUID-VAPOR OR SOLID-VAPOR STATE
   10 IF (RHO.GE.ACK(LOC+47)) GO TO 30
      IF (T.GE.TCT(MAT)) GO TO 30
      IF (T.GT.ACK(LOC+18)) GO TO 20
      IF (RHO.GE.ACK(LOC+23)) GO TO 30
   20 CALL ANTWOPH (T,RHO,MAT,P,E,S,CV,DPDT,DPDR,LOC,KPA)
C     KPA=2 IF LIQUID-VAPOR OR SOLID-VAPOR STATE
      IF (KPA.EQ.2) GO TO 140
C     IS MELT TRANSITION INCLUDED
   30 IF (ACK(LOC+46)) 80,80,40
   40 KPA=0
C     FATAL ERROR FLAG SET TO STOP IN ANLS
      CALL ANLS (T,RHO,DPDT,DPDR,LOC,MAT,KPA)
      IF (KPA-2) 50,70,60
C     SOLID STATE (EOS WITH MELT)
   50 KPA=4
      CMLT(7)=-1.
      CALL ANEOS1 (T,RHO,P,E,S,CV,DPDT,DPDR,LOC)
      CMLT(7)=0.
      GO TO 100
C     LIQUID STATE (EOS WITH MELT)
   60 KPA=6
      GO TO 90
C     LIQUID-SOLID STATE (EOS WITH MELT)
   70 KPA=5
      P=PM
      E=EM
      S=SM
      CV=CVM
      DPDT=DPDTM
      DPDR=DPDRM
      GO TO 100
C     ONE-PHASE STATE (EOS WITHOUT MELT)
   80 KPA=1
   90 CALL ANEOS1 (T,RHO,P,E,S,CV,DPDT,DPDR,LOC)
  100 IF (NMATS-2) 110,160,140
C     EOS TYPE 0 AND 1 TENSICN SUPPRESSION
  110 IF (P.GE.0.) GO TO 130
      IF (T.GE.ACK(LOC+18)) GO TO 120
      IF (RHO.GE.ACK(LOC+23)) GO TO 130
  120 P=DPDT=DPDR=0.
      KPA=3
  130 IF (NMATS) 150,150,160
  140 IF (NMATS-3) 150,150,160
  150 FKROS=1.E5
```

```
      GO TO 270
C     ELECTRONIC TERMS
  160 T32=T*SQRT(T)
      IF (T.GT.0.07) GO TO 170
      FKROS=.4*ACK(LOC+26)/ACK(LOC+29)
      ZBAR=0.
      GO TO 230
  170 NMATS=ACK(LOC+28)
      FN=ACK(LOC+27)
      IIZ=ACK(LOC+31)
      IF (NMATS.GT.1) GO TO 180
      Z=ZZS(IIZ)
      CALL ANION1 (T,RHO,Z,FN,PE,EE,SE,CVE,DPTE,DPRE,ZBAR,T32)
      IF (ZBAR.EQ.0.) GO TO 210
      Y=ZBAR**2
      GO TO 200
  180 Z=ACK(LOC+26)
      CALL ANION2 (T,RHO,FN,Z,NMATS,IIZ,T32,ZBAR,PE,EE,SE,DPTE,DPRE,CVE)
      IF (ZBAR.EQ.0.) GO TO 210
      Y=0.
      DO 190 I=1,NMATS
  190 Y=Y+COT(IIZ+I-1)*ZB(I)**2
  200 FKROS=(1.E11*RHO*ZBAR*Y/(ACK(LOC+29)*T32*T**2)+.4*Z)/ACK(LOC+29)
      GO TO 220
  210 FKROS=.4*Z/ACK(LOC+29)
      GO TO 230
  220 P=P+PE
      E=E+EE
      S=S+SE
      CV=CV+CVE
      DPDT=DPDT+DPTE
      DPDR=DPDR+DPRE
C     ELECTRONIC CONDUCTION TERM
      Y=ZBAR
      IF (Y.GE.ACK(LOC+42)) GO TO 240
  230 Y=ACK(LOC+42)
  240 CS=6.18E7*T32/(T*(RHO*ACK(LOC+27))**.3333333333)
      IF (CS.GT.1.41421356) GO TO 250
      CS=.34657359
      GO TO 260
  250 CS=ALOG(CS)
  260 Y=416.*Y*(S*T32/(T*RHO)
      FKROS=FKROS*Y/(Y+FKROS)
C     SOUND SPEED
  270 CS=DPDR+(T*DPDT**2)/(CV*RHO**2)
      IF (CS.LT.1.E-20) GC TO 280
      CS=SQRT(CS)
      GO TO 290
  280 CS=1.E-10
C     PHONON CONDUCTION TERM
  290 IF (ACK(LOC+22).EQ.0.) RETURN
      Y=ACK(LOC+22)*T**(3.-ACK(LOC+41))/RHO
      FKROS=FKROS*Y/(Y+FKROS)
      RETURN
      END
```

```
      SUBROUTINE ANEOS1 (T,RHO,P,E,S,CV,DPDT,DPDR,L)
C     ANEOS PACKAGE
C     NUCLEAR AND COLD COMPONENTS
      COMMON /ANES/ ACK(1080),ZZS(100),COT(100),FNI(100),RCT(21),TCT(21)
     1,RSOL(1000),RVAP(1000),TTWO(1000),SAVER(92),CMLT(8),ZB(92),DZB(40)
     2,BOLTS,EIP(4370),LOCSV(21),LOCKP(21),LOCKPL(21)
      FT=BOLTS*ACK(L+27)
      FTT=FT*T
      IF (ACK(L+30).NE.2.) GO TO 10
      DPDR=FTT
      E=1.5*FTT
      P=DPDR*RHO
      GO TO 60
   10 IF (RHO.GT.1.E-10) GO TO 20
      DPDR=FTT
      P=RHO*FTT
      E=ACK(L+10)+1.5*FTT
      GO TO 60
   20 CONTINUE
      RHO0=ACK(L+11)
      X1=RHO**.3333333333
      RHO00=ACK(L+19)
      X2=RHO/RHO00
      X3=X2**.3333333333
      X4=X2/X3
      X6=1./X3
      IF (X2.GT.1.) GO TO 70
      X5=1.-X6
      X7=EXP(ACK(L+5)*X5)
      X8=EXP(ACK(L+6)*X5)
      P=ACK(L+4)*(X7-X8)*X4
      DPDR=P/(1.5*RHO)+ACK(L+4)*(ACK(L+5)*X7-ACK(L+6)*X8)/(3.*X4*RHO00)
      E=3.*ACK(L+4)*((X7-1.)/ACK(L+5)-(X8-1.)/ACK(L+6))/RHO00
      IF (ACK(L+53).EQ.0.) GO TO 30
      IF (X2.GE.ACK(L+54)) GO TO 30
      X3=X2/ACK(L+54)
      X4=1.-X3
      X5=X4**2
      X6=ACK(L+53)*X2*X5/(5.*RHO00)
      E=E-X6*X5
      P=P+ACK(L+53)*(X3-.2)*X4*X5*X2**2
      DPDR=DPDR-X6*(X3*(30.*X3-20.)+2.)
   30 IF (RHO.GE.RHO0) GO TO 100
      THETA=RHO*ACK(L+16)
      GM=RHO*(ACK(L+17)+THETA)+1.
      GP=ACK(L+17)+2.*THETA
      THETA=ACK(L+14)*RHO*EXP(RHO*(ACK(L+17)+.5*THETA))
   40 PPP=ACK(L+13)*T*(X1/THETA)**2
      IF (PPP.GT.1.E5) GO TO 50
      X3=1./(1.+PPP)
      X4=2.+PPP
      X5=3.*GM+PPP
      S=FTT*X3
      EN=1.5*S*X4
      PN=RHO*S*X5
```

```
      CV=EN*(1.-PPP*X3/X4)/T
      X6=1.-3.*GM
      DPDT=PN*(1.+PPP*X6*X3/X5)/T
      DPDR=DPDR+PN*(1.+PPP*X3*X6**2/(1.5*X5))/RHO+3.*RHO*GP*S
      S=FT*(4.-3.*ALOG(THETA/T)+1.5*(ALOG(X3)-PPP*X3))
      GO TO 120
   50 DPDR=DPDR+FTT
      P=P+RHO*FTT
      E=E+1.5*FTT
   60 CV=1.5*FT
      DPDT=RHO*FT
      S=FT*(1.5*ALOG(T/ACK(L+13))-ALOG(RHO)+2.5)
      GO TO 130
   70 X8=ACK(L+33)*X6
      X5=EXP(-X8)
      X7=X5*ACK(L+32)
      IF (X2.GT.ACK(L+1)) GO TO 80
      P=X2*X4*X7-(ACK(L+34)+ACK(L+35)*X3+ACK(L+36)*X4)
      DPDR=(X7*X3*(5.*X3+ACK(L+33))-X6*(ACK(L+35)*X6+2.*ACK(L+36)))/(3.*
     1RHOOO)
      CALL EPINT3 (X8,X5,GM)
      E=(3.*ACK(L+32)*X4*GM+(ACK(L+34)+1.5*ACK(L+35)*X3+3.*ACK(L+36)*X4)
     1/X2-ACK(L+37))/RHOOO
      GO TO 100
   80 IF (X2.GT.ACK(L+2)) GO TO 90
      P=ACK(L+7)
      DPDR=0.
      E=ACK(L+8)+P*(X2-ACK(L+1))/(RHOOO*X2*ACK(L+1))
      GO TO 100
   90 P=X2*X4*X7-(ACK(L+38)+ACK(L+39)*X3+ACK(L+40)*X4)
      DPDR=(X7*X3*(5.*X3+ACK(L+33))-X6*(ACK(L+39)*X6+2.*ACK(L+40)))/(3.*
     1RHOOO)
      CALL EPINT3 (X8,X5,GM)
      E=ACK(L+9)+(3.*ACK(L+32)*X4*GM+(ACK(L+38)+1.5*ACK(L+39)*X3+3.*ACK(
     1L+40)*X4)/X2)/RHOOO
  100 X3=RHOO/RHO
      X4=1.-X3
      X5=ACK(L+24)
      X6=ACK(L+15)
      IF (X5.GT.0.) GO TO 110
      GM=X3*X6
      GP=-GM/RHO
      THETA=ACK(L+25)*EXP(X4*X6)
      GO TO 40
  110 GM=X3*X6+X5*X4**2
      GP=-X3*(X6-2.*X5*X4)/RHO
      THETA=ACK(L+25)*EXP(X4*X6-.5*X5*(3.-X3*(4.-X3)))*(RHO/RHOO)**X5
      GO TO 40
  120 E=E+EN
      P=P+PN
  130 IF (ACK(L+46)) 170,170,140
  140 IF (CMLT(7)) 170,160,150
  150 IF (T.GE.ACK(L+18)) GO TO 160
      IF (RHO.GE.ACK(L+46)) GO TO 170
      IF (T.LT.ACK(L+49)) GO TO 170
  160 X1=SQRT(T)
      X2=RHO**CMLT(1)*ACK(L+43)
      X3=RHO**CMLT(2)*ACK(L+44)
      X4=RHO**CMLT(3)*ACK(L+45)
      X5=X1*X2
      X6=X2/(2.*X1)
      S=S-X6
      DPDT=DPDT+CMLT(1)*X6*RHO
      CV=CV+.5*X6
      E=E+.5*X5+X3+X4
      P=P+(CMLT(1)*X5+CMLT(2)*X3+CMLT(3)*X4)*RHO
      DPDR=DPDR+(CMLT(4)*X5+CMLT(5)*X3+CMLT(6)*X4)
  170 RETURN
      END
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      SUBROUTINE ANEOS2 (IGK,NUM,ITAPE,IZETL)
C     SET UP FOR ANEOS PACKAGE
C     DIMENSIONS ARE SET FOR 20 EQUATIONS OF STATE
C     100 ELEMENTS (AN ELEMENT IS COUNTED ONCE IN EACH EOS)
C     1000 TWO-PHASE BOUNDARY POINTS
      DIMENSION IZETL(1)
      COMMON /ANES/ ACK(1080),ZZS(100),COT(100),FNI(100),RCT(21),TCT(21)
     1,RSOL(1000),RVAP(1000),TTWO(1000),SAVER(92),CMLT(8),ZB(92),DZB(40)
     2,BOLTS,EIP(4370),LOCSV(21),LOCKP(21),LOCKPL(21)
      DATA NACK,NLOCSV/4522,63/
      DATA IZ,IKPN/1,1/
      DATA IT/0/
C
      GO TO (10,1240,1250), IGK
   10 PRINT 1260
      CMLT(4)=CMLT(1)*(CMLT(1)+1.)
      CMLT(5)=CMLT(2)*(CMLT(2)+1.)
      CMLT(6)=CMLT(3)*(CMLT(3)+1.)
      DO 1220 IQ=1,NUM
      IF (IZETL(IQ).GT.0) GO TO 1220
      READ 1430, ISE,ISETAB,IZI,(DZB(I),I=1,5),RHUG,THUG
      PRINT 1440, ISE,ISETAB,IZI,(DZB(I),I=1,5),RHUG,THUG
      IF (ISE.GE.0) GO TO 30
      IF (ISE.LT.-20) GO TO 30
      DO 20 JJ=1,NUM
      MAT=IZETL(JJ)
      IF (MAT.EQ.ISE) GO TO 40
   20 CONTINUE
   30 PRINT 1450, ISE
      STOP 1000
   40 MAT=-MAT
      LOCSV(MAT)=IT
      LOCKP(MAT)=IKPN
      IF (ISETAB.EQ.0) READ 1460, (ZB(I),I=1,24)
      IF (ISETAB.NE.0) CALL ANDATA (IT,IZ,ISETAB)
   50 DO 60 I=1,40
   60 DZB(I)=0.
      IF (ZB(4).LE.0.) ZB(4)=.02567785
      DZB(28)=ZB(1)
      DZB(30)=ZB(2)
      DZB(11)=ZB(3)
      DZB(12)=ZB(4)
      DZB(20)=ZB(5)
      DZB(15)=ZB(7)
      DZB(25)=ZB(8)
      DZB(24)=ZB(10)/3.
      DZB(10)=ZB(11)
      DZB(18)=ZB(12)
      DZB(23)=ZB(17)
      DZB(1)=ZB(18)
      DZB(2)=ZB(19)
      DZB(7)=ZB(20)
      DZB(39)=ZB(21)
      DZB(40)=ZB(22)
      ACK(IT+46)=ACK(IT+54)=0.
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      IF (ZB(6)) 90,70,80
   70 IF (DZB(30)-2.) 130,110,130
   80 DZB(21)=ZB(6)
      TGAM=ZB(9)
      BOOT=0.
      GO TO 100
   90 BOOT=-ZB(6)
      GAM=ZB(9)
  100 IF (ZB(13).EQ.0.) GO TO 110
      S=ZB(14)
      IF (S.LE.0.) S=.95
      IF (S.GT..95) S=.95
      ACK(IT+54)=S
  110 ACK(IT+53)=ZB(13)
      ACK(IT+43)=ZB(23)
      ACK(IT+44)=ZB(24)
      ACK(IT+46)=0.
      CMLT(7)=1.
      IF (ISETAB.EQ.0) GO TO 120
      IF (DZB(30).EQ.2.) GO TO 120
      IF (IZI.LT.0) GO TO 120
      IF (IZI.GT.4) GO TO 120
      DZB(30)=IZI
  120 DZB(31)=IZ
      IF (DZB(3().GE.0.) GO TO 140
  130 PRINT 1400, DZB(30),(ZB(I),I=1,24)
      STOP
  140 IF (DZB(30).GT.4.) GO TO 130
      IF (DZB(23).LE.0..AND.DZB(30).NE.2.) DZB(23)=0.8*DZB(11)
      IF (DZB(25).LE.0..AND.DZB(30).NE.2.) DZB(25)=0.025
      ACK(IT+41)=ZB(16)
      IF (ZB(15).LE.0.) GO TO 150
      DZB(22)=5.48E12/ZB(15)
      ACK(IT+42)=DZB(22)/144.
      IF (ACK(IT+42).GT.0.1) ACK(IT+42)=0.1
      IF (ACK(IT+42).LT.1.E-4) ACK(IT+42)=1.E-4
      GO TO 160
  150 DZB(22)=0.
      ACK(IT+42)=0.1
  160 DO 170 I=1,8
  170 PRINT 1470, (J1,ZB(J1),J1=I,24,8)
      PRINT 1480
      J1=DZB(28)
      S=0.
      IZI=IZ+J1-1
      IF (ZZS(IZ).EQ.0.) READ 1560, (ZZS(I),COT(I),I=IZ,IZI)
      DO 180 I=IZ,IZI
      IF (COT(I).GT.0.) GO TO 180
      IKK=ZZS(I)
      IKK=(IKK*(IKK+1))/2
      COT(I)=-COT(I)/EIP(IKK)
  180 S=S+COT(I)
      DZB(26)=DZB(29)=0.
      S1=0.
      DO 200 I=IZ,IZI
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      COT(I)=COT(I)/S
      DZB(26)=DZB(26)+ZZS(I)*COT(I)
      IKK=ZZS(I)
      IKJ=IKK+(IKK*(IKK+1))/2
      IF (IKK.GE.1.AND.IKK.LE.92) GO TO 190
      PRINT 1490, IKK
      STOP 1017
  190 DZB(29)=DZB(29)+COT(I)*EIP(IKJ-IKK)
  200 S1=S1+COT(I)*EIP(IKJ-IKK)*1.66026E-24
      DZB(27)=0.
      DO 210 I=IZ,IZI
      FNI(I)=COT(I)/S1
  210 DZB(27)=DZB(27)+FNI(I)
      IF (DZB(30).EQ.2.) GO TO 240
      IF (BOOT.LE.0.) GO TO 240
      S1=3.*DZB(27)*BOLTS*DZB(12)*DZB(15)**2
      DZB(21)=DZB(11)*(BOOT**2-S1)
      S2=DZB(11)*BOOT**2/DZB(21)
      S2=S2*(2.*GAM-1.-(DZB(15)-2.)*(.5-.5/S2))
      S3=S1*DZB(11)/DZB(15)
      S4=S3*(1.+2.*S2)+DZB(21)
      S5=S4**2-8.*S2*S3**2
      IF (S5.LE.0.) GO TO 220
      S6=.5*(S4+SQRT(S5))
      S6=DZB(21)*S6/(S6-S3)**2
      S5=1.-S6
      IF (ABS(S5).LE.0.1) GO TO 230
      S6=1.-.1*S5/ABS(S5)
      GO TO 230
  220 S6=1.
  230 TGAM=3.*(S6*S2-DZB(15))
  240 S1=0.
      DO 250 I=IZ,IZI
      IKK=ZZS(I)
      IKK=(IKK*(IKK+1))/2
      S=EIP(IKK)*1.66026E-24
  250 S1=S1+ALOG(FNI(I)/(DZB(27)*(DZB(27)*S)**1.5))*FNI(I)/DZB(27)
      DZB(13)=4.36050E-42*DZB(27)**(5./3.)*EXP(2.*S1/3.)
      IKK=0
      GAM=DZB(15)+TGAM/3.
      IF (DZB(30).EQ.2) GO TO 410
      DZB(14)=DZB(25)*EXP(1.5-2.*DZB(15))/DZB(11)
      DZB(16)=(1.-2.*DZB(15))/DZB(11)**2
      DZB(17)=(3.*DZB(15)-2.)/DZB(11)
      I=0
      S3=GAM
      SPS=1.E6
C     SPS LIMITS POTENTIAL RANGE IF POSSIBLE
  260 S=1.-DZB(21)/(DZB(11)*DZB(10)*GAM**2)
      IF (S.LE.0.) GO TO 280
      S=SQRT(S)
      S1=ALOG(DZB(21)/(200.*SPS*GAM*S))
      S2=27.*GAM*(1.-S)
      IF (S2.GE.S1) GO TO 280
      I=I+1
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      IF (I.GT.400) GO TO 270
      GAM=0.99*GAM                                                      CHD 4383
      GO TO 260                                                         CHD 4384
  270 GAM=S3                                                            CHD 4385
  280 DFB1=GAM                                                          CHD 4386
  290 S=DZB(13)*DZB(12)*(DZB(11)**(1./3.)/DZB(25))**2                   CHD 4387
      SPS=S                                                             CHD 4388
      I=0                                                               CHD 4389
      S1=DZB(20)-DZB(11)*((3.*DZB(15)+S)/(1.+S))*DZB(27)*DZB(12)*BOLTS  CHD 4390
      IKK=IKK+1                                                         CHD 4391
      IF (IKK.EQ.2) GO TO 310                                           CHD 4392
      IF (DZB(15).EQ.1.) GO TO 300                                      CHD 4393
      S=1.+((2.*DZB(15)-1.)**2-2.)*S1/DZB(21)                           CHD 4394
      DZB(3)=DZB(21)*(SQRT(S**2+4.*DZB(15)*(DZB(15)-1.)*(1.-2.*S1/DZB(21CHD 4395
     1))**2)-S)*.5/(DZB(15)-1.)                                         CHD 4396
      GO TO 320                                                         CHD 4397
  300 DZB(3)=((DZB(21)-2.*S1)**2)/(DZB(21)-S1)                          CHD 4398
      GO TO 320                                                         CHD 4399
  310 CALL ANEOS1 (DZB(12),DZB(11),S,S2,S3,S4,S5,S6,IT)                 CHD 4400
      DZB(3)=DZB(3)*DZB(21)/(DZB(11)*S6)                                CHD 4401
  320 GAM=DFB1                                                          CHD 4402
  330 S2=DZB(3)/(DZB(11)*DZB(10)*GAM**2)                                CHD 4403
      IF (S2.LT.1.) GO TO 350                                           CHD 4404
      GAM=GAM*SQRT(1.00001*S2)                                          CHD 4405
      IF (I.GT.15) GAM=GAM*1.005                                        CHD 4406
      I=I+1                                                             CHD 4407
      IF (I.GT.40) STOP 20                                              CHD 4408
      IF (IKK.GE.2) GO TO 330                                           CHD 4409
      S1=DZB(20)-DZB(11)*((3.*DZB(15)+SPS)/(1.+SPS))*DZB(27)*DZB(12)*BOLCHD 4410
     1TS                                                                CHD 4411
      IF (GAM.EQ.1.) GO TO 340                                          CHD 4412
      S=1.+((2.*GAM-1.)**2-2.)*S1/DZB(21)                               CHD 4413
      DZB(3)=DZB(21)*(SQRT(S**2+4.*GAM*(GAM-1.)*(1.-2.*S1/DZB(21))**2)-SCHD 4414
     1)*.5/(GAM-1.)                                                     CHD 4415
      GO TO 330                                                         CHD 4416
  340 DZB(3)=((DZB(21)-2.*S1)**2)/(DZB(21)-S1)                          CHD 4417
      GO TO 330                                                         CHD 4418
  350 S3=1.                                                             CHD 4419
      S4=.8                                                             CHD 4420
  360 S5=.5*(S3+S4)                                                     CHD 4421
      S6=SQRT(1.-S2*S5)                                                 CHD 4422
      DZB(5)=3.*GAM*(1.+S6)                                             CHD 4423
      DZB(6)=3.*GAM*(1.-S6)                                             CHD 4424
      S6=6.*GAM*S6                                                      CHD 4425
      DZB(4)=S5**(-1./3.)                                               CHD 4426
      IF (S3-S4.LE.1.E-9) GO TO 390                                     CHD 4427
      S6=1.-3.*DZB(3)*(EXP(DZB(5)*(1.-DZB(4)))-EXP(DZB(6)*(1.-DZB(4))))/CHD 4428
     1(DZB(4)**2*S1*S6)                                                 CHD 4429
      IF (S6) 370,390,380                                               CHD 4430
  370 S4=S5                                                             CHD 4431
      GO TO 360                                                         CHD 4432
  380 S3=S5                                                             CHD 4433
      GO TO 360                                                         CHD 4434
  390 DZB(19)=DZB(11)/S5                                                CHD 4435
      DZB(4)=S1/(S5**(2./3.)*(EXP(DZB(5)*(1.-DZB(4)))-EXP(DZB(6)*(1.-DZBCHD 4436
                                                                        CHD 4437
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     1(4))))
 400 S=3.1415926536
     DZB(32)=(3.*6.6252E-27**2/(20.*9.1084E-28*S))*(S/3.)**(1./3.)*(DZB
    1(19)*DZB(26)*DZB(27))**(5./3.)
     DZB(33)=(S*9.1084E-28/.9)*(4.80288E-10/6.6252E-27)**2*(18.*DZB(26)
    1**(1./3.)/5.+11./(12.*S**2*DZB(26))**(1./3.))/(2.*DZB(19)*DZB(27))
    2**(1./3.)
     S2=DZB(33)
     S=DZB(32)*EXP(-S2)
     S9=DZB(15)
     DZB(15)=S*(+TGAM/3.
     DZB(34)=S*(6.+3.*DZB(33)+.5*DZB(33)**2)-9.*DZB(3)*DZB(15)
     DZB(35)=3.*DZB(3)*(6.*DZB(15)+1.)-S*(15.+7.*DZB(33)+DZB(33)**2)
     DZB(36)=S*(10.+4.*DZB(33)+.5*DZB(33)**2)-3.*DZB(3)*(3.*DZB(15)+1.)
     DZB(15)=S9
     S1=EXP(-S2)
     CALL EPINT3 (S2,S1,S)
     DZB(37)=3.*DZB(32)*S+DZB(34)+1.5*DZB(35)+3.*DZB(36)
 410 DO 420 I=1,40
 420 ACK(IT+I)=DZB(I)
     DO 430 I=1,92
     S=I
 430 SAVER(I)=ALOG(S+0.5)
     IF (IKK-1) 540,290,440
 440 IKK=0
     S1=DZB(11)/DZB(19)
     S2=DZB(3)
     S8=3.*DZB(15)
     S9=DZB(11)*DZB(27)*BOLTS*DZB(12)*(S8+SPS)/(1.+SPS)
     S8=S9*SPS*(1.+2.*(S8-1.)**2/(3.*(1.+SPS)))/(S8+SPS)
 450 IKK=IKK-1
     IF (IKK.LT.-500) GO TO 540
     S=-1.
     BOOT=.9999*S2
     ETAOT=S1
     GO TO 500
 460 PCO1=S3
     PCP1=S7
     BOOT=S2
     ETAOT=.9999*S1
     S=0.
     GO TO 500
 470 PCO2=S3
     PCP2=S7
     ETAOT=S1
     S=1.
     GO TO 500
 480 DFB1=10000.*(S3-PCO1)/S2
     DFB2=10000.*(S7-PCP1)/S2
     DFN1=10000.*(S3-PCO2)/S1
     DFN2=10000.*(S7-PCP2)/S1+(DZB(21)-S8)/S1**2
     S3=S3+S9-DZB(20)
     S7=S7-(DZB(21)-S8)/S1
     S=DFN1*DFB2-DFN2*DFB1
     IF (S.EQ.0.) GO TO 540
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      DFB1=(S7*DFB1-S3*DFB2)/S
      DFB2=(S3*DFN2-S7*DFN1)/S
      IF (ABS(DFB1).GT.0.002*S1) DFB1=0.002*S1*DFB1/ABS(DFB1)
      IF (ABS(DFB2).GT.0.002*S2) DFB2=0.002*S2*DFB2/ABS(DFB2)
      IF (S3.LT.0..AND.IKK.GT.-200) GO TO 490
      IF (ABS(DFB1).GT.1.E-10*S1) GO TO 490
      IF (ABS(DFB2).LE.1.E-10*S2) GO TO 530
  490 S1=S1+DFB1
      S2=S2+DFB2
      GO TO 450
  500 S4=1.-BOOT*ETAOT/(DZB(11)*DZB(10)*GAM**2)
      IF (S4) 510,510,520
  510 GAM=SQRT(1.00001*BOOT*ETAOT/(DZB(11)*DZB(10)))
      GO TO 450
  520 S4=SQRT(S4)
      S5=3.*GAM*(1.+S4)
      S6=3.*GAM*(1.-S4)
      S4=BOOT/(2.*GAM*S4)
      DFN1=ETAOT**.3333333333
      DFN2=EXP(S5*(1.-1./DFN1))
      DFB1=EXP(S6*(1.-1./DFN1))
      DFB2=DFN1**2
      S3=S4*(DFN2-DFB1)*(ETAOT/DFN1)
      S7=S4*((2.*DFN1+S5)*DFN2-(2.*DFN1+S6)*DFB1)/(3.*DFB2)
      IF (S) 460,470,480
  530 DZB(3)=S2
      DZB(19)=DZB(11)/S1
      DZB(4)=S4
      DZB(5)=S5
      DZB(6)=S6
      GO TO 400
  540 CONTINUE
      IF (ABS(DZB(15)+TGAM/3.-GAM).LT.1.E-4) GO TO 550
      S1=3.*(GAM-DZB(15))
      PRINT 1500, TGAM,S1
  550 CALL ANPHTR (DZB,MAT,TGAM)
      DO 560 I=1,40
  560 ACK(IT+I)=DZB(I)
      IF (DZB(18).GT.0.) GO TO 630
      IF (DZB(30).EQ.2.) GO TO 630
      S7=1.
  570 SPS=DZB(12)
      S=DZB(11)
      CALL ANEOS1 (SPS,S,S1,S2,S3,S4,S5,S6,IT)
      S9=S7*S2-DZB(18)
      IF (S9) 610,580,580
  580 SPS=SPS+.01
      S8=S2
      IF (SPS.GT.1.) GO TO 610
      JJ=0
  590 JJ=JJ+1
      IF (JJ.GT.1000) GO TO 610
      CALL ANEOS1 (SPS,S,S1,S2,S3,S4,S5,S6,IT)
      IF (ABS(S1).LE.10.) GO TO 600
      S5=S1/S6
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      IF (ABS(S5).GT.0.01*S) S5=0.01*S*S5/ABS(S5)
      S=S-S5
      GO TO 590
  600 IF (S2-S9) 580,620,620
  610 PRINT 1390, SPS,S,S9,S2,S1,JJ
      STOP
  620 ACK(IT+18)=DZB(18)=((S9-S8)*SPS+(S2-S9)*(SPS-.01))/(S2-S8)
  630 IF (ACK(IT+30).EQ.2.) ACK(IT+43)=0.
      IF (ACK(IT+43)) 640,830,650
  640 ACK(IT+43)=ACK(IT+18)*1.117E12/ACK(IT+29)
  650 IF (ACK(IT+44).EQ.0.) ACK(IT+44)=.95
  660 S1=S2=ACK(IT+49)=I1=0
      ACK(IT+47)=1.E50
      IF (ACK(IT+30).LT.2.) S2=-1.
      S=ACK(IT+18)
      GAM=ACK(IT+43)
      RCT(MAT)=.2*ACK(IT+19)
      CALL ANMAXW (S,S1,S2,IT,MAT,I1)
      IF (ACK(IT+43).EQ.0.) GO TO 850
      PCO2=CMLT(8)
      CMLT(8)=1.
      IF (I1.GE.0) GO TO 680
  670 PRINT 1270
      CMLT(8)=PCO2
      ACK(IT+46)=ACK(IT+43)=IKK=0
      S2=-1
      CALL ANMAXW (S,S1,S2,IT,MAT,IKK)
      IF (IKK.LT.0) GO TO 830
      CALL ANEOS1 (S,S1,S4,S5,S6,S7,S8,S9,IT)
      PRINT 1280, S
      DZB(18)=-S5-GAM
      S7=0.
      GO TO 570
  680 IF (ACK(IT+44).LT.0.) ACK(IT+44)=-ACK(IT+44)/S1
      S2=ACK(IT+44)*S1
      IF (S2.LT.S1) GO TO 690
      PRINT 1290, S2,S1
      GO TO 670
  690 CALL ANEOS1 (S,S1,S4,S5,S6,S7,S8,S9,IT)
      CALL ANEOS1 (S,S2,DFB1,DFB2,BOOT,S7,S8,S9,IT)
      S5=ACK(IT+43)+S5-DFB2
      S6=S6-BOOT+(ACK(IT+43)+S4*(1./S2-1./S1))/S
      S4=S4-DFB1
      ACK(IT+46)=S1
      ACK(IT+47)=S2
      S1=S4/S2
      S8=S6*S
      S9=(S1+(2.*CMLT(1)-CMLT(2))*S8-CMLT(2)*S5)/(CMLT(3)-CMLT(2))
      S8=S5+S8-S9
      ACK(IT+44)=S8/S2**CMLT(2)
      ACK(IT+45)=S9/S2**CMLT(3)
      ACK(IT+43)=-2.*SQRT(S)*S6/S2**CMLT(1)
      ACK(IT+48)=ACK(IT+50)=ACK(IT+51)=1.E50
      ACK(IT+52)=DFN1=ETAOT=I1=0
      PCO1=10.*S
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      IF (PC01.GT..8) PC01=.8                                          CHD 4603
      S3=S                                                             CHD 4604
  700 S3=1.02*S3                                                       CHD 4605
      IKK=1                                                            CHD 4606
      CALL ANLS (S3,S2,S1,BOOT,IT,MAT,IKK)                             CHD 4607
      IF (IKK.LT.0) GO TO 670                                          CHD 4608
      DFN2=(S3-S)/(S1-S2)                                              CHD 4609
      IF (DFN2.GT.DFN1) DFN1=DFN2                                      CHD 4610
      IF (S3.GT.PC01) GO TO 710                                        CHD 4611
      IF (BOOT.LE.ACK(IT+11)) GO TO 710                                CHD 4612
      S7=(S3-S)/(BOOT-ACK(IT+11))                                      CHD 4613
      IF (S7.LT.ACK(IT+51)) ACK(IT+51)=S7                              CHD 4614
      ETAOT=S3                                                         CHD 4615
  710 IF (BOOT/S1-1..LE.5.E-5) GO TO 720                               CHD 4616
      IF (S1.LE.100.*ACK(IT+11)) GO TO 730                             CHD 4617
  720 ACK(IT+48)=S3                                                    CHD 4618
      GO TO 750                                                        CHD 4619
  730 I1=I+1                                                           CHD 4620
      IF (I1-500) 700,700,740                                          CHD 4621
  740 PRINT 1300, S3,S1,BOOT                                           CHD 4622
      GO TO 670                                                        CHD 4623
  750 ACK(IT+50)=1.05*DFN1                                             CHD 4624
      IF (ETAOT.LE.0.) GO TO 760                                       CHD 4625
      ACK(IT+52)=ETAOT                                                 CHD 4626
      ACK(IT+51)=.9999*ACK(IT+51)                                      CHD 4627
  760 S1=1.E50                                                         CHD 4628
      I1=0                                                             CHD 4629
      S3=S                                                             CHD 4630
  770 S3=.990*S3                                                       CHD 4631
      IKK=1                                                            CHD 4632
      S8=S1                                                            CHD 4633
      IF (S8.LT.ACK(IT+47)) IKK=3                                      CHD 4634
      CALL ANLS (S3,S2,BOOT,S1,IT,MAT,IKK)                             CHD 4635
      IF (IKK.LT.0) GO TO 790                                          CHD 4636
      IF (S1.GT.ACK(IT+23)) GO TO 800                                  CHD 4637
  780 ACK(IT+49)=S3                                                    CHD 4638
      GO TO 820                                                        CHD 4639
  790 IF (IKK.NE.-3) GO TO 670                                         CHD 4640
      PRINT 1310, ACK(IT+23),S8                                        CHD 4641
      ACK(IT+23)=S8                                                    CHD 4642
      S3=DFN1                                                          CHD 4643
      GO TO 780                                                        CHD 4644
  800 I1=I1+1                                                          CHD 4645
      DFN1=S3                                                          CHD 4646
      IF (I1-500) 770,770,810                                          CHD 4647
  810 PRINT 1320, S3,S1,BOOT                                           CHD 4648
      GO TO 670                                                        CHD 4649
  820 CONTINUE                                                         CHD 4650
      CMLT(8)=PC02                                                     CHD 4651
      GO TO 870                                                        CHD 4652
  830 DO 840 I=43,52                                                   CHD 4653
  840 ACK(IT+I)=0.                                                     CHD 4654
      IF (ACK(IT+30)-2.) 870,870,660                                   CHD 4655
  850 IF (I1.LT.0) GO TO 860                                           CHD 4656
      ACK(IT+47)=S1                                                    CHD 4657
```

```
      GO TO 870
  860 ACK(IT+47)=ACK(IT+11)
  870 DO 880 I=1,18
  880 PRINT 1510, (I1,ACK(IT+I1),I1=I,54,18)
      PRINT 1480
      I1=ACK(IT+31)
      I2=ACK(IT+28)
      DO 890 I=1,I2
      PRINT 1520, I,ZZS(I1),I,COT(I1),I,FNI(I1)
  890 I1=I1+1
      IF (ACK(IT+12).LE.0.) GO TO 900
      IF (ACK(IT+11).LE.0.) GO TO 900
      CALL ANEOS (ACK(IT+12),ACK(IT+11),S1,S2,S3,S4,S5,S6,DZB(1),DZB(2),
     1I,MAT)
      DZB(3)=ACK(IT+11)*S6
      PRINT 1530, ACK(IT+12),ACK(IT+11),S1,S2,S3,S4,S5,S6,DZB(3),DZB(2)
  900 SPS=ACK(IT+30)
      CALL ANPHASE (MAT,IT,IKPN)
      IF (SPS-ACK(IT+30)) 910,920,910
  910 IF (ACK(IT+46).LE.0.) GO TO 920
      PRINT 1330, MAT
      ZB(2)=ACK(IT+30)
      GO TO 50
  920 LOCKPL(MAT)=IKPN-1
      PRINT 1540, MAT,LOCKP(MAT),MAT,LOCKPL(MAT)
      IF (ACK(IT+46).LE.0.) GO TO 1190
      DFN1=CMLT(8)
      CMLT(7)=PCP1=DFN2=I1=0
      CMLT(8)=1.
      PRINT 1350
      BOOT=ACK(IT+49)
  930 I2=2
      S7=1.E10
      CALL ANLS (BOOT,S7,S1,S2,IT,MAT,I2)
      IF (I2.GE.0) GO TO 940
      I1=1
      GO TO 1110
  940 CMLT(7)=-1.
      CALL ANEOS1 (BOOT,S2,S3,S4,S5,S6,S7,S8,IT)
      S9=S4-BOOT*S5+S3/S2
      CMLT(7)=0.
      PRINT 1360, BOOT,S2,S3,S4,S5,S9
      CALL ANEOS1 (BOOT,S1,S3,S4,S5,S6,S7,S8,IT)
      S9=S4-BOOT*S5+S3/S1
      PRINT 1370, I2,S1,S3,S4,S5,S9
C     CHECK FAST ITERATION
      CMLT(8)=0.
      DO 1100 I2=1,3
      IF (I2-2) 950,980,990
  950 PCO1=ACK(IT+47)+(BOOT-ACK(IT+18))/ACK(IT+50)
      IF (BOOT-ACK(IT+18)) 960,1100,970
  960 PCO1=ACK(IT+23)
  970 PCO2=S1
      GO TO 1000
  980 PCO1=S1
```

```
      PCO2=S2
      GO TO 1000                                                        CHD 4713
  990 PCO1=S2                                                           CHD 4714
      PCO2=S2+10.                                                       CHD 4715
 1000 IF (1.0001*PCO1.GE.PCO2) GO TO 1100                               CHD 4716
      DO 1090 IKJ=1,3                                                   CHD 4717
      IF (IKJ-2) 1010,1020,1030                                         CHD 4718
 1010 PCP2=.99                                                          CHD 4719
      GO TO 1040                                                        CHD 4720
 1020 PCP2=.5                                                           CHD 4721
      GO TO 1040                                                        CHD 4722
 1030 PCP2=.01                                                          CHD 4723
 1040 PCP2=PCP2*PCO1+(1.-PCP2)*PCO2                                     CHD 4724
      IF (PCP2.LE.ACK(IT+23)) GO TO 1090                                CHD 4725
      CALL ANEOS (BOOT,PCP2,S3,S4,S5,S6,S7,S8,S9,SPS,JJ,MAT)            CHD 4726
      IF (I2-2) 1050,1060,1070                                          CHD 4727
 1050 IF (JJ-6) 1080,1090,1080                                          CHD 4728
 1060 IF (JJ-5) 1080,1090,1080                                          CHD 4729
 1070 IF (JJ-4) 1080,1090,1080                                          CHD 4730
 1080 PRINT 1340, MAT,PCP2,BOOT,JJ                                      CHD 4731
      PCP1=MAT                                                          CHD 4732
 1090 CONTINUE                                                          CHD 4733
 1100 CONTINUE                                                          CHD 4734
      CMLT(8)=1.                                                        CHD 4735
 1110 DFN2=DFN2+1.                                                      CHD 4736
      IF (DFN2-3.) 1120,1130,1140                                       CHD 4737
 1120 BOOT=BOOT+(ACK(IT+18)-ACK(IT+49))/3.                              CHD 4738
      GO TO 1150                                                        CHD 4739
 1130 BOOT=ACK(IT+18)                                                   CHD 4740
      GO TO 1150                                                        CHD 4741
 1140 BOOT=BOOT*(ACK(IT+48)/ACK(IT+18))**.06                            CHD 4742
 1150 IF (BOOT.LT.ACK(IT+48)) GO TO 930                                 CHD 4743
      IF (PCP1) 1160,1170,1160                                          CHD 4744
 1160 CMLT(8)=MAT                                                       CHD 4745
      GO TO 1180                                                        CHD 4746
 1170 CMLT(8)=DFN1                                                      CHD 4747
 1180 IF (I1.EQ.1) PRINT 1380                                           CHD 4748
 1190 CMLT(7)=0.                                                        CHD 4749
      IF (ACK(IT+30).EQ.2.) GO TO 1210                                  CHD 4750
      IF (ACK(IT+1).GT.1.E50) GO TO 1210                                CHD 4751
      PRINT 1410                                                        CHD 4752
      S3=ACK(IT+11)                                                     CHD 4753
      IF (ACK(IT+1).GE.1.E50) S3=.05*S3                                 CHD 4754
      IF (ACK(IT+1).GE.1.E50) S2=S3                                     CHD 4755
      IF (ACK(IT+1).LT.1.E50) S2=(ACK(IT+2)*ACK(IT+19)-S3)/25.          CHD 4756
      DO 1200 I=1,50                                                    CHD 4757
      CMLT(7)=-1.                                                       CHD 4758
      CALL ANEOS1 (1.E-6,S3,S4,S5,S6,S7,S8,GAM,IT)                      CHD 4759
      S6=S3/ACK(IT+19)                                                  CHD 4760
      PRINT 1420, S3,S4,GAM,S5,S6                                       CHD 4761
 1200 S3=S3+S2                                                          CHD 4762
 1210 IT=IT+54                                                          CHD 4763
      IZ=IZI+1                                                          CHD 4764
      CMLT(7)=0.                                                        CHD 4765
      IF (THUG.LT.0.) THUG=DZB(12)                                      CHD 4766
                                                                        CHD 4767
```

```
      IF (RHUG.LT.0.) RHUG=DZB(11)                                      CHD 4768
      CALL ANHUG (MAT,RHUG,THUG)                                        CHD 4769
 1220 CONTINUE                                                          CHD 4770
      IF (IZ.GT.100) GO TO 1230                                         CHD 4771
      IF (IT.GT.1080) GO TO 1230                                        CHD 4772
      IF (IKPN.GT.1000) GO TO 1230                                      CHD 4773
      RETURN                                                            CHD 4774
 1230 PRINT 1550, IZ,IT,IKPN                                            CHD 4775
      STOP 1016                                                         CHD 4776
C                                                                       CHD 4777
C     WRITE RESTART DATA                                                CHD 4778
 1240 WRITE (ITAPE) (ACK(I),I=1,NACK),(LOCSV(I),I=1,NLOCSV)             CHD 4779
      RETURN                                                            CHD 4780
C                                                                       CHD 4781
C     READ RESTART DATA                                                 CHD 4782
 1250 READ (ITAFE) (ACK(I),I=1,NACK),(LOCSV(I),I=1,NLOCSV)              CHD 4783
      RETURN                                                            CHD 4784
C                                                                       CHD 4785
 1260 FORMAT (27H1 CHART D ANALYTIC EOS DATA,10X,12HVERSION 8/71)       CHD 4786
 1270 FORMAT (//,35H  UNABLE TO INCLUDE MELT TRANSITION,5X,21HWILL CONTICHD 4787
     1NUE WITHOUT)                                                      CHD 4788
 1280 FORMAT (34H0 MELT TEMPERATURE INCREASED FROM ,E12.5,/)            CHD 4789
 1290 FORMAT (//,7H  RHOL=,E13.6,4X,5HRHOS=,E13.6)                      CHD 4790
 1300 FORMAT (//,29H  HIGH TEMPERATURE MELT ERROR,3E15.6)               CHD 4791
 1310 FORMAT (/,42H0 WARNING - ZB(17) HAS BEEN INCREASED FROM,E12.5,3H TCHD 4792
     10,E12.5,24H FOR THE MELT TRANSITION,/)                            CHD 4793
 1320 FORMAT (//,28H  LOW TEMPERATURE MELT ERROR,3E15.6)                CHD 4794
 1330 FORMAT (29H1 RECALCULATION OF EOS NUMBER,I5)                      CHD 4795
 1340 FORMAT (34H  FAST ANLS ITERATION FAILURE MAT=,I5,/,6H  RHO=,E12.5,CHD 4796
     13X,2HT=,E12.5,2X,7HKPHASE=,I5)                                    CHD 4797
 1350 FORMAT (13H1  MELT CURVE,//,7X,1HT,10X,2HRS,10X,2HPS,10X,2HES,10X,CHD 4798
     12HSS,10X,2HGS,/,18X,2HRL,10X,2HPL,10X,2HEL,10X,2HSL,10X,2HGL)     CHD 4799
 1360 FORMAT (/,6E12.4)                                                 CHD 4800
 1370 FORMAT (I10,2X,5E12.4)                                            CHD 4801
 1380 FORMAT (///,27H  DO NOT USE THIS EOS......)                       CHD 4802
 1390 FORMAT (24H0 MELT TEMPERATURE ERROR,/,5E13.4,I6)                  CHD 4803
 1400 FORMAT (18H0 THERE IS NO TYPE,E12.5,4H EOS,/,(8E13.6))            CHD 4804
 1410 FORMAT (27H1 ZERO-TEMPERATURE ISOTHERM,//,8X,3HRHO,10X,1HP,9X,4HDPCHD 4805
     1DR,10X,1HE,10X,3HETA)                                             CHD 4806
 1420 FORMAT (2X,5E12.4)                                                CHD 4807
 1430 FORMAT (I3,I5,I2,5A10,2E10.3)                                     CHD 4808
 1440 FORMAT (34H1 EOS DATA FOR ANALYTIC EOS NUMBER,I6,5X,14HLIBRARY NUMCHD 4809
     1BER,I5,5X,4HTYPE,I3,//,2X,5A10,//,7H  RHUG=,E12.4,9X,5HTHUG=,E12.4CHD 4810
     2,/)                                                               CHD 4811
 1450 FORMAT (7H1 ISE =,I6)                                             CHD 4812
 1460 FORMAT (8E10.3)                                                   CHD 4813
 1470 FORMAT (3(5H   ZB(,I2,2H)=,E16.9))                                CHD 4814
 1480 FORMAT (1X)                                                       CHD 4815
 1490 FORMAT (34H1 THE IONIZATION POTENTIALS FOR Z=,I4,17H ARE NOT IN TACHD 4816
     1BLE)                                                              CHD 4817
 1500 FORMAT (48H0 TGAM FOR EXPANDED STATES HAS BEEN CHANGED FROM,E13.5,CHD 4818
     13H TO,E13.5,/)                                                    CHD 4819
 1510 FORMAT (3(4H   C(,I2,2H)=,E16.9))                                 CHD 4820
 1520 FORMAT (4H   Z(,I2,2H)=,F4.0,7H    COT(,I2,2H)=,E12.5,7H    FNI(,I2,2CHD 4821
     1H)=,E12.5)                                                        CHD 4822
 1530 FORMAT (28H0 REFERENCE POINT CONDITIONS,/,4H   T=,E14.6,7X,4HRHO=,ECHD 4823
     114.6,/,4H   P=,E14.6,7X,2HE=,E14.6,/,4H   S=,E14.6,7X,3HCV=,E14.6,/,CHD 4824
     27H   DPDT=,E14.6,4X,5HDPDR=,E14.6,/,5H   B0=,E14.6,6X,3HCS=,E14.6) CHD 4825
 1540 FORMAT (8H0 LOCKP(,I2,2H)=,I4,11H     LOCKPL(,I2,2H)=,I4)         CHD 4826
 1550 FORMAT (25H1 ARRAY OVERFLOW IN ANEOS,10X,3HIZ=,I5,5H   IT=,I5,7H   ICHD 4827
     1KPN=,I6)                                                          CHD 4828
 1560 FORMAT (5(F5.0,E10.3))                                            CHD 4829
      END                                                               CHD 4830
```

```
      SUBROUTINE ANION1 (T,RHO,Z,FN,P,E,S,CV,DPDT,DPDR,ZBAR,TTT)
C     ANEOS PACKAGE
C     SINGLE-ELEMENT IONIZATION CALCULATION
      COMMON /ANES/ ACK(1080),ZZS(100),COT(100),FNI(100),RCT(21),TCT(21)
     1,RSOL(1000),RVAP(1000),TTWO(1000),SAVER(92),CMLT(8),ZB(92),DZB(40)
     2,BOLTS,EIP(4370),LOCSV(21),LOCKP(21),LOCKPL(21)
      T32=6.E21*TTT/(RHO*FN)
      IZ=Z
      I1=(IZ*(IZ+1))/2+1
      FLT=ALOG(T32)
      EIU=EIP(I1)
      EIL=EIU/T
      FK1=T32*EXP(-EIL)
      IF (FK1.GT.0.5) GO TO 20
      K=0
      ZBAR=.5*(SQRT(FK1*(FK1+4.))-FK1)
      IF (ZBAR.GT.1.E-6) GO TO 10
      ZBAR=P=E=S=CV=DPDT=DPDR=0.
      GO TO 130
   10 DZBT=FK1*(1.-ZBAR)/(2.*ZBAR+FK1)
      DZBR=-DZBT/RHO
      DZBT=DZBT*(1.5+EIL)/T
      GO TO 100
   20 I2=I1+IZ-1
      EIU=EIP(I2)
      EIL=EIU/T
      FK2=T32*EXP(-EIL)
      IF (FK2.LT.Z-0.5) GO TO 30
      K=IZ-1
      FK1=FK2-Z+1.
      ZBAR=.5*(SQRT(FK1**2+4.*Z*FK2)-FK1)
      IF (FK1.GT.1.E7) ZBAR=Z
      DZBT=FK2*(Z-ZBAR)/(2.*ZBAR+FK1)
      DZBR=-DZBT/RHO
      DZBT=DZBT*(1.5+EIL)/T
      GO TO 100
   30 DO 40 I=1,IZ
      K=I-1
      ZBAR=I
      ZBAR=ZBAR+0.5
      EIU=EIP(I1+I)
      FI=EIU/T+SAVER(I)-FLT
      IF (FI.GE.0.) GO TO 50
   40 CONTINUE
      STOP 4040
   50 EIL=EIP(I1+K)
      DLL=(EIU-EIL)/T
      FIBAR=EIU
      ZBARU=ZBAR
      ZBARL=ZBAR-1.
      K=0
   60 FIP=1./ZBAR+DLL
      DZBAR=-FI/FIF
      ZZBAR=ZBAR
      ZBAR=ZBAR+DZBAR
```

```
      IF (ABS(DZBAR).LE.1.E-6*ZZBAR) GO TO 90                            CHD 4886
   70 K=K+1                                                              CHD 4887
      IF (K.GT.100) STOP 4041                                            CHD 4888
      IF (ZBAR.GT.0.) GO TO 80                                           CHD 4889
      ZBAR=ZBAR-.5*DZBAR                                                 CHD 4890
      GO TO 70                                                           CHD 4891
   80 FIBAR=EIL*(ZBARU-ZBAR)+EIU*(ZBAR-ZBARL)                            CHD 4892
      FI=FIBAR/T+ALOG(ZBAR)-FLT                                          CHD 4893
      GO TO 60                                                           CHD 4894
   90 DZBT=ZBAR/(T+ZBAR*(EIU-EIL))                                       CHD 4895
      DZBR=-T*DZBT/RHO                                                   CHD 4896
      DZBT=DZBT*(1.5+FIBAR/T)                                            CHD 4897
      K=ZBAR                                                             CHD 4898
  100 ZBARL=FN*BOLTS                                                     CHD 4899
      P=ZBAR*ZBARL*RHO*T                                                 CHD 4900
      DPDT=RHO*ZBARL*(ZBAR+T*DZBT)                                       CHD 4901
      DPDR=ZBARL*T*(ZBAR+RHO*DZBR)                                       CHD 4902
      E=0.                                                               CHD 4903
      IF (K.EQ.0) GO TO 120                                              CHD 4904
      DO 110 I=1,K                                                       CHD 4905
  110 E=E+EIP(I1+I-1)                                                    CHD 4906
  120 EIL=K                                                              CHD 4907
      EIU=EIP(I1+K)                                                      CHD 4908
      E=ZBARL*(1.5*ZBAR*T+E+(ZBAR-EIL)*EIU)                              CHD 4909
      CV=ZBARL*(1.5*(ZBAR+T*DZBT)+EIU*DZBT)                              CHD 4910
      S=ZBAR*ZBARL*(FLT+2.5-ALOG(ZBAR))                                  CHD 4911
  130 RETURN                                                             CHD 4912
      END                                                                CHD 4913
```

```
      SUBROUTINE ANION2 (T,RHO,FN,ZBARM,NMATS,IIZ,TTT,ZBAR,P,E,S,DPT,DPR
     1,CV)
C     ANEOS PACKAGE
C     MULTIPLE-ELEMENT IONIZATION CALCULATION
      COMMON /ANES/ ACK(1080),ZZS(100),COT(100),FNI(100),RCT(21),TCT(21)
     1,RSOL(1000),RVAP(1000),TTWO(1000),SAVER(92),CMLT(8),ZB(92),DZB(40)
     2,BOLTS,EIP(4370),LOCSV(21),LOCKP(21),LOCKPL(21)
      DATA ZRAT/.000045/
      IT=0
      ISK=IIZ-1
      XX=6.E21*TTT/(RHC*FN)
      ZBAR=ZRAT*XX
      IF (ZBAR.LT.1.E-6) GO TO 30
      IF (ZBAR.GT.ZBARM) ZBAF=.99*ZBARM
   10 IT=IT+1
      IF (IT.GT.200) STOP 200
      FLXX=T*ALOG(XX/ZBAR)
      ZC1=ZC2=ZC3=ZC4=ZC5=ZC6=0.
      DO 20 I=1,NMATS
      CALL ANION3 (T,RHO,XX,FLXX,IIZ,ZBAR,I,I1,S,P,E)
      C=COT(ISK+I)
      ZC1=ZC1+C*ZB(I)
      ZC2=ZC2+C*P
      ZC3=ZC3+C*S
      ZC4=ZC4+C*E
      KK=ZB(I)
      C=FNI(ISK+I)*EIP(I1+KK)
      ZC5=ZC5+C*S
   20 ZC6=ZC6+C*P
      DEL=(ZBAR-ZC1)/(ZC2-1.)
      YY=ZBAR+DEL
      IF (YY.GT.1.E-6) GO TO 70
      IF (ZBAR.LE.1.E-6) GO TO 40
      IF (YY.LT.0.) GO TO 60
   30 ZBAR=1.E-6
      GO TO 10
   40 ZBAR=E=P=S=CV=DPR=DPT=ZRAT=0.
      DO 50 I=1,NMATS
   50 ZB(I)=0.
      RETURN
   60 IF (YY.GE.0.) GO TO 70
      YY=YY-.5*DEL
      GO TO 60
   70 IF (YY.LE.ZBARM) GO TO 80
      YY=.7*ZBARM+.3*ZBAR
   80 IF (ABS(YY-ZBAR).LE.1.E-5*(YY+ZBAR)) GO TO 90
      ZBAR=YY
      GO TO 10
   90 E=ZC3/(1.-ZC2)
      S=ZC4/(1.-ZC2)
      ZC1=FN*BOLTS
      P=ZC1*ZBAR*RHO*T
      DPT=ZC1*(ZBAR+T*E)
      CV=1.5*DPT+(ZC5+E*ZC6)*BOLTS
      DPT=RHO*DPT
```

```
      DPR=ZC1*T*(ZBAR+RHO*S)                                            CHD 4969
      E=0.                                                              CHD 4970
      DO 120 I=1,NMATS                                                  CHD 4971
      IZ=ISK+I                                                          CHD 4972
      C=FNI(IZ)                                                         CHD 4973
      I1=ZZS(IZ)                                                        CHD 4974
      I1=(I1*(I1+1))/2                                                  CHD 4975
      KK=ZB(I)                                                          CHD 4976
      IF (KK.EQ.0) GO TO 110                                            CHD 4977
      DO 100 J=1,KK                                                     CHD 4978
  100 E=E+C*EIP(I1+J)                                                   CHD 4979
  110 S=KK                                                              CHD 4980
  120 E=E+C*(ZB(I)-S)*EIP(I1+KK+1)                                      CHD 4981
      E=1.5*ZBAR*ZC1*T+E*BOLTS                                          CHD 4982
      S=ZBAR*ZC1*(FLXX/T+2.5)                                           CHD 4983
      XX=ZBAR/XX                                                        CHD 4984
      IF (XX.GT.1.E-10) ZRAT=XX                                         CHD 4985
      RETURN                                                            CHD 4986
      END                                                               CHD 4987
```

```
      SUBROUTINE ANION3 (T,RHO,XX,FLXX,IIZ,ZBAR,JKI,I1,AI,BI,DI)
C     ANEOS PACKAGE
C     PART OF MULTIPLE-ELEMENT IONIZATION CALCULATION
      COMMON /ANES/ ACK(1080),ZZS(100),COT(100),FNI(100),RCT(21),TCT(21)
     1,RSOL(1000),RVAP(1000),TTWO(1000),SAVER(92),CMLT(8),ZB(92),DZB(40)
     2,BOLTS,EIP(4370),LOCSV(21),LOCKP(21),LOCKPL(21)
      IZ=Z=ZZS(IIZ+JKI-1)
      I1=(IZ*(IZ+1))/2+1
      FK=XX*EXP(-EIP(I1)/T)
      ZBARI=FK+ZBAR
      IF (ZBARI.GT.0.) GO TO 10
      ZBARI=BI=AI=DI=0.
      GO TO 70
   10 ZBARI=FK/(FK+ZBAR)
      IF (ZBARI.GT.0.5) GO TO 30
      IF (ZBARI.LT.1.E-10) GO TO 20
      BI=-ZBARI**2/FK
      AI=-ZBAR*BI*(1.5+EIP(I1)/T)/T
      DI=ZBAR*BI/RHO
      GO TO 70
   20 ZBARI=AI=BI=DI=0.
      GO TO 70
   30 I2=I1+IZ-1
      FK=XX*EXP(-EIP(I2)/T)
      ZBARI=Z-ZBAR/(ZBAR+FK)
      IF (ZBARI.LT.Z-0.5) GO TO 40
      BI=-FK/(FK+ZBAR)**2
      AI=-ZBAR*BI*(1.5+EIP(I2)/T)/T
      DI=ZBAR*BI/RHO
      GO TO 70
   40 DO 50 I=1,IZ
      N=I
      ZBARI=I
      ZBARI=ZBARI+0.5
      EIU=EIP(I1+I)
      FK=FLXX-EIU
      IF (FK) 60,60,50
   50 CONTINUE
      STOP 3030
   60 EIL=EIP(I1+N-1)
      DL=EIU-EIL
      ZBARI=N
      ZBARI=(EIU*(ZBARI-.5)-EIL*(ZBARI+.5)+FLXX)/DL
      BI=-T/(DL*ZBAR)
      AI=(FLXX/T+1.5)/DL
      DI=-T/(RHO*DL)
   70 ZB(JKI)=ZBARI
      RETURN
      END
```

```
      SUBROUTINE EPINT3 (ARG,EXPARG,ANS)
C     ANEOS PACKAGE
C     DETERMINES THIRD EXPONENTIAL INTEGRAL
C     EXPARG=EXF(-ARG)
C     EXPIN=FIRST EXPONENTIAL INTEGRAL
      DIMENSION CE(5)
      DATA CEO,CE,AE1,AE2,AE3,AE4,BE1,BE2,BE3,BE4/-.57721566,.99999193,-
     1.24991055,.05519968,-.00976004,.00107857,8.5733287,18.059017,8.634
     27609,.26777373,9.5733223,25.632956,21.099653,3.9584969/
      IF (ARG.GT.1.) GO TO 20
      EXPIN=CEO-ALOG(ARG)
      X1=1.
      DO 10 I=1,5
      X1=ARG*X1
   10 EXPIN=EXPIN+X1*CE(I)
      GO TO 40
   20 IF (ARG.LT.100.) GO TO 30
      EXPIN=0.
      GO TO 40
   30 EXPIN=EXPARG*(((((ARG+AE1)*ARG+AE2)*ARG+AE3)*ARG+AE4)/(ARG*((((ARG
     1+BE1)*ARG+BE2)*ARG+BE3)*ARG+BE4)))
   40 ANS=.5*(EXPARG-ARG*(EXPARG-ARG*EXPIN))
      RETURN
      END
```

```
      SUBROUTINE ANTWOPH (T,R,MAT,P,E,S,CV,DPDT,DPDR,LOC,KPA)
C     ANEOS PACKAGE
C     EVALUATES THERMODYNAMIC FUNCTIONS IN THE LIQUID-VAPOR AND
C     SOLID-VAPOR REGIONS
      COMMON /ANES/ ACK(1080),ZZS(100),COT(100),FNI(100),RCT(21),TCT(21)
     1,RSOL(1000),RVAP(1000),TTWO(1000),SAVER(92),CMLT(8),ZB(92),DZB(40)
     2,BOLTS,EIP(4370),LOCSV(21),LOCKP(21),LOCKPL(21)
      COMMON /BNES/ PM,EM,SM,CVM,DPDTM,DPDRM
      DATA SLP/1.03/
      K1=LOCKP(MAT)
      K2=LOCKPL(MAT)
      DO 10 I=K1,K2
      KJ=I+1
      IF (T.GE.TTWO(KJ)) GO TO 20
   10 CONTINUE
      STOP 1543
   20 KK=KJ-1
      TL=TTWO(KJ)
      TU=TTWO(KK)
      IF (KK.GT.K1) GO TO 30
      X1=((TU-T)/(TU-TL))**.3333333333
      R1=RSOL(KK)+(RSOL(KJ)-RSOL(KK))*X1
      IF (R.GE.SLP*R1) GO TO 40
      R2=RVAP(KK)-(RVAP(KK)-RVAP(KJ))*X1
      IF (R.LE.R2) GO TO 40
      R1P=(RSOL(KK)-RSOL(KJ))*X1/(3.*(TU-T))
      R2P=(RVAP(KK)-RVAP(KJ))*X1/(3.*(TU-T))
      GO TO 50
   30 DT=TU-TL
      R1=((T-TL)*RSOL(KK)+(TU-T)*RSOL(KJ))/DT
      IF (R.GE.SLP*R1) GO TO 40
      R2=((T-TL)*RVAP(KK)+(TU-T)*RVAP(KJ))/DT
      IF (R.GT.R2) GO TO 50
   40 KPA=1
      RETURN
   50 KPA=2
      CALL ANEOS1 (T,R2,P2,E2,S2,CV2,DPDT2,DPDR2,LOC)
      IF (R.LE.R1) GO TO 60
      CALL ANEOS1 (T,R,P,E,S,CV,DPDT,DPDR,LOC)
      IF (P.GE.P2) GO TO 40
      CALL ANEOS1 (T,R1,P1,E1,S1,CV1,DPDT1,DPDR1,LOC)
      P=P2
      DPDR=0.
      DPDT=(S2-S1)*(R1*R2)/(R1-R2)
      RETURN
   60 IF (ACK(LOC+46)) 110,110,70
   70 IF (TU-ACK(LOC+18)) 80,90,110
   80 CMLT(7)=-1.
      CALL ANEOS1 (T,R1,P1,E1,S1,CV1,DPDT1,DPDR1,LOC)
      CMLT(7)=0.
      GO TO 120
   90 KK=0
C     FATAL FLAG SET TO STOP IN ANLS
      CALL ANLS (T,R1,X1,X2,LOC,MAT,KK)
      IF (KK-2) 80,100,110
```

```
100 P1=PM
    E1=EM
    S1=SM
    CV1=CVM
    DPDT1=DPDTM
    DPDR1=DPDRM
    GO TO 120
110 CALL ANEOS1 (T,R1,P1,E1,S1,CV1,DPDT1,DPDR1,LOC)
120 X3=R1-R2
    X1=(R1-R)/X3
    X2=(R-R2)/X3
    FM1=R1*X2/R
    FM2=R2*X1/R
    E=FM1*E1+FM2*E2
    S=FM1*S1+FM2*S2
    IF (P1.LE.P2) GO TO 130
    DPDR=0.995*R1+0.005*R2
    IF (R.LE.DPDR) GO TO 130
    X4=R1-DPDR
    P=(P1*(R-DPDR)+P2*(R1-R))/X4
    DPDR=(P1-P2)/X4
    GO TO 140
130 P=P2
    DPDR=0.
140 DPDT=(S2-S1)*R1*R2/X3
    IF (KK.EQ.K1) GO TO 150
    X4=(RVAP(KK)-RVAP(KJ))/DT
    X5=(RSOL(KK)-RSOL(KJ))/DT
    GO TO 160
150 X4=R2P
    X5=R1P
160 CONTINUE
    X3=-(R1*X1*X4+R2*X2*X5)/(R*X3)
    X1=CV1+(P1-T*DPDT1)*X5/R1**2
    X2=CV2+(P2-T*DPDT2)*X4/R2**2
    CV=X3*(E1-E2)+FM1*X1+FM2*X2
    RETURN
    END
```

```
      SUBROUTINE ANPHASE (MAT,IT,IKPN)                                  CHD 5154
C     ANEOS PACKAGE                                                     CHD 5155
C     SET UP FOR LIQUID-VAPOR AND SOLID-VAPOR CALCULATION               CHD 5156
C     DETERMINES CRITICAL POINT                                         CHD 5157
      COMMON /ANES/ ACK(1080),ZZS(100),COT(100),FNI(100),RCT(21),TCT(21)CHD 5158
     1,RSOL(1000),RVAP(1000),TTWO(1000),SAVER(92),CMLT(8),ZB(92),DZB(40)CHD 5159
     2,BOLTS,EIP(4370),LOCSV(21),LOCKP(21),LOCKPL(21)                   CHD 5160
      COMMON /CNES/ P1,E1,S1,G1,P2,E2,S2,G2                             CHD 5161
      IF (ACK(IT+30).LE.2.) RETURN                                      CHD 5162
      NTY=0                                                             CHD 5163
      KLY=0                                                             CHD 5164
      CMLT(7)=0.                                                        CHD 5165
   10 KLY=KLY+1                                                         CHD 5166
      GO TO (20,30), KLY                                                CHD 5167
   20 RCT(MAT)=.3*ACK(IT+19)                                            CHD 5168
      TCT(MAT)=2.                                                       CHD 5169
      GO TO 40                                                          CHD 5170
   30 RCT(MAT)=ACK(IT+19)                                               CHD 5171
      TCT(MAT)=.05                                                      CHD 5172
   40 S3=.001                                                           CHD 5173
   50 R1=S3*RCT(MAT)                                                    CHD 5174
      T1=S3*TCT(MAT)                                                    CHD 5175
      KK=-2                                                             CHD 5176
      DO 70 I=1,9                                                       CHD 5177
      IF (3*((I-1)/3).NE.I-1) GO TO 60                                  CHD 5178
      KK=KK+1                                                           CHD 5179
      KN=-2                                                             CHD 5180
   60 KN=KN+1                                                           CHD 5181
      T2=KK                                                             CHD 5182
      T2=TCT(MAT)*(1.+.5*S3*T2)                                         CHD 5183
      R2=KN                                                             CHD 5184
      R2=RCT(MAT)*(1.+.5*S3*R2)                                         CHD 5185
      CALL ANEOS1 (T2,R2,P1,E1,S1,D1,D2,RSOL(IKPN+I),IT)                CHD 5186
      IF (I.NE.5) GO TO 70                                              CHD 5187
      RSOL(IKPN+10)=P1                                                  CHD 5188
      RSOL(IKPN+11)=E1                                                  CHD 5189
      RSOL(IKPN+12)=S1                                                  CHD 5190
   70 CONTINUE                                                          CHD 5191
      D1=RSOL(IKPN+5)                                                   CHD 5192
      D2=(RSOL(IKPN+6)-RSOL(IKPN+4))/R1                                 CHD 5193
      D3=(RSOL(IKPN+8)-RSOL(IKPN+2))/T1                                 CHD 5194
      D4=4.*(RSOL(IKPN+6)-2.*RSOL(IKPN+5)+RSOL(IKPN+4))/(R1**2)         CHD 5195
      D5=(RSOL(IKPN+9)-RSOL(IKPN+7)-RSOL(IKPN+3)+RSOL(IKPN+1))/(R1*T1)  CHD 5196
      DR2=D3*D4-D2*D5                                                   CHD 5197
      DR1=(D2*D2-D1*D4)/DR2                                             CHD 5198
      DR2=(D1*D5-D2*D3)/DR2                                             CHD 5199
      IF (ABS(DR1).GT.1.E-6*TCT(MAT)) GO TO 80                          CHD 5200
      IF (ABS(DR2).LE.1.E-6*RCT(MAT)) GO TO 130                         CHD 5201
   80 IF (ABS(DR1).LE..1*TCT(MAT)) GO TO 90                             CHD 5202
      DR1=.1*TCT(MAT)*DR1/ABS(DR1)                                      CHD 5203
   90 IF (ABS(DR2).LE..1*RCT(MAT)) GO TO 100                            CHD 5204
      DR2=.1*RCT(MAT)*DR2/ABS(DR2)                                      CHD 5205
  100 RCT(MAT)=RCT(MAT)+DR2                                             CHD 5206
      TCT(MAT)=TCT(MAT)+DR1                                             CHD 5207
      IF (S3.EQ.0.0001) GO TO 110                                       CHD 5208
```

```
      IF (ABS(DR1).GT.1.E-3*TCT(MAT)) GO TO 110
      IF (ABS(DR2).GT.1.E-3*RCT(MAT)) GO TO 110
      S3=.0001
  110 NTY=NTY+1
      IF (NTY-100) 50,10,120
  120 IF (NTY-200) 50,140,140
  130 IF (RSOL(IKPN+10).GT.0.) GO TO 260
C     LAST RESORT METHOD TO FIND CRITICAL POINT
  140 CONTINUE
      R1=ACK(IT+19)
      NTY=200
  150 KLY=0
      T1=-9.999
      T2=10.
  160 D4=.5*(T1+T2)
      CALL ANEOS1 (D4,R1,P1,E1,S1,D1,D2,D3,IT)
      KLY=KLY+1
      IF (KLY.GT.1000) GO TO 240
      IF (T2-T1.LE.1.E-6*D4) GO TO 210
      IF (D3) 170,210,180
  170 T1=D4
      GO TO 160
  180 IF (T1) 200,200,190
  190 T2=D4
      GO TO 160
  200 D5=0.
      GO TO 220
  210 IF (D4.LT.D5) GO TO 230
      D5=D4
  220 NTY=NTY+1
      R2=0.005*R1
      IF (R2.LT.1.E-4) R2=1.E-4
      R1=R1-R2
      IF (R1) 240,240,150
  230 TCT(MAT)=D5
      RCT(MAT)=R1+R2
      CALL ANEOS1 (TCT(MAT),RCT(MAT),RSOL(IKPN+10),RSOL(IKPN+11),RSOL(IK
     1PN+12),D1,D2,D3,IT)
      GO TO 260
  240 PRINT 440, MAT
  250 ACK(IT+30)=ACK(IT+30)-3.
      RETURN
  260 KN=IKPN+10
      KK=KN+2
      PRINT 450, MAT,RCT(MAT),TCT(MAT),(RSOL(I),I=KN,KK),NTY
      IF (RSOL(KN).LE.0.) GO TO 240
      IF (TCT(MAT).GT.ACK(IT+18)) GO TO 270
      PRINT 460, ACK(IT+18)
      GO TO 250
C     FIND LIQUID-VAPOR PHASE BOUNDARIES
  270 KK=60
      KN=20
      IF (ACK(IT+18).GT.0.15) KN=30
      IF (ACK(IT+18).GT.0.25) KN=40
      KLY=0
```

```
      RSOL(IKPN)=RVAP(IKPN)=RCT(MAT)
      TTWO(IKPN)=TCT(MAT)
      PRINT 470
      IK=IKPN+1
      D5=KK
      D5=(TCT(MAT)-ACK(IT+18))/D5
      D6=KN
      D6=ACK(IT+18)/D6
      DO 390 JJJ=1,2
      D4=D5
      JJJJ=KK+10
      T=TCT(MAT)
      D1=0.
      IF (ACK(IT+46).GT.0.) D1=ACK(IT+47)
      IF (JJJ.E(.1) GO TO 280
      D4=D6
      JJJJ=KN
      T=ACK(IT+18)
      IF (ACK(IT+46).LE.0.) GO TO 280
      JJJJ=KN+1
      T=.99*T+D4
      D1=0.
  280 DO 390 I=1,JJJJ
      IF (I.EQ.KK-9) D4=.5*D4
      T=T-D4
      IF (T.GT.0.95*TCT(MAT)) GO TO 390
      IF (JJJ.EQ.2.AND.T.GE.TTWO(IK-1)) GO TO 390
      IF (I.EQ.KK+10) T=ACK(IT+18)
      IF (T.LT.0.015) GO TO 400
      R2=NTY=0
      R1=D1
      IF (ACK(IT+46).GT.0..AND.T.EQ.ACK(IT+18)) R1=-R1
      IF (RVAP(IK-1).LE.1.E-100) R2=-1.
      IF (IK.GT.IKPN+1) GO TO 290
      IF (KLY.GE.12) GO TO 290
      NTY=-1
  290 CALL ANMAXW (T,R1,R2,IT,MAT,NTY)
      IF (NTY) 300,340,340
  300 KLY=KLY+1
      IF (IK.EQ.IKPN+1) GO TO 330
      IF (KLY-2) 310,320,320
  310 IF (T.EQ.ACK(IT+18)) GO TO 320
      PRINT 410
      GO TO 390
  320 PRINT 420
      GO TO 250
  330 IF (KLY-13) 390,310,320
  340 RSOL(IK)=R1
      RVAP(IK)=R2
      TTWO(IK)=T
      IK=IK+1
      KLY=0
      IF (T-ACK(IT+18)) 370,360,350
  350 IF (R1.LE.ACK(IT+47)) GO TO 370
      PRINT 430, T,R1
```

```
      GO TO 370                                                         CHD 5319
  360 IF (R1.LT.ACK(IT+23)) PRINT 480, ACK(IT+23),R1                    CHD 5320
      GO TO 380                                                         CHD 5321
  370 IF (JJJ.EQ.2.AND.I.EQ.1.AND.ACK(IT+46).GT.0.) GO TO 380           CHD 5322
      IF (5*(I/5).NE.I) GO TO 390                                       CHD 5323
  380 PRINT 490, T,R1,P1,E1,S1,G1,NTY,R2,P2,E2,S2,G2                    CHD 5324
  390 CONTINUE                                                          CHD 5325
  400 RSOL(IK)=ACK(IT+19)                                               CHD 5326
      RVAP(IK)=0.                                                       CHD 5327
      TTWO(IK)=0.                                                       CHD 5328
      IKPN=IK+1                                                         CHD 5329
      RETURN                                                            CHD 5330
C                                                                       CHD 5331
  410 FORMAT (23H  WILL LEAVE POINT OUT.)                               CHD 5332
  420 FORMAT (26H  WILL CHANGE FORM OF EOS.)                            CHD 5333
  430 FORMAT (62H  WARNING - NEGATIVE EXPANSION COEFFICIENT IN THE LIQUICHD 5334
     1D PHASE,/,2X,2HT=,E12.5,2X,4HRHO=,E12.5,5X,29HIMPROPER BEHAVIOR WICHD 5335
     2LL RESULT)                                                        CHD 5336
  440 FORMAT (68H0 THE CRITICAL POINT ITERATION WILL NOT CONVERGE FOR MACHD 5337
     1TERIAL NUMBER,I5,26H. WILL CHANGE FORM OF EOS.)                   CHD 5338
  450 FORMAT (36H1 TWO-PHASE CALCULATION FOR MATERIAL,I5,/,16H  CRITICALCHD 5339
     1 POINT,/,6H  RHO=,E15.7,7X,2HT=,E15.7,9X,2HP=,E15.7,/,2X,2HE=,E15.CHD 5340
     27,9X,2HS=,E15.7,9X,4HNTY=,I5,/)                                   CHD 5341
  460 FORMAT (26H0 THE MELTING TEMPERATURE(,E15.7,64H) IS GREATER THAN CCHD 5342
     1RITICAL TEMPERATURE. WILL CHANGE FORM OF EOS.)                    CHD 5343
  470 FORMAT (22H0 TWO-PHASE BOUNDARIES,/,7X,1HT,9X,6HRHOLIQ,8X,4HPLIQ,9CHD 5344
     1X,4HELIQ,9X,4HSLIQ,9X,4HGLIQ,/,17X,6HRHOVAP,8X,4HPVAP,9X,4HEVAP,9XCHD 5345
     2,4HSVAP,9X,4HGVAP)                                                CHD 5346
  480 FORMAT (40H0 WARNING - - THE MINIMUM SOLID DENSITY(,E12.5,43H) IS CHD 5347
     1GREATER THAN THE TRIPLE POINT DENSITY(,E12.5,2H).,/,68H  IMPROPER CHD 5348
     2SOLID BEHAVIOR WILL RESULT. TO CORRECT USE SMALLER VALUE.,/)      CHD 5349
  490 FORMAT (/,6E13.5,/,I13,5E13.5)                                    CHD 5350
      END                                                               CHD 5351
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      SUBROUTINE ANMAXW (T,RL,RV,L,MAT,IERR)                            CHD 5352
C     ANEOS PACKAGE                                                     CHD 5353
C     LIQUID-VAPOR AND SOLID-VAPOR MAXWELL CONSTRUCTION                 CHD 5354
      COMMON /ANES/ ACK(1080),ZZS(100),COT(100),FNI(100),RCT(21),TCT(21)CHD 5355
     1,RSOL(1000),RVAP(1000),TTWO(1000),SAVER(92),CMLT(8),ZB(92),DZB(40)CHD 5356
     2,BOLTS,EIP(4370),LOCSV(21),LOCKP(21),LOCKPL(21)                   CHD 5357
      COMMON /CNES/ P1,E1,S1,G1,P2,E2,S2,G2                             CHD 5358
      N=NP=0                                                            CHD 5359
      CM7=CMLT(7)                                                       CHD 5360
      IF (IERR.LT.0) NP=1                                               CHD 5361
      IF (RV.LT.0.) GO TO 230                                           CHD 5362
      RVO=RLO=RCT(MAT)                                                  CHD 5363
      RV=ACK(L+25)**3*EXP(3.*ACK(L+15)-1.-ACK(L+10)/(ACK(L+27)*BOLTS*T))CHD 5364
     1/(ACK(L+13)*T)**1.5                                               CHD 5365
      IF (RL) 10,20,30                                                  CHD 5366
   10 RL=-RL                                                            CHD 5367
      AL=0.                                                             CHD 5368
      GO TO 40                                                          CHD 5369
   20 RL=ACK(L+19)                                                      CHD 5370
   30 AL=1.                                                             CHD 5371
   40 RLM=RL                                                            CHD 5372
      DP2=1.E-3*RL                                                      CHD 5373
      IF (RV.GT.DP2) RV=DP2                                             CHD 5374
      IF (RV.LT.1.E-100) RV=1.E-100                                     CHD 5375
   50 IERR=0                                                            CHD 5376
   60 CALL ANEOS1 (T,RV,P2,E2,S2,D1,D2,DP2,L)                           CHD 5377
      IF (DP2.GT.0.) GO TO 80                                           CHD 5378
      RVO=RV                                                            CHD 5379
      RV=.99*RV                                                         CHD 5380
      IF (IERR.GT.30) RV=.5*RV                                          CHD 5381
      IERR=IERR+1                                                       CHD 5382
      IF (IERR-900) 60,60,70                                            CHD 5383
   70 IERR=-1                                                           CHD 5384
      GO TO 220                                                         CHD 5385
   80 G2=E2-T*S2+P2/RV                                                  CHD 5386
      IERR=0                                                            CHD 5387
   90 IF (T.LT.ACK(L+18)) CMLT(7)=-1.                                   CHD 5388
      CALL ANEOS1 (T,RL,P1,E1,S1,D1,D2,DP1,L)                           CHD 5389
      CMLT(7)=CM7                                                       CHD 5390
      IF (DP1.GT.0.) GO TO 110                                          CHD 5391
      RLO=RL                                                            CHD 5392
      RL=1.005*RL                                                       CHD 5393
      IERR=IERR+1                                                       CHD 5394
      IF (IERR-900) 90,90,100                                           CHD 5395
  100 IERR=-2                                                           CHD 5396
      GO TO 220                                                         CHD 5397
  110 G1=E1-T*S1+P1/RL                                                  CHD 5398
      SP=P1-P2                                                          CHD 5399
      SG=G1-G2                                                          CHD 5400
      DRL=AL*RL*(SP-RV*SG)/(DP1*(RV-RL))                                CHD 5401
      DRV=RV*(SP-RL*SG)/(DP2*(RV-RL))                                   CHD 5402
      IF (ABS(DRL).GT.1.E-6*RL) GO TO 120                               CHD 5403
      IF (ABS(DRV).LE.1.E-6*RV) GO TO 200                               CHD 5404
  120 IF (N.GT.40) DRL=.5*DRL                                           CHD 5405
      IF (N.LT.60) GO TO 130                                            CHD 5406
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      DRL=.05*DRL
      IF (ABS(SP).GT.1.E-2*(P1+P2+1.E4)) GO TO 130
      IF (ABS(SG).LE.1.E-2*(ABS(G1)+ABS(G2))) GO TO 200
  130 SP=RL+DRL
      IF (SP.GT.RLO) GO TO 150
  140 DRL=.5*DRL
      GO TO 130
  150 IF (DRL.GT.0.1*RL) GO TO 140
  160 SG=RV+DRV
      IF (SG.GT.0.) GO TO 180
  170 DRV=.5*DRV
      GO TO 160
  180 IF (SG.GE.RVC) GO TO 170
      RV=SG
      RL=SP
      N=N+1
      IF (N-500) 50,50,190
  190 IERR=-3
      GO TO 210
  200 IERR=N
      IF (RL.LE.RLM) RETURN
      PRINT 310, T,RL
      RETURN
  210 IF (RV.LT.1.E-100) GO TO 230
  220 IF (NP.EQ.0) PRINT 320, T,IERR,RV,RL
      RETURN
C     VAPOR DENSITY TOO SMALL TO CALCULATE
C     LIQUID-SOLID POINT AT P=0.
  230 RL=RLM=ACK(L+19)
      N=0
      IF (T.LT.ACK(L+18)) CMLT(7)=-1.
      P2=.5*RL
      E2=RL
  240 CALL ANEOS1 (T,RL,P1,E1,S1,D1,D2,DP1,L)
      IF (P1.LT.0..AND.N.LT.800) GO TO 250
      IF (ABS(P1).LE.1.E-3) GO TO 300
      IF (E2-P2.LE.1.E-9) GO TO 300
  250 IF (P1) 260,300,270
  260 P2=RL
      GO TO 280
  270 E2=RL
  280 RL=.5*(E2+P2)
      N=N+1
      IF (N-900) 240,240,290
  290 IERR=-4
      GO TO 220
  300 RV=1.E-100
      CMLT(7)=CM7
      CALL ANEOS1 (T,RV,P2,E2,S2,D1,D2,DP1,L)
      GO TO 200
C
  310 FORMAT (55H0 WARNING - POSSIBLE NEGATIVE EXPANSION COEFFICIENT  T=
     1,E12.5,5H RHC=,E12.5)
  320 FORMAT (42H0 ANMAXM TWO-PHASE CONVERGENCE ERROR AT T=,E12.5,6H IER
     1R=,I5,2E15.7)
      END
```

```
      SUBROUTINE ANLS (T,RHO,RL,RS,L,MAT,IERR)
C     ANEOS PACKAGE
C     SOLID-LIQUID TWO-PHASE MAXWELL CONSTRUCTION (MELT)
      COMMON /ANES/ ACK(1080),ZZS(100),COT(100),FNI(100),RCT(21),TCT(21)
     1,RSOL(1000),RVAP(1000),TTWO(1000),SAVER(92),CMLT(8),ZB(92),DZB(40)
     2,BOLTS,EIP(4370),LOCSV(21),LOCKP(21),LOCKPL(21)
      COMMON /BNES/ PM,EM,SM,CVM,DPDTM,DPDRM
      NP=0
      IF (CMLT(8)) 10,50,10
   10 IF (IERR-1) 50,20,30
   20 NP=1
      GO TO 70
   30 IF (IERR.EQ.3) GO TO 40
      NP=2
      IF (T-ACK(L+18)) 70,70,90
   40 NP=3
      GO TO 70
   50 IF (T-ACK(L+18)) 60,60,80
   60 IF (RHO.GE.ACK(L+46)) GO TO 250
      IF (RHO.LT.ACK(L+23)) GO TO 260
      IF (T.LT.ACK(L+49)) GO TO 250
   70 RL=ACK(L+47)
      RS=ACK(L+46)
      GO TO 120
   80 IF (RHO.LE.ACK(L+47)) GO TO 260
      IF (T.GE.ACK(L+48)) GO TO 260
   90 RL=ACK(L+47)+(T-ACK(L+18))/ACK(L+50)
      IF (RHO.LE.RL) GO TO 260
      RS=RL*ACK(L+46)/ACK(L+47)
      IF (CMLT(8)) 120,100,120
  100 IF (T.GT.ACK(L+52)) GO TO 110
      SS46=ACK(L+18)+ACK(L+51)*(RHO-ACK(L+11))
      IF (T.LT.SS46) GO TO 250
  110 IF (RHO.LE.RS) GO TO 120
      GSX=0.05
      RL=0.99*RHO
      RS=1.01*RHO
      GO TO 130
  120 GSX=0.02
  130 IERR=0
      SS46=ACK(L+46)
  140 ACK(L+46)=0.
      CALL ANEOS1 (T,RS,PS,ES,SS,CVS,DPDTS,DPDRS,L)
      ACK(L+46)=SS46
      IF (DPDRS.LE.0.) GO TO 300
      CALL ANEOS1 (T,RL,PL,EL,SL,CVL,DPDTL,DPDRL,L)
      IF (DPDRL.LE.0.) GO TO 300
      X1=PL-PS
      GL=EL-T*SL+PL/RL
      GS=ES-T*SS+PS/RS
      X2=GL-GS
      DRL=DPDRS*(1./RS-1./RL)
      IF (DRL.EQ.0.) GO TO 270
      DRS=(X2-X1/RL)/DRL
      DRL=(DRS*DPDRS-X1)/DPDRL
```

```
      IF (CMLT(8)) 210,150,210                                          CHD 5518
  150 IF (1.04*RS-RHO) 160,210,180                                      CHD 5519
  160 IF (DRL) 170,210,210                                              CHD 5520
  170 IF (DRS) 250,210,210                                              CHD 5521
  180 IF (RL-1.04*RHO) 210,210,190                                      CHD 5522
  190 IF (DRL) 210,210,200                                              CHD 5523
  200 IF (DRS) 210,210,260                                              CHD 5524
  210 ADRS=ABS(DRS)                                                     CHD 5525
      ADRL=ABS(DRL)                                                     CHD 5526
      IF (ADRS.GT.1.E-7*RS) GO TO 220                                   CHD 5527
      IF (ADRL.LE.1.E-7*RL) GO TO 240                                   CHD 5528
  220 IF (IERR.LT.400) GO TO 230                                        CHD 5529
      DRS=.1*DRS                                                        CHD 5530
      DRL=.1*DRL                                                        CHD 5531
      IF (IERR.GT.500) GO TO 280                                        CHD 5532
  230 GL=GSX*RS                                                         CHD 5533
      IF (ADRS.GT.GL) DRS=GL*DRS/ADRS                                   CHD 5534
      GL=GSX*RL                                                         CHD 5535
      IF (ADRL.GT.GL) DRL=GL*DRL/ADRL                                   CHD 5536
      RS=RS+DRS                                                         CHD 5537
      RL=RL+DRL                                                         CHD 5538
      IF (RS.LE.RL) RS=1.00001*RL                                       CHD 5539
      IERR=IERR+1                                                       CHD 5540
      GO TO 140                                                         CHD 5541
  240 NERR=IERR                                                         CHD 5542
      IF (RHO.LE.RL) GO TO 260                                          CHD 5543
      IF (RHO.GE.RS) GO TO 250                                          CHD 5544
      IERR=2                                                            CHD 5545
      GO TO 310                                                         CHD 5546
  250 IERR=1                                                            CHD 5547
      GO TO 320                                                         CHD 5548
  260 IERR=3                                                            CHD 5549
      GO TO 320                                                         CHD 5550
  270 IERR=-1                                                           CHD 5551
      GO TO 290                                                         CHD 5552
  280 IERR=-2                                                           CHD 5553
  290 PRINT 330, T,RHO,IERR,RS,RL,DRS,DRL                               CHD 5554
      IF (NP.GE.1) RETURN                                               CHD 5555
      STOP                                                              CHD 5556
  300 IERR=-4                                                           CHD 5557
      IF (NP.LE.2) GO TO 290                                            CHD 5558
      IERR=-3                                                           CHD 5559
      RETURN                                                            CHD 5560
C     IN LIQUID-SOLID REGION HERE                                       CHD 5561
  310 X2=RHO*(RS-RL)                                                    CHD 5562
      DRS=RS*(RHO-RL)/X2                                                CHD 5563
      DRL=RL*(RS-RHO)/X2                                                CHD 5564
      DPDTM=(SL-SS)*((RS*RL)/(RS-RL))                                   CHD 5565
      DRLDT=(DP[TM-DPDTL)/DPDRL                                         CHD 5566
      DRSDT=(DPDTM-DPDTS)/DPDRS                                         CHD 5567
      X1=-RHO*(RL*(RHO-RL)*DRSDT+RS*(RS-RHO)*DRLDT)/X2**2               CHD 5568
      EM=DRS*ES+DRL*EL                                                  CHD 5569
      SM=DRS*SS+DRL*SL                                                  CHD 5570
      CVM=X1*(ES-EL)+DRS*(CVS+(PS-T*DPDTS)*DRSDT/RS**2)+DRL*(CVL+(PL-T*DCHD 5571
     1PDTL)*DRLDT/RL**2)                                                CHD 5572

      DPDRM=0.                                                          CHD 5573
      PM=DRS*PS+DRL*PL                                                  CHD 5574
  320 IF (NP.EQ.2) IERR=NERR                                            CHD 5575
      RETURN                                                            CHD 5576
C                                                                       CHD 5577
  330 FORMAT (///,21H0 FATAL ERROR IN ANLS,2E12.5,I5,4E13.5)            CHD 5578
      END                                                               CHD 5579
```

```
      SUBROUTINE ANHUG (M,RO,TO)
C     ANEOS PACKAGE
C     HUGONIOT CALCULATION
      DIMENSION TS(48), CD(8)
      COMMON /BIG/ B(1)
      EQUIVALENCE (PO,B(1)), (EO,B(2)), (SO,B(3)), (D1,B(4)), (D2,B(5)),
     1 (D3,B(6)), (D4,B(7)), (VO,B(8)), (T,B(9)), (R,B(10)), (P,B(11)),
     2(E,B(12)), (S,B(13)), (CV,B(14)), (PT,B(15)), (PR,B(16)), (F,B(17)
     3), (DF,B(18)), (DR,B(19)), (V,B(20)), (U,B(21)), (TS(1),B(22))
      EQUIVALENCE (CD(1),B(75))
      DATA (TS(I),I=1,48)/.026,.0265,.0275,.0285,.03,.035,.04,.05,.06,.0
     18,.1,.12,.14,.16,.18,.2,.25,.3,.35,.4,.45,.5,.55,.6,.65,.7,.75,.8,
     2.85,.9,.95,1.,1.1,1.2,1.3,1.4,1.5,1.7,2.,2.5,3.,4.,5.,6.,7.,8.,9.,
     310./
      IF (RO.LE.0.) RETURN
      IF (TO.LE.0.) RETURN
      PRINT 40
      CALL ANEOS (1.E-6,RO,CD(1),CD(2),CD(3),CD(4),CD(5),CD(6),CD(7),CD(
     18),KP,M)
      CALL ANEOS (TO,RO,PO,EO,SO,D1,D2,D3,D4,VO,KP,M)
      D1=0.
      D2=1.
      PRINT 60
      PRINT 50, RO,TO,PO,CD(1),EO,SO,VO,D1,D2
      N=51
      DO 30 I=1,48
      T=TS(I)
      IF (T.LE.TO) GO TO 30
      IF (N.GT.50) R=RO
      N=0
   10 CALL ANEOS (T,R,P,E,S,CV,PT,PR,D1,D2,KP,M)
      F=E-EO+.5*(PO+P)*(RO-R)/(R*RO)
      DF=(P-T*PT)/R**2+.5*PR*(RO-R)/(RO*R)-.5*(PO+P)/R**2
      IF (DF.EQ.0.) GO TO 30
      DR=-F/DF
      IF (ABS(DR).LE.1.E-8*R) GO TO 20
      D1=1.
      IF (DR.LT.0.) D1=-1.
      IF (ABS(DR).GT..5*R) DR=.5*R*D1
      R=R+DR
      N=N+1
      IF (N-50) 10,10,30
   20 V=SQRT((P-PO)/(RO*(1.-RO/R)))
      U=V*(1.-RO/R)
      D1=R/RO
      DF=1H
      IF (KP.EQ.4) DF=5HSOLID
      IF (KP.EQ.5) DF=4HMELT
      IF (KP.EQ.6) DF=6HLIQUID
      CALL ANEOS (1.E-6,R,CD(1),CD(2),CD(3),CD(4),CD(5),CD(6),CD(7),CD(8
     1),KP,M)
      PRINT 50, R,T,P,CD(1),E,S,V,U,D1,N,DF
   30 CONTINUE
      RETURN
C
   40 FORMAT (10H1 HUGONIOT)
   50 FORMAT (9E12.4,I3,2X,A6)
   60 FORMAT (9H0      RHO,10X,1HT,11X,1HP,10X,2HPC,11X,1HE,11X,1HS,11X,1
     1HV,11X,1HU,7X,8HRHO/RHOO)
      END
```

```
      SUBROUTINE ANPHTR (C,MAT,TGAM)
C     ANEOS PACKAGE
C     MODIFIES THE ZERO-TEMPERATURE ISOTHERM OF THE ANALYTICAL EOS
C     FOR A TEMFERATURE INDEPENDENT PHASE TRANSITION
      DIMENSION C(1)
      IF (C(30).EQ.2.) RETURN
      IF (C(1).GT.C(19)) GO TO 20
   10 C(1)=1.E100
      C(2)=C(7)=C(8)=C(9)=C(38)=C(39)=C(40)=0.
      RETURN
   20 S3=C(15)+TGAM/3.
      S1=S3-2.5
      S2=S3+2.5
      S4=EXP(-C(33))*C(32)
      S5=(15.+7.*C(33)+C(33)**2)*S4
      S6=(10.+4.*C(33)+.5*C(33)**2)*S4
      S4=(6.+3.*C(33)+.5*C(33)**2)*S4
      ETA1=C(1)/C(19)
      S7=ETA1**.3333333333
      S8=C(32)*ETA1*S7**2*EXP(-C(33)/S7)
   30 C34=S4-9.*S3*C(3)
      C35=3.*C(3)*(6.*S3+1.)-S5
      C36=S6-3.*C(3)*(3.*S3+1.)
      PTR=S8-(C34+C35*S7+C36*S7**2)
      IF (C(7).EQ.0.) GO TO 70
      IF (ABS(PTR-C(7)).LE.1.E-4*(PTR+C(7))) GO TO 70
      IF (S2-S1.LT.1.E-7) GO TO 70
      IF (PTR-C(7)) 50,70,40
   40 S2=S3
      GO TO 60
   50 S1=S3
   60 S3=.5*(S1+S2)
      GO TO 30
   70 IF (C(2).LT.C(1)) C(2)=C(1)
      ETA2=C(2)/C(19)
      C37=C(37)-C(34)+C34-1.5*(C(35)-C35)-3.*(C(36)-C36)
      S1=C(33)/S7
      S2=EXP(-S1)
      CALL EPINT3 (S1,S2,S4)
      C8=(3.*C(32)*S4*S7**2+C34/ETA1+1.5*C35*S7/ETA1+3.*C36/S7-C37)/C(19
     1)
      DP1=C(32)*S7*(5.*S7+C(33))*EXP(-C(33)/S7)/3.-(C35/S7+2.*C36)/(3.*S
     17)
      DP2=C(32)*((10.+6.*C(33)/S7)/S7+C(33)**2/ETA1)*EXP(-C(33)/S7)/9.+2
     1.*(C35/S7+C36)/(9.*ETA1*S7)
      IF (C(39)) 80,90,100
   80 DP3=-DP1*C(39)
      GO TO 110
   90 DP3=DP1*ETA2/ETA1
      GO TO 110
  100 DP3=C(39)
  110 IF (C(40)) 120,130,140
  120 DP4=-DP2*C(40)
      GO TO 150
  130 DP4=DP2*(ETA2/ETA1)**2
```

```
      GO TO 150
  140 DP4=C(40)
  150 S1=ETA2**.3333333333
      S2=EXP(-C(33)/S1)
      S4=C(32)*S1*(5.*S1+C(33))*S2-3.*DP3
      S5=9.*ETA2*DP4-C(32)*(10.*S1**2+6.*C(33)*S1+C(33)**2)*S2
      C39=S1*S1*(S5-S4)
      C40=S1*(S4-.5*S5)
      C38=C(32)*S1**2*ETA2*S2-PTR-(C39+C40*S1)*S1
      EN2=C8+PTR*(ETA2-ETA1)/(C(19)*ETA1*ETA2)
      S4=C(33)/S1
      CALL EPINT3 (S4,S2,S5)
      C9=EN2-(3.*C(32)*S5*S1**2+C38/ETA2+(1.5*C39/S1+3.*C40)/S1)/C(19)
      S4=3.*(S3-C(15))
      PRINT 180, PTR,C(7),DP1,DP3,DP2,DP4,C8,EN2,S4,TGAM
      IF (C(7).GT.C.) GO TO 160
      IF (ETA2.GT.ETA1) GO TO 170
      IF (C(39).NE.0.) GO TO 170
      IF (C(40).NE.0.) GO TO 170
      PRINT 190
      GO TO 10
  160 IF (ABS(PTR-C(7)).LE.1.E-3*(PTR+C(7))) GO TO 170
      PRINT 200
  170 PRINT 210
      C(1)=ETA1
      C(2)=ETA2
      C(7)=PTR
      C(8)=C8
      C(9)=C9
      C(34)=C34
      C(35)=C35
      C(36)=C36
      C(37)=C37
      C(38)=C38
      C(39)=C39
      C(40)=C40
      RETURN
C
  180 FORMAT (//,74H  ZERO-TEMPERATURE ISOTHERM HAS BEEN MODIFIED FOR A 
     1SOLID PHASE TRANSITION,//,12H  PCTR(CAL)=,E13.6,10X,12HPCTR(INPUT)
     2=,E13.6,/,15H  DPDETA(ETA1)=,E13.6,7X,13HDPDETA(ETA2)=,E13.6,/,17H
     3  D2PDETA2(ETA1)=,E13.6,5X,15HD2PDETA2(ETA2)=,E13.6,/,11H  EC(ETA1
     4)=,E13.6,11X,9HEC(ETA2)=,E13.6,/,11H  TGAMSTAR=,E13.6,11X,5HTGAM=,
     5E13.6)
  190 FORMAT (64H0 ALL DEFAULT OPTIONS WERE USED.  NO TRANSITION WILL BE
     1 INCLUDED,/,1H1)
  200 FORMAT (38H0 SOMETHING IS WRONG - CHECK CAREFULLY)
  210 FORMAT (1H1)
      END
```

```
      SUBROUTINE ANDATA (IT,IZ,ISETAB)
C     ANEOS PACKAGE
C     DATA STATEMENTS
C     ATOMIC WEIGHT OF ELEMENT Z IS (Z*(Z+1))/2
C     FIRST IONIZATION POTENTIAL OF ELEMENT Z IS (Z*(Z+1))/2+1
C     LAST IONIZATION POTENTIAL OF ELEMENT Z IS (Z*(Z+1))/2+Z
      COMMON /ANES/ ACK(1080),ZZS(100),COT(100),FNI(100),RCT(21),TCT(21)
     1,RSOL(1000),RVAP(1000),TTWO(1000),SAVER(92),CMLT(8),ZB(92),DZB(40)
     2,BOLTS,EIP(4370),LOCSV(21),LOCKP(21),LOCKPL(21)
      COMMON /BIG/ BIGDUM(1)
      DIMENSION TABLE(200), TABPL(200), DTAB(5000)
      DATA CMLT/.3,.1,.2,5*0./
      DATA ACK,ZZS/1180*0./
      DATA BOLTS/1.60207E-12/
C     Z =  1
      DATA (EIP(I),I=1,2)/1.00801,1.3595E+01/
C     Z =  2
      DATA (EIP(I),I=3,5)/4.00280,2.4581E+01,5.4403E+01/
C     Z =  3
      DATA (EIP(I),I=6,9)/6.93900,5.3900E+00,7.5619E+01,1.2242E+02/
C     Z =  4
      DATA (EIP(I),I=10,14)/9.01300,9.3200E+00,1.8206E+01,1.5385E+02,2.1
     1766E+02/
C     Z =  5
      DATA (EIP(I),I=15,20)/10.81200,8.2960E+00,2.5149E+01,3.7920E+01,2.
     15930E+02,3.4013E+02/
C     Z =  6
      DATA (EIP(I),I=21,27)/12.01161,1.1256E+01,2.4376E+01,4.7871E+01,6.
     14476E+01,3.9199E+02,4.8984E+02/
C     Z =  7
      DATA (EIP(I),I=28,35)/14.00730,1.4530E+01,2.9593E+01,4.7426E+01,7.
     17450E+01,9.7863E+01,5.5192E+02,6.6683E+02/
C     Z =  8
      DATA (EIP(I),I=36,44)/16.00000,1.3614E+01,3.5108E+01,5.4886E+01,7.
     17394E+01,1.1387E+02,1.3808E+02,7.3911E+02,8.7112E+02/
C     Z =  9
      DATA (EIP(I),I=45,54)/18.99920,1.7418E+01,3.4980E+01,6.2646E+01,8.
     17140E+01,1.1421E+02,1.5712E+02,1.8514E+02,9.5360E+02,1.1020E+03/
C     Z = 10
      DATA (EIP(I),I=55,65)/20.18400,2.1559E+01,4.1070E+01,6.3500E+01,9.
     17020E+01,1.2630E+02,1.5791E+02,2.0720E+02,2.3910E+02,1.1956E+03,1.
     23604E+03/
C     Z = 11
      DATA (EIP(I),I=66,77)/22.99100,5.1380E+00,4.7290E+01,7.1650E+01,9.
     18880E+01,1.3837E+02,1.7209E+02,2.0844E+02,2.6416E+02,2.9978E+02,1.
     24648E+03,1.6461E+03/
C     Z = 12
      DATA (EIP(I),I=78,90)/24.31300,7.6440E+00,1.5031E+01,8.0120E+01,1.
     10929E+02,1.4123E+02,1.8649E+02,2.2490E+02,2.6596E+02,3.2790E+02,3.
     26736E+02,1.7612E+03,1.9590E+03/
C     Z = 13
      DATA (EIP(I),I=91,104)/26.98200,5.9840E+00,1.8823E+01,2.8440E+01,1
     1.1996E+02,1.5377E+02,1.9042E+02,2.4138E+02,2.8453E+02,3.3010E+02,3
     2.9850E+02,4.4190E+02,2.0855E+03,2.2990E+03/
C     Z = 14
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      DATA (EIP(I),I=105,119)/28.09000,8.1490E+00,1.6340E+01,3.3460E+01,
     14.5130E+01,1.6673E+02,2.0511E+02,2.4641E+02,3.0307E+02,3.5096E+02,
     24.0130E+02,4.7600E+02,5.2320E+02,2.4360E+03,2.6660E+03/
C     Z = 15
      DATA (EIP(I),I=120,135)/30.97500,1.0484E+01,1.9720E+01,3.0156E+01,
     15.1354E+01,6.5007E+01,2.2041E+02,2.6331E+02,3.0926E+02,3.7160E+02,
     24.2430E+02,4.7940E+02,5.6030E+02,6.1140E+02,2.8150E+03,3.0610E+03/
C     Z = 16
      DATA (EIP(I),I=136,152)/32.06600,1.0357E+01,2.3400E+01,3.5000E+01,
     14.7290E+01,7.2500E+01,8.8029E+01,2.8099E+02,3.2880E+02,3.7895E+02,
     24.4700E+02,5.0580E+02,5.6600E+02,6.5100E+02,7.0600E+02,3.2200E+03,
     33.4820E+03/
C     Z = 17
      DATA (EIP(I),I=153,170)/35.45400,1.3010E+01,2.3800E+01,3.9900E+01,
     15.3500E+01,6.7800E+01,9.6700E+01,1.1427E+02,3.4830E+02,4.0070E+02,
     24.5530E+02,5.3090E+02,5.9300E+02,6.6300E+02,7.4900E+02,8.0700E+02,
     33.6540E+03,3.9310E+03/
C     Z = 18
      DATA (EIP(I),I=171,189)/39.94900,1.5755E+01,2.7620E+01,4.0900E+01,
     15.9790E+01,7.5000E+01,9.1300E+01,1.2400E+02,1.4346E+02,4.2260E+02,
     24.7940E+02,5.3890E+02,6.2100E+02,6.8700E+02,7.5500E+02,8.5400E+02,
     39.1600E+02,4.1150E+03,4.4070E+03/
C     Z = 19
      DATA (EIP(I),I=190,209)/39.10300,4.3390E+00,3.1810E+01,4.6000E+01,
     16.0900E+01,8.2600E+01,9.9700E+01,1.1800E+02,1.5500E+02,1.7594E+02,
     25.0380E+02,5.6400E+02,6.2900E+02,7.1700E+02,7.8800E+02,8.7000E+02,
     39.6600E+02,1.0310E+03,4.6030E+03,4.9100E+03/
C     Z = 20
      DATA (EIP(I),I=210,230)/40.08000,6.1110E+00,1.1868E+01,5.1210E+01,
     16.7000E+01,8.4390E+01,1.0900E+02,1.2800E+02,1.4330E+02,1.8800E+02,
     22.1130E+02,5.9180E+02,6.5500E+02,7.2700E+02,8.2000E+02,8.9600E+02,
     39.9000E+02,1.0840E+03,1.1530E+03,5.1190E+03,5.4710E+03/
C     Z = 21
      DATA (EIP(I),I=231,252)/44.95800,6.5400E+00,1.2800E+01,2.4750E+01,
     17.3900E+01,9.2000E+01,1.1100E+02,1.3900E+02,1.5900E+02,1.8000E+02,
     22.2600E+02,2.5000E+02,6.8700E+02,7.5800E+02,8.3000E+02,9.3000E+02,
     31.0100E+03,1.1150E+03,1.2100E+03,1.2820E+03,5.4833E+03,6.0354E+03/
C     Z = 22
      DATA (EIP(I),I=253,275)/47.90000,6.8200E+00,1.3570E+01,2.7470E+01,
     14.3240E+01,9.9800E+01,1.2000E+02,1.4100E+02,1.7200E+02,1.9300E+02,
     22.1700E+02,2.6600E+02,2.9100E+02,7.8800E+02,8.6400E+02,9.4100E+02,
     31.0460E+03,1.1320E+03,1.2450E+03,1.3410E+03,1.4178E+03,6.0493E+03,
     46.6277E+03/
C     Z = 23
      DATA (EIP(I),I=276,299)/50.94400,6.7400E+00,1.4650E+01,2.9400E+01,
     14.8000E+01,6.5000E+01,1.2900E+02,1.5100E+02,1.7400E+02,2.0600E+02,
     22.3050E+02,2.5800E+02,3.0900E+02,3.3600E+02,8.9700E+02,9.7600E+02,
     31.0570E+03,1.1700E+03,1.2600E+03,1.3800E+03,1.4805E+03,1.5603E+03,
     46.6438E+03,7.2484E+03/
C     Z = 24
      DATA (EIP(I),I=300,324)/52.00000,6.7640E+00,1.6490E+01,3.0950E+01,
     15.0000E+01,7.3000E+01,9.1000E+01,1.6100E+02,1.8500E+02,2.1000E+02,
     22.4900E+02,2.7200E+02,2.9900E+02,3.5500E+02,3.8400E+02,1.0130E+03,
     31.0950E+03,1.1820E+03,1.3010E+03,1.3950E+03,1.5252E+03,1.6263E+03,
     41.7097E+03,7.2667E+03,7.8974E+03/
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C       Z = 25                                                          CHD 5854
      DATA (EIP(I),I=325,350)/54.94000,7.4330E+00,1.5636E+01,3.3690E+01,CHD 5855
     15.3000E+01,7.6000E+01,1.0000E+02,1.1900E+02,1.9600E+02,2.2200E+02,CHD 5856
     22.4800E+02,2.8800E+02,3.1500E+02,3.5000E+02,4.0400E+02,4.3500E+02,CHD 5857
     31.1360E+03,1.2220E+03,1.3130E+03,1.4380E+03,1.5380E+03,1.6780E+03,CHD 5858
     41.7790E+03,1.8660E+03,7.9180E+03,8.5750E+03/                      CHD 5859
C       Z = 26                                                          CHD 5860
      DATA (EIP(I),I=351,377)/55.84900,7.8700E+00,1.6180E+01,3.0643E+01,CHD 5861
     15.7000E+01,7.9000E+01,1.0300E+02,1.3000E+02,1.5100E+02,2.3500E+02,CHD 5862
     22.6200E+02,2.9000E+02,3.3000E+02,3.5500E+02,3.9000E+02,4.5700E+02,CHD 5863
     34.8900E+02,1.2660E+03,1.3540E+03,1.4500E+03,1.5830E+03,1.6870E+03,CHD 5864
     41.8370E+03,1.9380E+03,2.0290E+03,8.5990E+03,9.2810E+03/           CHD 5865
C       Z = 27                                                          CHD 5866
      DATA (EIP(I),I=378,405)/58.93560,7.8600E+00,1.7050E+01,3.3490E+01,CHD 5867
     15.3000E+01,8.3000E+01,1.0800E+02,1.3400E+02,1.6400E+02,1.9000E+02,CHD 5868
     22.9000E+02,3.0500E+02,3.3700E+02,3.8000E+02,4.1200E+02,4.4400E+02,CHD 5869
     35.1200E+02,5.4700E+02,1.4030E+03,1.4950E+03,1.5949E+03,1.7342E+03,CHD 5870
     41.8429E+03,2.0045E+03,2.1045E+03,2.1989E+03,9.3098E+03,1.0018E+04/CHD 5871
C       Z = 28                                                          CHD 5872
      DATA (EIP(I),I=406,434)/58.71000,7.6330E+00,1.8150E+01,3.5160E+01,CHD 5873
     15.6000E+01,7.9000E+01,1.1200E+02,1.4000E+02,1.6900E+02,2.0200E+02,CHD 5874
     22.3000E+02,3.2100E+02,3.5000E+02,3.8500E+02,4.3000E+02,4.5500E+02,CHD 5875
     35.0000E+02,5.3000E+02,6.0700E+02,1.5410E+03,1.6421E+03,1.7465E+03,CHD 5876
     41.8922E+03,2.0055E+03,2.1789E+03,2.2779E+03,2.3755E+03,1.0048E+04,CHD 5877
     51.0782E+04/                                                       CHD 5878
C       Z = 29                                                          CHD 5879
      DATA (EIP(I),I=435,464)/63.55000,7.7240E+00,2.0290E+01,3.6830E+01,CHD 5880
     15.9000E+01,8.2000E+01,1.1000E+02,1.4000E+02,1.7000E+02,2.0600E+02,CHD 5881
     22.4100E+02,2.6500E+02,3.7000E+02,4.0000E+02,4.4000E+02,4.8000E+02,CHD 5882
     35.2000E+02,5.6000E+02,6.3000E+02,6.7100E+02,1.6940E+03,1.7960E+03,CHD 5883
     41.9050E+03,2.0570E+03,2.1750E+03,2.3600E+03,2.4580E+03,2.5590E+03,CHD 5884
     51.0813E+04,1.1573E+04/                                            CHD 5885
C       Z = 30                                                          CHD 5886
      DATA (EIP(I),I=465,495)/65.37000,9.3910E+00,1.7960E+01,3.9700E+01,CHD 5887
     16.2000E+01,8.6000E+01,1.1500E+02,1.4500E+02,1.8000E+02,2.1000E+02,CHD 5888
     22.5000E+02,2.7935E+02,3.1100E+02,4.2000E+02,4.5000E+02,4.9000E+02,CHD 5889
     35.4000E+02,5.8000E+02,6.2000E+02,7.0000E+02,7.4111E+02,1.8500E+03,CHD 5890
     41.9555E+03,2.0680E+03,2.2225E+03,2.3593E+03,2.5473E+03,2.6592E+03,CHD 5891
     52.7671E+03,1.1665E+04,1.2441E+04/                                 CHD 5892
C       Z = 31                                                          CHD 5893
      DATA (EIP(I),I=496,527)/69.72000,6.0000E+00,2.0510E+01,3.0700E+01,CHD 5894
     16.4200E+01,9.0000E+01,1.1800E+02,1.4400E+02,1.7400E+02,2.1800E+02,CHD 5895
     22.5500E+02,2.8922E+02,3.2071E+02,3.6584E+02,4.7072E+02,5.0313E+02,CHD 5896
     35.4522E+02,5.9701E+02,6.4272E+02,6.8534E+02,7.7042E+02,8.1423E+02,CHD 5897
     42.0127E+03,2.1217E+03,2.2379E+03,2.3948E+03,2.5503E+03,2.7414E+03,CHD 5898
     52.8673E+03,2.9821E+03,1.2543E+04,1.3336E+04/                      CHD 5899
C       Z = 32                                                          CHD 5900
      DATA (EIP(I),I=528,560)/72.60000,7.8800E+00,1.5930E+01,3.4210E+01,CHD 5901
     14.5700E+01,9.3400E+01,1.1300E+02,1.4800E+02,1.7700E+02,2.1200E+02,CHD 5902
     22.6200E+02,2.9525E+02,3.3145E+02,3.6510E+02,4.2370E+02,5.2445E+02,CHD 5903
     35.5929E+02,6.0345E+02,6.5704E+02,7.0845E+02,7.5370E+02,8.4387E+02,CHD 5904
     48.9038E+02,2.1822E+03,2.2948E+03,2.4145E+03,2.5739E+03,2.7482E+03,CHD 5905
     52.9423E+03,3.0821E+03,3.2038E+03,1.3449E+04,1.4259E+04/           CHD 5906
C       Z = 33                                                          CHD 5907
      DATA (EIP(I),I=561,594)/74.92420,9.8100E+00,1.8630E+01,2.8340E+01,CHD 5908
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     13.4330E+01,8.2000E+01,9.9000E+01,1.1700E+02,1.4100E+02,1.5700E+02,CHD 5964
     21.7600E+02,2.2200E+02,2.5000E+02,4.2500E+02,4.7500E+02,5.2237E+02,CHD 5965
     35.6871E+02,6.1463E+02,6.7173E+02,7.2597E+02,7.7811E+02,8.2897E+02,CHD 5966
     49.9536E+02,1.0631E+03,1.1173E+03,1.1781E+03,1.2460E+03,1.3431E+03,CHD 5967
     51.4094E+03,1.5402E+03,1.6083E+03,3.7833E+03,3.9240E+03,4.0722E+03,CHD 5968
     64.2515E+03,4.5758E+03,4.7943E+03,5.0454E+03,5.2225E+03,2.1676E+04,CHD 5969
     72.2616E+04/
C      Z = 41                                                           CHD 5970
      DATA (EIP(I),I=861,902)/92.91000,6.8800E+00,1.4320E+01,2.5040E+01,CHD 5971
     13.8300E+01,5.0000E+01,1.0300E+02,1.2500E+02,1.4300E+02,1.6700E+02,CHD 5972
     21.8500E+02,2.0300E+02,2.4888E+02,2.8281E+02,4.8379E+02,5.3443E+02,CHD 5973
     35.8270E+02,6.3074E+02,6.7838E+02,7.3654E+02,7.9341E+02,8.4753E+02,CHD 5974
     49.0055E+02,1.0804E+03,1.1440E+03,1.2006E+03,1.2635E+03,1.3332E+03,CHD 5975
     51.4360E+03,1.5049E+03,1.6408E+03,1.7117E+03,4.0140E+03,4.1583E+03,CHD 5976
     64.3100E+03,4.4918E+03,4.8349E+03,5.0564E+03,5.3214E+03,5.5054E+03,CHD 5977
     72.2827E+04,2.3784E+04/                                            CHD 5978
C      Z = 42                                                           CHD 5979
      DATA (EIP(I),I=903,945)/95.95000,7.1000E+00,1.6150E+01,2.7130E+01,CHD 5980
     14.6400E+01,6.1200E+01,6.8000E+01,1.2600E+02,1.5300E+02,1.6900E+02,CHD 5981
     21.9700E+02,2.1000E+02,2.3334E+02,2.7746E+02,3.1732E+02,5.4561E+02,CHD 5982
     35.9689E+02,6.4606E+02,6.9579E+02,7.4515E+02,8.0437E+02,8.6387E+02,CHD 5983
     49.1998E+02,9.7515E+02,1.1685E+03,1.2280E+03,1.2870E+03,1.3520E+03,CHD 5984
     51.4235E+03,1.5320E+03,1.6035E+03,1.7445E+03,1.8180E+03,4.2516E+03,CHD 5985
     64.3993E+03,4.5546E+03,4.7388E+03,5.1007E+03,5.3252E+03,5.6042E+03,CHD 5986
     75.7952E+03,2.4005E+04,2.4978E+04/                                 CHD 5987
C      Z = 43                                                           CHD 5988
      DATA (EIP(I),I=946,989)/99.00000,7.2800E+00,1.5260E+01,3.1000E+01,CHD 5989
     14.3000E+01,5.9000E+01,7.6000E+01,9.4000E+01,1.6100E+02,1.8300E+02,CHD 5990
     21.9900E+02,2.2400E+02,2.4072E+02,2.6538E+02,3.0775E+02,3.5353E+02,CHD 5991
     36.1044E+02,6.6237E+02,7.1244E+02,7.6385E+02,8.1493E+02,8.7522E+02,CHD 5992
     49.3735E+02,9.9545E+02,1.0528E+03,1.2596E+03,1.3149E+03,1.3764E+03,CHD 5993
     51.4434E+03,1.5167E+03,1.6309E+03,1.7051E+03,1.8512E+03,1.9274E+03,CHD 5994
     64.4959E+03,4.6472E+03,4.8060E+03,4.9927E+03,5.3734E+03,5.6009E+03,CHD 5995
     75.8938E+03,6.0917E+03,2.5210E+04,2.6199E+04/                      CHD 5996
C      Z = 44                                                           CHD 5997
      DATA (EIP(I),I=990,1034)/101.07000,7.3640E+00,1.6760E+01,2.8460E+0CHD 5998
     11,4.6000E+01,6.3000E+01,8.1000E+01,1.0000E+02,1.1900E+02,1.9300E+0CHD 5999
     22,2.1600E+02,2.2500E+02,2.5295E+02,2.7314E+02,2.9912E+02,3.3973E+0CHD 6000
     32,3.9144E+02,6.7830E+02,7.3086E+02,7.8184E+02,8.3494E+02,8.8774E+0CHD 6001
     42,9.4910E+02,1.0138E+03,1.0739E+03,1.1334E+03,1.3537E+03,1.4049E+0CHD 6002
     53,1.4688E+03,1.5379E+03,1.6130E+03,1.7329E+03,1.8097E+03,1.9609E+0CHD 6003
     63,2.0398E+03,4.7470E+03,4.9018E+03,5.0642E+03,5.2534E+03,5.6528E+0CHD 6004
     73,5.8834E+03,6.1902E+03,6.3950E+03,2.6442E+04,2.7448E+04/         CHD 6005
C      Z = 45                                                           CHD 6006
      DATA (EIP(I),I=1035,1080)/102.91000,7.4600E+00,1.8070E+01,3.1050E+CHD 6007
     101,4.6000E+01,6.7000E+01,8.5000E+01,1.0500E+02,1.2600E+02,1.4700E+CHD 6008
     202,2.2600E+02,2.5000E+02,2.6700E+02,2.8360E+02,3.0726E+02,3.3457E+CHD 6009
     302,3.7341E+02,4.3105E+02,7.4918E+02,8.0238E+02,8.5426E+02,9.0906E+CHD 6010
     402,9.6357E+02,1.0260E+03,1.0934E+03,1.1554E+03,1.2171E+03,1.4508E+CHD 6011
     503,1.4979E+03,1.5642E+03,1.6354E+03,1.7123E+03,1.8379E+03,1.9173E+CHD 6012
     603,2.0736E+03,2.1552E+03,5.0049E+03,5.1632E+03,5.3292E+03,5.5209E+CHD 6013
     703,5.9390E+03,6.1727E+03,6.4934E+03,6.7051E+03,2.7701E+04,2.8724E+CHD 6014
     804/                                                               CHD 6015
C      Z = 46                                                           CHD 6016
      DATA (EIP(I),I=1081,1127)/106.40000,8.3300E+00,1.9420E+01,3.2920E+CHD 6017
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     15.0100E+01,6.2600E+01,1.2750E+02,1.5000E+02,1.8200E+02,2.1800E+02,CHD 5909
     22.5300E+02,3.0264E+02,3.3851E+02,3.7671E+02,4.1251E+02,4.8458E+02,CHD 5910
     35.8121E+02,6.1846E+02,6.6471E+02,7.2008E+02,7.7721E+02,8.2508E+02,CHD 5911
     49.2033E+02,9.6955E+02,2.3586E+03,2.4747E+03,2.5979E+03,2.7598E+03,CHD 5912
     52.9529E+03,3.1500E+03,3.3037E+03,3.4324E+03,1.4383E+04,1.5208E+04/CHD 5913
C      Z = 34                                                          CHD 5914
      DATA (EIP(I),I=595,629)/78.96000,9.7500E+00,2.1500E+01,3.2000E+01,CHD 5915
     14.3000E+01,6.8000E+01,8.2000E+01,1.5500E+02,1.8700E+02,2.2300E+02,CHD 5916
     22.6000E+02,2.9560E+02,3.4631E+02,3.8480E+02,4.2499E+02,4.6294E+02,CHD 5917
     35.4849E+02,6.4099E+02,6.8066E+02,7.2899E+02,7.8616E+02,8.4899E+02,CHD 5918
     48.9949E+02,9.9982E+02,1.0517E+03,2.5417E+03,2.6613E+03,2.7881E+03,CHD 5919
     52.9525E+03,3.1643E+03,3.3645E+03,3.5321E+03,3.6677E+03,1.5343E+04,CHD 5920
     61.6185E+04/                                                       CHD 5921
C                                                                      CHD 5922
C      Z = 35
      DATA (EIP(I),I=630,665)/79.91200,1.1840E+01,2.1600E+01,3.5900E+01,CHD 5923
     14.7300E+01,5.9700E+01,8.8600E+01,1.0300E+02,1.9300E+02,2.2800E+02,CHD 5924
     22.6600E+02,3.0390E+02,3.4122E+02,3.9299E+02,4.3411E+02,4.7629E+02,CHD 5925
     35.1640E+02,6.1541E+02,7.0379E+02,7.4587E+02,7.9629E+02,8.5525E+02,CHD 5926
     49.2379E+02,9.7691E+02,1.0823E+03,1.1370E+03,2.7317E+03,2.8548E+03,CHD 5927
     52.9851E+03,3.1520E+03,3.3826E+03,3.5858E+03,3.7673E+03,3.9099E+03,CHD 5928
     61.6330E+04,1.7189E+04/                                            CHD 5929
C      Z = 36                                                          CHD 5930
      DATA (EIP(I),I=666,702)/83.80000,1.3996E+01,2.4560E+01,3.6900E+01,CHD 5931
     15.2000E+01,6.5000E+01,7.9000E+01,1.1000E+02,1.2600E+02,2.3400E+02,CHD 5932
     22.7000E+02,3.1123E+02,3.5082E+02,3.8986E+02,4.4269E+02,4.8644E+02,CHD 5933
     35.3061E+02,5.7287E+02,6.8536E+02,7.6961E+02,8.1411E+02,8.6661E+02,CHD 5934
     49.2736E+02,1.0016E+03,1.0574E+03,1.1679E+03,1.2252E+03,2.9284E+03,CHD 5935
     53.0550E+03,3.1890E+03,3.3583E+03,3.6076E+03,3.8139E+03,4.0094E+03,CHD 5936
     64.1588E+03,1.7345E+04,1.8220E+04/                                 CHD 5937
C      Z = 37                                                          CHD 5938
      DATA (EIP(I),I=703,740)/85.48000,4.1760E+00,2.7500E+01,4.0000E+01,CHD 5939
     15.2000E+01,7.1000E+01,8.5000E+01,1.0000E+02,1.3500E+02,1.5100E+02,CHD 5940
     22.7700E+02,3.1672E+02,3.5948E+02,4.0076E+02,4.4152E+02,4.9542E+02,CHD 5941
     35.4179E+02,5.8795E+02,6.3236E+02,7.5833E+02,8.3845E+02,8.8537E+02,CHD 5942
     49.3995E+02,1.0025E+03,1.0825E+03,1.1408E+03,1.2564E+03,1.3164E+03,CHD 5943
     53.1319E+03,3.2621E+03,3.3996E+03,3.5714E+03,3.8395E+03,4.0488E+03,CHD 5944
     64.2582E+03,4.4145E+03,1.8387E+04,1.9278E+04/                      CHD 5945
C      Z = 38                                                          CHD 5946
      DATA (EIP(I),I=741,779)/87.63000,5.6920E+00,1.1027E+01,4.3000E+01,CHD 5947
     15.7000E+01,7.2000E+01,9.2000E+01,1.0700E+02,1.2400E+02,1.6200E+02,CHD 5948
     21.7900E+02,3.2400E+02,3.6646E+02,4.1076E+02,4.5372E+02,4.9620E+02,CHD 5949
     35.5117E+02,6.0017E+02,6.4832E+02,6.9488E+02,8.3432E+02,9.1032E+02,CHD 5950
     49.5965E+02,1.0163E+03,1.0806E+03,1.1663E+03,1.2273E+03,1.3480E+03,CHD 5951
     51.4107E+03,3.3423E+03,3.4759E+03,3.6170E+03,3.7913E+03,4.0781E+03,CHD 5952
     64.2905E+03,4.5138E+03,4.6771E+03,1.9456E+04,2.0364E+04/           CHD 5953
C      Z = 39                                                          CHD 5954
      DATA (EIP(I),I=780,819)/88.90800,6.3800E+00,1.2230E+01,2.0500E+01,CHD 5955
     16.2000E+01,7.7000E+01,9.3000E+01,1.1600E+02,1.3100E+02,1.4800E+02,CHD 5956
     21.9100E+02,2.0600E+02,3.7299E+02,4.1922E+02,4.6505E+02,5.0971E+02,CHD 5957
     35.5391E+02,6.0994E+02,6.6156E+02,7.1170E+02,7.6042E+02,9.1332E+02,CHD 5958
     49.8520E+02,1.0369E+03,1.0957E+03,1.1618E+03,1.2532E+03,1.3168E+03,CHD 5959
     51.4426E+03,1.5080E+03,3.5594E+03,3.6966E+03,3.8412E+03,4.0180E+03,CHD 5960
     64.3236E+03,4.5390E+03,4.7762E+03,4.9464E+03,2.0553E+04,2.1477E+04/CHD 5961
C      Z = 40                                                          CHD 5962
      DATA (EIP(I),I=820,860)/91.22000,6.8400E+00,1.3130E+01,2.2980E+01,CHD 5963
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     101,4.9000E+01,6.6000E+01,9.0000E+01,1.1000E+02,1.3200E+02,1.5500E+CHD 6019
     202,1.7800E+02,2.6100E+02,2.7807E+02,2.9711E+02,3.1594E+02,3.4308E+CHD 6020
     302,3.7170E+02,4.0879E+02,4.7236E+02,8.2308E+02,8.7692E+02,9.2970E+CHD 6021
     402,9.8619E+02,1.0424E+03,1.1059E+03,1.1759E+03,1.2400E+03,1.3038E+CHD 6022
     503,1.5510E+03,1.5940E+03,1.6626E+03,1.7360E+03,1.8146E+03,1.9460E+CHD 6023
     603,2.0280E+03,2.1893E+03,2.2737E+03,5.2696E+03,5.4314E+03,5.6010E+CHD 6024
     703,5.7951E+03,6.2320E+03,6.4687E+03,6.8034E+03,7.0220E+03,2.8988E+CHD 6025
     804,3.0027E+04/                                                    CHD 6026
C      Z = 47                                                           CHD 6027
      DATA (EIP(I),I=1128,1175)/107.87400,7.5740E+00,2.1480E+01,3.4820E+CHD 6028
     101,5.2000E+01,7.0000E+01,8.9000E+01,1.1600E+02,1.3900E+02,1.6200E+CHD 6029
     202,1.8700E+02,2.0155E+02,2.7788E+02,3.0784E+02,3.2893E+02,3.4999E+CHD 6030
     302,3.8059E+02,4.1054E+02,4.4587E+02,5.1537E+02,9.0000E+02,9.5448E+CHD 6031
     402,1.0082E+03,1.0663E+03,1.1243E+03,1.1888E+03,1.2615E+03,1.3275E+CHD 6032
     503,1.3935E+03,1.6542E+03,1.6930E+03,1.7641E+03,1.8395E+03,1.9200E+CHD 6033
     603,2.0570E+03,2.1417E+03,2.3081E+03,2.3951E+03,5.5411E+03,5.7065E+CHD 6034
     703,5.8796E+03,6.0762E+03,6.5319E+03,6.7716E+03,7.1202E+03,7.3457E+CHD 6035
     803,3.0302E+04,3.1357E+04/                                         CHD 6036
C      Z = 48                                                           CHD 6037
      DATA (EIP(I),I=1176,1224)/112.41000,8.9910E+00,1.6904E+01,3.7470E+CHD 6038
     101,5.5000E+01,7.3000E+01,9.4000E+01,1.1500E+02,1.4600E+02,1.7000E+CHD 6039
     202,1.9500E+02,2.0986E+02,2.2680E+02,2.9645E+02,3.3931E+02,3.6244E+CHD 6040
     302,3.8574E+02,4.1981E+02,4.5108E+02,4.8464E+02,5.6007E+02,9.7965E+CHD 6041
     402,1.0351E+03,1.0897E+03,1.1495E+03,1.2092E+03,1.2748E+03,1.3501E+CHD 6042
     503,1.4181E+03,1.4862E+03,1.7604E+03,1.7951E+03,1.8686E+03,1.9461E+CHD 6043
     603,2.0284E+03,2.1711E+03,2.2584E+03,2.4299E+03,2.5196E+03,5.8194E+CHD 6044
     703,5.9883E+03,6.1649E+03,6.3641E+03,6.8385E+03,7.0813E+03,7.4437E+CHD 6045
     803,7.6762E+03,3.1643E+04,3.2714E+04/                              CHD 6046
C      Z = 49                                                           CHD 6047
      DATA (EIP(I),I=1225,1274)/114.82000,5.7850E+00,1.8860E+01,2.8030E+CHD 6048
     101,5.4400E+01,7.7000E+01,9.8000E+01,1.2000E+02,1.4400E+02,1.7800E+CHD 6049
     202,2.0400E+02,2.1702E+02,2.3442E+02,2.5375E+02,3.1673E+02,3.7247E+CHD 6050
     302,3.9765E+02,4.2318E+02,4.6073E+02,4.9332E+02,5.2512E+02,6.0648E+CHD 6051
     402,1.0623E+03,1.1187E+03,1.1742E+03,1.2357E+03,1.2971E+03,1.3638E+CHD 6052
     503,1.4417E+03,1.5117E+03,1.5819E+03,1.8696E+03,1.9002E+03,1.9761E+CHD 6053
     603,2.0557E+03,2.1397E+03,2.2882E+03,2.3781E+03,2.5547E+03,2.6471E+CHD 6054
     703,6.1045E+03,6.2769E+03,6.4571E+03,6.6587E+03,7.1519E+03,7.3977E+CHD 6055
     803,7.7741E+03,8.0135E+03,3.3011E+04,3.4099E+04/                   CHD 6056
C      Z = 50                                                           CHD 6057
      DATA (EIP(I),I=1275,1325)/118.70000,7.3420E+00,1.4628E+01,3.0490E+CHD 6058
     101,4.0720E+01,7.2300E+01,1.0300E+02,1.2600E+02,1.5000E+02,1.7600E+CHD 6059
     202,2.1300E+02,2.2452E+02,2.4074E+02,2.6068E+02,2.8240E+02,3.3870E+CHD 6060
     302,4.0734E+02,4.3456E+02,4.6233E+02,5.0334E+02,5.3726E+02,5.6730E+CHD 6061
     402,6.5458E+02,1.1480E+03,1.2053E+03,1.2617E+03,1.3249E+03,1.3880E+CHD 6062
     503,1.4558E+03,1.5363E+03,1.6083E+03,1.6807E+03,1.9818E+03,2.0083E+CHD 6063
     603,2.0867E+03,2.1683E+03,2.2542E+03,2.4083E+03,2.5008E+03,2.6825E+CHD 6064
     703,2.7777E+03,6.3964E+03,6.5723E+03,6.7561E+03,6.9602E+03,7.4721E+CHD 6065
     803,7.7210E+03,8.1113E+03,8.3576E+03,3.4406E+04,3.5511E+04/        CHD 6066
C      Z = 51                                                           CHD 6067
      DATA (EIP(I),I=1326,1377)/121.76000,8.6390E+00,1.6500E+01,2.5300E+CHD 6068
     101,4.4100E+01,5.6000E+01,1.0800E+02,1.3200E+02,1.5700E+02,1.8400E+CHD 6069
     202,2.1100E+02,2.3060E+02,2.4674E+02,2.6615E+02,2.8863E+02,3.1275E+CHD 6070
     302,3.6238E+02,4.4391E+02,4.7317E+02,5.0317E+02,5.4766E+02,5.8289E+CHD 6071
     402,6.1117E+02,7.0439E+02,1.2367E+03,1.2949E+03,1.3522E+03,1.4172E+CHD 6072
     503,1.4820E+03,1.5508E+03,1.6339E+03,1.7080E+03,1.7825E+03,2.0971E+CHD 6073
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      603,2.1195E+03,2.2002E+03,2.2840E+03,2.3716E+03,2.5315E+03,2.6266E+CHD 6074
      703,2.8133E+03,2.9112E+03,6.6951E+03,6.8746E+03,7.0619E+03,7.2684E+CHD 6075
      803,7.7992E+03,8.0510E+03,8.4553E+03,8.7085E+03,3.5829E+04,3.6950E+CHD 6076
      904/                                                              CHD 6077
C      Z = 52                                                           CHD 6078
       DATA (EIP(I),I=1378,1430)/127.61000,9.0100E+00,1.8600E+01,3.1000E+CHD 6079
      101,3.8000E+01,6.0000E+01,7.2000E+01,1.3700E+02,1.6400E+02,1.9200E+CHD 6080
      202,2.2000E+02,2.2810E+02,2.4990E+02,2.7066E+02,2.9327E+02,3.1829E+CHD 6081
      302,3.4480E+02,3.8775E+02,4.8217E+02,5.1348E+02,5.4571E+02,5.9367E+CHD 6082
      402,6.3023E+02,6.5675E+02,7.5589E+02,1.3285E+03,1.3876E+03,1.4458E+CHD 6083
      503,1.5124E+03,1.5790E+03,1.6489E+03,1.7346E+03,1.8106E+03,1.8873E+CHD 6084
      603,2.2154E+03,2.2336E+03,2.3168E+03,2.4026E+03,2.4920E+03,2.6576E+CHD 6085
      703,2.7554E+03,2.9472E+03,3.0478E+03,7.0006E+03,7.1836E+03,7.3745E+CHD 6086
      803,7.5835E+03,8.1330E+03,8.3879E+03,8.8061E+03,9.0662E+03,3.7279E+CHD 6087
      904,3.8416E+04/                                                   CHD 6088
C      Z = 53                                                           CHD 6089
       DATA (EIP(I),I=1431,1484)/126.90900,1.0454E+01,1.9090E+01,3.2000E+CHD 6090
      101,4.2000E+01,6.6000E+01,8.1000E+01,9.9000E+01,1.7000E+02,2.0000E+CHD 6091
      202,2.2900E+02,2.3500E+02,2.4690E+02,2.7090E+02,2.9628E+02,3.2208E+CHD 6092
      302,3.4964E+02,3.7855E+02,4.1483E+02,5.2214E+02,5.5549E+02,5.8996E+CHD 6093
      402,6.4139E+02,6.7927E+02,7.0403E+02,8.0910E+02,1.4232E+03,1.4833E+CHD 6094
      503,1.5424E+03,1.6107E+03,1.6790E+03,1.7499E+03,1.8383E+03,1.9163E+CHD 6095
      603,1.9951E+03,2.3367E+03,2.3508E+03,2.4364E+03,2.5243E+03,2.6155E+CHD 6096
      703,2.7868E+03,2.8872E+03,3.0841E+03,3.1874E+03,7.3129E+03,7.4994E+CHD 6097
      803,7.6938E+03,7.9053E+03,8.4736E+03,8.7315E+03,9.1636E+03,9.4307E+CHD 6098
      903,3.8756E+04,3.9909E+04/                                        CHD 6099
C      Z = 54                                                           CHD 6100
       DATA (EIP(I),I=1485,1539)/131.30000,1.2129E+01,2.1210E+01,3.2120E+CHD 6101
      101,3.8300E+01,5.1500E+01,6.4200E+01,9.1400E+01,1.0660E+02,1.7520E+CHD 6102
      202,1.9620E+02,2.1860E+02,2.4230E+02,2.6740E+02,2.9360E+02,3.2360E+CHD 6103
      302,3.5260E+02,3.8270E+02,4.1400E+02,4.4360E+02,5.6380E+02,5.9920E+CHD 6104
      402,6.3590E+02,6.9080E+02,7.3000E+02,7.5300E+02,8.6400E+02,1.5210E+CHD 6105
      503,1.5820E+03,1.6420E+03,1.7120E+03,1.7820E+03,1.8540E+03,1.9450E+CHD 6106
      603,2.0250E+03,2.1060E+03,2.4610E+03,2.4710E+03,2.5590E+03,2.6490E+CHD 6107
      703,2.7420E+03,2.9190E+03,3.0220E+03,3.2240E+03,3.3300E+03,7.6320E+CHD 6108
      803,7.8220E+03,8.0200E+03,8.2340E+03,8.8210E+03,9.0820E+03,9.5280E+CHD 6109
      903,9.8020E+03,4.0260E+04,4.1430E+04/                             CHD 6110
C      Z = 55                                                           CHD 6111
       DATA (EIP(I),I=1540,1595)/132.91000,3.8930E+00,2.5100E+01,3.5000E+CHD 6112
      101,4.6000E+01,6.2000E+01,7.4000E+01,1.0100E+02,1.2000E+02,1.4400E+CHD 6113
      202,2.0500E+02,2.2490E+02,2.4863E+02,2.7364E+02,3.0009E+02,3.2763E+CHD 6114
      302,3.5963E+02,3.8998E+02,4.2147E+02,4.5411E+02,4.9318E+02,6.1037E+CHD 6115
      402,6.4710E+02,6.8506E+02,7.4517E+02,7.8576E+02,8.1586E+02,9.2476E+CHD 6116
      502,1.6178E+03,1.6808E+03,1.7431E+03,1.8150E+03,1.8870E+03,1.9613E+CHD 6117
      603,2.0574E+03,2.1396E+03,2.2230E+03,2.5628E+03,2.5982E+03,2.6884E+CHD 6118
      703,2.7807E+03,2.8760E+03,3.0692E+03,3.1747E+03,3.3826E+03,3.4910E+CHD 6119
      803,7.9631E+03,8.1571E+03,8.3599E+03,8.5790E+03,9.2258E+03,9.4932E+CHD 6120
      903,9.9508E+03,1.0231E+04,4.1958E+04,4.3151E+04/                  CHD 6121
C      Z = 56                                                           CHD 6122
       DATA (EIP(I),I=1596,1652)/137.35000,5.2100E+00,1.0001E+01,3.6000E+CHD 6123
      101,4.9000E+01,6.2000E+01,8.0000E+01,9.3000E+01,1.2000E+02,1.4300E+CHD 6124
      202,1.5700E+02,2.3120E+02,2.5529E+02,2.8035E+02,3.0668E+02,3.3447E+CHD 6125
      302,3.6335E+02,3.9735E+02,4.2905E+02,4.6194E+02,4.9591E+02,5.4445E+CHD 6126
      402,6.5863E+02,6.9669E+02,7.3592E+02,8.0123E+02,8.4321E+02,8.8041E+CHD 6127
      502,9.8721E+02,1.7177E+03,1.7827E+03,1.8472E+03,1.9210E+03,1.9951E+CHD 6128
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     603,2.0717E+03,2.1728E+03,2.2572E+03,2.3430E+03,2.6675E+03,2.7285E+CHD 6129
     703,2.8209E+03,2.9154E+03,3.0130E+03,3.2225E+03,3.3305E+03,3.5442E+CHD 6130
     803,3.6550E+03,8.3009E+03,8.4990E+03,8.7065E+03,8.9308E+03,9.6374E+CHD 6131
     903,9.9111E+03,1.0380E+04,1.0667E+04,4.3682E+04,4.4898E+04/         CHD 6132
C     Z = 57                                                             CHD 6133
      DATA (EIP(I),I=1653,1710)/138.92000,5.6100E+00,1.1430E+01,1.9170E+CHD 6134
     101,5.2000E+01,6.6000E+01,8.0000E+01,1.0000E+02,1.1400E+02,1.4400E+CHD 6135
     202,1.6500E+02,2.0400E+02,2.5910E+02,2.8739E+02,3.1378E+02,3.4142E+CHD 6136
     302,3.7056E+02,4.0078E+02,4.3678E+02,4.6983E+02,5.0411E+02,5.3942E+CHD 6137
     402,5.9743E+02,7.0860E+02,7.4799E+02,7.8848E+02,8.5900E+02,9.0237E+CHD 6138
     502,9.4667E+02,1.0514E+03,1.8206E+03,1.8876E+03,1.9544E+03,2.0301E+CHD 6139
     603,2.1062E+03,2.1851E+03,2.2913E+03,2.3779E+03,2.4661E+03,2.7753E+CHD 6140
     703,2.8618E+03,2.9564E+03,3.0532E+03,3.1531E+03,3.3788E+03,3.4893E+CHD 6141
     803,3.7089E+03,3.8221E+03,8.6456E+03,8.8478E+03,9.0600E+03,9.2895E+CHD 6142
     903,1.0056E+04,1.0336E+04,1.0817E+04,1.1110E+04,4.5434E+04,4.6674E+CHD 6143
     $04/                                                                CHD 6144
C     Z = 58                                                             CHD 6145
      DATA (EIP(I),I=1711,1769)/140.13000,6.9000E+00,1.2300E+01,2.0000E+CHD 6146
     101,3.5000E+01,7.0000E+01,8.5000E+01,1.0000E+02,1.2200E+02,1.3700E+CHD 6147
     202,1.6500E+02,1.8900E+02,2.2523E+02,2.8870E+02,3.2118E+02,3.4890E+CHD 6148
     302,3.7786E+02,4.0834E+02,4.3990E+02,4.7790E+02,5.1230E+02,5.4798E+CHD 6149
     402,5.8462E+02,6.5210E+02,7.6026E+02,8.0098E+02,8.4274E+02,9.1846E+CHD 6150
     502,9.6322E+02,1.0146E+03,1.1172E+03,1.9265E+03,1.9955E+03,2.0645E+CHD 6151
     603,2.1421E+03,2.2203E+03,2.3015E+03,2.4127E+03,2.5015E+03,2.5921E+CHD 6152
     703,2.8862E+03,2.9981E+03,3.0949E+03,3.1939E+03,3.2961E+03,3.5381E+CHD 6153
     803,3.6511E+03,3.8765E+03,3.9921E+03,8.9971E+03,9.2033E+03,9.4203E+CHD 6154
     903,9.6549E+03,1.0481E+04,1.0767E+04,1.1260E+04,1.1560E+04,4.7213E+CHD 6155
     $04,4.8476E+04/                                                     CHD 6156
C     Z = 59                                                             CHD 6157
      DATA (EIP(I),I=1770,1829)/140.91300,5.8000E+00,1.6786E+01,2.3848E+CHD 6158
     101,3.3130E+01,4.9317E+01,8.9000E+01,1.0600E+02,1.2200E+02,1.4600E+CHD 6159
     202,1.6200E+02,1.9700E+02,2.1132E+02,2.4816E+02,3.2000E+02,3.5667E+CHD 6160
     302,3.8572E+02,4.1600E+02,4.4782E+02,4.8072E+02,5.2072E+02,5.5647E+CHD 6161
     402,5.9355E+02,6.3152E+02,7.0847E+02,8.1362E+02,8.5567E+02,8.9870E+CHD 6162
     502,9.7962E+02,1.0258E+03,1.0843E+03,1.1848E+03,2.0355E+03,2.1065E+CHD 6163
     603,2.1777E+03,2.2572E+03,2.3375E+03,2.4210E+03,2.5372E+03,2.6282E+CHD 6164
     703,2.7212E+03,3.0000E+03,3.1375E+03,3.2365E+03,3.3377E+03,3.4422E+CHD 6165
     803,3.7005E+03,3.8160E+03,4.0472E+03,4.1652E+03,9.3553E+03,9.5656E+CHD 6166
     903,9.7873E+03,1.0027E+04,1.0913E+04,1.1206E+04,1.1710E+04,1.2017E+CHD 6167
     $04,4.9020E+04,5.0305E+04/                                          CHD 6168
C     Z = 60                                                             CHD 6169
      DATA (EIP(I),I=1830,1890)/144.25000,6.3000E+00,1.6051E+01,2.8371E+CHD 6170
     101,3.7096E+01,4.7959E+01,6.5334E+01,1.1000E+02,1.2800E+02,1.4700E+CHD 6171
     202,1.7100E+02,1.8357E+02,2.1904E+02,2.3533E+02,2.7278E+02,3.5644E+CHD 6172
     302,3.9387E+02,4.2425E+02,4.5584E+02,4.8901E+02,5.2325E+02,5.6525E+CHD 6173
     402,6.0235E+02,6.4082E+02,6.8013E+02,7.6655E+02,8.6869E+02,9.1207E+CHD 6174
     502,9.5636E+02,1.0425E+03,1.0900E+03,1.1556E+03,1.2540E+03,2.1474E+CHD 6175
     603,2.2204E+03,2.2939E+03,2.3753E+03,2.4576E+03,2.5434E+03,2.6647E+CHD 6176
     703,2.7579E+03,2.8533E+03,3.1424E+03,3.2798E+03,3.3810E+03,3.4845E+CHD 6177
     803,3.5913E+03,3.8658E+03,3.9838E+03,4.2209E+03,4.3413E+03,9.7204E+CHD 6178
     903,9.9347E+03,1.0161E+04,1.0406E+04,1.1352E+04,1.1651E+04,1.2167E+CHD 6179
     $04,1.2480E+04,5.0853E+04,5.2162E+04/                               CHD 6180
C     Z = 61                                                             CHD 6181
      DATA (EIP(I),I=1891,1952)/147.00000,6.0000E+00,1.8016E+01,2.8001E+CHD 6182
     101,4.1656E+01,5.2043E+01,6.4487E+01,8.3050E+01,1.3500E+02,1.5400E+CHD 6183
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202,1.7300E+02,1.9224E+02,2.0684E+02,2.4277E+02,2.6105E+02,2.9911E+CHD 6184
302,3.9457E+02,4.3276E+02,4.6447E+02,4.9737E+02,5.3189E+02,5.6747E+CHD 6185
402,6.1147E+02,6.4992E+02,6.8978E+02,7.3043E+02,8.2632E+02,9.2545E+CHD 6186
502,9.7016E+02,1.0157E+03,1.1070E+03,1.1560E+03,1.2287E+03,1.3250E+CHD 6187
603,2.2624E+03,2.3374E+03,2.4131E+03,2.4964E+03,2.5808E+03,2.6689E+CHD 6188
703,2.7952E+03,2.8906E+03,2.9884E+03,3.2879E+03,3.4252E+03,3.5286E+CHD 6189
803,3.6343E+03,3.7434E+03,4.0342E+03,4.1547E+03,4.3976E+03,4.5204E+CHD 6190
903,1.0092E+04,1.0311E+04,1.0542E+04,1.0792E+04,1.1798E+04,1.2103E+CHD 6191
$04,1.2630E+04,1.2950E+04,5.2714E+04,5.4046E+04/                    CHD 6192
C     Z = 62                                                          CHD 6193
      DATA (EIP(I),I=1953,2015)/150.36000,5.6000E+00,1.1300E+01,3.1432E+CHD 6194
     101,4.1651E+01,5.6640E+01,6.8690E+01,8.2715E+01,1.0247E+02,1.6100E+CHD 6195
     202,1.8100E+02,1.9434E+02,2.1518E+02,2.3181E+02,2.6821E+02,2.8847E+CHD 6196
     302,3.2714E+02,4.3441E+02,4.7335E+02,5.0639E+02,5.4061E+02,5.7647E+CHD 6197
     402,6.1339E+02,6.5939E+02,6.9919E+02,7.4045E+02,7.8243E+02,8.8779E+CHD 6198
     502,9.8391E+02,1.0299E+03,1.0768E+03,1.1733E+03,1.2236E+03,1.3034E+CHD 6199
     603,1.3976E+03,2.3804E+03,2.4574E+03,2.5354E+03,2.6206E+03,2.7070E+CHD 6200
     703,2.7974E+03,2.9288E+03,3.0264E+03,3.1266E+03,3.4364E+03,3.5736E+CHD 6201
     803,3.6792E+03,3.7872E+03,3.8986E+03,4.2056E+03,4.3286E+03,4.5774E+CHD 6202
     903,4.7026E+03,1.0471E+04,1.0693E+04,1.0929E+04,1.1185E+04,1.2250E+CHD 6203
     $04,1.2562E+04,1.3101E+04,1.3427E+04,5.4602E+04,5.5956E+04/       CHD 6204
C     Z = 63                                                          CHD 6205
      DATA (EIP(I),I=2016,2079)/151.96000,5.6700E+00,1.1200E+01,2.9377E+CHD 6206
     101,4.6547E+01,5.7000E+01,7.3323E+01,8.7036E+01,1.0264E+02,1.2358E+CHD 6207
     202,1.8700E+02,2.0165E+02,2.1738E+02,2.3982E+02,2.5848E+02,2.9535E+CHD 6208
     302,3.1758E+02,3.5686E+02,4.7595E+02,5.1564E+02,5.5001E+02,5.8555E+CHD 6209
     402,6.2275E+02,6.6101E+02,7.0901E+02,7.5016E+02,7.9282E+02,8.3613E+CHD 6210
     502,9.5096E+02,1.0441E+03,1.0914E+03,1.1395E+03,1.2413E+03,1.2930E+CHD 6211
     603,1.3799E+03,1.4720E+03,2.5014E+03,2.5804E+03,2.6607E+03,2.7478E+CHD 6212
     703,2.8362E+03,2.9289E+03,3.0654E+03,3.1652E+03,3.2678E+03,3.5879E+CHD 6213
     803,3.7250E+03,3.8328E+03,3.9431E+03,4.0568E+03,4.3800E+03,4.5055E+CHD 6214
     903,4.7602E+03,4.8878E+03,1.0856E+04,1.1083E+04,1.1324E+04,1.1584E+CHD 6215
     $04,1.2709E+04,1.3027E+04,1.3578E+04,1.3911E+04,5.6517E+04,5.7895E+CHD 6216
     $04/                                                              CHD 6217
C     Z = 64                                                          CHD 6218
      DATA (EIP(I),I=2080,2144)/157.25000,6.1600E+00,1.2000E+01,2.9835E+CHD 6219
     101,4.8541E+01,6.3361E+01,7.4049E+01,9.1706E+01,1.0708E+02,1.2427E+CHD 6220
     202,1.4639E+02,2.0732E+02,2.2401E+02,2.4212E+02,2.6616E+02,2.8685E+CHD 6221
     302,3.2418E+02,3.4839E+02,3.8829E+02,5.1918E+02,5.5963E+02,5.9533E+CHD 6222
     402,6.3218E+02,6.7073E+02,7.1033E+02,7.6033E+02,8.0283E+02,8.4688E+CHD 6223
     502,8.9153E+02,1.0158E+03,1.1059E+03,1.1546E+03,1.2040E+03,1.3109E+CHD 6224
     603,1.3640E+03,1.4580E+03,1.5480E+03,2.6254E+03,2.7064E+03,2.7889E+CHD 6225
     703,2.8779E+03,2.9684E+03,3.0634E+03,3.2049E+03,3.3069E+03,3.4119E+CHD 6226
     803,3.7424E+03,3.8794E+03,3.9894E+03,4.1019E+03,4.2179E+03,4.5574E+CHD 6227
     903,4.6854E+03,4.9459E+03,5.0759E+03,1.1249E+04,1.1479E+04,1.1725E+CHD 6228
     $04,1.1990E+04,1.3175E+04,1.3500E+04,1.4062E+04,1.4401E+04,5.8459E+CHD 6229
     $04,5.9860E+04/                                                   CHD 6230
C     Z = 65                                                          CHD 6231
      DATA (EIP(I),I=2145,2210)/158.93000,6.7000E+00,2.0650E+01,2.8106E+CHD 6232
     101,4.9557E+01,6.8792E+01,8.1875E+01,9.2797E+01,1.1179E+02,1.2883E+CHD 6233
     202,1.4759E+02,1.7091E+02,2.2934E+02,2.4806E+02,2.6857E+02,2.9419E+CHD 6234
     302,3.1692E+02,3.5472E+02,3.8091E+02,4.2141E+02,5.6412E+02,6.0532E+CHD 6235
     402,6.4235E+02,6.8052E+02,7.2041E+02,7.6135E+02,8.1335E+02,8.5720E+CHD 6236
     502,9.0265E+02,9.4863E+02,1.0824E+03,1.1695E+03,1.2195E+03,1.2701E+CHD 6237
     603,1.3823E+03,1.4368E+03,1.5379E+03,1.6258E+03,2.7525E+03,2.8355E+CHD 6238
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     703,2.9203E+03,3.0112E+03,3.1037E+03,3.2010E+03,3.3476E+03,3.4518E+CHD 6239
     803,3.5592E+03,3.9000E+03,4.0369E+03,4.1491E+03,4.2639E+03,4.3822E+CHD 6240
     903,4.7379E+03,4.8684E+03,5.1348E+03,5.2672E+03,1.1648E+04,1.1882E+CHD 6241
     $04,1.2132E+04,1.2403E+04,1.3648E+04,1.3979E+04,1.4552E+04,1.4898E+CHD 6242
     $04,6.0428E+04,6.1853E+04/                                         CHD 6243
C     Z = 66                                                            CHD 6244
      DATA (EIP(I),I=2211,2277)/162.50000,6.8000E+00,2.0272E+01,3.6227E+CHD 6245
     101,4.5299E+01,7.0367E+01,9.0132E+01,1.0209E+02,1.1324E+02,1.3357E+CHD 6246
     202,1.5227E+02,1.7262E+02,1.9712E+02,2.5306E+02,2.7381E+02,2.9670E+CHD 6247
     302,3.2393E+02,3.4868E+02,3.8695E+02,4.1512E+02,4.5623E+02,6.1075E+CHD 6248
     402,6.5271E+02,6.9107E+02,7.3055E+02,7.7179E+02,8.1407E+02,8.6807E+CHD 6249
     502,9.1327E+02,9.6011E+02,1.0074E+03,1.1507E+03,1.2347E+03,1.2861E+CHD 6250
     603,1.3380E+03,1.4553E+03,1.5112E+03,1.6194E+03,1.7052E+03,2.8826E+CHD 6251
     703,2.9676E+03,3.0546E+03,3.1474E+03,3.2420E+03,3.3416E+03,3.4932E+CHD 6252
     803,3.5996E+03,3.7094E+03,4.0611E+03,4.1974E+03,4.3118E+03,4.4288E+CHD 6253
     903,4.5494E+03,4.9214E+03,5.0544E+03,5.3266E+03,5.4614E+03,1.2054E+CHD 6254
     $04,1.2292E+04,1.2547E+04,1.2823E+04,1.4128E+04,1.4465E+04,1.5050E+CHD 6255
     $04,1.5403E+04,6.2425E+04,6.3872E+04/                              CHD 6256
C     Z = 67                                                            CHD 6257
      DATA (EIP(I),I=2278,2345)/164.93700,6.0000E+00,2.0781E+01,3.4931E+CHD 6258
     101,5.2892E+01,6.3580E+01,9.2265E+01,1.1256E+02,1.2400E+02,1.3539E+CHD 6259
     202,1.5705E+02,1.7741E+02,1.9934E+02,2.2503E+02,2.7848E+02,3.0126E+CHD 6260
     302,3.2654E+02,3.5537E+02,3.8215E+02,4.2088E+02,4.5103E+02,4.9276E+CHD 6261
     402,6.5908E+02,7.0180E+02,7.4149E+02,7.8228E+02,8.2487E+02,8.6849E+CHD 6262
     502,9.2449E+02,9.7104E+02,1.0193E+03,1.0679E+03,1.2206E+03,1.3017E+CHD 6263
     603,1.3544E+03,1.4075E+03,1.5301E+03,1.5874E+03,1.7027E+03,1.7864E+CHD 6264
     703,3.0157E+03,3.1027E+03,3.1919E+03,3.2866E+03,3.3833E+03,3.4852E+CHD 6265
     803,3.6418E+03,3.7504E+03,3.8626E+03,4.2253E+03,4.3609E+03,4.4775E+CHD 6266
     903,4.5967E+03,4.7196E+03,5.1079E+03,5.2434E+03,5.5214E+03,5.6586E+CHD 6267
     $03,1.2466E+04,1.2709E+04,1.2969E+04,1.3250E+04,1.4614E+04,1.4957E+CHD 6268
     $04,1.5554E+04,1.5913E+04,6.4449E+04,6.5919E+04/                   CHD 6269
C     Z = 68                                                            CHD 6270
      DATA (EIP(I),I=2346,2414)/167.27000,6.0000E+00,2.0623E+01,3.5849E+CHD 6271
     101,5.0678E+01,7.0645E+01,8.2949E+01,1.1525E+02,1.3607E+02,1.4665E+CHD 6272
     202,1.5924E+02,1.8223E+02,2.0426E+02,2.2777E+02,2.5464E+02,3.0560E+CHD 6273
     302,3.3041E+02,3.5808E+02,3.8850E+02,4.1732E+02,4.5652E+02,4.8864E+CHD 6274
     402,5.3098E+02,7.0912E+02,7.5259E+02,7.9361E+02,8.3572E+02,8.7965E+CHD 6275
     502,9.2461E+02,9.8261E+02,1.0305E+03,1.0801E+03,1.1301E+03,1.2923E+CHD 6276
     603,1.3704E+03,1.4244E+03,1.4788E+03,1.6066E+03,1.6652E+03,1.7876E+CHD 6277
     703,1.8692E+03,3.1518E+03,3.2408E+03,3.3323E+03,3.4289E+03,3.5276E+CHD 6278
     803,3.6318E+03,3.7935E+03,3.9043E+03,4.0189E+03,4.3925E+03,4.5274E+CHD 6279
     903,4.6462E+03,4.7677E+03,4.8929E+03,5.2974E+03,5.4354E+03,5.7193E+CHD 6280
     $03,5.8589E+03,1.2886E+04,1.3132E+04,1.3397E+04,1.3683E+04,1.5107E+CHD 6281
     $04,1.5457E+04,1.6065E+04,1.6431E+04,6.6500E+04,6.7993E+04/        CHD 6282
C     Z = 69                                                            CHD 6283
      DATA (EIP(I),I=2415,2484)/168.94100,6.0000E+00,2.1331E+01,3.6333E+CHD 6284
     101,5.2006E+01,6.7513E+01,8.9485E+01,1.0341E+02,1.3932E+02,1.6068E+CHD 6285
     202,1.7100E+02,1.8478E+02,2.0911E+02,2.3280E+02,2.5789E+02,2.8595E+CHD 6286
     302,3.3442E+02,3.6126E+02,3.9132E+02,4.2334E+02,4.5418E+02,4.9385E+CHD 6287
     402,5.2795E+02,5.7090E+02,7.6085E+02,8.0507E+02,8.4742E+02,8.9085E+CHD 6288
     502,9.3612E+02,9.8242E+02,1.0424E+03,1.0917E+03,1.1427E+03,1.1940E+CHD 6289
     603,1.3657E+03,1.4407E+03,1.4961E+03,1.5517E+03,1.6847E+03,1.7448E+CHD 6290
     703,1.8743E+03,1.9538E+03,3.2910E+03,3.3820E+03,3.4757E+03,3.5742E+CHD 6291
     803,3.6750E+03,3.7815E+03,3.9482E+03,4.0612E+03,4.1782E+03,4.5627E+CHD 6292
     903,4.6970E+03,4.8180E+03,4.9417E+03,5.0692E+03,5.4900E+03,5.6305E+CHD 6293
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     $03,5.9202E+03,6.0622E+03,1.3312E+04,1.3563E+04,1.3832E+04,1.4123E+
     $04,1.5607E+04,1.5963E+04,1.6583E+04,1.6956E+04,6.8578E+04,7.0095E+
     $04/
C       Z = 70
      DATA (EIP(I),I=2485,2555)/173.04000,6.2000E+00,1.2100E+01,3.7750E+
     101,5.3132E+01,6.9249E+01,8.5435E+01,1.0941E+02,1.2495E+02,1.6448E+
     202,1.8637E+02,1.9563E+02,2.1203E+02,2.3769E+02,2.6304E+02,2.8971E+
     302,3.1897E+02,3.6494E+02,3.9381E+02,4.2626E+02,4.5987E+02,4.9275E+
     402,5.3288E+02,5.6897E+02,6.1252E+02,8.1428E+02,8.5926E+02,9.0294E+
     502,9.4768E+02,9.9430E+02,1.0419E+03,1.1039E+03,1.1545E+03,1.2070E+
     603,1.2596E+03,1.4407E+03,1.5128E+03,1.5695E+03,1.6264E+03,1.7646E+
     703,1.8260E+03,1.9626E+03,2.0400E+03,3.4331E+03,3.5261E+03,3.6221E+
     803,3.7225E+03,3.8253E+03,3.9341E+03,4.1059E+03,4.2211E+03,4.3405E+
     903,4.7359E+03,4.8695E+03,4.9927E+03,5.1187E+03,5.2485E+03,5.6855E+
     $03,5.8285E+03,6.1241E+03,6.2685E+03,1.3745E+04,1.4000E+04,1.4274E+
     $04,1.4570E+04,1.6114E+04,1.6476E+04,1.7108E+04,1.7487E+04,7.0684E+
     $04,7.2223E+04/
C       Z = 71
      DATA (EIP(I),I=2556,2627)/174.98000,6.1000E+00,1.5000E+01,1.9000E+
     101,5.5256E+01,7.1017E+01,8.7581E+01,1.0444E+02,1.3043E+02,1.4758E+
     202,1.9073E+02,2.1314E+02,2.2197E+02,2.4097E+02,2.6797E+02,2.9498E+
     302,3.2324E+02,3.5367E+02,3.9715E+02,4.2806E+02,4.6289E+02,4.9810E+
     402,5.3301E+02,5.7361E+02,6.1167E+02,6.5584E+02,8.6941E+02,9.1515E+
     502,9.6016E+02,1.0062E+03,1.0542E+03,1.1032E+03,1.1672E+03,1.2191E+
     603,1.2729E+03,1.3269E+03,1.5175E+03,1.5865E+03,1.6445E+03,1.7028E+
     703,1.8461E+03,1.9090E+03,2.0527E+03,2.1280E+03,3.5783E+03,3.6733E+
     803,3.7716E+03,3.8739E+03,3.9787E+03,4.0898E+03,4.2667E+03,4.3841E+
     903,4.5059E+03,4.9121E+03,5.0451E+03,5.1705E+03,5.2988E+03,5.4309E+
     $03,5.8841E+03,6.0296E+03,6.3311E+03,6.4779E+03,1.4185E+04,1.4444E+
     $04,1.4722E+04,1.5024E+04,1.6627E+04,1.6996E+04,1.7640E+04,1.8025E+
     $04,7.2816E+04,7.4379E+04/
C       Z = 72
      DATA (EIP(I),I=2628,2700)/178.50000,7.0000E+00,1.4900E+01,2.1000E+
     101,3.1000E+01,7.3850E+01,8.9991E+01,1.0700E+02,1.2454E+02,1.5253E+
     202,1.7130E+02,2.1807E+02,2.4101E+02,2.5000E+02,2.7161E+02,2.9995E+
     302,3.2862E+02,3.5846E+02,3.9008E+02,4.3107E+02,4.6401E+02,5.0123E+
     402,5.3804E+02,5.7497E+02,6.1604E+02,6.5608E+02,7.0086E+02,9.2624E+
     502,9.7273E+02,1.0191E+03,1.0664E+03,1.1158E+03,1.1661E+03,1.2321E+
     603,1.2854E+03,1.3406E+03,1.3959E+03,1.5960E+03,1.6620E+03,1.7213E+
     703,1.7808E+03,1.9294E+03,1.9936E+03,2.1444E+03,2.2176E+03,3.7265E+
     803,3.8235E+03,3.9240E+03,4.0282E+03,4.1351E+03,4.2485E+03,4.4304E+
     903,4.5500E+03,4.6742E+03,5.0914E+03,5.2237E+03,5.3513E+03,5.4818E+
     $03,5.6162E+03,6.0857E+03,6.2337E+03,6.5410E+03,6.6902E+03,1.4631E+
     $04,1.4894E+04,1.5178E+04,1.5484E+04,1.7148E+04,1.7523E+04,1.8178E+
     $04,1.8570E+04,7.4976E+04,7.6562E+04/
C       Z = 73
      DATA (EIP(I),I=2701,2774)/180.95500,7.8800E+00,1.6200E+01,2.2000E+
     101,3.3000E+01,4.5000E+01,9.3531E+01,1.1005E+02,1.2751E+02,1.4573E+
     202,1.7572E+02,1.9611E+02,2.4649E+02,2.6996E+02,2.7865E+02,3.0396E+
     302,3.3362E+02,3.6396E+02,3.9538E+02,4.2819E+02,4.6668E+02,5.0165E+
     402,5.4127E+02,5.7967E+02,6.1864E+02,6.6017E+02,7.0219E+02,7.4758E+
     502,9.8477E+02,1.0320E+03,1.0797E+03,1.1284E+03,1.1790E+03,1.2307E+
     603,1.2987E+03,1.3533E+03,1.4099E+03,1.4666E+03,1.6761E+03,1.7391E+
     703,1.7998E+03,1.8606E+03,2.0143E+03,2.0800E+03,2.2379E+03,2.3090E+
     803,3.8777E+03,3.9767E+03,4.0795E+03,4.1856E+03,4.2945E+03,4.4102E+
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     903,4.5972E+03,4.7190E+03,4.8456E+03,5.2737E+03,5.4053E+03,5.5351E+
     $03,5.6679E+03,5.8046E+03,6.2903E+03,6.4408E+03,6.7540E+03,6.9056E+
     $03,1.5085E+04,1.5352E+04,1.5640E+04,1.5952E+04,1.7675E+04,1.8057E+
     $04,1.8723E+04,1.9122E+04,7.7163E+04,7.8772E+04/
C      Z = 74
      DATA (EIP(I),I=2775,2849)/183.86000,7.9800E+00,1.7700E+01,2.4000E+
     101,3.5000E+01,4.8000E+01,6.1000E+01,1.1430E+02,1.3120E+02,1.4910E+
     202,1.6800E+02,2.0000E+02,2.2200E+02,2.7600E+02,3.0000E+02,3.0900E+
     302,3.3800E+02,3.6900E+02,4.0100E+02,4.3400E+02,4.6800E+02,5.0400E+
     402,5.4100E+02,5.8300E+02,6.2300E+02,6.6400E+02,7.0600E+02,7.5000E+
     502,7.9600E+02,1.0450E+03,1.0930E+03,1.1420E+03,1.1920E+03,1.2440E+
     603,1.2970E+03,1.3670E+03,1.4230E+03,1.4810E+03,1.5390E+03,1.7580E+
     703,1.8180E+03,1.8800E+03,1.9420E+03,2.1010E+03,2.1680E+03,2.3330E+
     803,2.4020E+03,4.0320E+03,4.1330E+03,4.2380E+03,4.3460E+03,4.4570E+
     903,4.5750E+03,4.7670E+03,4.8910E+03,5.0200E+03,5.4590E+03,5.5900E+
     $03,5.7220E+03,5.8570E+03,5.9960E+03,6.4980E+03,6.6510E+03,6.9700E+
     $03,7.1240E+03,1.5545E+04,1.5816E+04,1.6109E+04,1.6426E+04,1.8209E+
     $04,1.8597E+04,1.9275E+04,1.9680E+04,7.9377E+04,8.1009E+04/
C      Z = 75
      DATA (EIP(I),I=2850,2925)/186.30000,7.8700E+00,1.6600E+01,2.6000E+
     101,3.8000E+01,5.1000E+01,6.4000E+01,7.9000E+01,1.4108E+02,1.5874E+
     202,1.7753E+02,1.9719E+02,2.2869E+02,2.5169E+02,3.1019E+02,3.3594E+
     302,3.8743E+02,4.1693E+02,4.4830E+02,4.8068E+02,5.1418E+02,5.4868E+
     402,5.8505E+02,6.2243E+02,6.6443E+02,7.0480E+02,7.4618E+02,7.8868E+
     502,8.3305E+02,8.7930E+02,1.1339E+03,1.1822E+03,1.2314E+03,1.2818E+
     603,1.3342E+03,1.3874E+03,1.4558E+03,1.5122E+03,1.5704E+03,1.6288E+
     703,1.8494E+03,1.9098E+03,1.9722E+03,2.0347E+03,2.1822E+03,2.2494E+
     803,2.4138E+03,2.4831E+03,4.2363E+03,4.3369E+03,4.4414E+03,4.5491E+
     903,4.6597E+03,4.7769E+03,4.9593E+03,5.0828E+03,5.2113E+03,5.6116E+
     $03,5.7787E+03,5.9106E+03,6.0457E+03,6.1848E+03,6.6422E+03,6.7948E+
     $03,7.1104E+03,7.2643E+03,1.5930E+04,1.6228E+04,1.6547E+04,1.6886E+
     $04,1.8807E+04,1.9217E+04,1.9882E+04,2.0308E+04,8.1834E+04,8.3485E+
     $04/
C      Z = 76
      DATA (EIP(I),I=2926,3002)/190.20000,8.7000E+00,1.7000E+01,2.5000E+
     101,4.0000E+01,5.4000E+01,6.8000E+01,8.3000E+01,9.9000E+01,1.6895E+
     202,1.8737E+02,2.0705E+02,2.2747E+02,2.5847E+02,2.8247E+02,3.4547E+
     302,3.7297E+02,4.6755E+02,4.9755E+02,5.2930E+02,5.6205E+02,5.9605E+
     402,6.3105E+02,6.6780E+02,7.0555E+02,7.4755E+02,7.8830E+02,8.3005E+
     502,8.7305E+02,9.1780E+02,9.6430E+02,1.2246E+03,1.2731E+03,1.3226E+
     603,1.3733E+03,1.4261E+03,1.4796E+03,1.5463E+03,1.6031E+03,1.6616E+
     703,1.7203E+03,1.9426E+03,2.0033E+03,2.0661E+03,2.1291E+03,2.2651E+
     803,2.3326E+03,2.4963E+03,2.5658E+03,4.4436E+03,4.5439E+03,4.6479E+
     903,4.7551E+03,4.8654E+03,4.9819E+03,5.1546E+03,5.2776E+03,5.4056E+
     $03,5.7671E+03,5.9704E+03,6.1021E+03,6.2374E+03,6.3766E+03,6.7894E+
     $03,6.9416E+03,7.2539E+03,7.4076E+03,1.6322E+04,1.6647E+04,1.6991E+
     $04,1.7354E+04,1.9412E+04,1.9844E+04,2.0495E+04,2.0943E+04,8.4318E+
     $04,8.5989E+04/
C      Z = 77
      DATA (EIP(I),I=3003,3080)/192.20000,9.0000E+00,1.7000E+01,2.7000E+
     101,3.9000E+01,5.7000E+01,7.2000E+01,8.8000E+01,1.0400E+02,1.2100E+
     202,1.9791E+02,2.1709E+02,2.3766E+02,2.5884E+02,2.8934E+02,3.1434E+
     302,3.8184E+02,4.1109E+02,5.4938E+02,5.7988E+02,6.1200E+02,6.4513E+
     402,6.7963E+02,7.1513E+02,7.5225E+02,7.9038E+02,8.3238E+02,8.7350E+
     502,9.1563E+02,9.5913E+02,1.0043E+03,1.0510E+03,1.3169E+03,1.3656E+
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     603,1.4154E+03,1.4665E+03,1.5196E+03,1.5734E+03,1.6385E+03,1.6956E+CHD 6404
     703,1.7544E+03,1.8135E+03,2.0374E+03,2.0985E+03,2.1616E+03,2.2251E+CHD 6405
     803,2.3496E+03,2.4174E+03,2.5805E+03,2.6503E+03,4.6540E+03,4.7538E+CHD 6406
     903,4.8573E+03,4.9642E+03,5.0741E+03,5.1898E+03,5.3530E+03,5.4755E+CHD 6407
     $03,5.6030E+03,5.9257E+03,6.1651E+03,6.2967E+03,6.4321E+03,6.5715E+CHD 6408
     $03,6.9396E+03,7.0915E+03,7.4003E+03,7.5540E+03,1.6720E+04,1.7073E+CHD 6409
     $04,1.7442E+04,1.7828E+04,2.0024E+04,2.0478E+04,2.1116E+04,2.1585E+CHD 6410
     $04,8.6829E+04,8.8520E+04/                                         CHD 6411
C      Z = 78                                                           CHD 6412
      DATA (EIP(I),I=3081,3159)/195.10000,9.0000E+00,1.8560E+01,2.8000E+CHD 6413
     101,4.1000E+01,5.5000E+01,7.5000E+01,9.2000E+01,1.0900E+02,1.2700E+CHD 6414
     202,1.4600E+02,2.2795E+02,2.4790E+02,2.6935E+02,2.9130E+02,3.2130E+CHD 6415
     302,3.4730E+02,4.1930E+02,4.5030E+02,6.3290E+02,6.6390E+02,6.9640E+CHD 6416
     402,7.2990E+02,7.6490E+02,8.0090E+02,8.3840E+02,8.7690E+02,9.1890E+CHD 6417
     502,9.6040E+02,1.0029E+03,1.0469E+03,1.0924E+03,1.1394E+03,1.4109E+CHD 6418
     603,1.4599E+03,1.5099E+03,1.5614E+03,1.6149E+03,1.6689E+03,1.7324E+CHD 6419
     703,1.7899E+03,1.8489E+03,1.9084E+03,2.1339E+03,2.1954E+03,2.2589E+CHD 6420
     803,2.3229E+03,2.4359E+03,2.5039E+03,2.6664E+03,2.7364E+03,4.8673E+CHD 6421
     903,4.9668E+03,5.0698E+03,5.1763E+03,5.2858E+03,5.4008E+03,5.5543E+CHD 6422
     $03,5.6763E+03,5.8033E+03,6.0873E+03,6.3628E+03,6.4943E+03,6.6298E+CHD 6423
     $03,6.7693E+03,7.0928E+03,7.2443E+03,7.5498E+03,7.7033E+03,1.7126E+CHD 6424
     $04,1.7506E+04,1.7900E+04,1.8309E+04,2.0643E+04,2.1119E+04,2.1743E+CHD 6425
     $04,2.2233E+04,8.9367E+04,9.1077E+04/                              CHD 6426
C      Z = 79                                                           CHD 6427
      DATA (EIP(I),I=3160,3239)/196.97700,9.2200E+00,2.0500E+01,3.0000E+CHD 6428
     101,4.4000E+01,5.8000E+01,7.3000E+01,9.6000E+01,1.1400E+02,1.3300E+CHD 6429
     202,1.5300E+02,1.8587E+02,2.5908E+02,2.7979E+02,3.0213E+02,3.2484E+CHD 6430
     302,3.5434E+02,3.8134E+02,4.5784E+02,4.9059E+02,7.1813E+02,7.4963E+CHD 6431
     402,7.8250E+02,8.1638E+02,8.5188E+02,8.8838E+02,9.2625E+02,9.6513E+CHD 6432
     502,1.0071E+03,1.0490E+03,1.0919E+03,1.1364E+03,1.1823E+03,1.2295E+CHD 6433
     603,1.5066E+03,1.5559E+03,1.6061E+03,1.6580E+03,1.7119E+03,1.7661E+CHD 6434
     703,1.8280E+03,1.8859E+03,1.9451E+03,2.0050E+03,2.2321E+03,2.2940E+CHD 6435
     803,2.3579E+03,2.4224E+03,2.5239E+03,2.5921E+03,2.7540E+03,2.8243E+CHD 6436
     903,5.0837E+03,5.1828E+03,5.2853E+03,5.3915E+03,5.5006E+03,5.6148E+CHD 6437
     $03,5.7587E+03,5.8802E+03,6.0067E+03,6.2520E+03,6.5636E+03,6.6950E+CHD 6438
     $03,6.8306E+03,6.9702E+03,7.2491E+03,7.4002E+03,7.7023E+03,7.8557E+CHD 6439
     $03,1.7538E+04,1.7946E+04,1.8365E+04,1.8796E+04,2.1269E+04,2.1767E+CHD 6440
     $04,2.2377E+04,2.2888E+04,9.1933E+04,9.3663E+04/                   CHD 6441
C      Z = 80                                                           CHD 6442
      DATA (EIP(I),I=3240,3320)/200.60000,1.0430E+01,1.8751E+01,3.4200E+CHD 6443
     101,4.6000E+01,6.1000E+01,7.7000E+01,9.4000E+01,1.2000E+02,1.3900E+CHD 6444
     202,1.5900E+02,1.9125E+02,2.2682E+02,2.9130E+02,3.1277E+02,3.3600E+CHD 6445
     302,3.5947E+02,3.8847E+02,4.1647E+02,4.9747E+02,5.3197E+02,8.0505E+CHD 6446
     402,8.3705E+02,8.7030E+02,9.0455E+02,9.4055E+02,9.7755E+02,1.0158E+CHD 6447
     503,1.0551E+03,1.0971E+03,1.1393E+03,1.1826E+03,1.2276E+03,1.2738E+CHD 6448
     603,1.3213E+03,1.6041E+03,1.6536E+03,1.7041E+03,1.7563E+03,1.8106E+CHD 6449
     703,1.8651E+03,1.9253E+03,1.9836E+03,2.0431E+03,2.1033E+03,2.3321E+CHD 6450
     803,2.3943E+03,2.4586E+03,2.5236E+03,2.6136E+03,2.6821E+03,2.8433E+CHD 6451
     903,2.9138E+03,5.3031E+03,5.4019E+03,5.5039E+03,5.6096E+03,5.7184E+CHD 6452
     $03,5.8319E+03,5.9661E+03,6.0871E+03,6.2131E+03,6.4196E+03,6.7674E+CHD 6453
     $03,6.8986E+03,7.0344E+03,7.1741E+03,7.4084E+03,7.5591E+03,7.8579E+CHD 6454
     $03,8.0111E+03,1.7957E+04,1.8392E+04,1.8836E+04,1.9291E+04,2.1901E+CHD 6455
     $04,2.2421E+04,2.3018E+04,2.3550E+04,9.4526E+04,9.6275E+04/        CHD 6456
C      Z = 81                                                           CHD 6457
      DATA (EIP(I),I=3321,3402)/204.38000,6.1060E+00,2.0420E+01,2.9800E+CHD 6458
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     101,5.0700E+01,6.4000E+01,8.1000E+01,9.8000E+01,1.1600E+02,1.4500E+
     202,1.6600E+02,1.9596E+02,2.3058E+02,2.6887E+02,3.2461E+02,3.4684E+
     302,3.7096E+02,3.9519E+02,4.2369E+02,4.5269E+02,5.3819E+02,5.7444E+
     402,8.9368E+02,9.2618E+02,9.5980E+02,9.9443E+02,1.0309E+03,1.0684E+
     503,1.1071E+03,1.1467E+03,1.1887E+03,1.2313E+03,1.2749E+03,1.3204E+
     603,1.3671E+03,1.4148E+03,1.7032E+03,1.7529E+03,1.8037E+03,1.8563E+
     703,1.9109E+03,1.9657E+03,2.0243E+03,2.0829E+03,2.1427E+03,2.2033E+
     803,2.4337E+03,2.4963E+03,2.5609E+03,2.6264E+03,2.7049E+03,2.7737E+
     903,2.9343E+03,3.0051E+03,5.5256E+03,5.6239E+03,5.7254E+03,5.8308E+
     $03,5.9392E+03,6.0519E+03,6.1766E+03,6.2971E+03,6.4226E+03,6.5903E+
     $03,6.9742E+03,7.1053E+03,7.2412E+03,7.3811E+03,7.5707E+03,7.7211E+
     $03,8.0164E+03,8.1696E+03,1.8382E+04,1.8845E+04,1.9315E+04,1.9792E+
     $04,2.2540E+04,2.3082E+04,2.3666E+04,2.4219E+04,9.7146E+04,9.8914E+
     $04/
C      Z = 82
      DATA (EIP(I),I=3403,3485)/207.20000,7.4150E+00,1.5028E+01,3.1930E+
     101,4.2310E+01,6.8800E+01,8.4000E+01,1.0300E+02,1.2200E+02,1.4200E+
     202,1.7300E+02,2.0100E+02,2.3400E+02,2.7100E+02,3.1200E+02,3.5900E+
     302,3.8200E+02,4.0700E+02,4.3200E+02,4.6000E+02,4.9000E+02,5.8000E+
     402,6.1800E+02,9.8400E+02,1.0170E+03,1.0510E+03,1.0860E+03,1.1230E+
     503,1.1610E+03,1.2000E+03,1.2400E+03,1.2820E+03,1.3250E+03,1.3690E+
     603,1.4150E+03,1.4620E+03,1.5100E+03,1.8040E+03,1.8540E+03,1.9050E+
     703,1.9580E+03,2.0130E+03,2.0680E+03,2.1250E+03,2.1840E+03,2.2440E+
     803,2.3050E+03,2.5370E+03,2.6000E+03,2.6650E+03,2.7310E+03,2.7980E+
     903,2.8670E+03,3.0270E+03,3.0980E+03,5.7510E+03,5.8490E+03,5.9500E+
     $03,6.0550E+03,6.1630E+03,6.2750E+03,6.3900E+03,6.5100E+03,6.6350E+
     $03,6.7640E+03,7.1840E+03,7.3150E+03,7.4510E+03,7.5910E+03,7.7360E+
     $03,7.8860E+03,8.1780E+03,8.3310E+03,1.8815E+04,1.9305E+04,1.9800E+
     $04,2.0300E+04,2.3186E+04,2.3750E+04,2.4320E+04,2.4895E+04,9.9793E+
     $04,1.0158E+05/
C      Z = 83
      DATA (EIP(I),I=3486,3569)/208.98800,7.2870E+00,1.6680E+01,2.5560E+
     101,4.5300E+01,5.6000E+01,8.8300E+01,1.0700E+02,1.2700E+02,1.4800E+
     202,1.6900E+02,2.0356E+02,2.3283E+02,2.6524E+02,3.0127E+02,3.4084E+
     302,3.9803E+02,4.2211E+02,4.4813E+02,4.7407E+02,5.1209E+02,5.4289E+
     402,6.2559E+02,6.7219E+02,1.0171E+03,1.0519E+03,1.0877E+03,1.1247E+
     503,1.1636E+03,1.2034E+03,1.2444E+03,1.2863E+03,1.3321E+03,1.3771E+
     603,1.4231E+03,1.4711E+03,1.5199E+03,1.5701E+03,1.8732E+03,1.9251E+
     703,1.9781E+03,2.0328E+03,2.0898E+03,2.1468E+03,2.2127E+03,2.2736E+
     803,2.3356E+03,2.3987E+03,2.6392E+03,2.7042E+03,2.7709E+03,2.8387E+
     903,2.9454E+03,3.0171E+03,3.1853E+03,3.2586E+03,5.9099E+03,6.0119E+
     $03,6.1169E+03,6.2259E+03,6.3379E+03,6.4546E+03,6.5989E+03,6.7233E+
     $03,6.8528E+03,6.9864E+03,7.4229E+03,7.5581E+03,7.6978E+03,7.8421E+
     $03,8.1184E+03,8.2734E+03,8.5802E+03,8.7403E+03,1.9469E+04,1.9939E+
     $04,2.0416E+04,2.0901E+04,2.3968E+04,2.4521E+04,2.5131E+04,2.5697E+
     $04,1.0270E+05,1.0479E+05/
C      Z = 84
      DATA (EIP(I),I=3570,3654)/210.00000,8.4300E+00,1.9000E+01,2.7000E+
     101,3.8000E+01,6.1000E+01,7.3000E+01,1.1200E+02,1.3200E+02,1.5400E+
     202,1.7600E+02,2.0181E+02,2.3520E+02,2.6575E+02,2.9757E+02,3.3262E+
     302,3.7077E+02,4.3815E+02,4.6330E+02,4.9035E+02,5.1722E+02,5.6527E+
     402,5.9687E+02,6.7227E+02,7.2747E+02,1.0518E+03,1.0886E+03,1.1261E+
     503,1.1651E+03,1.2058E+03,1.2476E+03,1.2906E+03,1.3343E+03,1.3838E+
     603,1.4308E+03,1.4788E+03,1.5288E+03,1.5796E+03,1.6318E+03,1.9441E+
     703,1.9978E+03,2.0528E+03,2.1093E+03,2.1683E+03,2.2273E+03,2.3021E+
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     803,2.3648E+03,2.4288E+03,2.4941E+03,2.7431E+03,2.8101E+03,2.8786E+CHD 6514
     903,2.9481E+03,3.0946E+03,3.1688E+03,3.3453E+03,3.4208E+03,6.0719E+CHD 6515
     $03,6.1779E+03,6.2869E+03,6.3999E+03,6.5159E+03,6.6371E+03,6.8109E+CHD 6516
     $03,6.9396E+03,7.0736E+03,7.2119E+03,7.6649E+03,7.8041E+03,7.9476E+CHD 6517
     $03,8.0961E+03,8.5039E+03,8.6639E+03,8.9854E+03,9.1526E+03,2.0130E+CHD 6518
     $04,2.0580E+04,2.1039E+04,2.1509E+04,2.4756E+04,2.5299E+04,2.5949E+CHD 6519
     $04,2.6505E+04,1.0563E+05,1.0802E+05/                              CHD 6520
C      Z = 85                                                           CHD 6521
      DATA (EIP(I),I=3655,3740)/211.00000,9.3000E+00,2.0000E+01,2.9000E+CHD 6522
     101,4.1000E+01,5.1000E+01,7.8000E+01,9.1000E+01,1.3800E+02,1.6000E+CHD 6523
     202,1.8300E+02,2.0998E+02,2.3570E+02,2.6793E+02,2.9976E+02,3.3099E+CHD 6524
     302,3.6507E+02,4.0179E+02,4.7936E+02,5.0558E+02,5.3366E+02,5.6147E+CHD 6525
     402,6.1954E+02,6.5194E+02,7.2004E+02,7.8384E+02,1.0883E+03,1.1269E+CHD 6526
     503,1.1661E+03,1.2071E+03,1.2498E+03,1.2934E+03,1.3384E+03,1.3840E+CHD 6527
     603,1.4373E+03,1.4863E+03,1.5363E+03,1.5883E+03,1.6409E+03,1.6953E+CHD 6528
     703,2.0166E+03,2.0723E+03,2.1293E+03,2.1875E+03,2.2485E+03,2.3095E+CHD 6529
     803,2.3931E+03,2.4578E+03,2.5238E+03,2.5911E+03,2.8486E+03,2.9176E+CHD 6530
     903,2.9879E+03,3.0591E+03,3.2454E+03,3.3223E+03,3.5070E+03,3.5848E+CHD 6531
     $03,6.2368E+03,6.3468E+03,6.4598E+03,6.5768E+03,6.6968E+03,6.8227E+CHD 6532
     $03,7.0258E+03,7.1590E+03,7.2975E+03,7.4403E+03,7.9098E+03,8.0532E+CHD 6533
     $03,8.2005E+03,8.3532E+03,8.8923E+03,9.0573E+03,9.3936E+03,9.5680E+CHD 6534
     $03,2.0798E+04,2.1228E+04,2.1669E+04,2.2124E+04,2.5552E+04,2.6084E+CHD 6535
     $04,2.6774E+04,2.7321E+04,1.0859E+05,1.1128E+05/                   CHD 6536
C      Z = 86                                                           CHD 6537
      DATA (EIP(I),I=3741,3827)/222.00000,1.0746E+01,2.1000E+01,2.9000E+CHD 6538
     101,4.4000E+01,5.5000E+01,6.7000E+01,9.7000E+01,1.1100E+02,1.6600E+CHD 6539
     202,1.9000E+02,2.1852E+02,2.4505E+02,2.7069E+02,3.0175E+02,3.3485E+CHD 6540
     302,3.6550E+02,3.9860E+02,4.3390E+02,5.2165E+02,5.4895E+02,5.7805E+CHD 6541
     402,6.0680E+02,6.7490E+02,7.0810E+02,7.6890E+02,8.4130E+02,1.1264E+CHD 6542
     503,1.1669E+03,1.2079E+03,1.2509E+03,1.2954E+03,1.3409E+03,1.3879E+CHD 6543
     603,1.4354E+03,1.4924E+03,1.5434E+03,1.5954E+03,1.6494E+03,1.7039E+CHD 6544
     703,1.7604E+03,2.0909E+03,2.1484E+03,2.2074E+03,2.2674E+03,2.3304E+CHD 6545
     803,2.3934E+03,2.4859E+03,2.5524E+03,2.6204E+03,2.6899E+03,2.9559E+CHD 6546
     903,3.0269E+03,3.0989E+03,3.1719E+03,3.3979E+03,3.4774E+03,3.6704E+CHD 6547
     $03,3.7504E+03,6.4048E+03,6.5188E+03,6.6358E+03,6.7568E+03,6.8808E+CHD 6548
     $03,7.0113E+03,7.2438E+03,7.3813E+03,7.5243E+03,7.6718E+03,8.1578E+CHD 6549
     $03,8.3053E+03,8.4563E+03,8.6133E+03,9.2838E+03,9.4538E+03,9.8048E+CHD 6550
     $03,9.9863E+03,2.1473E+04,2.1883E+04,2.2306E+04,2.2746E+04,2.6354E+CHD 6551
     $04,2.6876E+04,2.7606E+04,2.8143E+04,1.1158E+05,1.1457E+05/        CHD 6552
C      Z = 87                                                           CHD 6553
      DATA (EIP(I),I=3828,3915)/223.00000,4.0000E+00,2.2000E+01,3.3000E+CHD 6554
     101,4.3000E+01,5.9000E+01,7.1000E+01,8.4000E+01,1.1700E+02,1.3300E+CHD 6555
     202,1.9700E+02,2.2782E+02,2.5514E+02,2.8121E+02,3.0676E+02,3.3666E+CHD 6556
     302,3.7103E+02,4.0109E+02,4.3322E+02,4.6709E+02,5.6503E+02,5.9341E+CHD 6557
     402,6.2353E+02,6.5322E+02,7.3134E+02,7.6534E+02,8.1884E+02,8.9984E+CHD 6558
     502,1.1663E+03,1.2086E+03,1.2514E+03,1.2964E+03,1.3428E+03,1.3901E+CHD 6559
     603,1.4391E+03,1.4885E+03,1.5493E+03,1.6023E+03,1.6563E+03,1.7123E+CHD 6560
     703,1.7686E+03,1.8273E+03,2.1669E+03,2.2263E+03,2.2873E+03,2.3490E+CHD 6561
     803,2.4140E+03,2.4790E+03,2.5804E+03,2.6488E+03,2.7188E+03,2.7904E+CHD 6562
     903,3.0649E+03,3.1379E+03,3.2116E+03,3.2864E+03,3.5521E+03,3.6343E+CHD 6563
     $03,3.8355E+03,3.9178E+03,6.5758E+03,6.6938E+03,6.8148E+03,6.9398E+CHD 6564
     $03,7.0678E+03,7.2030E+03,7.4648E+03,7.6067E+03,7.7542E+03,7.9063E+CHD 6565
     $03,8.4088E+03,8.5605E+03,8.7152E+03,8.8765E+03,9.6783E+03,9.8533E+CHD 6566
     $03,1.0219E+04,1.0408E+04,2.2155E+04,2.2545E+04,2.2949E+04,2.3374E+CHD 6567
     $04,2.7163E+04,2.7674E+04,2.8444E+04,2.8972E+04,1.1459E+05,1.1789E+CHD 6568
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     $05/
C     Z = 88
      DATA (EIP(I),I=3916,4004)/226.05000,5.2770E+00,1.0144E+01,3.4000E+
     101,4.6000E+01,5.8000E+01,7.6000E+01,8.9000E+01,1.0300E+02,1.4000E+
     202,1.5600E+02,2.3848E+02,2.6672E+02,2.9284E+02,3.1845E+02,3.4392E+
     302,3.7265E+02,4.0830E+02,4.3777E+02,4.6892E+02,5.0137E+02,6.0950E+
     402,6.3895E+02,6.7010E+02,7.0072E+02,7.8887E+02,8.2367E+02,8.6987E+
     502,9.5947E+02,1.2078E+03,1.2521E+03,1.2966E+03,1.3436E+03,1.3918E+
     603,1.4411E+03,1.4921E+03,1.5433E+03,1.6078E+03,1.6628E+03,1.7188E+
     703,1.7768E+03,1.8351E+03,1.8958E+03,2.2446E+03,2.3058E+03,2.3688E+
     803,2.4323E+03,2.4993E+03,2.5663E+03,2.6766E+03,2.7468E+03,2.8188E+
     903,2.8926E+03,3.1756E+03,3.2506E+03,3.3261E+03,3.4026E+03,3.7081E+
     $03,3.7928E+03,4.0023E+03,4.0868E+03,6.7499E+03,6.8719E+03,6.9969E+
     $03,7.1259E+03,7.2579E+03,7.3976E+03,7.6889E+03,7.8351E+03,7.9871E+
     $03,8.1439E+03,8.6629E+03,8.8186E+03,8.9771E+03,9.1426E+03,1.0076E+
     $04,1.0256E+04,1.0636E+04,1.0832E+04,2.2843E+04,2.3213E+04,2.3599E+
     $04,2.4009E+04,2.7978E+04,2.8479E+04,2.9289E+04,2.9808E+04,1.1764E+
     $05,1.2123E+05/
C     Z = 89
      DATA (EIP(I),I=4005,4094)/227.00000,6.9000E+00,1.2100E+01,2.0000E+
     101,4.9000E+01,6.2000E+01,7.6000E+01,9.5000E+01,1.0900E+02,1.2300E+
     202,1.6400E+02,1.9276E+02,2.8105E+02,3.0672E+02,3.3162E+02,3.5678E+
     302,3.8217E+02,4.0973E+02,4.4666E+02,4.7554E+02,5.0572E+02,5.3674E+
     402,6.5506E+02,6.8558E+02,7.1776E+02,7.4932E+02,8.4749E+02,8.8309E+
     502,9.2199E+02,1.0202E+03,1.2511E+03,1.2972E+03,1.3434E+03,1.3924E+
     603,1.4426E+03,1.4937E+03,1.5467E+03,1.5998E+03,1.6681E+03,1.7251E+
     703,1.7831E+03,1.8431E+03,1.9032E+03,1.9661E+03,2.3239E+03,2.3871E+
     803,2.4521E+03,2.5173E+03,2.5863E+03,2.6553E+03,2.7744E+03,2.8466E+
     903,2.9206E+03,2.9964E+03,3.2879E+03,3.3649E+03,3.4422E+03,3.5204E+
     $03,3.8657E+03,3.9531E+03,4.1708E+03,4.2576E+03,6.9269E+03,7.0529E+
     $03,7.1819E+03,7.3149E+03,7.4509E+03,7.5953E+03,7.9159E+03,8.0666E+
     $03,8.2231E+03,8.3844E+03,8.9199E+03,9.0798E+03,9.2421E+03,9.4118E+
     $03,1.0476E+04,1.0661E+04,1.1057E+04,1.1260E+04,2.3538E+04,2.3888E+
     $04,2.4256E+04,2.4651E+04,2.8801E+04,2.9291E+04,3.0141E+04,3.0651E+
     $04,1.2070E+05,1.2460E+05/
C     Z = 90
      DATA (EIP(I),I=4095,4185)/232.04700,6.9500E+00,1.2000E+01,2.0000E+
     101,2.9200E+01,6.5000E+01,8.0000E+01,9.4000E+01,1.1500E+02,1.3000E+
     202,1.4500E+02,2.1200E+02,2.3060E+02,3.2470E+02,3.4780E+02,3.7150E+
     302,3.9620E+02,4.2150E+02,4.4790E+02,4.8610E+02,5.1440E+02,5.4360E+
     402,5.7320E+02,7.0170E+02,7.3330E+02,7.6650E+02,7.9900E+02,9.0720E+
     502,9.4360E+02,9.7520E+02,1.0820E+03,1.2960E+03,1.3440E+03,1.3920E+
     603,1.4430E+03,1.4950E+03,1.5480E+03,1.6030E+03,1.6580E+03,1.7300E+
     703,1.7890E+03,1.8490E+03,1.9110E+03,1.9730E+03,2.0380E+03,2.4050E+
     803,2.4700E+03,2.5370E+03,2.6040E+03,2.6750E+03,2.7460E+03,2.8740E+
     903,2.9480E+03,3.0240E+03,3.1020E+03,3.4020E+03,3.4810E+03,3.5600E+
     $03,3.6400E+03,4.0250E+03,4.1150E+03,4.3410E+03,4.4300E+03,7.1070E+
     $03,7.2370E+03,7.3700E+03,7.5070E+03,7.6470E+03,7.7960E+03,8.1460E+
     $03,8.3010E+03,8.4620E+03,8.6280E+03,9.1800E+03,9.3440E+03,9.5100E+
     $03,9.6840E+03,1.0880E+04,1.1070E+04,1.1480E+04,1.1690E+04,2.4240E+
     $04,2.4570E+04,2.4920E+04,2.5300E+04,2.9630E+04,3.0110E+04,3.1000E+
     $04,3.1500E+04,1.2380E+05,1.2800E+05/
C     Z = 91
      DATA (EIP(I),I=4186,4277)/231.00000,6.0000E+00,1.1891E+01,2.1016E+
     101,3.3121E+01,4.5471E+01,7.8306E+01,9.2306E+01,1.0601E+02,1.3146E+
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     202,1.4581E+02,1.6116E+02,2.1636E+02,2.3526E+02,3.3146E+02,3.5506E+CHD 6624
     302,3.7931E+02,4.0456E+02,4.3046E+02,4.5741E+02,4.9651E+02,5.2541E+CHD 6625
     402,5.5526E+02,5.8556E+02,7.1691E+02,7.4926E+02,7.8321E+02,8.1646E+CHD 6626
     502,9.2706E+02,9.6426E+02,1.0326E+03,1.1060E+03,1.3242E+03,1.3732E+CHD 6627
     603,1.4227E+03,1.4747E+03,1.5277E+03,1.5822E+03,1.6382E+03,1.6947E+CHD 6628
     703,1.7682E+03,1.8282E+03,1.8897E+03,1.9532E+03,2.0167E+03,2.0832E+CHD 6629
     803,2.4582E+03,2.5247E+03,2.5932E+03,2.6617E+03,2.7342E+03,2.8067E+CHD 6630
     903,2.9377E+03,3.0137E+03,3.0912E+03,3.1712E+03,3.4777E+03,3.5582E+CHD 6631
     $03,3.6392E+03,3.7212E+03,4.1162E+03,4.2067E+03,4.4377E+03,4.5287E+CHD 6632
     $03,7.2660E+03,7.3980E+03,7.5340E+03,7.6740E+03,7.8175E+03,7.9695E+CHD 6633
     $03,8.3275E+03,8.4865E+03,8.6510E+03,8.8205E+03,9.3850E+03,9.5525E+CHD 6634
     $03,9.7225E+03,9.9005E+03,1.1123E+04,1.1318E+04,1.1738E+04,1.1953E+CHD 6635
     $04,2.4782E+04,2.5117E+04,2.5477E+04,2.5867E+04,3.0292E+04,3.0782E+CHD 6636
     $04,3.1692E+04,3.2207E+04,1.2709E+05,1.3024E+05/                   CHD 6637
C     Z = 92                                                            CHD 6638
      DATA (EIP(I),I=4278,4370)/238.04000,6.1200E+00,1.1450E+01,1.7920E+CHD 6639
     101,3.1120E+01,4.7330E+01,6.2830E+01,9.2700E+01,1.0570E+02,1.1910E+CHD 6640
     202,1.4900E+02,1.6270E+02,1.7840E+02,2.2180E+02,2.4100E+02,3.3930E+CHD 6641
     302,3.6340E+02,3.8820E+02,4.1400E+02,4.4050E+02,4.6800E+02,5.0800E+CHD 6642
     402,5.3750E+02,5.6800E+02,5.9900E+02,7.3320E+02,7.6630E+02,8.0100E+CHD 6643
     502,8.3500E+02,9.4800E+02,9.8600E+02,1.0910E+03,1.1310E+03,1.3540E+CHD 6644
     603,1.4040E+03,1.4550E+03,1.5080E+03,1.5620E+03,1.6180E+03,1.6750E+CHD 6645
     703,1.7330E+03,1.8080E+03,1.8690E+03,1.9320E+03,1.9970E+03,2.0620E+CHD 6646
     803,2.1300E+03,2.5130E+03,2.5810E+03,2.6510E+03,2.7210E+03,2.7950E+CHD 6647
     903,2.8690E+03,3.0030E+03,3.0810E+03,3.1600E+03,3.2420E+03,3.5550E+CHD 6648
     $03,3.6370E+03,3.7200E+03,3.8040E+03,4.2090E+03,4.3000E+03,4.5360E+CHD 6649
     $03,4.6290E+03,7.4280E+03,7.5620E+03,7.7010E+03,7.8440E+03,7.9910E+CHD 6650
     $03,8.1460E+03,8.5120E+03,8.6750E+03,8.8430E+03,9.0160E+03,9.5930E+CHD 6651
     $03,9.7640E+03,9.9380E+03,1.0120E+04,1.1370E+04,1.1570E+04,1.2000E+CHD 6652
     $04,1.2220E+04,2.5330E+04,2.5670E+04,2.6040E+04,2.6440E+04,3.0960E+CHD 6653
     $04,3.1460E+04,3.2390E+04,3.2920E+04,1.3040E+05,1.3250E+05/        CHD 6654
C                                                                       CHD 6655
C     ******************************************************************CHD 6656
C     LIBRARY OF ANALYTICAL EOS                                         CHD 6657
C                                                                       CHD 6658
      EQUIVALENCE (TABLE(1),BIGDUM(101)), (TABPL(1),BIGDUM(301)), (DTAB(CHD 6659
     11),BIGDUM(501))                                                   CHD 6660
C                                                                       CHD 6661
C     THE FOLLOWING ARE EXAMPLES FOR ILLUSTRATIVE PURPOSES              CHD 6662
C     DATA MIGHT NOT BE THE BEST AVAILABLE                              CHD 6663
C                                                                       CHD 6664
      DATA NUMTAB/9/                                                    CHD 6665
C     DRY AIR        SC-RR-70-28                                        CHD 6666
      DATA TABLE(1),TABPL(1)/1.,1./                                     CHD 6667
      DATA (DTAB(I),I=1,31)/8HAIR(DRY),3.,2.,22*0.,7.,.78455,8.,.21075,1CHD 6668
     18.,.0047/                                                         CHD 6669
C     GOLD           SC-RR-70-28                                        CHD 6670
      DATA TABLE(2),TABPL(2)/2.,32./                                    CHD 6671
      DATA (DTAB(I),I=32,58)/4HGOLD,1.,4.,19.3,0.,0.,1.75E12,3.054,.0155CHD 6672
     11,0.,2.,1.45E10,.1151,12*0.,79.,1./                               CHD 6673
C     ALUMINUM       SC-RR-70-28                                        CHD 6674
      DATA TABLE(3),TABPL(3)/3.,59./                                    CHD 6675
      DATA (DTAB(I),I=59,85)/8HALUMINUM,1.,4.,2.7,0.,0.,7.63E11,2.06,.03CHD 6676
     143,-1.,2.,1.2E11,.08,12*0.,13.,1./                                CHD 6677
C     BERYLLIUM      SC-RR-70-28                                        CHD 6678
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      DATA TABLE(4),TABPL(4)/4.,86./                                    CHD 6679
      DATA (DTAB(I),I=86,112)/9HBERYLLIUM,1.,4.,1.845,0.,0.,-7.97E5,1.17CHD 6680
     1,.09995,1.091,2.,3.69E11,.134,12*0.,4.,1./                        CHD 6681
C     IRON  130 KBAR PHASE TRANSITION    SC-RR-70-28                    CHD 6682
      DATA TABLE(5),TABPL(5)/5.,113./                                   CHD 6683
      DATA (DTAB(I),I=113,139)/10HIRON 130PT,1.,4.,7.85,0.,0.,1.93E12,1.CHD 6684
     175,0.,0.,2.,7.3E10,.282,5*0.,8.36,8.75,1.12E11,2.3E12,5.E12,2*0.,2CHD 6685
     26.,1./                                                            CHD 6686
C     ALUMINUM WITH MELT TRANSITION AND CONDUCTION                      CHD 6687
      DATA TABLE(6),TABPL(6)/6.,140./                                   CHD 6688
      DATA (DTAB(I),I=140,166)/10HALUMINUM/M,1.,4.,2.7,0.,0.,7.63E11,2.0CHD 6689
     16,.0343,-1.,2.,1.2E11,-6.639E9,3.5E12,.8,2.7E11,0.,2.305,5*0.,3.98CHD 6690
     2E9,.924,13.,1./                                                   CHD 6691
C     LEAD WITH MELT TRANSITION AND CONDUCTION                          CHD 6692
      DATA TABLE(7),TABPL(7)/7.,167./                                   CHD 6693
      DATA (DTAB(I),I=167,193)/6HLEAD/M,1.,4.,11.35,0.,0.,-2.051E5,2.77,CHD 6694
     1.0076,1.46,2.,9.5E9,-4.08E8,2.E12,0.,4.E10,0.,9.94,5*0.,2.30E8,.96CHD 6695
     27,82.,1./                                                         CHD 6696
C     BERYLLIUM WITH MELT TRANSITION AND CONDUCTION                     CHD 6697
      DATA TABLE(8),TABPL(8)/8.,194./                                   CHD 6698
      DATA (DTAB(I),I=194,220)/4HBE/M,1.,4.,1.851,0.,0.,-7.998E5,1.16,.0CHD 6699
     19995,1.124,2.,3.69E11,-3.68E10,0.,0.,2.9E10,-.54347,6*0.,1.3E10,0.CHD 6700
     2,4.,1./                                                           CHD 6701
C     COPPER WITH MELT TRANSITION AND CONDUCTION                        CHD 6702
      DATA TABLE(9),TABPL(9)/9.,221./                                   CHD 6703
      DATA (DTAB(I),I=221,247)/8HCOPPER/M,1.,4.,8.94,0.,0.,-3.94E5,1.99,CHD 6704
     1.0271,1.489,2.,5.25E10,-4.637E9,6.E12,.7,4.4E11,7*0.,2.055E9,-8.21CHD 6705
     27,29.,1./                                                         CHD 6706
C                                                                       CHD 6707
C     SELECT EOS FROM TABLE                                             CHD 6708
      TAB=ISETAB                                                        CHD 6709
      DO 10 I=1,NUMTAB                                                  CHD 6710
      IF (TAB.NE.TABLE(I)) GO TO 10                                     CHD 6711
      IS=TABPL(I)                                                       CHD 6712
      GO TO 20                                                          CHD 6713
   10 CONTINUE                                                          CHD 6714
      PRINT 50, ISETAB                                                  CHD 6715
      STOP                                                              CHD 6716
   20 PRINT 60, ISETAB,DTAB(IS)                                         CHD 6717
      DO 30 I=1,24                                                      CHD 6718
      IS=IS+1                                                           CHD 6719
   30 ZB(I)=DTAB(IS)                                                    CHD 6720
      J1=ZB(1)                                                          CHD 6721
      JK=IZ-1                                                           CHD 6722
      DO 40 I=1,J1                                                      CHD 6723
      JK=JK+1                                                           CHD 6724
      ZZS(JK)=DTAB(IS+1)                                                CHD 6725
      COT(JK)=DTAB(IS+2)                                                CHD 6726
   40 IS=IS+2                                                           CHD 6727
      RETURN                                                            CHD 6728
C                                                                       CHD 6729
   50 FORMAT (19H1 THERE IS NO TABLE,I6,13H IN DATA LIST)               CHD 6730
   60 FORMAT (20H0 LIBRARY EOS NUMBER,I6,3H ( ,A10,15H ) IS REQUESTED,/)CHD 6731
      END                                                               CHD 6732
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      SUBROUTINE ZAPPER                                                 CHD 6733
C     READS DTF OR BUCKL TAPE AND SETS UP CHART SOURCES.                CHD 6734
      COMMON /A/ JBND(21),ITRIED(400),IZPTL(400),IZPRL(400),KPHASE(400),CHD 6735
     1KACT(401),ISPALL(400),NSPALL,OBS,IBS,ICYCLE,IDTMAX,IDTMIN,JPRIN,NCCHD 6736
     2OUNT,NMTRLS,NZN,NZ,NZP,NDUMP,NBPRES,NOSOUR,NACTION,NORAD,IGM,NRADCCHD 6737
     3K,MOVIE,IMPEXP,IMPA,KRD4,NOHYD                                    CHD 6738
      COMMON D(400),DO(400),T(400),TO(400),P(400),XM(400),XM2(401),X(401CHD 6739
     1),XO(401),V(401),VO(401),XL(400),XLO(400),VL(400),VLO(401),CSOD(40CHD 6740
     20),Q(400),SXD(400),SZD(400),FPATH(400),FLUX(401),E(400),PPPT(400),CHD 6741
     3PEPTIN(400),PSPALL(400),SD(400),TEMP(400),TSAVE(400),PSAVE(400),ESCHD 6742
     4AVE(400),TEMPR(401),TMSPALL(20),DT,DTMAX,DTMIN,DTTEMP,DTRAD,TIME,TCHD 6743
     5PN,TEND,DTRADT,BL,BQ,DTIMEP(25),DLTTMX(25),DTMINN(25),TIMEP(25),TDCHD 6744
     6TMINN(25),TIMES(25),WORKF,WORKB,ENO,ESOURS,TBPRES(25),PINNER(25),PCHD 6745
     7OUTER(25),XMATUP(21),DTCS,DTP,TITH(25),TEINTH(25),TEOUTH(25),FLINFCHD 6746
     8,FLINFO,FLINB,FLINBC,FLOUF,FLOUFO,FLOUB,FLOUBO,RADEB,RADEF,SCRADF,CHD 6747
     9SCRADB,SPLA(20),SPLB(20),SPLC(20),SPLD(20),ENTSV(400),TMOV(10),DTMCHD 6748
     $OV(10),TRADOFF,SWEP,YIELD(20,8),DRATIO(400),SWPOR                 CHD 6749
      COMMON /C/ TEMPA,TEMPB,TEMPC,TEMPD,TEMPE,TEMPF,TEMPG,TEMPH,TEMPI,TCHD 6750
     1EMPJ,TEMPK,TEMPL,TEMPM,TEMPN,TEMPAB,TBPU,PBDRYO,PBDRYI,TRADMIN,RADCHD 6751
     2K1,RADK2,RADK3,RADK4,RADK5,RADK6,TEBOUT,TEBIN,TTHIU               CHD 6752
      COMMON /D/ IS,IS1,ICALL,ITLOW,JTLOW,INES                          CHD 6753
      DIMENSION SD2(1), SD3(1), TSOUR1(1), TSOUR2(1), TSOUR3(1), TSOUR4(CHD 6754
     11)                                                                CHD 6755
      EQUIVALENCE (SD2(1),SD(1)), (SD3(1),TEMP(1)), (TSOUR1(1),TSAVE(1))CHD 6756
     1, (TSOUR2(1),PSAVE(1)), (TSOUR3(1),ESAVE(1)), (TSOUR4(1),TEMPR(1))CHD 6757
      DIMENSION NBDTF(1)                                                CHD 6758
      EQUIVALENCE (NBDTF(1),VLO(1))                                     CHD 6759
      READ 440, TEMPAB,TEMPB,TEMPC,TEMPD,TEMPF,TEMPG,IS,IS1             CHD 6760
      JJ=7                                                              CHD 6761
      IF (IS.EQ.1) JJ=17                                                CHD 6762
      IS=JJ                                                             CHD 6763
      IF (TEMPAB.GE.0.) GO TO 10                                        CHD 6764
      TEMPA=-TEMPAB                                                     CHD 6765
      TEMPAB=4.185E7*TEMPA                                              CHD 6766
      GO TO 20                                                          CHD 6767
   10 TEMPA=TEMPAB/4.185E7                                              CHD 6768
   20 READ (IS,450) (XO(I),I=1,9),ICALL                                 CHD 6769
      IF (ICALL.GT.0) GO TO 30                                          CHD 6770
      PRINT 460, (XO(I),I=1,9)                                          CHD 6771
      GO TO 40                                                          CHD 6772
   30 PRINT 470, (XO(I),I=1,9)                                          CHD 6773
   40 PRINT 480, TEMPA,TEMPAB                                           CHD 6774
      IF (IS1.EQ.1) PRINT 490                                           CHD 6775
      IF (ICALL.GT.0) GO TO 170                                         CHD 6776
      READ (IS,500) NZDTF,NMATDTF                                       CHD 6777
      PRINT 510, NZDTF,NMATDTF                                          CHD 6778
      JJ=NMATDTF+1                                                      CHD 6779
      NZDTFP=NZDTF+1                                                    CHD 6780
      READ (IS,500) (NBDTF(I),I=1,JJ)                                   CHD 6781
      NBDTF(JJ+1)=10000                                                 CHD 6782
      READ (IS,520) (DO(I),VO(I),I=1,NZDTF)                             CHD 6783
      XO(1)=X(1)                                                        CHD 6784
      DO 50 I=1,NZDTF                                                   CHD 6785
   50 XO(I+1)=XO(I)-DO(I)/D(I)                                          CHD 6786
      PRINT 530                                                         CHD 6787
```

```
      JL=1                                                              CHD 6788
      TEMPA=0.                                                          CHD 6789
      DO 90 I=1,NZDTFP                                                  CHD 6790
      DO 60 J=1,NZP                                                     CHD 6791
      IF (ABS(XO(I)-X(J)).GT.1.E-5*ABS(XO(I)+X(J))) GO TO 60            CHD 6792
      XO(I)=X(J)                                                        CHD 6793
      GO TO 70                                                          CHD 6794
   60 CONTINUE                                                          CHD 6795
   70 IF (I.NE.NBDTF(JL+1)) GO TO 80                                    CHD 6796
      IF (I.EQ.NZDTFP) GO TO 80                                         CHD 6797
      JJ=JL+1                                                           CHD 6798
      PRINT 540, JL,JJ                                                  CHD 6799
      JL=JJ                                                             CHD 6800
   80 XX=XO(1)-XO(I)                                                    CHD 6801
      IF (I.EQ.NZDTFP) GO TO 90                                         CHD 6802
      TEMPA=TEMPA+DO(I)                                                 CHD 6803
      PRINT 550, XO(I),XX,I,TEMPA,VO(I),JL                              CHD 6804
   90 CONTINUE                                                          CHD 6805
      PRINT 550, XO(NZDTFP),XX,NZDTFP                                   CHD 6806
      JL=1                                                              CHD 6807
      XX=X(1)                                                           CHD 6808
      FR=0.                                                             CHD 6809
      DO 150 I=1,NZ                                                     CHD 6810
      I1=I+1                                                            CHD 6811
      SD3(I)=0.                                                         CHD 6812
  100 JJ=JL+1                                                           CHD 6813
      IF (JJ.GT.NZDTFP) GO TO 160                                       CHD 6814
      IF (X(I1)-XO(JJ)) 110,120,140                                     CHD 6815
  110 JK=0                                                              CHD 6816
      GO TO 130                                                         CHD 6817
  120 JK=1                                                              CHD 6818
  130 SD3(I)=SD3(I)+(1.-FR)*VO(JL)                                      CHD 6819
      FR=0.                                                             CHD 6820
      JL=JJ                                                             CHD 6821
      XX=XO(JJ)                                                         CHD 6822
      IF (JK.EQ.0) GO TO 100                                            CHD 6823
      GO TO 150                                                         CHD 6824
  140 F1=(XX-X(I1))/(XO(JL)-XO(JJ))                                     CHD 6825
      SD3(I)=SD3(I)+F1*VO(JL)                                           CHD 6826
      FR=FR+F1                                                          CHD 6827
      XX=X(I1)                                                          CHD 6828
  150 SD2(I)=TEMPAB*SD3(I)/XM(I)                                        CHD 6829
  160 JL=1                                                              CHD 6830
      GO TO 350                                                         CHD 6831
  170 READ (IS,560) JL,TEMPH,JJ                                         CHD 6832
C     JL IS THE LAYER NUMBER, JL IS NEGATIVE FOR LAST LAYER             CHD 6833
      NZDTFP=IABS(JL)                                                   CHD 6834
      IF (NZDTFP.GT.1) GO TO 180                                        CHD 6835
      PRINT 570                                                         CHD 6836
      TEMPL=0.                                                          CHD 6837
      GO TO 190                                                         CHD 6838
  180 IIK=NZDTFP-1                                                      CHD 6839
      PRINT 540, IIK,NZDTFP                                             CHD 6840
  190 JK1=JBND(NZDTFP)                                                  CHD 6841
      JK2=JBND(NZDTFP+1)                                                CHD 6842
```

```
      TEMPJ=D(JK1)
      TEMPI=TEMPJ*(X(JK1)-X(JK2))
      IF (TEMPH.LE.0.) TEMPH=TEMPI
      IF (ABS(TEMPI-TEMPH).LE.1.E-3*TEMPI) GO TO 200
      PRINT 580, NZDTFP,TEMPH,TEMPI
  200 READ (IS,590) (XO(I),VO(I),I=1,JJ)
      XX=X(JK1)
      XO(1)=XX
      XO(JJ)=X(JK2)
      JK3=JJ-1
      DO 210 I=2,JK3
  210 XO(I)=XX-XO(I)/TEMPJ
      DO 220 I=1,JJ
      XX=X(1)-XO(I)
      IIK=I-1
      IF (I.EQ.1) IIK=1
      TEMPL=TEMPL+D(JK1)*(XO(IIK)-XO(I))
  220 PRINT 600, XO(I),XX,I,TEMPL,VO(I),JL
      LK2=JK2-1
      DO 340 I=JK1,LK2
      JK4=JK5=0
      DO 270 JK=1,JJ
      IF (JK4.GT.0) GO TO 250
      IF (X(I)-XO(JK)) 270,240,230
  230 JK4=JK-1
      GO TO 250
  240 JK4=JK
  250 IF (X(I+1)-XO(JK)) 270,260,260
  260 JK5=JK
      GO TO 280
  270 CONTINUE
  280 JK6=JK4+1
      JK7=JK5-1
      EBL=(VO(JK5)*(XO(JK7)-X(I+1))+VO(JK7)*(X(I+1)-XO(JK5)))/(XO(JK7)-X
     10(JK5))
      EBU=(VO(JK4)*(XO(JK6)-X(I))+VO(JK6)*(X(I)-XO(JK4)))/(XO(JK6)-XO(JK
     14))
      IF (JK7-JK6) 290,300,310
C     NO POINTS INTERIOR TO ZONE
  290 SD2(I)=.5*(EBL+EBU)*(X(I)-X(I+1))
      GO TO 330
C     ONE POINT INTERIOR TO ZONE
  300 SD2(I)=.5*(EBL*(XO(JK7)-X(I+1))+EBU*(X(I)-XO(JK7))+VO(JK7)*(X(I)-X
     1(I+1)))
      GO TO 330
C     TWO OR MORE POINTS INTERIOR TO ZONE
  310 SD2(I)=.5*(EBL*(XO(JK7)-X(I+1))+EBU*(X(I)-XO(JK6))+VO(JK7)*(XO(JK7
     1-1)-X(I+1))+VO(JK6)*(X(I)-XO(JK6+1)))
      JK6=JK6+1
      JK7=JK7-1
      IF (JK6.GT.JK7) GO TO 330
      DO 320 JK=JK6,JK7
  320 SD2(I)=SD2(I)+.5*VO(JK)*(XO(JK-1)-XO(JK+1))
  330 SD3(I)=D(I)*SD2(I)
  340 SD2(I)=TEMPAB*SD3(I)/XM(I)
```

```
      IF (JL.GT.0) GO TO 170
  350 JL=1
      TEMPA=0.
      NOSOUR=0
      PRINT 610
      DO 380 I=1,NZP
      XX=X(1)-X(I)
      IF (I.EQ.NZP) GO TO 390
C     DROP SOURCES OF LESS THAN 0.1 CAL/GM
      IF (SD2(I).GT.4.185E6) GO TO 360
      SD2(I)=SD3(I)=0.
  360 IF (SD3(I).NE.0.) NOSOUR=I
      IF (I.NE.JBND(JL+1)) GO TO 370
      JJ=JL+1
      PRINT 540, JL,JJ
      JL=JJ
  370 TEMPA=TEMPA+D(I)*(X(I)-X(I+1))
      PRINT 620, X(I),XX,I,TEMPA,SD3(I),SD2(I),JL
  380 CONTINUE
  390 PRINT 620, X(NZP),XX,NZP
      XX=1./3.E10
      IF (IS1.NE.1) XX=0.
      DO 400 I=1,NOSOUR
      SD3(I)=XX*(X(1)-X(I))
      TSOUR1(I)=TEMPB+SD3(I)
      TSOUR2(I)=TEMPC+SD3(I)
      TSOUR3(I)=TEMPD+SD3(I)
      TSOUR4(I)=TEMPF+SD3(I)
      SD3(I)=2.*SD2(I)/(TEMPF-TEMPC+TEMPG*(TEMPD-TEMPB))
  400 SD2(I)=TEMPG*SD3(I)
      IF (ICALL.GT.0) RETURN
      IF (NMATDTF.LE.1) GO TO 430
      JJ=NMTRLS+1
      DO 420 J=1,NMATDTF
      JL=NBDTF(J)
      DO 410 I=1,JJ
      IS=JBND(I)
      IF (X(IS).EQ.XO(JL)) GO TO 420
  410 CONTINUE
      PRINT 630, J,NBDTF(J),XO(JL)
  420 CONTINUE
  430 CONTINUE
      RETURN
C
  440 FORMAT (6E10.3,2I5)
  450 FORMAT (9A8,I8)
  460 FORMAT (25H0 HEADING ON DTF TAPE IS ,9A8)
  470 FORMAT (27H0 HEADING ON BUCKL TAPE IS ,9A8)
  480 FORMAT (14H0 TOTAL FLUX =,E15.7,10H CAL/CM2 =,E15.7,9H ERGS/CM2)
  490 FORMAT (30H0 TIME RETARDATION IS INCLUDED)
  500 FORMAT (16I5)
  510 FORMAT (9H0 NZDTF =,I4,11H  NMATDTF =,I4)
  520 FORMAT (2E20.10)
  530 FORMAT (24H0 DTF DEPOSITION PROFILE,/,71H           X(I)          X(I)-X
     1(1)         I   MASS DEPTH(I) NORMAL EDEP(I)     MAT,/)

  540 FORMAT (17H0 END OF MATERIAL,I3,18H START OF MATERIAL,I3,/)
  550 FORMAT (2E15.7,I5,2E15.7,I5)
  560 FORMAT (I4,E16.7,I4)
  570 FORMAT (26H0 BUCKL DEPOSITION PROFILE,/,70H          XB(I)          X(1)
     1-XB(I)      I      MASS DEPTH      NORMAL EDEP     MAT,/)
  580 FORMAT (47H0 SOMETHING IS WRONG WITH BUCKL INPUT FOR LAYER,I6,/,21
     1H  INPUT MASS DEPTH IS,E15.7,24H AND CALCULATED VALUE IS,E15.7)
  590 FORMAT (5E16.5)
  600 FORMAT (2E15.7,I5,2E15.7,I5)
  610 FORMAT (26H1 CHART DEPOSITION PROFILE,/,85H           X(I)          X(I)
     1-X(1)          I   MASS DEPTH(I) NORMAL EDEP(I)       EDEP(I)      MAT,/)
  620 FORMAT (2E15.7,I5,3E15.7,I5)
  630 FORMAT (40H0SOMETHING APPEARS TO BE WRONG IN ZAPPER,/,23H DTF MATE
     1RIAL BOUNDARY ,I3,16H  ZONE BOUNDARY ,I4,8H  AT X =,E15.7,/,31H DO
     2ES NOT LIE ON CHART BOUNDARY)
      END
```

```
      SUBROUTINE ZONE (IG,IR,IL,IM,JBAD,RR,RL,D,DLEFT,RA,ER,X,Y,Z)     CHD 6969
C     ZONING ROUTINE                                                   CHD 6970
      DIMENSION X(1), Y(1), Z(1)                                       CHD 6971
      IF (RA.GT.0.) GO TO 50                                           CHD 6972
      IF (D.LE.0.OR.DLEFT.LE.0.) STOP 2020                             CHD 6973
      RAP=RR-RL                                                        CHD 6974
      RAU=RR-D                                                         CHD 6975
      RAL=RL+DLEFT                                                     CHD 6976
      IF (IG-2) 10,20,30                                               CHD 6977
   10 FM1=D/RAP                                                        CHD 6978
      FM2=DLEFT/RAP                                                    CHD 6979
      GO TO 40                                                         CHD 6980
   20 FM1=(D*(RR+RAU))/(RAP*(RR+RL))                                   CHD 6981
      FM2=(DLEFT*(RL+RAL))/(RAP*(RR+RL))                               CHD 6982
      GO TO 40                                                         CHD 6983
   30 FM1=(D*(RR**2+RR*RAU+RAU**2))/(RAP*(RR**2+RR*RL+RL**2))          CHD 6984
      FM2=(DLEFT*(RL**2+RL*RAL+RAL**2))/(RAP*(RR**2+RR*RL+RL**2))      CHD 6985
   40 RA=(1.-FM1)/(1.-FM2)                                             CHD 6986
      IFQ=1                                                            CHD 6987
      IRL=0                                                            CHD 6988
      GO TO 60                                                         CHD 6989
   50 IFQ=0                                                            CHD 6990
      IRL=0                                                            CHD 6991
      IF (DLEFT.LE.0.) GO TO 60                                        CHD 6992
      IRL=1                                                            CHD 6993
      D=DLEFT                                                          CHD 6994
   60 IF (ER.LT..001) ER=.001                                          CHD 6995
      IMN=IM-IR+1                                                      CHD 6996
      RAU=(1.+ER)*RA                                                   CHD 6997
      RAL=(1.-ER)*RA                                                   CHD 6998
      SRA=RA                                                           CHD 6999
      ANUM=1./3.                                                       CHD 7000
      IT=IST=ISQ=JKS=0                                                 CHD 7001
      IF (IRL.EQ.0) GO TO 260                                          CHD 7002
      CC=.001*RA                                                       CHD 7003
C     ZONE IN INCREASING POSITION DIRECTION                            CHD 7004
      IMM=IM-IMN                                                       CHD 7005
      I=IM-1                                                           CHD 7006
      Y(IM)=RL                                                         CHD 7007
      Y(I)=RL+D                                                        CHD 7008
   70 I1=I                                                             CHD 7009
      I2=I+1                                                           CHD 7010
      I=I-1                                                            CHD 7011
      XX=Y(I2)/Y(I1)                                                   CHD 7012
      IF (IG-2) 80,90,100                                              CHD 7013
   80 Y(I)=Y(I1)*(1.+RA*(1.-XX))                                       CHD 7014
      GO TO 110                                                        CHD 7015
   90 Y(I)=Y(I1)*SQRT(1.+RA*(1.-XX)*(1.+XX))                           CHD 7016
      GO TO 110                                                        CHD 7017
  100 Y(I)=Y(I1)*(1.+RA*(1.-XX)*(1.+XX*(1.+XX)))**ANUM                 CHD 7018
  110 IF (Y(I)-RR) 120,140,130                                         CHD 7019
  120 IF (I-IMM) 330,330,70                                            CHD 7020
  130 IF (IT.EQ.1) GO TO 160                                           CHD 7021
      IT=1                                                             CHD 7022
      IF (Y(I)-RR.LT.RR-Y(I1)) GO TO 140                               CHD 7023
```

```
      IOP=I1
      KSW=1
      GO TO 150
  140 IOP=I
      KSW=-1
      CC=-CC
  150 ION=IOP+1
  160 IF (I.GT.IOP) GO TO 120
      FM1=Y(IOP)-Y(ION)
      FM2=RR-Y(ION)
      IF (IG-2) 190,170,180
  170 FM1=FM1*(Y(IOP)+Y(ION))
      FM2=FM2*(RR+Y(ION))
      GO TO 190
  180 FM1=FM1*(Y(IOP)**2+Y(ION)*(Y(IOP)+Y(ION)))
      FM2=FM2*(RR**2+Y(ION)*(RR+Y(ION)))
  190 IF (ABS(FM1-FM2).LE.1.E-4*(FM1+FM2)) GO TO 240
      IF (KSW) 200,200,210
  200 IF (Y(IOP)-RR) 220,240,230
  210 IF (RR-Y(IOP)) 220,240,230
  220 RA=RA-CC
      CC=.1*CC
      IST=IST+1
      IF (IST-9) 230,230,500
  230 RA=RA+CC
      ISQ=ISQ+1
      IF (ISQ.GT.1000) GO TO 500
      IF (RA.GT.RAU) GO TO 520
      IF (RA.LT.RAL) GO TO 520
      I=IM-1
      GO TO 70
  240 DO 250 I=ION,IM
      I1=IR-ION+I+1
  250 X(I1)=Y(I)
      IL=I1
      RETURN
  260 I=2
C     ZONE IN DECREASING POSITION DIRECTION
      CC=.001*RA
      Y(1)=RR
      Y(2)=RR-D
  270 I1=I
      I2=I-1
      I=I+1
      XX=Y(I2)/Y(I1)
      IF (IG-2) 280,290,300
  280 Y(I)=Y(I1)*(1.-RA*(XX-1.))
      GO TO 310
  290 XX=1.-RA*(XX-1.)*(XX+1.)
      IF (XX.LT.0.) GO TO 350
      Y(I)=Y(I1)*SQRT(XX)
      GO TO 310
  300 XX=1.-RA*(XX-1.)*(XX*(1.+XX)+1.)
      IF (XX.LT.0.) GO TO 350
      Y(I)=Y(I1)*XX**ANUM
```

```
310 IF (RL-Y(I)) 320,410,340
320 IF (I.LT.IMN) GO TO 270
    IF (IFQ.EQ.0) GO TO 330
    IF (JKS.EQ.0) GO TO 330
    NFR=0
    GO TO 900
330 PRINT 960, RL,RR
    PRINT 970, IMN
    GO TO 950
340 IF (IT.EQ.1) GO TO 430
    IT=1
    IF (Y(I)-RL.GT.RL-Y(I1)) GO TO 410
    IOP=I1
    KSW=1
    GO TO 420
350 IF (IT.EG.1) GO TO 360
    IT=1
    IOP=I1
    KSW=1
360 ION=IOP-1
    I=I1
    IF (I.GE.IOP) GO TO 370
    IF (KSW) 510,490,490
370 I=IOP
    Y(I)=RL
    INS=ION-1
    FQL=Y(ION)-Y(I)
    FQN=Y(INS)-Y(ION)
    IF (IG-2) 400,380,390
380 FQL=FQL*(Y(ION)+Y(I))
    FQN=FQN*(Y(INS)+Y(ION))
    GO TO 400
390 FQL=FQL*(Y(ION)**2+Y(ION)*Y(I)+Y(I)**2)
    FQN=FQN*(Y(INS)**2+Y(INS)*Y(ION)+Y(ION)**2)
400 FQN=FQL/FQN
    IF (ABS(FQN-RA).LT.1.E-4*RA) GO TO 540
    IF (KSW) 490,490,510
410 IOP=I
    KSW=-1
    CC=-CC
420 ION=IOP-1
430 IF (I.LT.IOP) GO TO 320
    FM1=Y(ION)-Y(IOP)
    FM2=Y(ION)-RL
    IF (IG-2) 460,440,450
440 FM1=FM1*(Y(IOP)+Y(ION))
    FM2=FM2*(Y(ION)+RL)
    GO TO 460
450 FM1=FM1*(Y(IOP)**2+Y(ION)*(Y(IOP)+Y(ION)))
    FM2=FM2*(RL**2+Y(ION)*(RL+Y(ION)))
460 IF (ABS(FM1-FM2).LT.1.E-4*(FM1+FM2)) GO TO 540
    IF (KSW) 470,470,480
470 IF (RL-Y(IOP)) 490,490,510
480 IF (Y(IOP)-RL) 490,490,510
490 RA=RA-CC
```

```
      CC=.1*CC
      IST=IST+1
      IF (IST.LE.9) GO TO 510
  500 PRINT 960, RL,RR
      PRINT 980, IST,ISQ
      GO TO 950
  510 RA=RA+CC
      ISQ=ISQ+1
      IF (ISQ.GT.1000) GO TO 500
      IF (RA.LE.RAU) GO TO 530
  520 PRINT 960, RL,RR
      PRINT 990, RA,RAU,RAL
      GO TO 950
  530 IF (RA.LT.RAL) GO TO 520
      I=2
      GO TO 270
  540 IF (IFQ.EQ.0) GO TO 550
      XX=Y(ION)-RL
      IF (ABS(XX-DLEFT).GT.ER*DLEFT) GO TO 570
  550 DO 560 I=2,IOP
      I1=IR-1+I
  560 X(I1)=Y(I)
      IL=I1
      X(IL)=RL
      RETURN
  570 IF (IOP.GT.26) GO TO 580
      PRINT 960, RL,RR
      PRINT 1030
      PRINT 1020
      PRINT 1000
      JBAD=JBAD+3
      GO TO 550
  580 RAI=1./RA
      RAIL=1./((1.+.999*ER)*RA)
      RAIU=1./((1.-.999*ER)*RA)
      I1=I-1
      I2=I-2
      IF (XX.GT.DLEFT) NFR=0
      IF (XX.LT.DLEFT) NFR=1
      Z(1)=RL
      Z(2)=RL+DLEFT
      I=2
  590 J1=I
      J2=I-1
      I=I+1
      XX=Z(J2)/Z(J1)
      IF (IG-2) 600,610,620
  600 Z(I)=Z(J1)*(1.+RAI*(1.-XX))
      FM1=Z(I)-Z(J1)
      GO TO 630
  610 Z(I)=Z(J1)*SQRT(1.+RAI*(1.-XX)*(1.+XX))
      FM1=(Z(I)-Z(J1))*(Z(I)+Z(J1))
      GO TO 630
  620 Z(I)=Z(J1)*(1.+RAI*(1.-XX)*(1.+XX*(1.+XX)))**ANUM
      FM1=(Z(I)-Z(J1))*(Z(I)**2+Z(J1)*(Z(I)+Z(J1)))
```

```
630 IF (Z(I).LE.RR) GO TO 650                                   CHD 7189
640 PRINT 960, RL,RR                                            CHD 7190
    PRINT 1030                                                  CHD 7191
    GO TO 950                                                   CHD 7192
650 IF (I.LT.4) GO TO 590                                       CHD 7193
    FM2=Y(3)-Y(4)                                               CHD 7194
    FM3=Y(3)-Z(3)                                               CHD 7195
    IF (IG-2) 680,660,670                                       CHD 7196
660 FM2=FM2*(Y(3)+Y(4))                                         CHD 7197
    FM3=FM3*(Y(3)+Z(3))                                         CHD 7198
    GO TO 680                                                   CHD 7199
670 FM2=FM2*(Y(3)**2+Y(3)*Y(4)+Y(4)**2)                         CHD 7200
    FM3=FM3*(Y(3)**2+Y(3)*Z(3)+Z(3)**2)                         CHD 7201
680 IF (Y(4).LT.Z(4)) GO TO 640                                 CHD 7202
    RAP=(1.-FM1/FM3)/(1.-FM2/FM3)                               CHD 7203
    IF (RAP.EQ.1.) XX=FM3/FM1                                   CHD 7204
    IF (RAP.NE.1.) XX=1.+ALOG(FM2/FM1)/ALOG(RAP)                CHD 7205
    NUM=XX+.5                                                   CHD 7206
    IF (NUM.GT.IMN) GO TO 330                                   CHD 7207
    XS=ALOG(RAP)                                                CHD 7208
    XX=NUM                                                      CHD 7209
    IF (RAP.NE.1.) FM1=FM3*(1.-RAP)/(1.-EXP(XX*XS))             CHD 7210
    IF (RAP.EQ.1.) FM1=FM3/XX                                   CHD 7211
    I=3                                                         CHD 7212
    KLL=NUM-1                                                   CHD 7213
    DO 730 KN=1,KLL                                             CHD 7214
    XX=KN                                                       CHD 7215
    IF (RAP.EQ.1) GO TO 690                                     CHD 7216
    FM4=FM1*(1.-EXP(XX*XS))/(1.-RAP)                            CHD 7217
    GO TO 700                                                   CHD 7218
690 FM4=XX*FM1                                                  CHD 7219
700 I=I+1                                                       CHD 7220
    Z(I)=Z(3)**IG+FM4                                           CHD 7221
    IF (IG-2) 730,710,720                                       CHD 7222
710 Z(I)=SQRT(Z(I))                                             CHD 7223
    GO TO 730                                                   CHD 7224
720 Z(I)=Z(I)**ANUM                                             CHD 7225
730 CONTINUE                                                    CHD 7226
    X(IR+1)=Y(2)                                                CHD 7227
    X(IR+2)=Y(3)                                                CHD 7228
    IOP=IR+2                                                    CHD 7229
    DO 740 I1=2,I                                               CHD 7230
    IOP=IOP+1                                                   CHD 7231
    I2=I-I1+2                                                   CHD 7232
740 X(IOP)=Z(I2)                                                CHD 7233
    IL=IOP+1                                                    CHD 7234
    X(IL)=RL                                                    CHD 7235
    IF (IL-IR.LT.24) GO TO 850                                  CHD 7236
    K=11                                                        CHD 7237
    N=12                                                        CHD 7238
    J1=IR                                                       CHD 7239
750 FM1=X(J1+K)-X(J1+N)                                         CHD 7240
    FM2=X(J1+1)-X(J1+2)                                         CHD 7241
    FM3=X(J1+2)-X(J1+K)                                         CHD 7242
    IF (IG-2) 780,760,770                                       CHD 7243
```

```
  760 FM1=FM1*(X(J1+K)+X(J1+N))
      FM2=FM2*(X(J1+1)+X(J1+2))
      FM3=FM3*(X(J1+2)+X(J1+K))
      GO TO 780
  770 FM1=FM1*(X(J1+K)**2+X(J1+K)*X(J1+N)+X(J1+N)**2)
      FM2=FM2*(X(J1+1)**2+X(J1+1)*X(J1+2)+X(J1+2)**2)
      FM3=FM3*(X(J1+2)**2+X(J1+2)*X(J1+K)+X(J1+K)**2)
  780 RAI=(FM2/FM1)**.1
      XX=K-2
      IF (RAI.NE.1.) XX=(1.-EXP(XX*ALOG(RAI)))/(1.-RAI)
      XX=FM3/XX
      XP=XX/FM1
      XQ=0.
      IF (XP.GT.RAIU) XQ=XX-RAIU*FM1
      IF (XP.LT.RAIL) XQ=XX-RAIL*FM1
      XS=0.
      XP=FM2/(XX*RAI**(K-3))
      IF (XP.GT.RAIU) XS=XX*RAI**(K-3)-FM2/RAIU
      IF (XP.LT.RAIL) XS=XX*RAI**(K-3)-FM2/RAIL
      GO TO 800
  790 XQ=XS=0.
  800 ION=J1+K
      IOP=-1
  810 ION=ION-1
      IOP=IOP+1
      IF (IOP.EQ.0) XP=-XQ
      IF (IOP.EQ.1) XP=-.5*XQ
      IF (IOP.EQ.2) XP=XS/16.
      IF (IOP.EQ.3) XP=.5*XQ+3.*XS/16.
      IF (IOP.EQ.4) XP=.75*(XQ+XS)
      IF (IOP.EQ.5) XP=.5*XS+3.*XQ/16.
      IF (IOP.EQ.6) XP=XQ/16.
      IF (IOP.EQ.7) XP=-.5*XS
      IF (IOP.EQ.8) STOP 511
      XYT=XX*RAI**IOP+XP
      IF (XYT.LE.0.) GO TO 790
      X(ION)=XYT+X(ION+1)**IG
      IF (IG-2) 840,820,830
  820 X(ION)=SQRT(X(ION))
      GO TO 840
  830 X(ION)=X(ION)**ANUM
  840 IF (ION.GT.J1+3) GO TO 810
      IF (J1.NE.IR) GO TO 850
      J1=IL-N-1
      GO TO 750
  850 KLL=0
      ION=0
      IOP=IL-1
      DO 890 I=IR,IOP
      ION=ION+1
      Z(ION)=X(I+1)-X(I)
      IF (IG-2) 880,860,870
  860 Z(ION)=Z(ION)*(X(I+1)+X(I))
      GO TO 880
  870 Z(ION)=Z(ION)*(X(I+1)**2+X(I+1)*X(I)+X(I)**2)
```

```
 880 IF (I.EQ.IR) GO TO 890                                              CHD 7299
     IF (Z(ION)/Z(ION-1).GT.(1.+ER)*RA)  KLL=1                           CHD 7300
     IF (Z(ION)/Z(ION-1).LT.(1.-ER)*RA)  KLL=1                           CHD 7301
 890 CONTINUE                                                            CHD 7302
     IF (KLL.EQ.0) RETURN                                                CHD 7303
 900 JKS=JKS+1                                                           CHD 7304
     IF (JKS.EQ.1) DNFR=D                                                CHD 7305
     IF (JKS-10) 910,920,940                                             CHD 7306
 910 IF (NFR.EQ.1) D=.9995*D                                             CHD 7307
     IF (NFR.EQ.0) D=1.0005*D                                            CHD 7308
     GO TO 930                                                           CHD 7309
 920 D=DNFR                                                              CHD 7310
 930 IT=IST=ISQ=0                                                        CHD 7311
     RA=SRA                                                              CHD 7312
     GO TO 260                                                           CHD 7313
 940 JBAD=JBAD+3                                                         CHD 7314
     PRINT 960, RL,RR                                                    CHD 7315
     PRINT 101(                                                          CHD 7316
     PRINT 1020                                                          CHD 7317
     PRINT 1000                                                          CHD 7318
     RETURN                                                              CHD 7319
 950 PRINT 1020                                                          CHD 7320
     IL=IR                                                               CHD 7321
     JBAD=1                                                              CHD 7322
     RETURN                                                              CHD 7323
C                                                                        CHD 7324
 960 FORMAT (30H0THE REGION WITH BOUNDARIES AT,E12.4,4H AND,E12.4,25H CCHD 7325
    1AN NOT BE ZONED BECAUSE)                                            CHD 7326
 970 FORMAT (45H THE NUMBER OF ZONES REQUIRED IS GREATER THAN,I5,22H THCHD 7327
    1E MAXIMUM AVAILABLE)                                                CHD 7328
 980 FORMAT (34H ITERATION WILL NOT CONVERGE  IST=,I5,6H  ISQ=,I6)       CHD 7329
 990 FORMAT (9H RATIO IS,E12.4,13H  NOT BETWEEN,2E12.4)                  CHD 7330
1000 FORMAT (47H0HOWEVER, WILL CONTINUE RUN AND STOP AT CYCLE 0,/,47H ICHD 7331
    1F ZONING IS SATISFACTORY RESTART AND GO.......,/)                   CHD 7332
1010 FORMAT (34H PROPER OVERLAP CANNOT BE OBTAINED,/,30H THE ERROR LIMICHD 7333
    1T IS TOO :EVERE)                                                    CHD 7334
1020 FORMAT (35H TO ZONE SUCCESSFULLY CHANGE INPUTS)                     CHD 7335
1030 FORMAT (70H WIDTH OF FIRST AND LAST ZONES ARE TOO LARGE A FRACTIONCHD 7336
    1 OF TOTAL WIDTH)                                                    CHD 7337
     END                                                                 CHD 7338
```

Appendix H

CHART D INPUT INSTRUCTIONS

Appendix H

CHART D INPUT INSTRUCTIONS

Card 1 Format (13A6)

78-column problem identification - any BCD information.

If the problem is a restart, this name must agree exactly with the name on the restart tape.

Card 2 Format (6I5, 3E10.3)

Variable 1.	(1-5)	ITIMEL - Computer time limit in seconds. Shortly before this allotted time is used, the code writes a restart tape dump, edits last cycle, and terminates. If ITIMEL = 0, the job card time limit is used. If ITIMEL < 0, the problem will generate and stop on cycle 0.
Variable 2.	(6-10)	NG - A switch to signify whether the problem is to be generated or restarted. If NG ≥ 0, generate the problem from the following data cards. If NG < 0, restart. The code reads -NG tape dumps before restarting.
Variable 3.	(11-15)	NDUMP - The time interval in seconds of computer time between writing restart tape dumps. If NDUMP = 0, the code sets NDUMP = 9999 (2.75 hours).
Variable 4.	(16-20)	IS - A switch to select restart output tape. If IS ≤ 0, restart output on tape 10 (standard). If IS > 0, restart output on tape 11 (optional). Under the latter option, tape 10 information past the restart point is not destroyed.
Variable 5.	(21-25)	IS1 - A switch to select extra binary edit output on tape 2. If IS1 ≤ 0, tape 2 edit is not written. If IS1 > 0, tape 2 edit is written.
Variable 6.	(26-30)	NEDREJ - A switch to force edits whenever a fracture or rejoin takes place. If NEDREJ = 0, no extra edit following fracture or rejoin. If NEDREJ > 0, standard edit following fracture or rejoin. If NEDREJ < 0, one line edit following fracture or rejoin.
Variable 7.	(31-40)	FRACDT - Fraction of Courant stability used to calculate sound speed time step. (Normally 0.8, in no case greater than 1). If FRACDT ≤ 0, FRACDT = 0.8.

Variable 8. (41-50)
: DTINCR - Factor used to increase time step from one cycle to the next (normally ~ 1.05). If DTINCR ≤ 0, DTINCR = 1.05.

Variable 9. (51-60)
: TEND - The end of problem time. If TEND ≤ 0, TEND is set to very large number and run is terminated on ITIMEL variable.

> If the problem is being restarted, the preceding cards are the only data cards required.

Card 3 Format (16I5)

Variable 1. (1-5)
: IGM - A geometry switch.
If IGM = 1, plane geometry.
If IGM = 2, cylindrical geometry.
If IGM = 3, spherical geometry.

Variable 2. (6-10)
: NRZC - The number of different zoning regions (see card set 11). There is no limit on the size of NRZC.

Variable 3. (11-15)
: NMTRLS - The number of material layers in the problem. A material is counted more than once if there is another material between the various pieces (see card set 11). NMTRLS ≤ NRZC. NMTRLS ≤ 20.

Variable 4. (16-20)
: NPRIN - The number of edit (print out) frequency intervals (see card set 5). 1 ≤ NPRIN ≤ 24.

Variable 5. (21-25)
: NDTMAX - The number of maximum input Δt intervals (see card set 6). 0 ≤ NDTMAX ≤ 24. If NDTMAX ≤ 0, the maximum Δt is set to a very large number.

Variable 6. (26-30)
: NDTMINN - The number of minimum input Δt intervals (see card set 7). 0 ≤ NDTMINN ≤ 24. If NDTMINN ≤ 0, the minimum Δt is zero.

Variable 7. (31-35)
: NBPRES - The number of points in the boundary pressure histories (see card set 9).
NBPRES ≤ 24. If NBPRES ≤ 0, there are no boundary pressures.

Variable 8. (36-40)

NOSOUR - A switch for internal energy sources. If NOSOUR ≤ 0, there are no internal sources. If NOSOUR > 0, there are internal sources and NOSOUR is the type of input information (see card set 13). NOSOUR = 1, 2, 3, 4, 5, and 6 are possible.

Variable 9. (41-45)

IBS - A switch to determine if boundary NZP (smallest X) is free to move or fixed in space.
If IBS = 0, boundary NZP is free.
If IBS = 1, boundary NZP is fixed (V ≡ 0).

Variable 10. (46-50)

OBS - A switch to determine if boundary 1 (largest X) is free to move or fixed in space.
If OBS = 0, boundary 1 is free.
If OBS = 1, boundary 1 is fixed (V ≡ 0).

Variable 11. (51-55)

NSPALL - A switch for fracture calculations.
If NSPALL < 0, no material fracture is allowed.
If NSPALL = 0, material fracturing is allowed.
If NSPALL > 0, voids will be zoned into the initial configuration with card set 15. The latter may only be used for plane geometry.
If NSPALL < 0 and type 7 zoning (see card set 11) is used, this input is ignored.

Variable 12. (56-60)

NACTION - The number of regions with initially active zones (see card set 14).
If NACTION = 0, only zones with sources or moving boundaries are active on cycle 1.

Variable 13. (61-65)

NORAD - A radiation switch.
If NORAD = 0, no radiation diffusion is calculated.
If NORAD = 1, implicit radiation diffusion.
If NORAD = 2, explicit radiation diffusion.
If NORAD = 3, approximate implicit radiation diffusion.
If NORAD = 4, the code attempts to use faster of 1, 2, 3.
The hydrodynamic calculation can be suppressed with options 1 through 4 by using the negative of the option number.

Variable 14. (66-70)

NTHIST - The number of points in the boundary temperatures histories (see card set 10).
NTHIST ≤ 24. (Ignored if NORAD = 0.)
If NTHIST ≤ 0, there are no boundary temperatures.

Variable 15. (71-75)

NRADCK - A switch for the radiation flux limiter. (Ignored if NORAD = 0.)

If NRADCK = 0, the limiter is used (normal option).

If NRADCK $\neq$ 0, the limiter is not used.

Variable 16. (76-80)

MOVIE - The number of movie frame frequency intervals. (See card set 8). MOVIE $\leq$ 9.

If MOVIE = 0, no movie tape is produced.

If MOVIE > 0, movie tape is produced on unit 3.

Card 4 Format (8E10.3)

Variable 1. (1-10)

BL - The constant in the linear viscosity term (normally 0.1).

Variable 2. (11-20)

BQ - The constant in the quadratic viscosity term (normally 2.0).

Note: Both BL and BQ should not be zero.

If BL + BQ = 0, code sets BL = 0.1 and BQ = 2.0.

Variable 3. (21-30)

XM2(1) - Temporary storage for the fictitious outer boundary mass (boundary 1) (normally 0).

Variable 4. (31-40)

XM2(2) - Temporary storage for the fictitious inner boundary mass (boundary NZP) (normally 0).

Variable 5. (41-50)

SCRADF - A scale factor for the front surface boundary temperature. (Ignored if NORAD = 0.)

If SCRADF > 0, the incident flux is scaled by SCRADF.

If SCRADF = 0, the code sets SCRADF = 1.

If SCRADF < 0, no radiation is allowed to pass through the front surface in either direction, i.e., FLUX(1) = 0.

Variable 6. (51-60)

SCRADB - A scale factor for the back surface boundary temperature. Inputs are the same as for Variable 5. (Ignored if NORAD = 0.) In cylindrical or spherical geometry, SCRADB is set = -1 when there is no central void. If there is a central void, and SCRADB $\geq$ 0, any radiation passing into the void will be lost. SCRADB < 0 is the physically realistic choice.

Variable 7. (61-70)

TRADOFF - The earliest time at which the code will check to see if the radiation can be turned off (normally 0).

Variable 8. (71-80) SWEP - elastic-plastic switch.

If SWEP = 0, no elastic-plastic calculation.

If SWEP = 1, elastic-plastic calculation.

Card Set 5 Format (8E10. 3) Edit (Print Out) Information

The times refer to problem times in seconds. There are NPRIN sets of these variables (see card 3).

Variable Odd. TIMEP (I) - The time at which edit intervals switch from DTIMEP (I-1) to DTIMEP (I).
[TIMEP (1) = 0, always.]

Variable Even. DTIMEP (I) - The time interval between edits from TIMEP (I) to TIMEP (I+1).

For times > TIMEP (NPRIN), the last value of DTIMEP is used to the end of the problem.

Card Set 6 Format (8E10. 3) Maximum Time Step Information

Present only if NDTMAX > 0 (see card 3).

There are NDTMAX sets of these variables.

Variable Odd. TIMES (I) - The time at which the maximum time step switches from DLTTMX (I-1) to DLTTMX (I). [TIMES (1) = 0, always.]

Variable Even. DLTTMX (I) - The maximum time step allowed between TIMES(I) and TIMES(I+1).
For times > TIMES (NDTMAX), the last value of DLTTMX is used to the end of the problem.

Card Set 7 Format (8E10. 3) Minimum Time Step Information

Present only if NDTMINN > 0 (see card 3).

There are NDTMINN sets of these variables.

Variable Odd. TDTMINN (I) - The time at which the minimum time step switches from DTMINN (I-1) to DTMINN (I).
[TDTMINN (1) = 0 always.]

Variable Even. DTMINN (I) - The minimum time step allowed between TDTMINN (I) and TDTMINN (I+1). For times > TDTMINN (NDTMINN), the last value of DTMINN is used to the end of the problem. In case of any conflict, the minimum time step criterion is never violated.

Card Set 8 Format (8E10. 3) Movie Frame Frequency

Present only if MOVIE > 0 (see card 3).

There are MOVIE sets of these variables.

Variable Odd.	TMOV(I) - The time at which the movie edit frequency switches from DTMOV(I-1) to DTMOV(I). [TMOV(1) = 0, always.] The dumps are terminated when the time ≥ TMOV (MOVIE).
Variable Even.	DTMOV(I) - The movie edit frequency time interval from TMOV(I) to TMOV(I+1).

Card Set 9 Format (3E10. 3) Boundary Pressure Information

Present only if NBPRES > 0 (see card 3).

There are NBPRES cards with:

Variable 1. (1-10)	TBPRES(I) - The time of the I^{th} boundary pressure history point. [TBPRES(1) = 0, always.]
Variable 2. (11-20)	PINNER(I) - The boundary pressure at boundary NZP (smallest X) at time TBPRES(I).
Variable 3. (21-30)	POUTER(I) - The boundary pressure at boundary 1 (largest X) at time TBPRES (I). The code does a linear interpolation in time between these points. For times > TBPRES (NBPRES), the last boundary pressures are used to the end of the problem.

Card Set 10 Format (3E10. 3) Boundary Temperature Information

Present only if NTHIST > 0 (see card 3).

There are NTHIST cards with:

Variable 1. (1-10)	TITH(I) - The time of the I^{th} boundary temperature history point. [TITH(1) = 0, always.]
Variable 2. (11-20)	TEINTH(I) - The boundary temperature at boundary NZP (smallest X) at time TITH(I).

Variable 3. (21-30) TEOUTH(I) - The boundary temperature at boundary 1 (largest X) at time TITH(I).

The code does a linear interpolation in time between these points. For times > TITH(NTHIST), the last boundary temperatures are used to the end of the problem.

Card Set 11 - Zoning the Problem

The problem is zoned with a series of different regions, each of which is zoned independently. These are NRZC zoning regions and NMTRLS material layers, with NRZC ≥ NMTRLS. There can be several regions per material layer but not more than one material in any region. The material boundaries must be a subset of the region boundaries.

Each region is zoned by first giving a set of region information cards and then by using one, and only one, of the seven types of zoning routines. The regions are considered in order, starting with the outermost (largest X) and working inward.

Material Boundary Card Format (8E10.3)

Variable. XMATUP(I), I = 1, (NMTRLS + 1). These are the positions of the boundaries of the various materials, starting with the largest X first. In case Type 7 zoning (voids) is used, the lower boundary of the void is used if the void is between different materials. A void is not counted as a material.

Next are NRZC sets of the following cards:

Region Information Card 1. Format (I5, 5E10.3, I5)

This is always the first card for zoning a region with any of the seven types below.

Variable 1. (1-5) ITYPE = 90 + number of the zoning type to be used for this region.

Variable 2. (6-15) X_{up} - The upper boundary of the region being zoned. Except for the first region, this must always equal the lower boundary of the preceding region. X_{up} for the first region is the outer (first) boundary of the problem. For Type 6 zoning in the first region, this is ignored.

Variable 3. (16-25) X_{low} - The lower boundary of the region. For the last region this denotes the inner (last) boundary of the problem. For Type 6 zoning in the last region, this is ignored.

Variable 4. (26-35) — ρ_o - The initial density to be used for each zone in this region. When Type 1 zoning is used, this density can be superseded for specified zones.

Variable 5. (36-45) — T_o - The initial temperature to be used for each zone in this region. When Type 1 zoning is used, this temperature can be superseded for specified zones.

If $T_o \leq 0$, code sets $T_o = 0.02567785$ (298°K).

Variable 6. (46-55) — V_o - The initial velocity to be used for the upper boundary of each zone in this region. When Type 1 zoning is used, this velocity can be superseded for specified zones.

Variable 7. (56-60) — IES - The equation-of-state number for the material in this region.

IES > 0 for tabular EOS.

$-20 \leq$ IES ≤ -1 for analytic EOS (see card set 12).

For Type 7 zoning, variables 4 to 7 are ignored.

<u>Region Information Card 2. Format (8E10.3)</u>

This is always the second card for zoning a region and contains the information for the elastic-plastic or distended material calculation. The eight input variables are named YIELD(I), I = 1, 8.

Use only one of the following forms.

I. Nonporous - hydrodynamic material and type 7 zoning.

a blank card

II. Elastic-Plastic Material (see Section IV-2 and variable 8, card 4).

Variable 1. (1-10) - Y_o

Variable 2. (11-20) - Y_1

Variable 3. (21-30) — 0. - Computed internally. The absolute melt energy ($\mathscr{E}_m'$) as determined from the equation of state is stored in this location. If a positive number is entered here, it will override the internally computed value.

Variable 4. (31-40) — ρ_o - Reference density. If zero, the density is taken to be the same as ρ_o on region information card 1.

Variable 5. (41-50)	ν_o - Reference Poisson's ratio.

Variable 6. (51-60)	α - Fraction of melt energy at which the material starts to lose strength (normally 0.8)

If $\alpha \leq 0$, code sets $\alpha = 0.8$.

Variable 7. (61-70)	Blank

Variable 8. (71-80)	Blank

III. Distended or Porous Material (see Section V-5)

Variable 1. (1-10)	ρ_{so} - Normal solid density at the temperature given by T_o on region information card 1. This is used to calculate the initial distention ratio.

Variable 2. (11-20)	k_o' - A constant used in computing the temperature dependence of the crush strength.

If $k_o' = 0$, code sets $k_o' = -2$.

Variable 3. (21-30)	(-1.) This is a switch.

Variable 4. (31-40)	$\mathscr{P}_e$ - The elastic limit pressure of the material at full distention.

Variable 5. (41-50)	$\mathscr{P}_s$ - The elastic limit pressure as all voids vanish in the quadratic model, or (-a) - constant in the exponential model.

Variable 6. (51-60)	C_{eo} - Sound speed in the material at full distention. If no value is given, the normal solid sound speed is used.

Variable 7. (61-70)	Blank

Variable 8. (71-80)	Blank

Region Information Card 3. Format (8E10.3)

This is always the third card for zoning a region and contains the information for the material fracture calculation. The eight input variables are named FRACT(I), I = 1, 8.

Use only one of the four following forms.

I. Suppression of Material Fracture (NSPALL < 0 on card 3) or type 7 zoning.

A blank card.

II. Stress Gradient Model (see Section VII for notation).

Variable 1 (1-10)	σ_u - ultimate tensile strength ($\sigma_u > 0$).
Variable 2 (11-20)	T_s - strength vanishing temperature. If $T_s \le 0$, code sets $T_s = 10$.
Variable 3 (21-30)	A.
Variable 4. (31-40)	B. If B = 0, code sets B = 1.
Variable 5. (41-50)	C. If C = 0, code sets C = 1.
Variable 6. (51-60)	σ_o - static tensile strength ($\sigma_o > 0$). If $\sigma_o = 0$ code sets $\sigma_o = \sigma_u$.
Variable 7. (61-70)	Blank
Variable 8. (71-80)	Blank

III. Cumulative Damage Model (see Section VII for notation).

Variable 1. (1-10)	K(0). (normally 0).
Variable 2. (11-20)	T_s - strength vanishing temperature. If $T_s \le 0$, code sets $T_s = 10$.
Variable 3. (21-30)	σ_o - static tensile strength ($\sigma_o > 0$).

Variable 4. λ.
(31-40)

Variable 5. (-C) (must be negative).
(41-50)

Variable 6. K_s.
(51-60)

Variable 7. Blank
(61-70)

Variable 8. Blank
(71-80)

IV. Tensile Strength Limit (see Section VII for notation).

Variable 1. σ_s - Maximum tensile strength ($\sigma_s > 0$).
(1-10)

Variable 2. T_s - Strength vanishing temperature.
(11-20)

If $T_s \leq 0$, code sets $T_s = 10$.

Variable 3. Blank
(21-30)

Variable 4. Blank
(31-40)

Variable 5. C.
(41-50)

If C = 0, code sets C = 1.

Variable 6. Blank
(51-60)

Variable 7. Blank
(61-70)

Variable 8. Blank
(71-80)

Seven Zoning Options

Zoning Type 1 - ΔX(Hand) Zoning

First Data Card Format (I5)

Variable 1. (1-5)	NDXC - The number of ΔX zoning cards used to zone this region.

Next NDXC Data Card Format (I5, 4E10.3)

Variable 1. (1-5)	The number of zones desired with this ΔX.
Variable 2. (6-15)	The ΔX to be used for these zones.
Variable 3. (16-25)	ρ_o* - Used as the density for these zones if $\rho_o^* > 0$; it overrides the specified region density. If $\rho_o^* = 0$, the specified region density is used.
Variable 4. (26-35)	T_o* - Used as the temperature for these zones if $T_o^* > 0$; it overrides the specified region temperature. If $T_o^* = 0$, the specified region temperature is used.
Variable 5. (36-45)	V_o* - Used as the velocity of the upper boundary for these zones if $V_o^* \neq 0$; it overrides the specified region velocity. If $V_o^* = 0$, the specified region velocity is used.

The sum of zone widths must equal the difference between the upper and lower region boundaries.

Zoning Type 2 - Specification of Both Region Boundary Zone Widths (see Appendix B)

Only Data Card Format (3E10.3)

Variable 1. (1-10)	W_1 - Width of first zone in region (largest X). If $W_1 < 0$, width of first zone is $-W_1$ times the width of last zone in last region scaled for density. W_1 cannot be negative for the first region.
Variable 2. (11-20)	W_ℓ - Width of last zone in region (smallest X).
Variable 3. (21-30)	Maximum fraction error allowed in ratio of adjacent zone masses (0.01 is 1 percent).

If the specified input is inconsistent with reality, the zoning will fail.

Zoning Type 3 - Increasing-Decreasing Mass Ratio (suggested only for plane geometry)

Only Data Card Format (2E10.3)

Variable 1. (1-10)
: W - Specifies the width of the first and last zones of the region. If $W = 0$, an error has occurred. If $W > 0$, W is the width of the first and last zones of the region. If $W < 0$, $-W$ times the width of the last zone of the last region is the new zone width for the first and last zones of this region. W cannot be negative in the first region. The zoning routine comes as close to this value as possible.

Variable 2. (11-20)
: RATIO - The ratio of adjacent zone masses to be used in the upper (first) half of this region. 1/RATIO is the ratio of adjacent zone masses to be used in the lower (last) half of the region. RATIO may not be 1.

If RATIO > 1, this provides thin zones at the region boundaries and thick zones in the region center in order to conserve the number of zones. RATIO < 1 results in thicker zones at the boundaries than at the center. The zone widths are symmetric about the region center.

Zoning Type 4 - Specification of One Region Boundary Zone Width and Mass Ratio (see Appendix B)

Only Data Card Format (4E10.3)

Variable 1. (1-10)
: W_1 - Width of first zone in region (largest X).
If $W_1 < 0$, width of first zone is RATIO times the width of last zone in last region scaled for density. W_1 cannot be negative for the first region.

Variable 2. (11-20)
: W_ℓ - Width of last zone in region (smallest X).

Variable 3. (21-30)
: RATIO - Adjacent zone mass ratio.

Variable 4. (31-40)
: Maximum fraction error allowed.

Note: Either W_1 or W_ℓ must be zero. RATIO then applies to moving away from the nonzero value.

Zoning Type 5 - Specification of Mass Ratio and Number of Zones (see Appendix B)

Only Data Card Format (I5, E10.3)

Variable 1. (1-5) Number of zones desired in region.

Variable 2. (6-15) Mass ratio in increasing position direction.

Zoning Type 6 - Free Boundary (only for the first or last region)

Only Data Card Format (I5, 3E10.3)

Variable 1. (1-5) ℓ - Number of zones desired in region.

Variable 2. (6-15) RATIO - Mass ratio in direction away from interior of problem.

Variable 3. (16-25) X_m - Maximum or minimum position.

Variable 4. (26-35) Width of interior zone.

The region will be zoned away from the interior until either ℓ zones are used or a position of X_m is encountered. If $\ell \leq 0$, ℓ is ignored. If $X_m = 0$, X_m is ignored. A correction will be made to XMATUP(1) or XMATUP(NMTRLS + 1).

Zoning Type 7 - Voids

Used only on interior boundaries and cannot be used when a type 5 energy source is present.

There are no data cards.

Card Set 12 - Analytic Equation-of-State Data

Any inputs for analytic equations of state go here. See Appendix I for format.

Card Set 13 - Internal Source Information

Present only if NOSOUR > 0 (see card 3). There are six types of internal sources. However, only one of the six can be used in a given problem. NOSOUR on card 3 determines the type. Type 1 is the hardest to input, but all other types are reduced to Type 1 for code use. See Section VIII-4 for notation.

Source Type 1 - Hand Input for Each Zone

Card 1 Format (I10)

Variable 1. (1-10)	NOSOUR - The last zone (largest zone number) in the problem to have a source.

All Other Cards Format (I5, 6E10.3)

Variable 1. (1-5)	I = Zone number.
Variable 2. (6-15)	τ_1 for Zone I.
Variable 3. (16-25)	τ_2 for Zone I.
Variable 4. (26-35)	τ_3 for Zone I.
Variable 5. (36-45)	τ_4 for Zone I.
Variable 6. (46-55)	$\dot{\mathscr{S}}_2$ for Zone I.
Variable 7. (56-65)	$\dot{\mathscr{S}}_3$ for Zone I.

Cards must be ordered by increasing zone number with the smallest number first. The reading is terminated when the zone number = NOSOUR. Zones with number < NOSOUR are not required to have a source and may be omitted from the sequence.

Source Type 2 - Input Total Energy per Zone

Card 1 is the same as the first Type 1 card.

All Other Data Cards Format (I5, 3E10.3)

Variable 1. (1-5)	I = Zone number.
Variable 2. (6-15)	$\tau_1 = \tau_2$.
Variable 3. (16-25)	$\tau_3 = \tau_4$.

Variable 4. (26-35) Zone energy (ergs).

Order requirement on zone input is the same as for Type 1.

$$\dot{\mathscr{S}}_2 = \dot{\mathscr{S}}_3 = \frac{\text{zone energy}}{(\tau_4 - \tau_1)M_i} \ .$$

Source Type 3 - Input Total Specific Energy per Zone

Same as Type 2, except Variable 4 is the zone specific energy (ergs/gm).

Source Type 4 - Source Region

Card 1 Format (I10)

Variable 1. (1-10) KK - The number of source regions.

Next KK Data Cards (one for each region) Format (5E10.3)

Variable 1. (1-10) Right-hand boundary of source region (largest X).

Variable 2. (11-20) Left-hand boundary of source region (smallest X).

Variable 3. (21-30) Energy source strength, the total energy to be introduced between right and left boundaries.

Variable 4. (31-40) $\tau_1 = \tau_2$.

Variable 5. (41-50) $\tau_3 = \tau_4$

The code will try to match X values with zone boundaries. If it is unable to do this, it will take the right-hand boundary at the first boundary to right of the region and the left-hand boundary at the first boundary to the left.

Caution note on Type 4 when KK > 1: If some regions overlap, the code will lose some of the input energy, since all but the last source in any overlapped zone is dropped. This results in a diagnostic message.

Source Type 5 - Externally Generated Energy Profile (for plane geometry only)

Only Input Card Format (6E10.3, 2I5)

Variable 1. (1-10)	$F_o = \pm \lvert \text{total incident flux} \rvert$. If $F_o \geq 0$ flux in ergs/cm^2. If $F_o < 0$ flux in cal/cm^2.
Variable 2. (11-20)	τ_1.
Variable 3. (21-30)	τ_2.
Variable 4. (31-40)	τ_3.
Variable 5. (41-50)	τ_4.
Variable 6. (51-60)	$\dot{\mathscr{S}}_2 / \dot{\mathscr{S}}_3$ (see Type 1, same for all zones).
Variable 7. (61-65)	A switch to select data input tape. If $\neq 1$, input tape unit is 7. If = 1, input tape unit is 17 = card reader.
Variable 8. (66-70)	A switch for time retardation from front surface. If $\neq 1$, there is no time retardation. If = 1, time retardation is included.

See Section VIII-5. If card input is indicated, insert cards discussed in Appendix D at this point.

Source Type 6 - HE Burn Format (8E10.3) (See Section X-2)

Variable 1. (1-10)	X_o - Point of initiation of burn.
Variable 2. (11-20)	t_o - Detonation time (start of burn).
Variable 3. (21-30)	X_R - Right-hand boundary (largest X) of burn region.
Variable 4. (31-40)	X_L - Left-hand boundary (smallest X) of burn region.
Variable 5. (41-50)	D - Detonation velocity.
Variable 6. (51-60)	Q - Chemical energy release per unit mass. or $(-P_{CJ})$ - Chapman-Jouguet pressure. The self-detonation calculation is active only if P_{CJ} is defined.

Variable 7. (61-70) N - Number of zones in the detonation front (normally ~3).

Variable 8. (71-80) Switch = 1 if more HE burn region cards are to follow.
Switch = 0 if no more cards are to follow.

Card Set 14 - Initial Zone Activation Format (8E10. 3)

Present only if NACTION > 0 (see card 3).

There are NACTION sets of these variables.

Variable Odd. Lower boundary of active region.

Variable Even. Upper boundary of active region.

Card Set 15 - Rezone for Initial Voids with Type 5 Energy Source

Can be used only in plane geometry.

Present only if NSPALL > 0 (card 3).

Card 1 Format (I5)

Variable 1. (1-5) JJJ - Number of breaks in materials.

Next JJJ Cards Format (I5, E15. 7)

Variable 1. (1-5) JJ - The material zone boundary number at the break.

Variable 2. (6-20) The space between the parts of the material.

Initial space can only be made at an interior boundary, i. e., $2 \leq JJ \leq NMTRLS$.

Appendix I

INPUT CARDS FOR THE ANALYTIC EQUATION OF STATE

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INPUT CARDS FOR THE ANALYTIC EQUATION OF STATE

The input cards described here form card set 12 in the preceding section but are also used in the program CKEOS[5] and other hydrodynamic codes with the ANEOS package. There is one set of cards for each analytic equation of state. These data are coupled to the rest of the code by an equation-of-state number which must agree with that defined in the zoning section. An analytic equation of state must have a negative number greater than or equal to (-20). Positive numbers are reserved for tabular forms which require no input cards.

All temperatures below are assumed in units of electron volts. (See Reference 4 for a complete description.) Note that some variables have been moved from their locations in Reference 3 and new ones are present.

Card 1. Format (I3, I5, I2, 5A10, 2E10.3)

Variable 1. (1-3)	Equation-of-state number (negative number).
Variable 2. (4-8)	Library equation-of-state number if desired; otherwise, zero. †
Variable 3. (9-10)	Used only with a library equation of state. This variable determines the type of analytic calculation (see Variable 2, card 2 below). If out of range 0 to 4 or library information is only for a gas, this input is ignored.
Variables 4-8. (11-60)	Fifty-column identification label - any BCD information.
Variable 9. (61-70)	RHUG - The initial density for the Hugoniot calculation. If zero, the calculation is skipped. If negative, the initial density is taken to be the reference density (Variable 3, card 2 below).
Variable 10. (71-80)	THUG - The initial temperature for the Hugoniot calculation. If zero, the calculation is skipped. If negative, the initial temperature is taken to be the reference temperature (Variable 4, card 2 below).

†See the end of SUBROUTINE ANDATA in Appendix G.

The Hugoniot calculation should normally be used only to test new equation-of-state information.

If a library equation of state is requested, no further data cards are required.

Cards 2, 3, and 4. Format (8E10. 3)

In the listing the following variables are called ZB(I), I = 1, 24.

Variable 1. (1-10) — The number of elements in this material.

Variable 2. (11-20) — Switch for type of equation of state.

0. - Solid-gas without electronic terms and without detailed treatment of the liquid-vapor region.

1. - Solid-gas with electronic terms but without detailed treatment of the liquid-vapor region.

2. - Gas only with electronic terms.

3. - Same as 0., but with a detailed treatment of the liquid-vapor region.

4. - Same as 1., but with a detailed treatment of the liquid-vapor region.

Variable 3. (21-30) — ρ_o - Reference density.

Variable 4. (31-40) — T_o - Reference temperature.
If $T_o \leq 0$, code sets $T_o = 0.02567785$ev (298°K).

Variable 5. (41-50) — P_o - Reference pressure (normally 0).

Variable 6. (51-60) — B_o - Reference bulk modulus (position number)
or
($-S_o$) constant in linear Hugoniot shock-particle velocity relation (negative number).

Variable 7. (61-70) — Γ_o - Reference Grüneisen coefficient.

Variable 8. (71-80) — θ_o - Reference Debye temperature. If $\theta_o \leq 0$, code sets $\theta_o = 0.025$.

Variable 9. (1-10)

T_Γ - Parameter

$T_\Gamma = -1$, Slater theory;

$T_\Gamma = 0$, Dugdale and MacDonald theory;

$T_\Gamma = 1$, free-volume theory

or

S_1 - constant in linear Hugoniot shock-particle velocity relation. Input variable is defined in relation to variable 6.

Variable 10. (11-20)

$3C_{24}$ - Three times the limiting value of the Grüneisen coefficient for large compressions, usually either 2 or 0. When a value of 2 is used, $C_{24} = 2/3$.

Variable 11. (21-30)

E_s - Zero temperature separation energy.

Variable 12. (31-40)

T_m - melting temperature

or

$(-E_m)$ - energy to the melting point at zero pressure relative to the reference point. This is not the same as $\mathscr{E}_m$ due to reference point energy.

Variable 13. (41-50)

C_{53} - parameter for low density P_c modification to move critical point (normally zero).

Variable 14. (51-60)

C_{54} - parameter for low density P_c modification to move critical point (normally zero)

If $C_{54} = 0$ and $C_{53} \neq 0$, code sets $C_{54} = 0.95$.

Variable 15. (61-70)

H_o - Thermal conductivity coefficient. If zero, thermal conduction is not included. Note that the units of $H = H_o T^{C_{41}}$ are ergs/(cm sec eV).

Variable 16. (71-80)

C_{41} - Temperature dependence of thermal conduction coefficient (see Variable 15).

Variable 17. (1-10)

ρ_{min} - Lowest allowed solid density, usually about $0.8\,\rho_o$. If zero or negative, code sets $\rho_{min} = 0.8\,\rho_o$.

Variable 18. (11-20) Parameter D_1

Variable 19. (21-30) Parameter D_2

Variable 20. (31-40) Parameter D_3

Variable 21. (41-50) Parameter D_4

Variable 22. (51-60) Parameter D_5

Solid - solid phase transition parameters (normally 0).

Variable 23. (61-70)

H_f - Heat of fusion to determine melt transition parameters.

If $H_f = 0$, no transition is included.

If $H_f < 0$, code sets $H_f = 1.117 \times 10^{12}\ T_m/A$ (ergs/gm) where A is the average atomic weight.

NOTE: Code will run slower if the melt transition is included. Use only when necessary and after testing.

Variable 24. (71-80)

ρ_ℓ/ρ_s - Ratio of liquid to solid density at melt point.

or

$(-\rho_\ell)$ - Density of liquid at melt point.

If $H_f \neq 0$ and $\rho_\ell/\rho_s = 0$, code sets $\rho_\ell/\rho_s = 0.95$.

For a gaseous equation of state, Variables 5 through 14 and 17 through 24 are read but not used.

Card 5. Format (5(F5.0, E10.3))

There is one set of the following variables for each element in Variable 1, card 2. I = 1, number of elements.

Variable Odd. Z(I) - atomic number of elements.

Variable Even. Unnormalized atomic number fraction of element [COT(I)] , or

- Unnormalized atomic weight fraction of element.

All elements should be defined in the same way.

Appendix J

A METHOD FOR OBTAINING FILM OUTPUT LISTING

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A METHOD FOR OBTAINING FILM OUTPUT LISTING

It is possible to have the standard edit information listed on the line printer or film or both. This involves manipulation of the standard output file after execution of the program but before the end of the job. The exact method is very machine-dependent, and the one given here will, in all probability, only work with the Sandia Albuquerque system as of September 1971. The idea is, of course, machine-independent and can be used for any program.

After the program has been executed, the printed output is contained in the user file OUTPUT. It is desired to transfer these data to a file named, for example, FILM in a form suitable for the SC 4020 plotter print mode. The following set of control cards will accomplish this and also yield the normal line printer listing. The LGO card is the usual load and execute command which, in standard operation, would be followed by the end-of-file card (7-8-9 punch in column 1).

```
LGØ.
RFL, 12000.
UNLØAD, LGØ.
UNLØAD, $$$.  ($$$=ANY ØTHER TAPES USED)
REQUEST, FILM, HI, S.    VRN=(YØUR TAPE)
REWIND, ØUTPUT.
REWIND, FILM.
CØPYCS, ØUTPUT, FILM.
UNLØAD, FILM.
(7-8-9)
```

The RFL (request field length) and unload cards are to keep the system personnel happy. The loading and copying require almost no central processor time but might take appreciable real time if the physical tape FILM cannot be mounted quickly. If a line printer listing is not desired, the file OUTPUT should be rewound after the copy operation.

To obtain the film listing, a peripheral request card should be submitted to send the tape to the SC 4020.