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Improvements in the Chart D Radiation-Hydrodynamic Code II: A Revised Program

S. L. Thompson, H. S. Lauson

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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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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 ≃ 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)

$\mathcal{J}$ = 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,

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

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 $\dot{\mathscr{S}}$ 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

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

$$= 0 \; , \text{ if } \frac{\partial \rho}{\partial t} \le 0 \quad , \tag{2.4}$$

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

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

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

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

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

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

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

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

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

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

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

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

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

$$\lambda_r = \frac{1}{\rho K_r} . \quad (2.13)$$

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

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

This expression can be rewritten as

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

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 (FOS) must be given for each material. In CHART D two types of FOS 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 $\mathscr{T}$ 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.

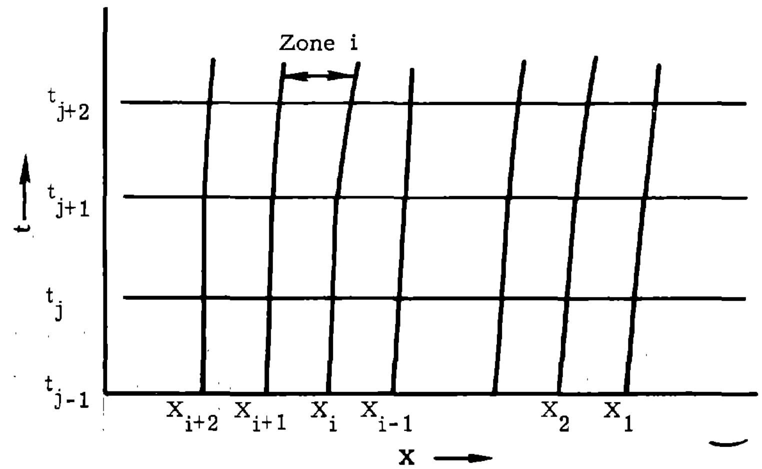

Fig. 2. 1 The space-time mesh.

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 $\Phi_i^{j+1/2}$, $\Phi^j_{i+1/2}$, or $\Phi^{j+1/2}_{i+1/2}$.

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

$$\begin{aligned} \Delta t &= t_{j+1} - t_j \ , \\ \Delta t'' &= t_j - t_{j-1} \ , \\ \Delta t' &= \frac{1}{2}\,(\Delta t + \Delta t'') \ . \end{aligned} \qquad (2.19)$$

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

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

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

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

$$\text{if } \Delta V < 0 ; \qquad (2.28)$$

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

where

$$\Delta V = V_i^{j+1/2} - V_{i+1}^{j+1/2} . \qquad (2.29)$$

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

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

The finite difference form of this expression is

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

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

$$\alpha_i = E_i^j + \left\{\frac{1}{2} P_i^j + Q_i^{j+1/2}\right\}\left\{\frac{\rho_i^{j+1} - \rho_i^j}{\rho_i^j \rho_i^{j+1}}\right\} + \mathcal{S}_i^{j+1/2}\,\Delta t \tag{3.3}$$

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

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

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

$$\mathcal{B}_1 X_1 - \mathcal{C}_1 X_2 + G_1 = 0 \ ,$$

$$-\mathcal{A}_i X_{i-1} + \mathcal{B}_i X_i - \mathcal{C}_i X_{i+1} + G_i = 0 \ , \quad i = 2, \ldots, N-1 \ , \tag{3.10}$$

$$-\mathcal{A}_N X_{N-1} + \mathcal{B}_N X_N + G_N = 0 \ ,$$

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

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

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

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

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

and

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

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

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

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 $\eta_1 = \eta_{N+1} = \sigma$. 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

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

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

and

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

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

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

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

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

Boundary options are treated as before.

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

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

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

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

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

and

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

where

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

and

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

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

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

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

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

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

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

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

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

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

$$\eta_i \le \sigma \quad . \tag{3.59}$$

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

$$\eta_i \le \frac{c\left\{\rho_i F_i + \rho_{i-1} F_{i-1}\right\}}{2T_i^4 \left| 1 - \left(\frac{T_{i-1}}{T_i}\right)^4 \right|} \quad . \tag{3.60}$$

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

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

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

and

$$\left.\begin{aligned} d_x &= \frac{\partial V}{\partial x} \\ d_y &= d_z = \frac{V}{x} \end{aligned}\right\} \delta = 3 \ . \tag{4.13}$$

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

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

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 $\sigma_z^{\,d}$. 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

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

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

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

and for $\delta = 1$ or 3,

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

The sound speed appropriate to elastic material is

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

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,

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

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

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

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

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

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 $\mathcal{E}_m$ 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 ($\alpha \le 1$), and

$$F(E) = 1,\ E \le \alpha\mathcal{E}_m\ ,$$

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

$$F(E) = 0,\ E \ge \mathcal{E}_m\ .$$

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

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

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 $\alpha \rightarrow 1$. 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.

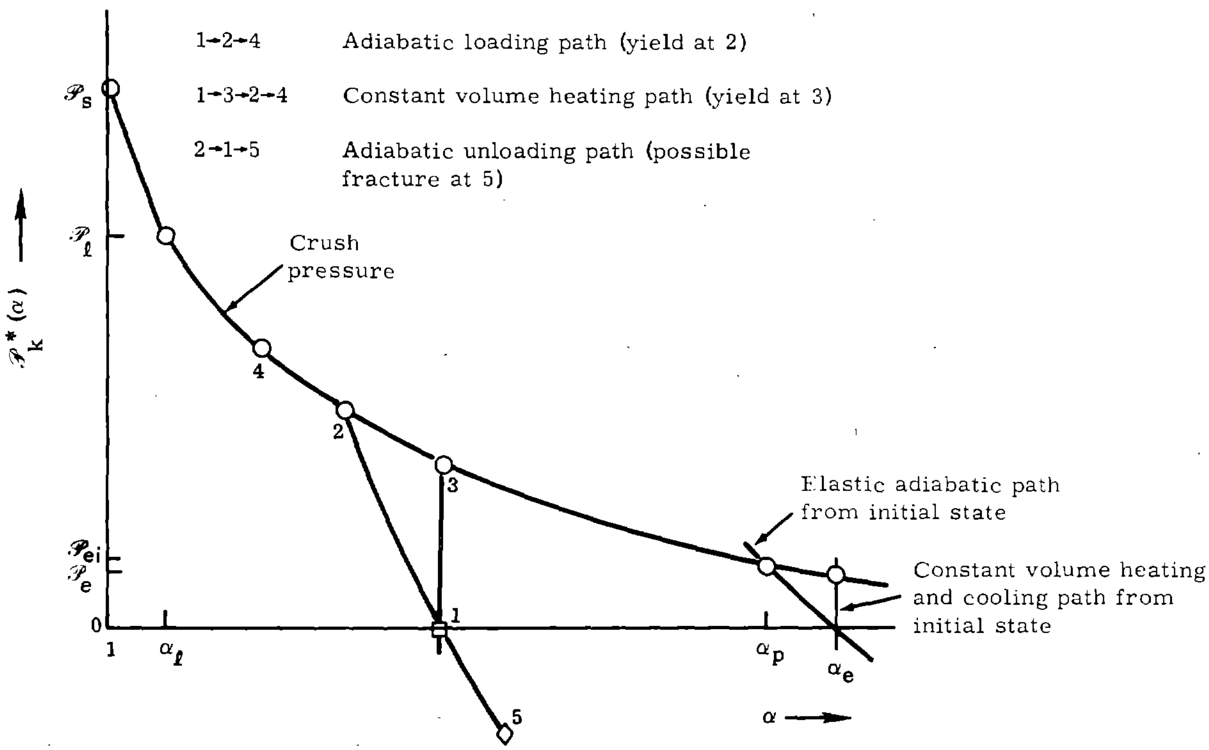

Fig. 5.1 Pressure-distention relation.

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) → 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

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

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 (δ = 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.

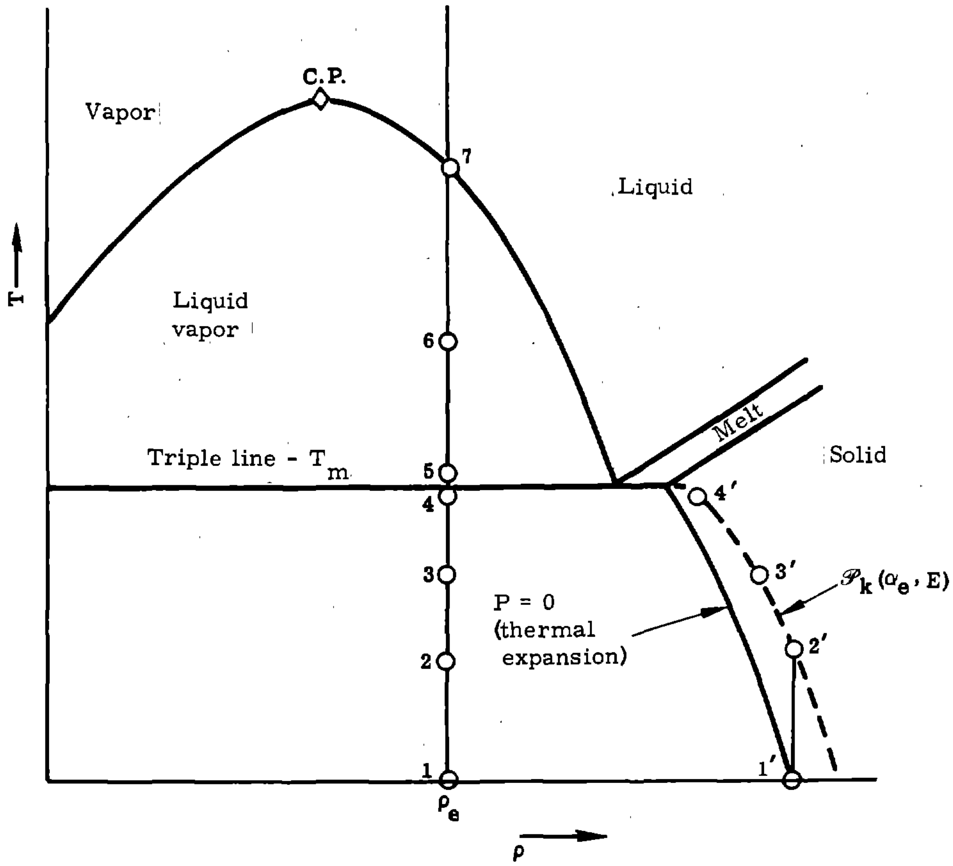

Fig. 5.2 Phase diagram of a simple material.

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) = $\mathscr{P}_c$, 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) = $\mathscr{E}_m$, 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.

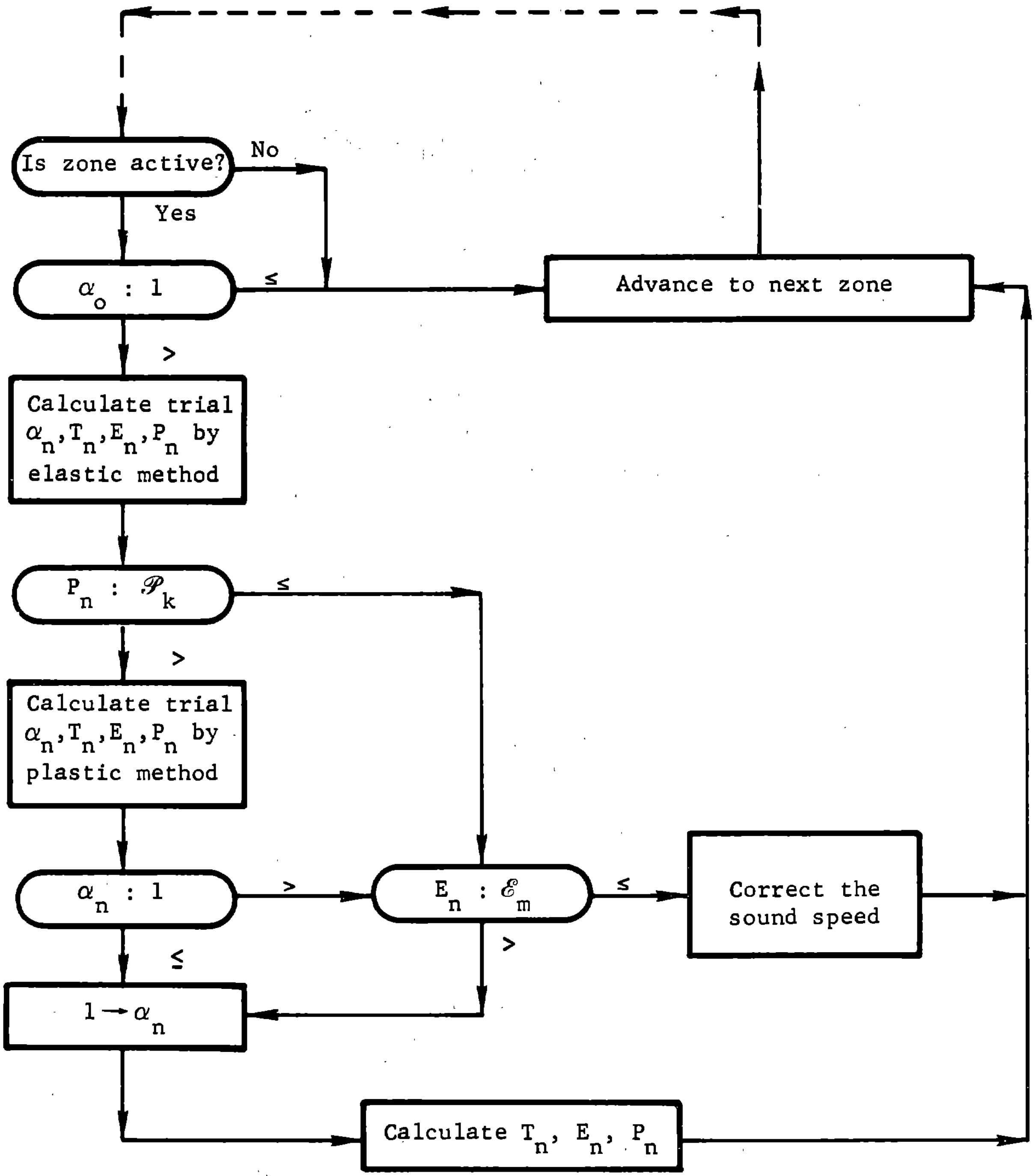

Fig. 5.3 Flow diagram for each zone in a porous material layer.

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 (α_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.

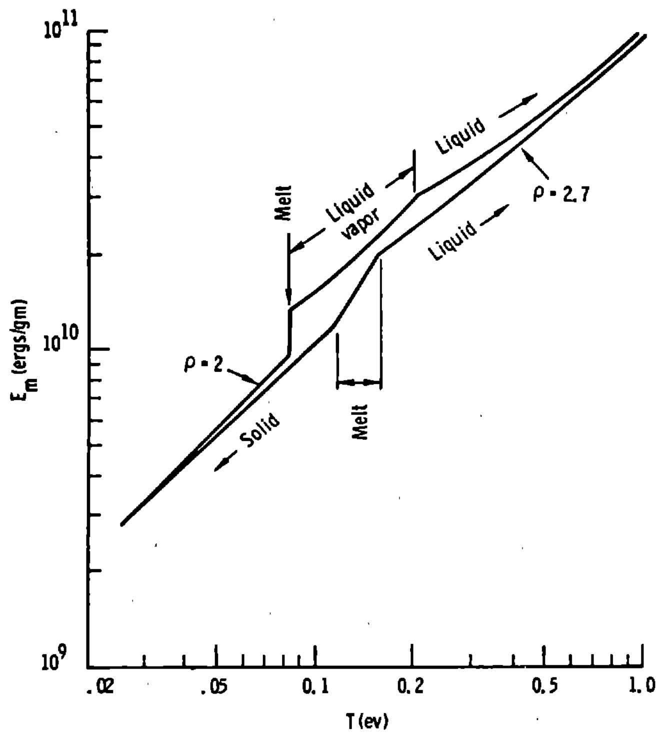

Fig. 5.4 Energy-temperature relation for aluminum at constant density.

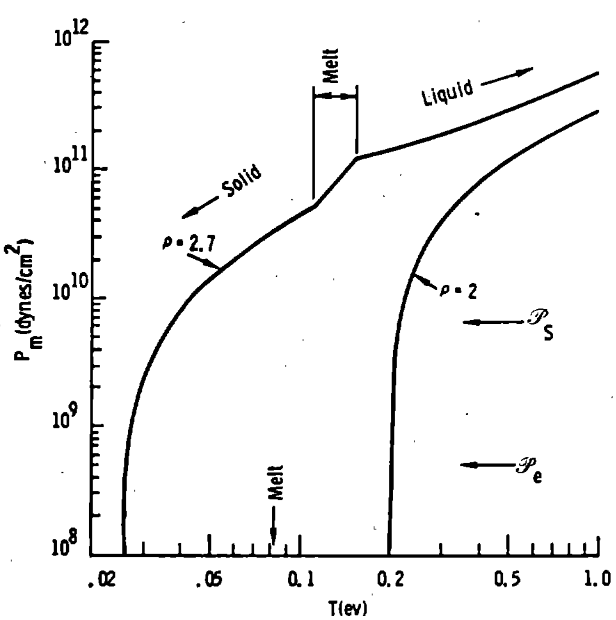

Fig. 5.5 Pressure-temperature relation for aluminum at constant density.

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

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

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

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

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

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

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	1.66575E+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	3.87657E+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	1.02123E+06	3.50466E+05	2.93702E+11
1.52885E+00	4.12768E+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	4.22266E+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

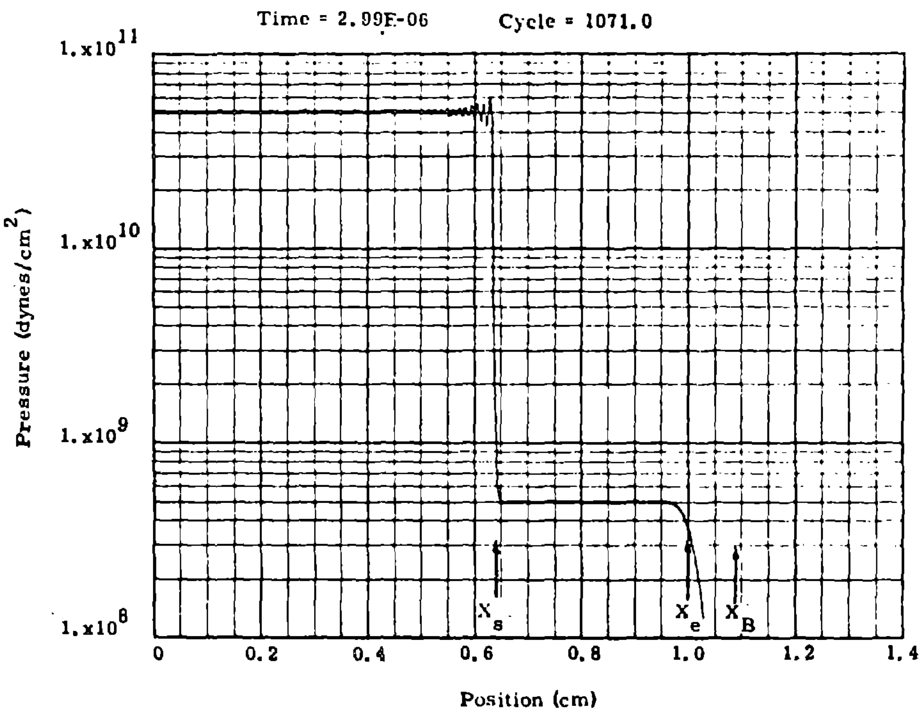

Fig. 5.6 Sample results from test problem 1. X_s, X_e and X_B are the exact values of the positions of the shock front, elastic wave, and back surface.

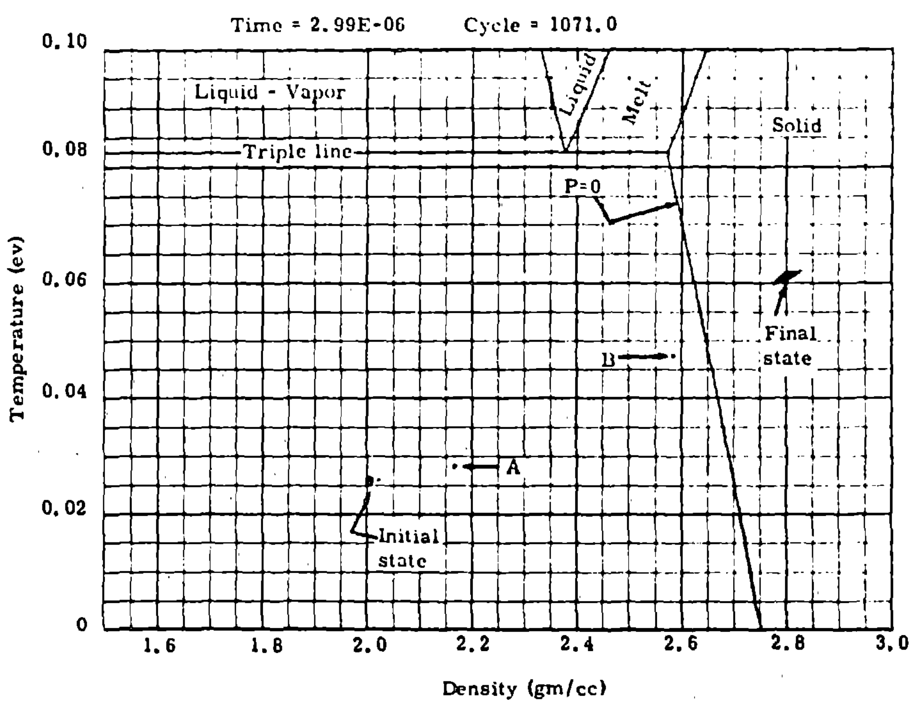

Fig. 5.7 Sample results from test problem 1. A and B are zones being crushed.

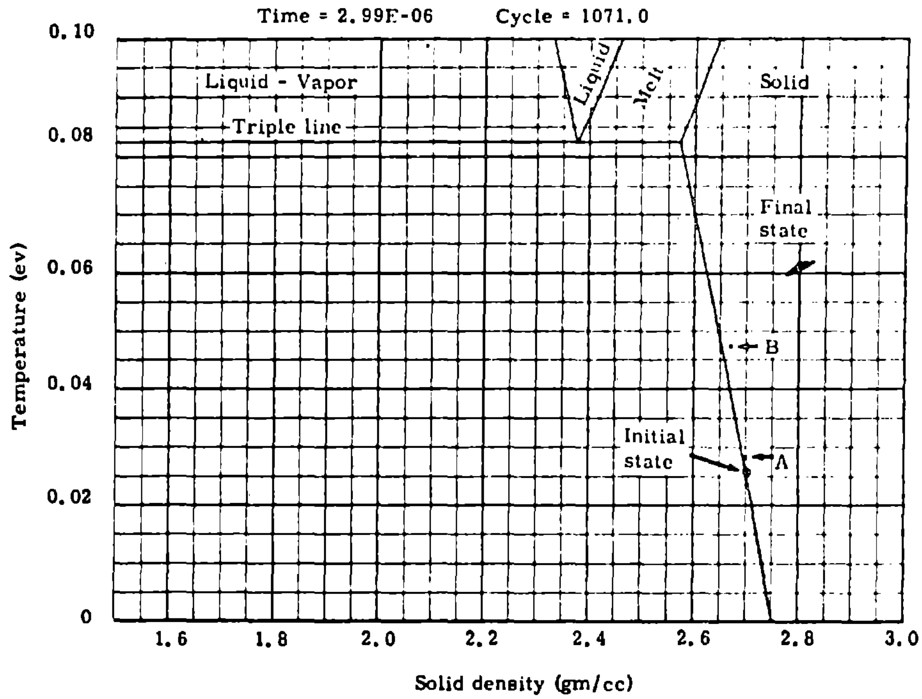

Fig. 5.8 Sample results from test problem 1. A and B are zones being crushed.

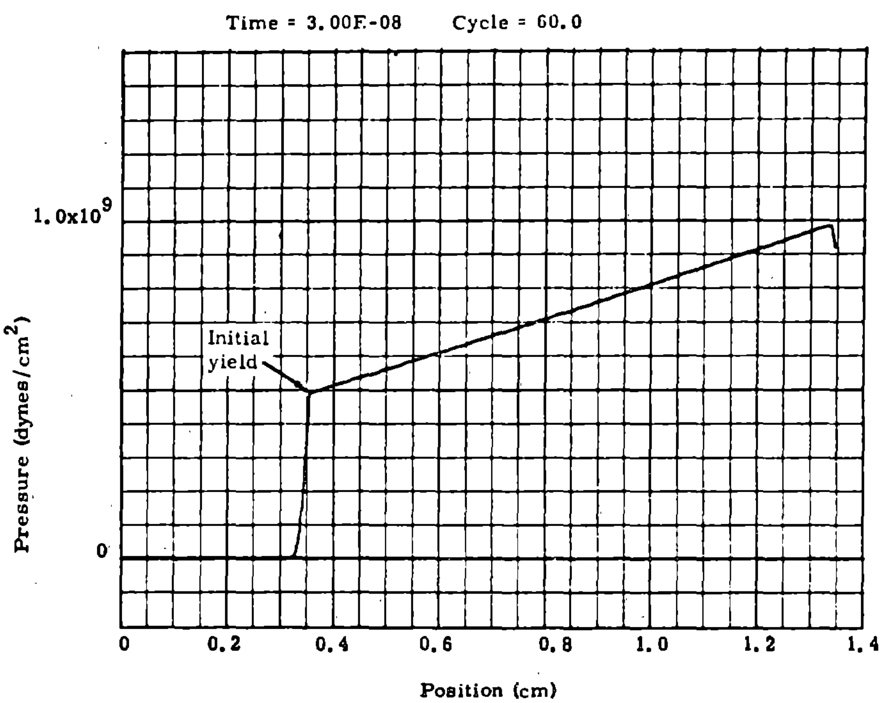

Fig. 5.9 Sample results from test problem 2. No material has melted at this time.

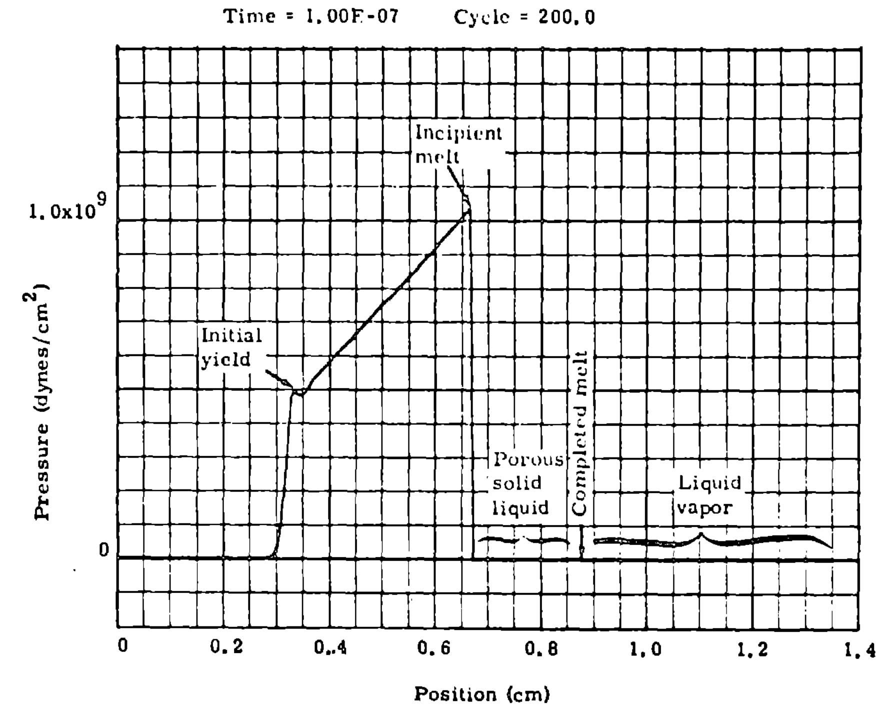

Fig. 5.10 Sample results from test problem 2.

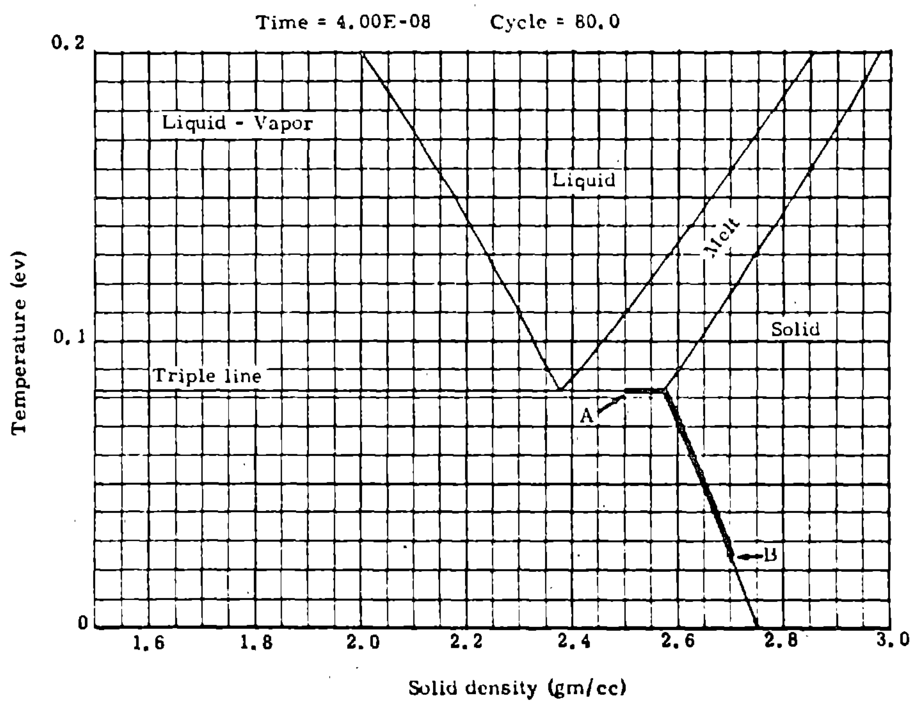

Fig. 5.11 Sample results from test problem 2. A represents the material at X=1.35 cm and B the initial state. The point of initial yield is near B.

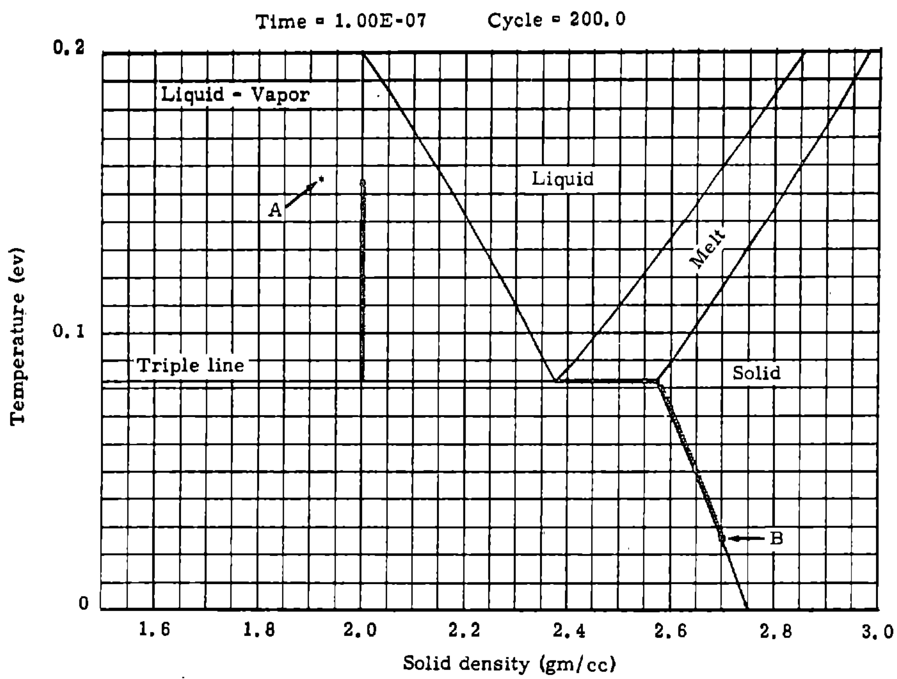

Fig. 5.12 Sample results from test problem 2. A represents the material at X=1.35 cm and B the initial state. The time is the same as that in Fig. 5.10

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.

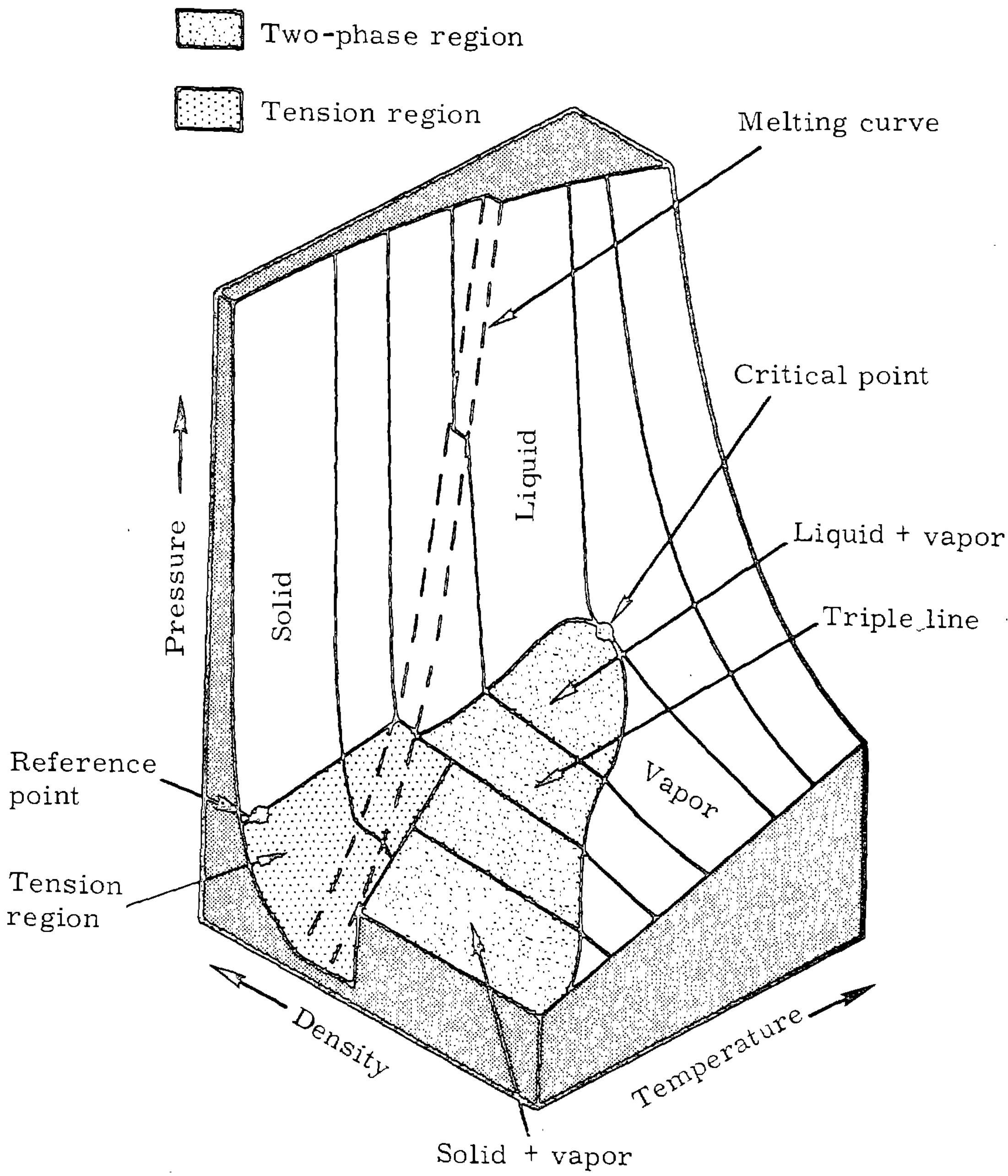

Fig. 6.1 A typical P, ρ, T thermodynamic surface.

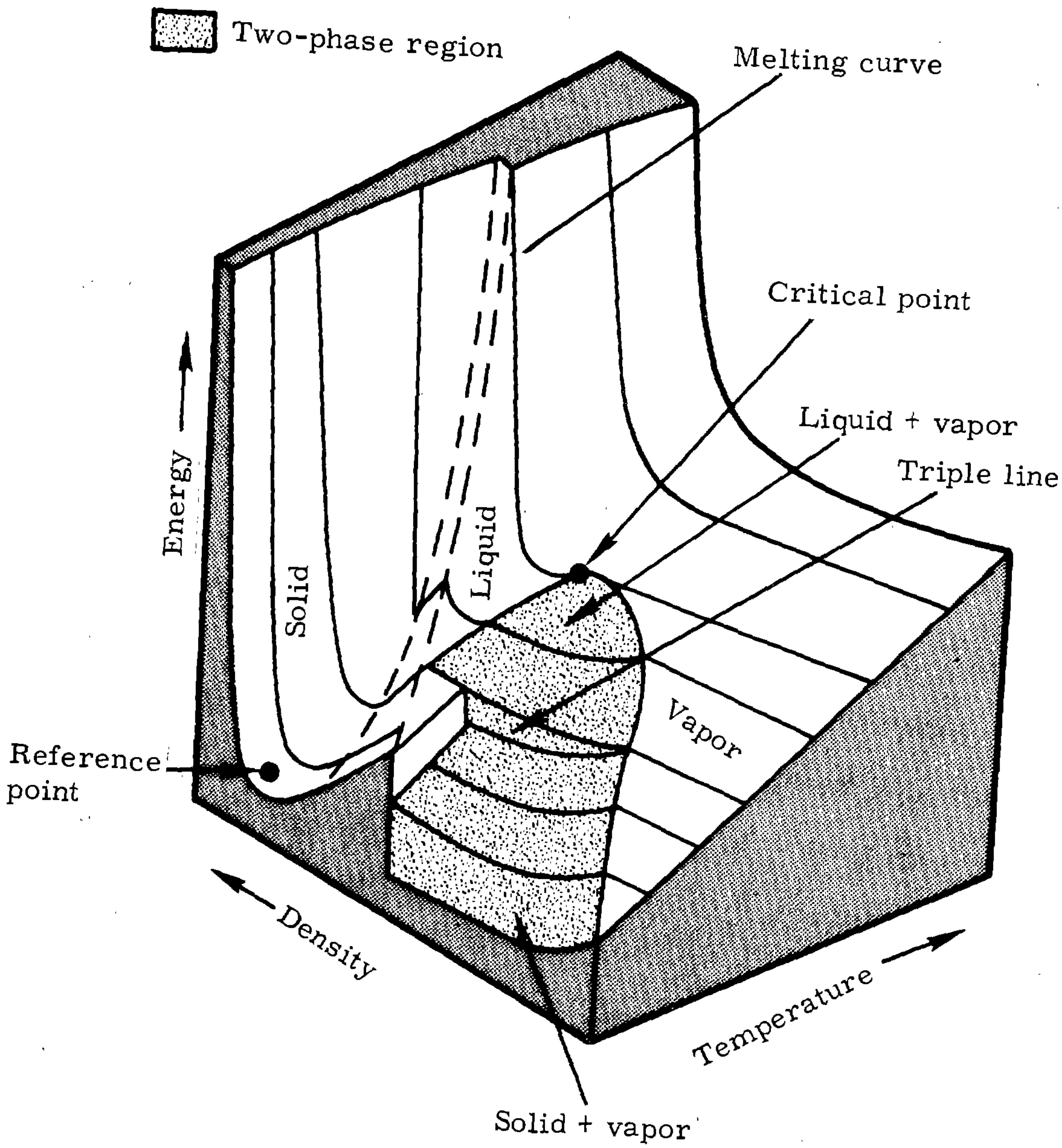

Fig. 6.2 A typical E, ρ, T thermodynamic surface.

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 $F(\rho, T)$, 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 $T \rightarrow 0$. 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.

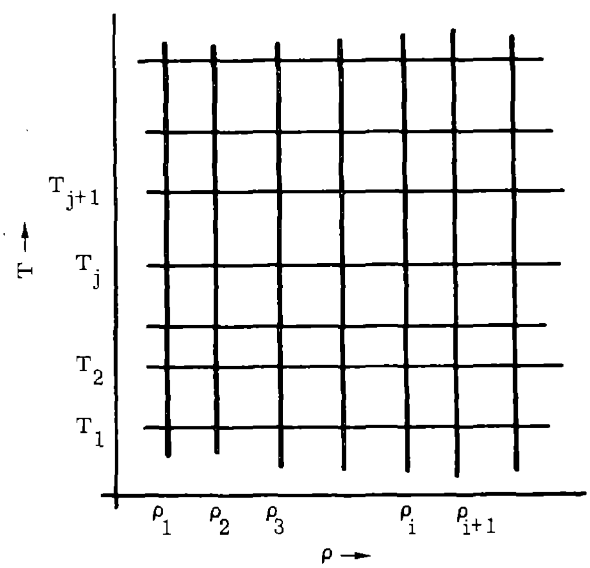

Fig. 6.3 ρ-T mesh for tabular EOS.

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

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

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

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

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

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

Three compression regions are defined:

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

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:

<u>Region 1</u>

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

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

<u>Region 2</u>

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

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

<u>Region 3</u>

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

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

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

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

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

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.

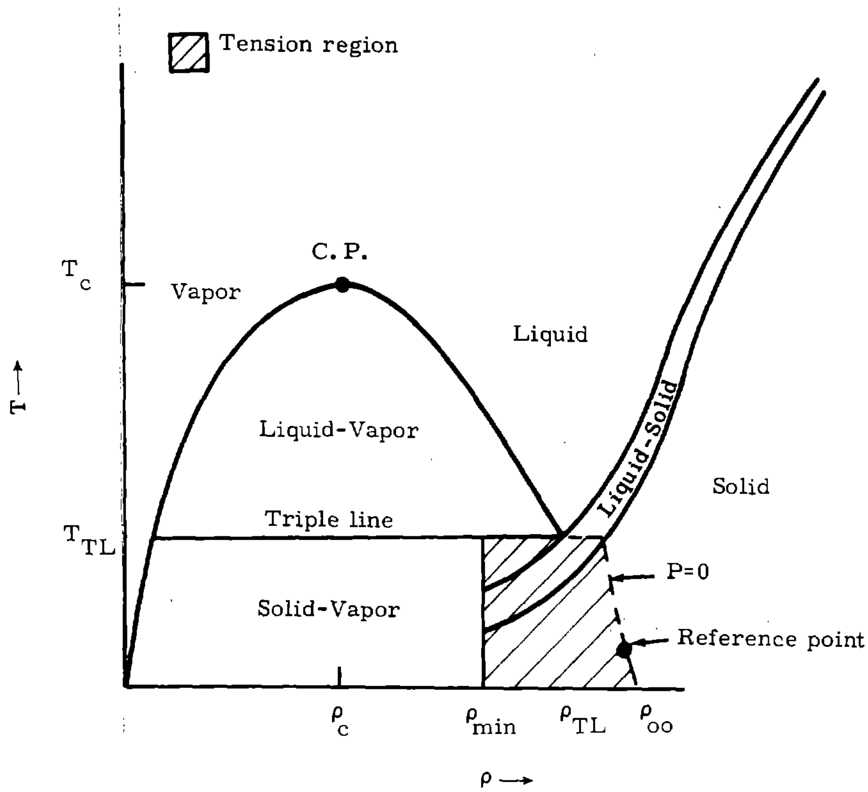

Fig. 6.4 Phase diagram of a simple material.

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

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

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

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

and

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

where

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

and

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

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

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

The mixed-phase thermodynamic functions are

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

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

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

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

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

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

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

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,

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

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 $E = E(\rho, T)$.

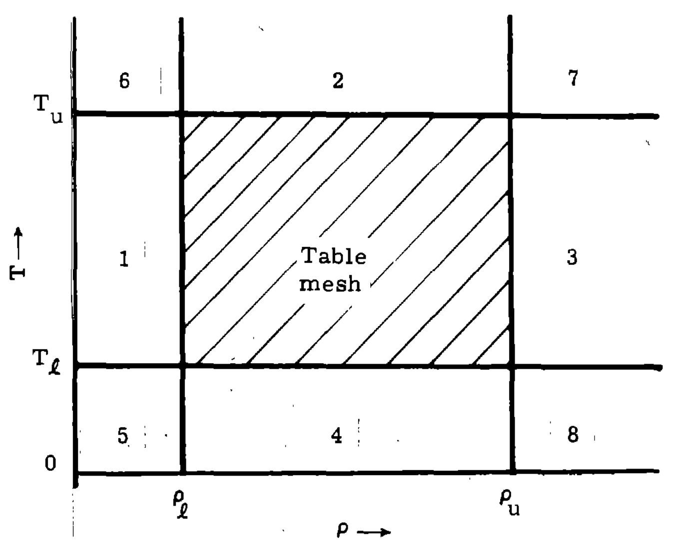

Fig. 6.5 Regions for extrapolation outside of table mesh.

Region 1

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

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

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

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

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

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

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

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

Region 2

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

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

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

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

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

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

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

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

Region 3

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

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

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

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

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

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

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

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

Region 4

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Region 8

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

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

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

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

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

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

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

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

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

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

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

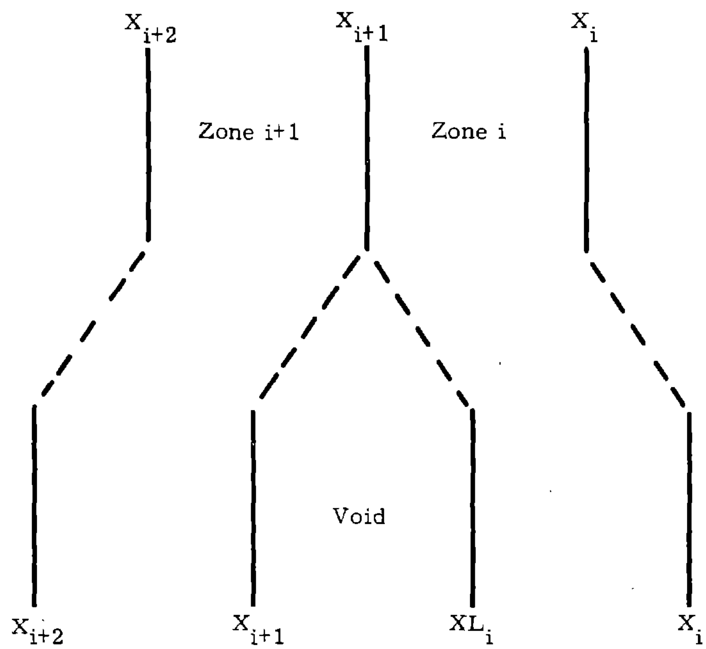

Fig. 7.1 Situation before and after fracture.

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

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

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:

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

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

$$f(\sigma) = (-\sigma - \sigma_o)^\lambda, \quad \sigma < - \sigma_o \tag{7.4}$$

$$= 0 \ , \quad \sigma \ge - \sigma_o \ ,$$

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

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

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.

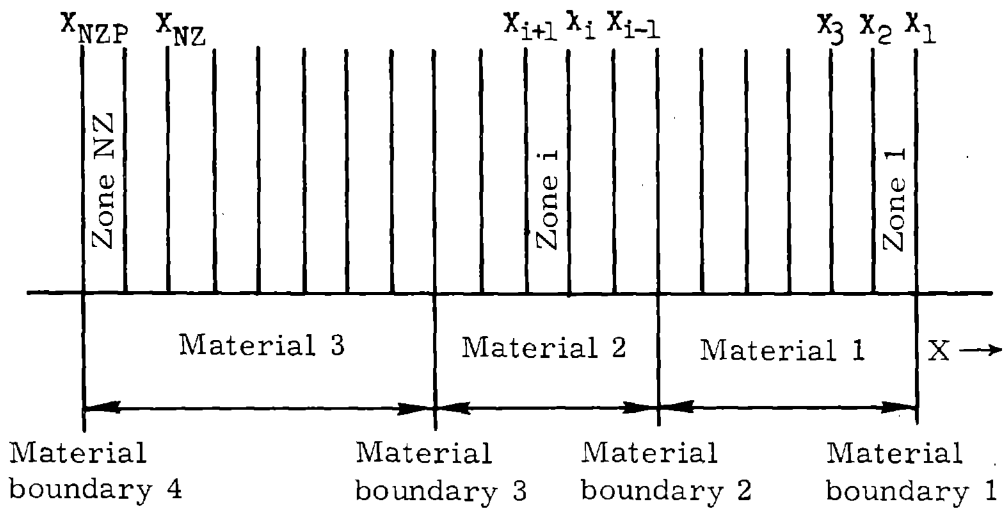

Fig. 8.1 Example of zone and material numbering. Note that $X_1 > X_2 > X_3 > X_i > X_{NZ} > X_{NZP}$.

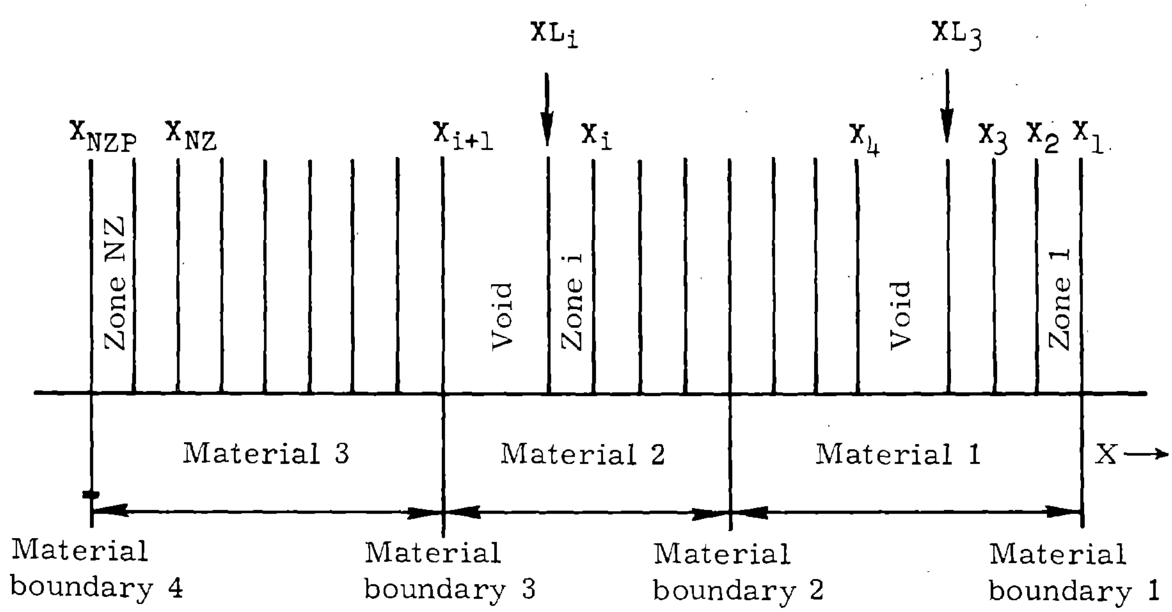

Fig. 8.2 Example of zone and material numbering with voids.

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.

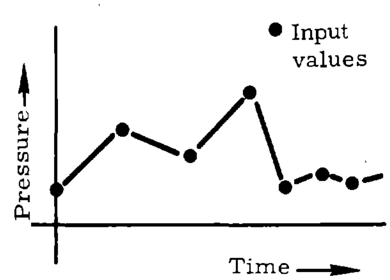

Fig. 8.3 A boundary pressure-time history.

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.

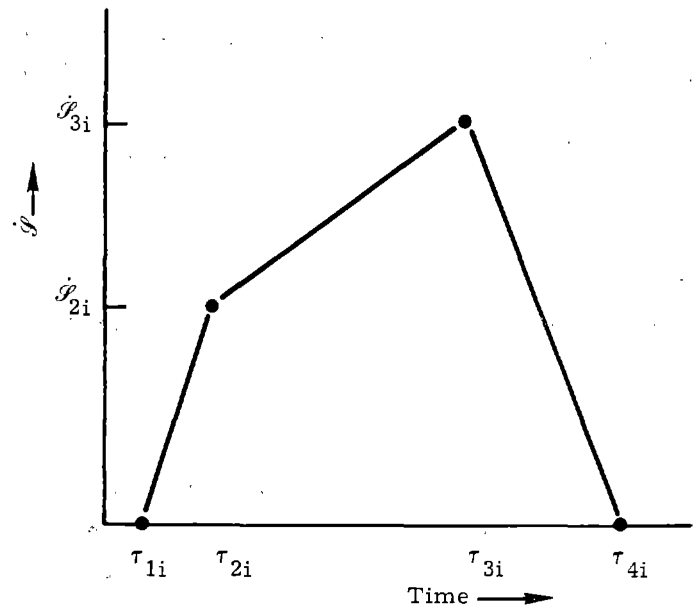

Fig. 8.4 Source strength-time history for zone i.

The total energy added to zone i through time t is

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

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.

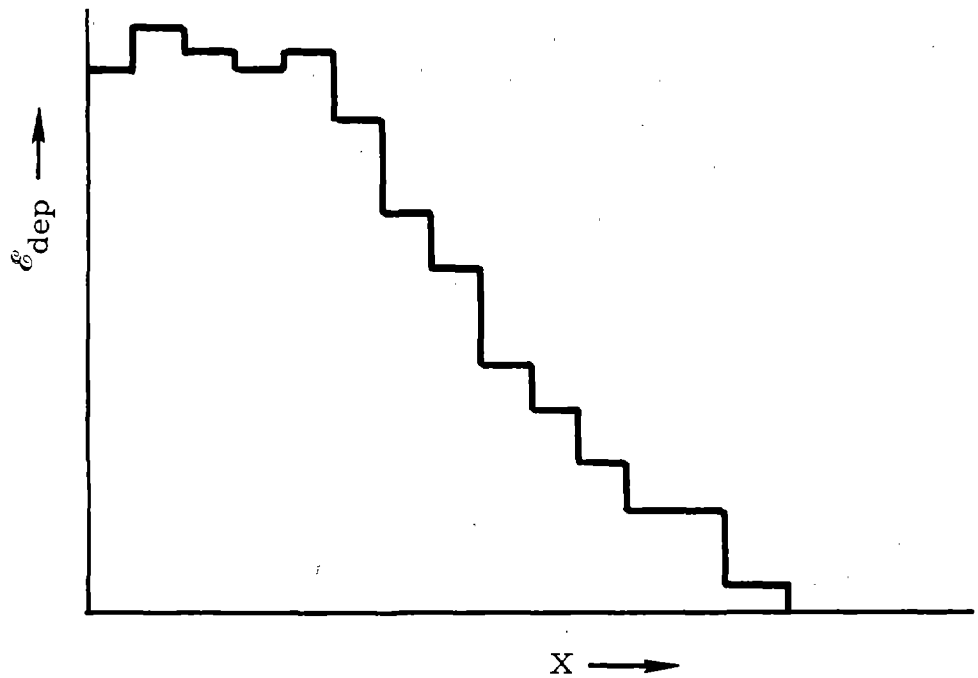

Fig. 8.5 A histogram energy deposition profile.

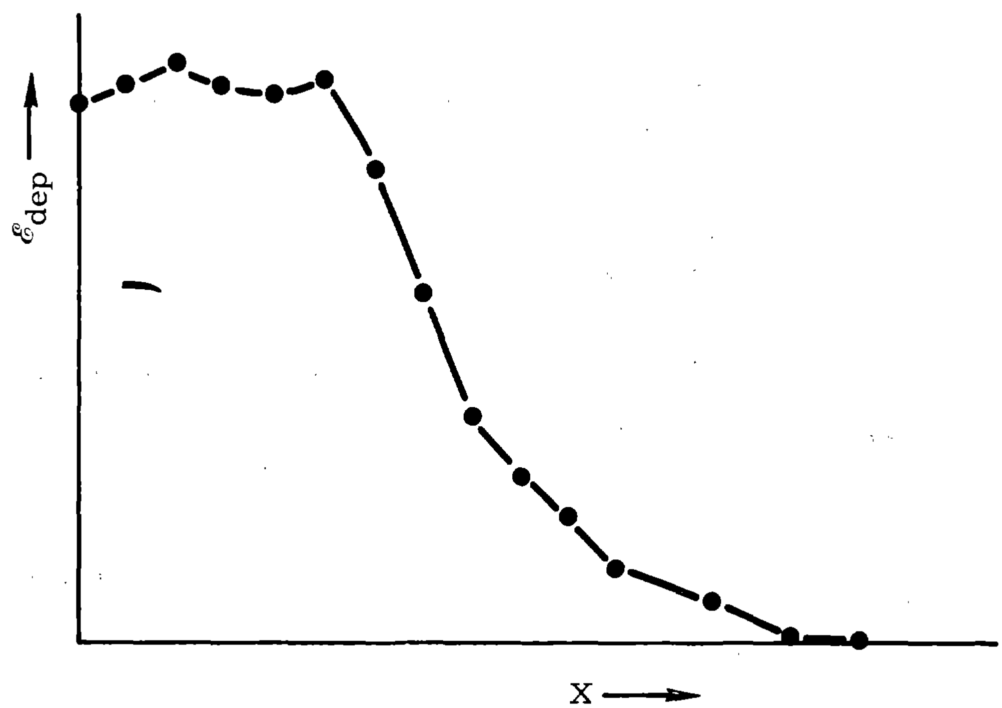

Fig. 8.6 A point energy deposition profile.

The above procedure determines the value of $\mathscr{E}_{dep\ i}(\infty)$ 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

$$\Delta t_\ell = f_2 \Delta t'' , \qquad (9.5)$$

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

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

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 $\rho_o = 1.82$ gm/cc and $D = 8.75 \times 10^5$ 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.

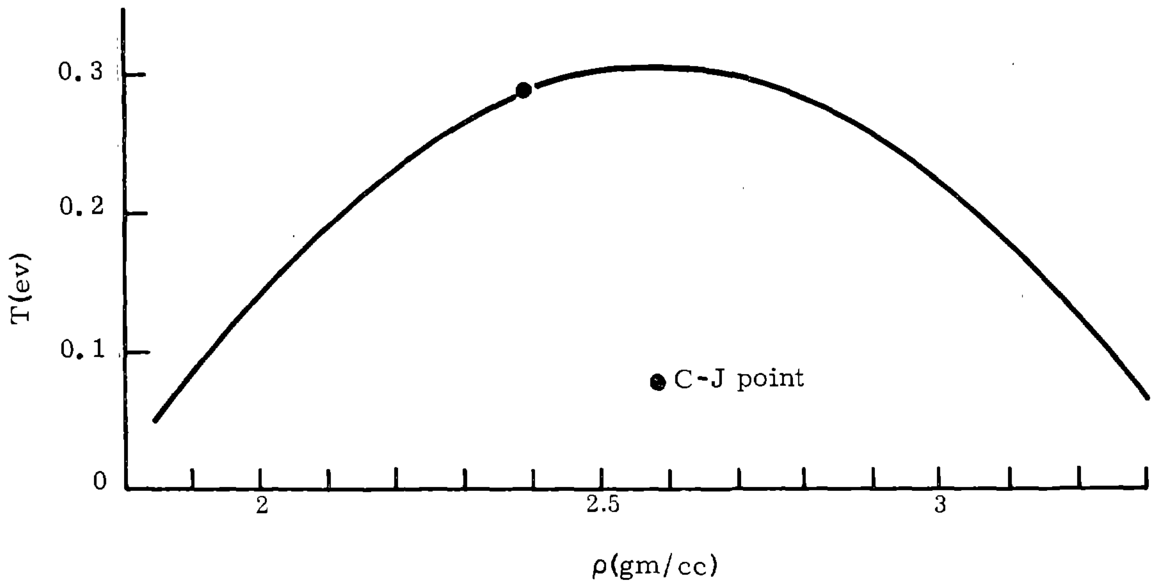

Fig. 10.1 Solution of Eq. (10.6) for RDX.

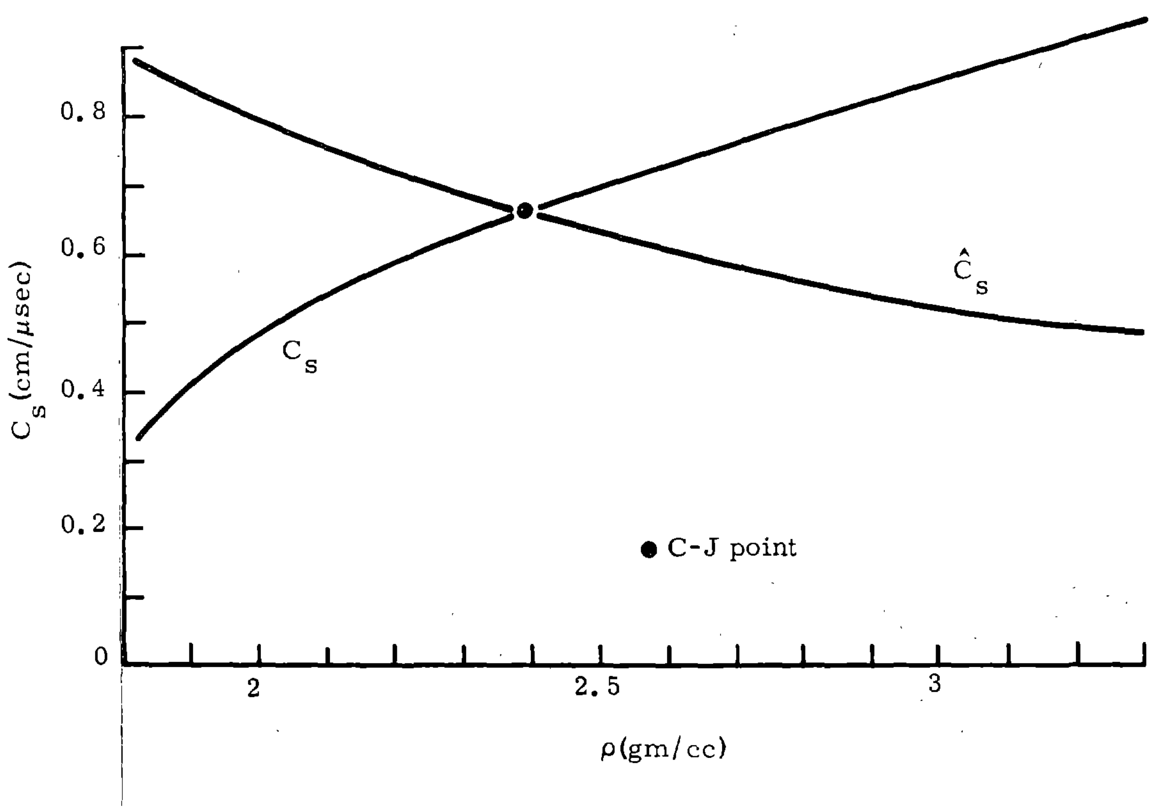

Fig. 10.2 Solutions of Eqs. (10.6) and (10.7) for RDX.

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.

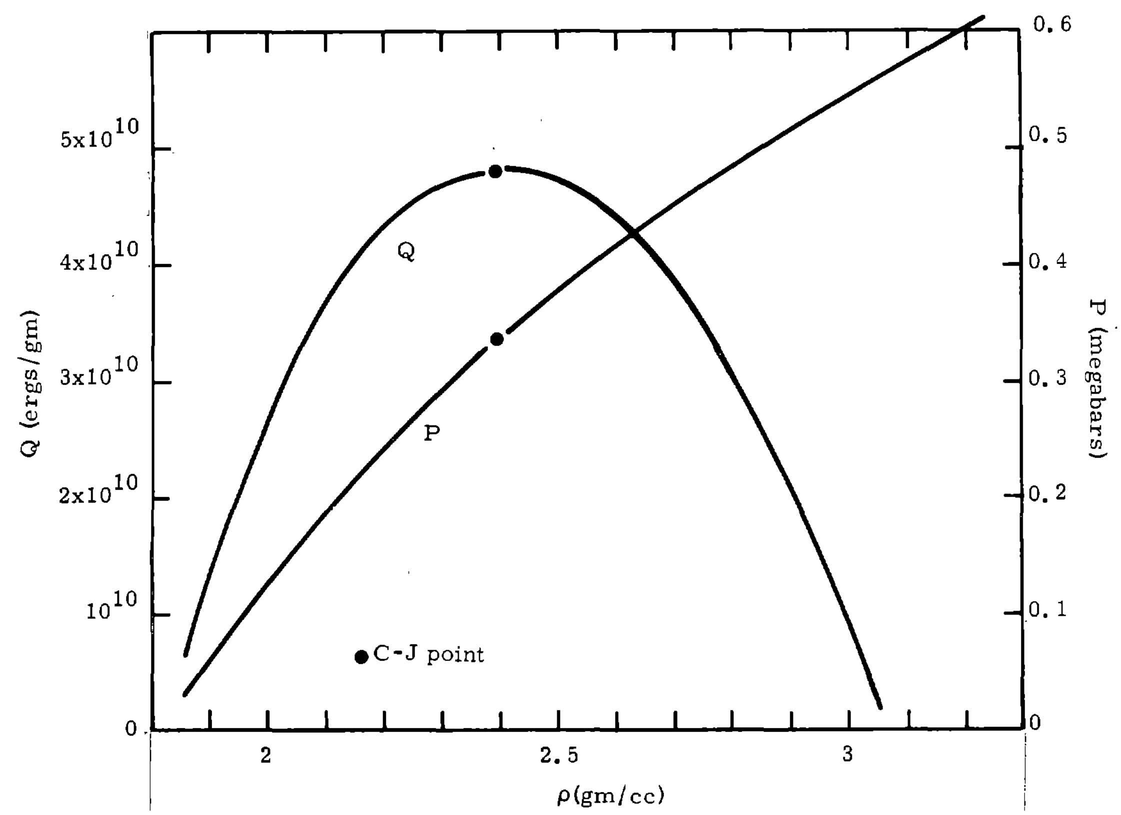

Fig. 10.3 Solutions of Eqs. (10.3) and (10.6) for RDX.

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. Fntire 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

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

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

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

where

$$\mathscr{E}_o = \mathscr{E}_{tot1}(0) \tag{11.10}$$

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

$$\Delta\mathscr{E} = \mathscr{E}_{tot1} - \mathscr{E}_{tot2} \tag{11.11}$$

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

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

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

Appendix A

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

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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

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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:

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

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

$$\mathcal{M} = \sum_{i=1}^{\ell} M_i = M_1 \sum_{i=1}^{\ell} R^{i-1} \quad ,$$

$$= M_1 \left\{\frac{1 - R^{\ell}}{1 - R}\right\} \text{ if } R \neq 1 \quad , \tag{B.2}$$

$$= \ell M_1 \text{ if } R = 1 \quad .$$

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

$$\ell = \ln\left\{1 - (1 - R)\mathcal{M}/M_1\right\}/\ln R \quad \text{if } R \neq 1$$

$$= \mathcal{M}/M_1 \quad \text{if } R = 1 \quad . \tag{B.4}$$

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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

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

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,

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

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.

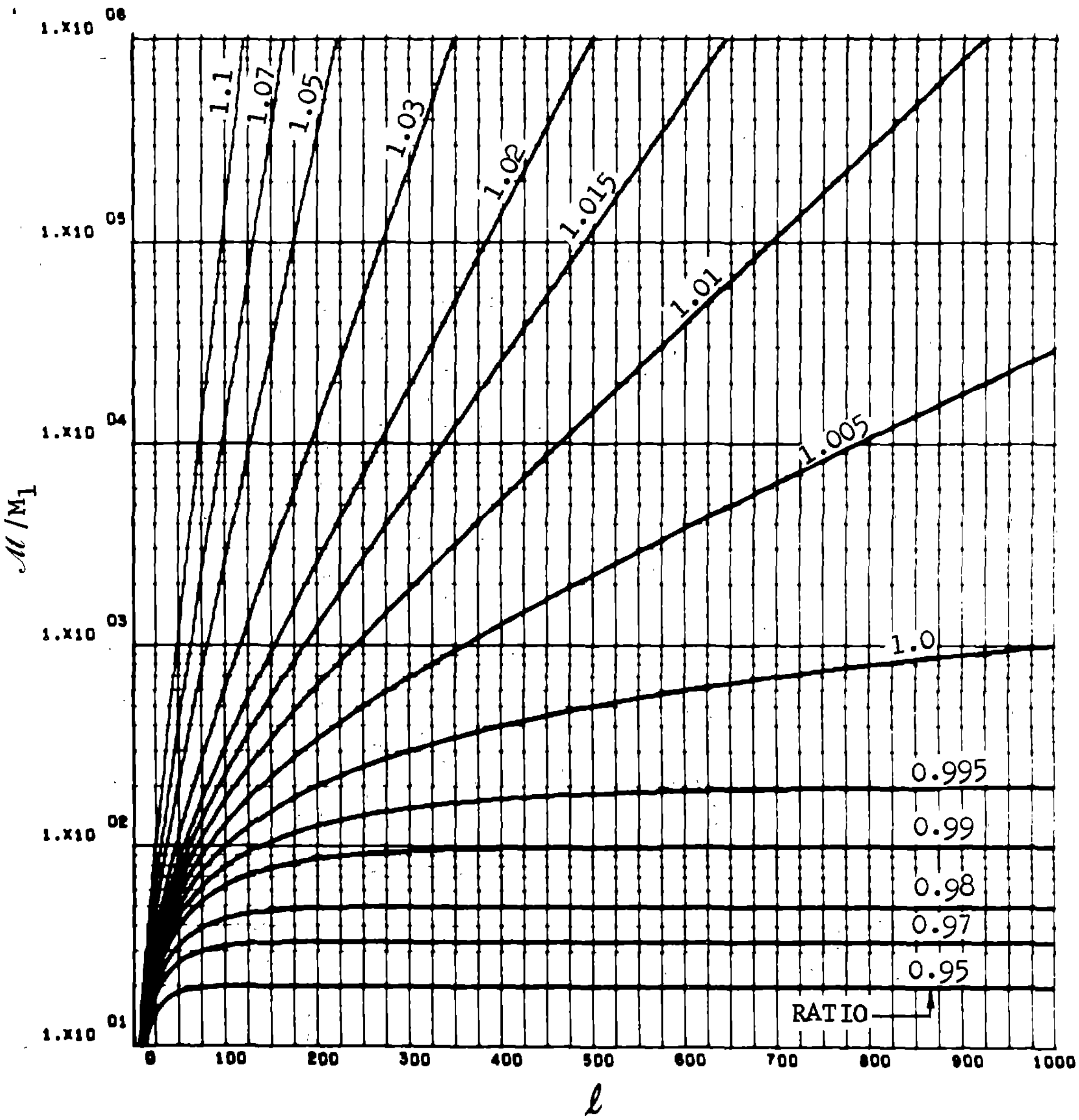


Fig. B.1 Ratio of total region mass to first zone mass versus number of zones ℓ for various mass ratios.

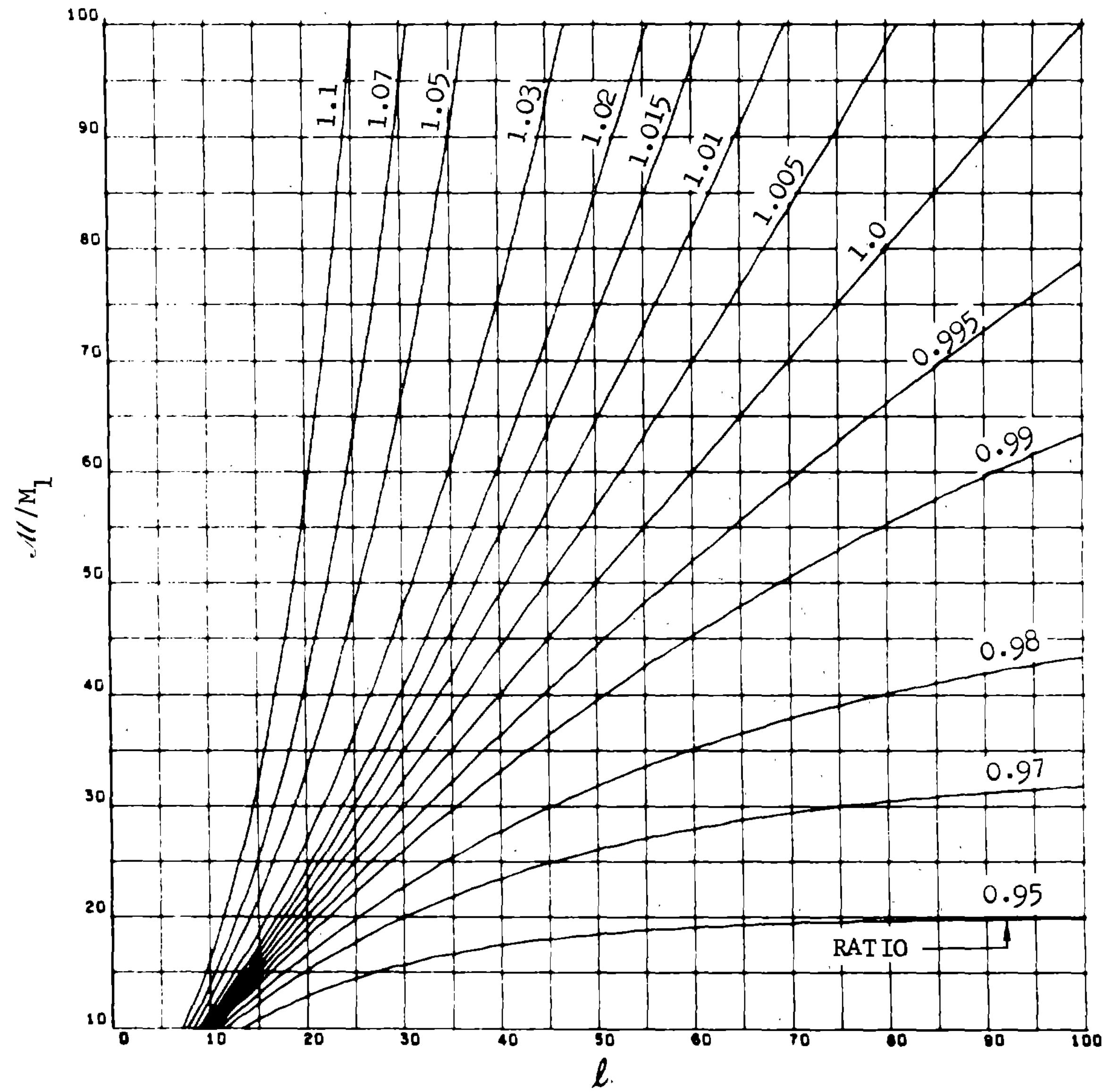


Fig. B.2 Ratio of total region mass to first zone mass versus number of zones ℓ for various mass ratios.

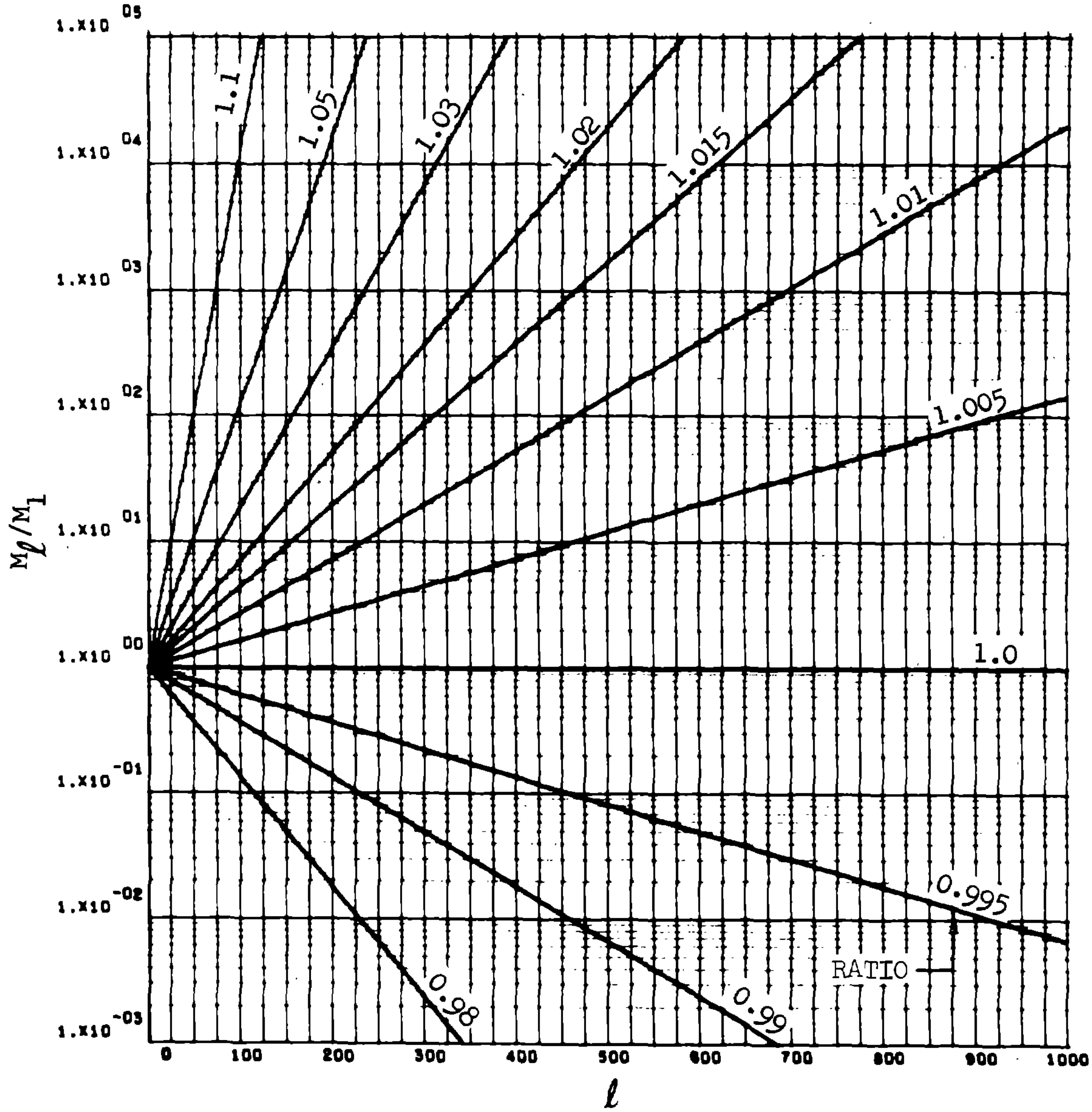


Fig. B. 3 Ratio of ℓ^{th} zone mass to first zone mass versus ℓ for various mass ratios.

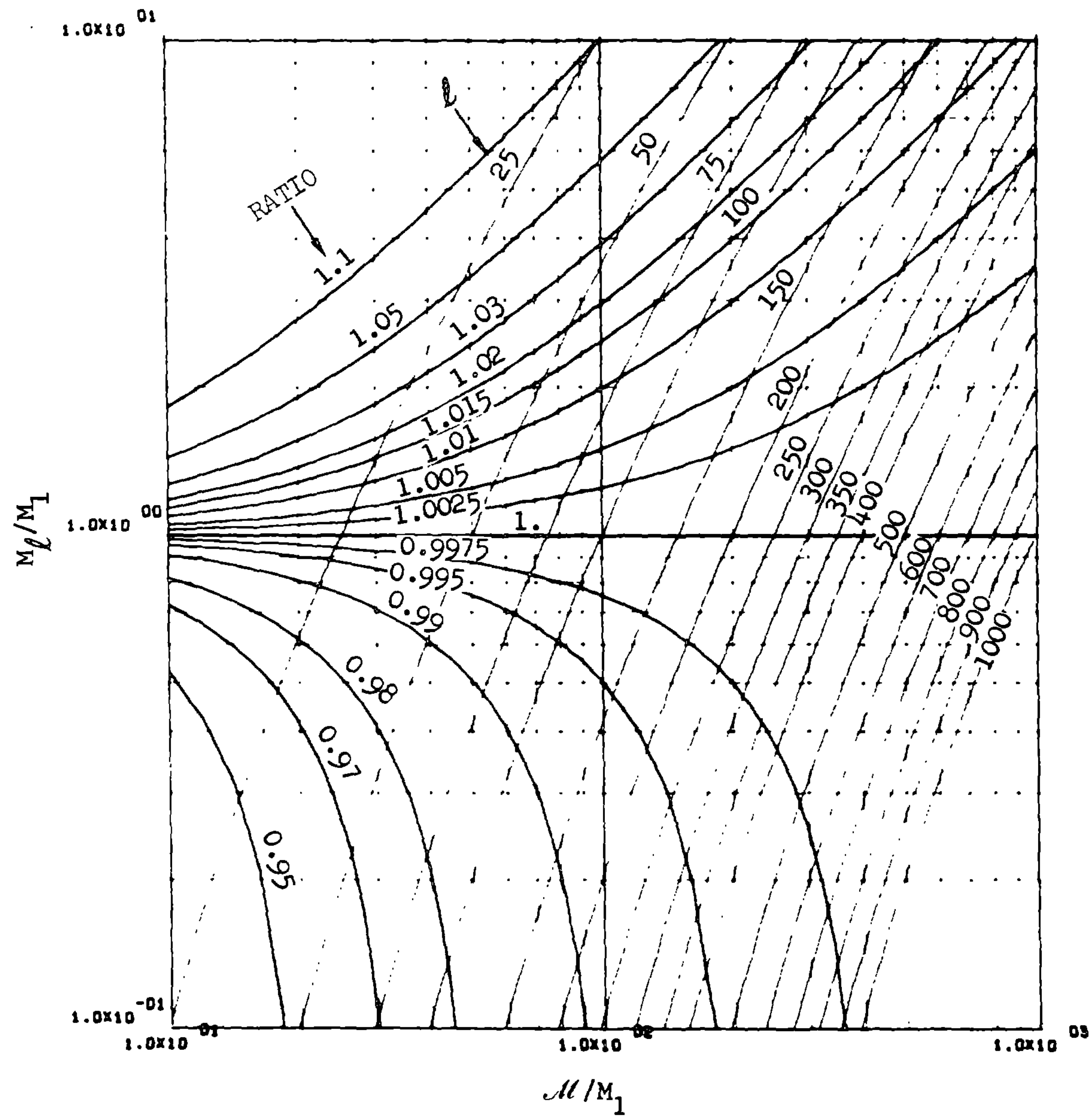


Fig. B.4 Ratio of ℓ^{th} zone mass to first zone mass versus ratio of total mass of ℓ zones to first zone mass for various mass ratios and ℓ.

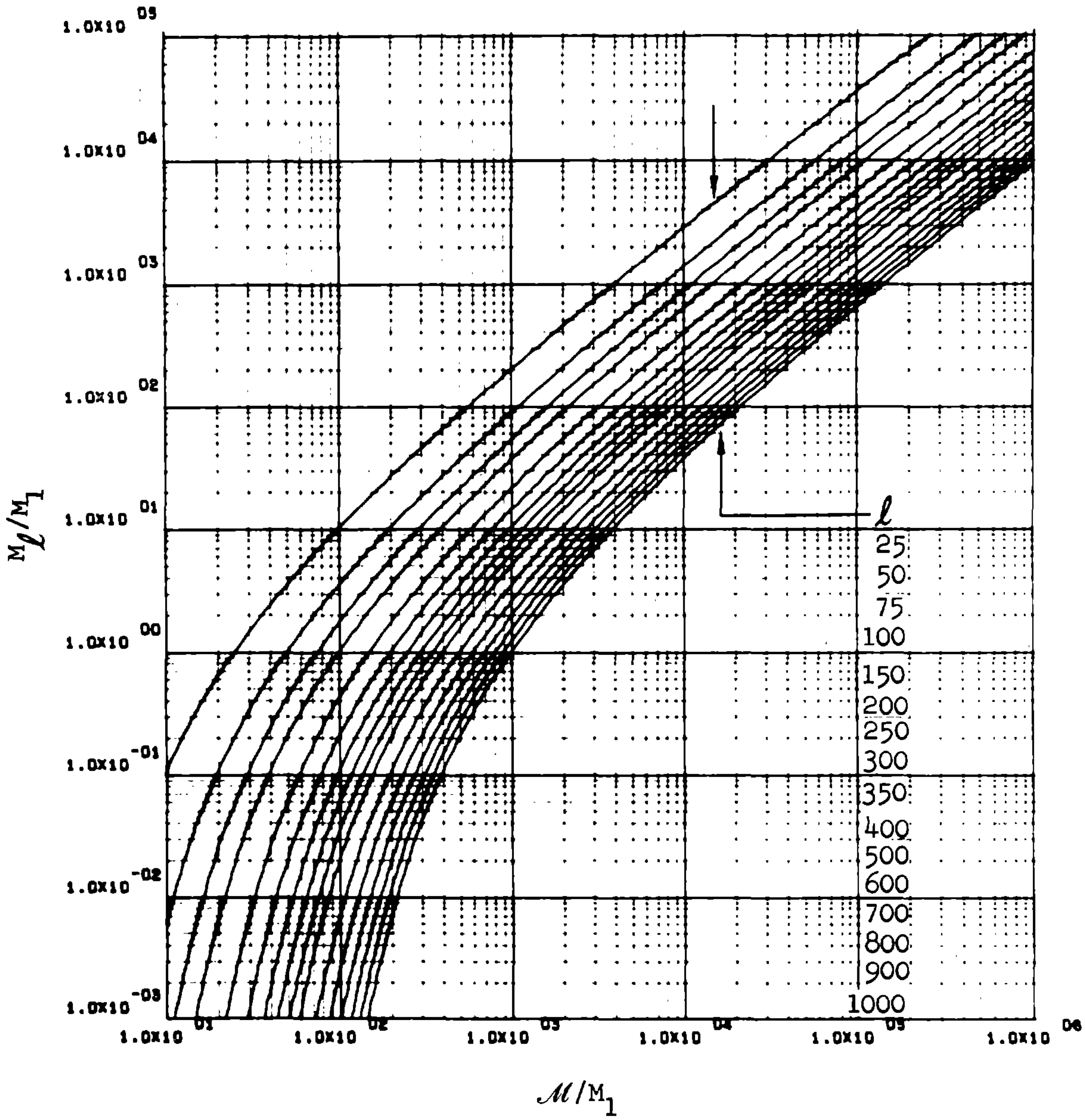


Fig. B.5 Ratio of ℓ^{th} zone mass to first zone mass versus ratio of total mass of ℓ zones to first zone mass for various ℓ .

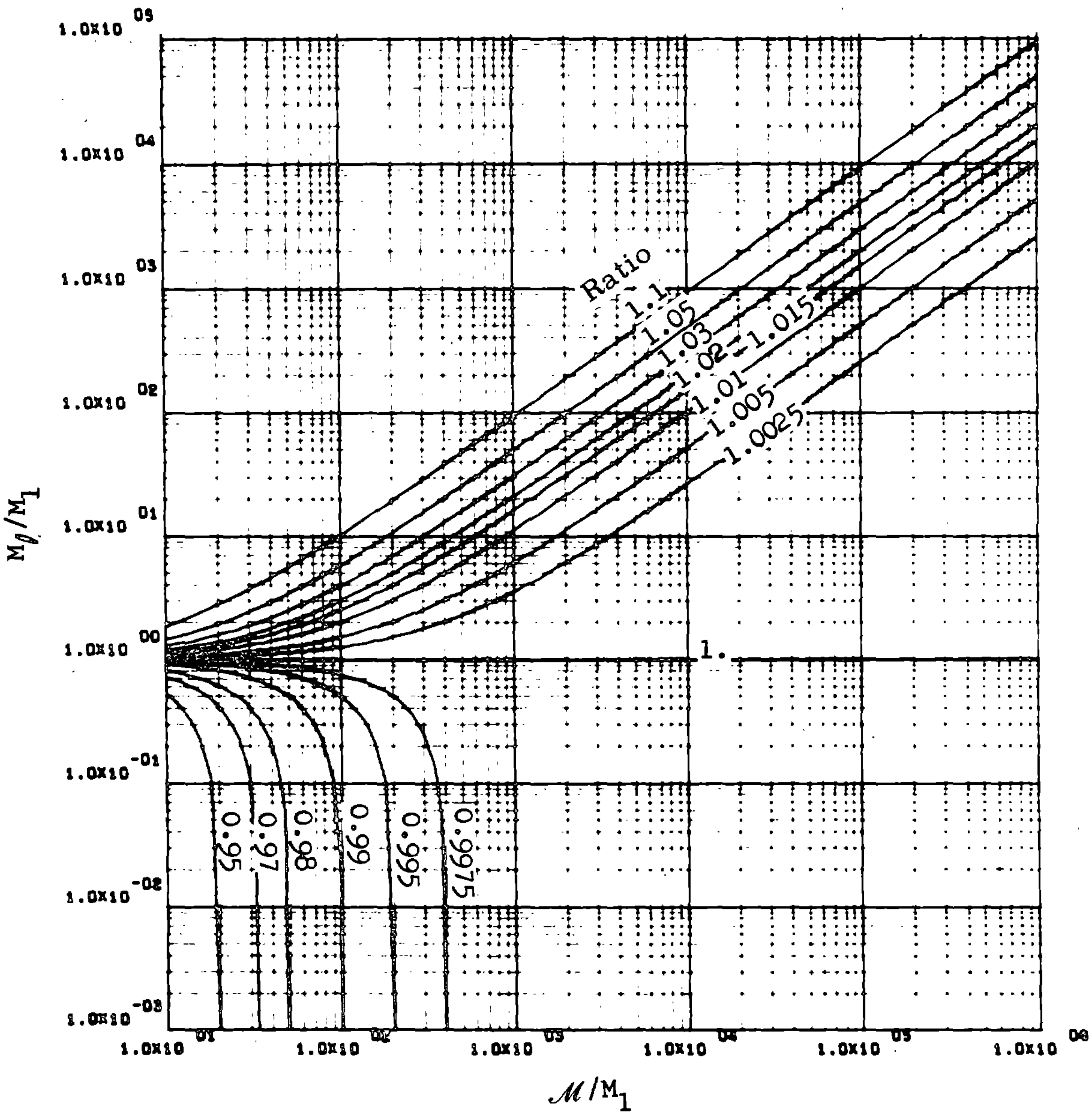


Fig. B.6 Ratio of ℓ^{th} zone mass to first zone mass versus ratio of total mass of ℓ zones to first zone mass for various mass ratios.

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.

Preceding page blank 117,118

```
******************* 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 CHAPTD
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.

Preceding page blank 121/122

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

Preceding page blank 125-126

ENTSV(I) = specific entropy of zone I

SXD(I) = X stress deviator of zone I

SZD(I) = Z stress deviator of zone I

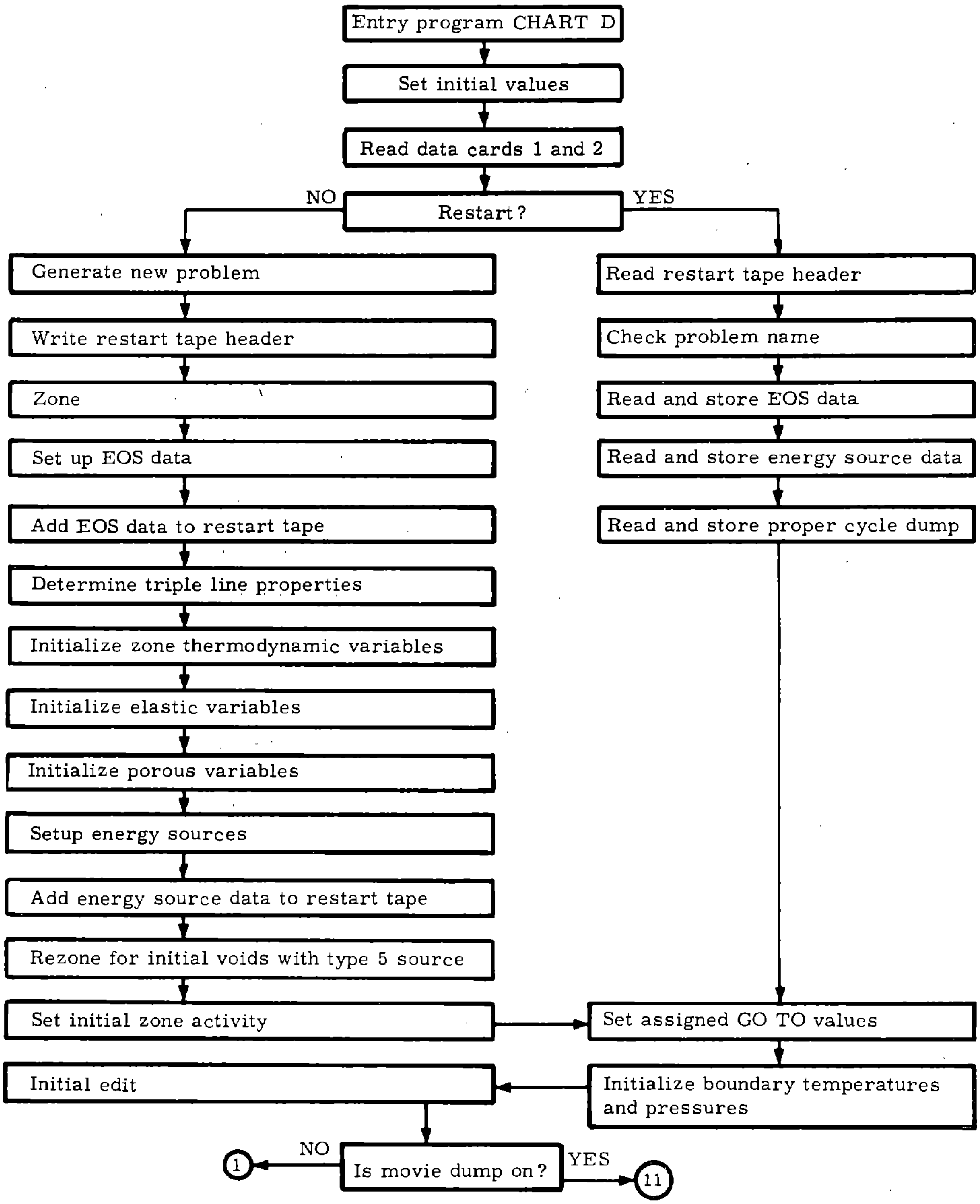
DRATIO(I) = distention ratio of zone I

Appendix F

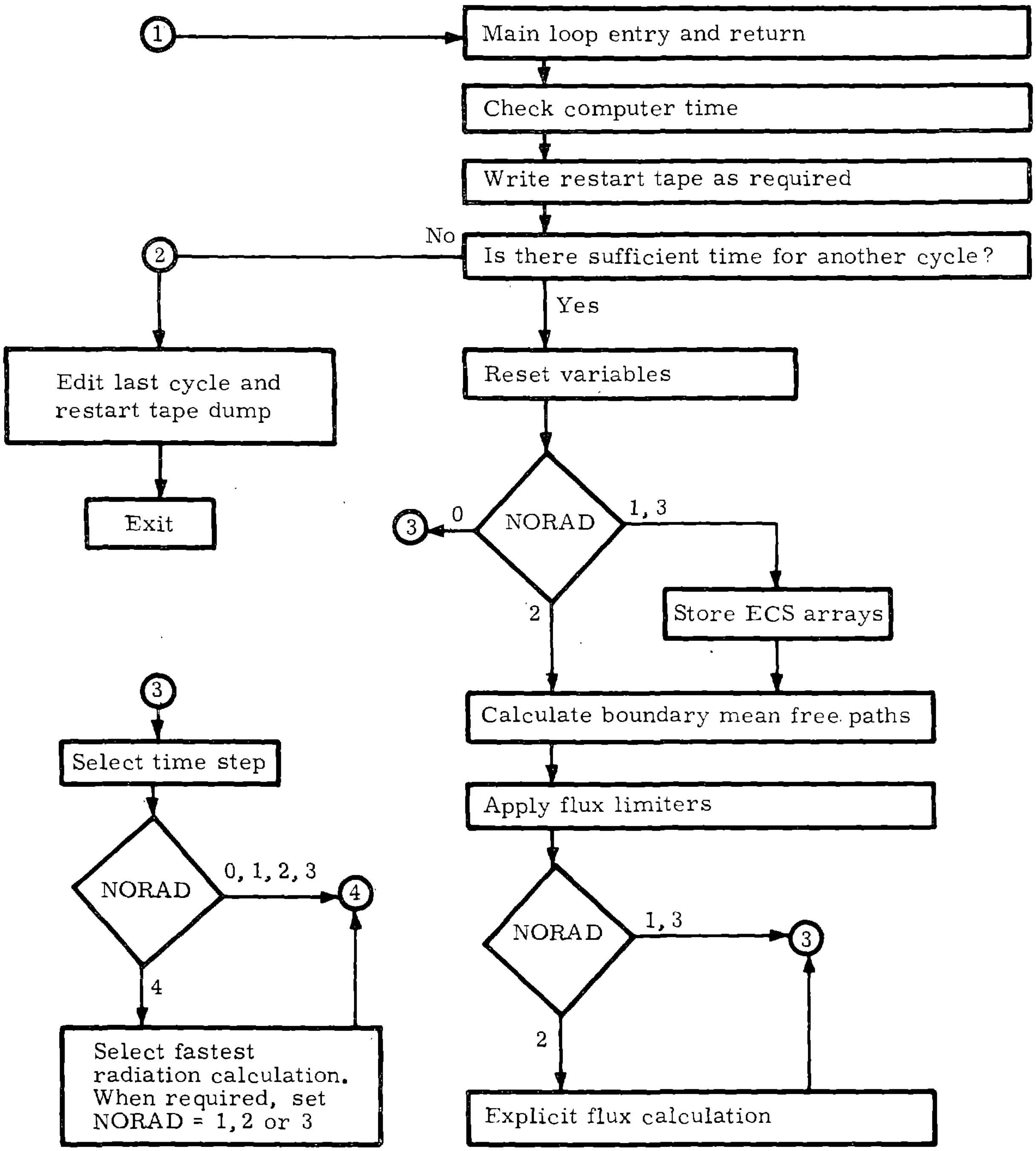
FLOW CHART OF MAIN PROGRAM

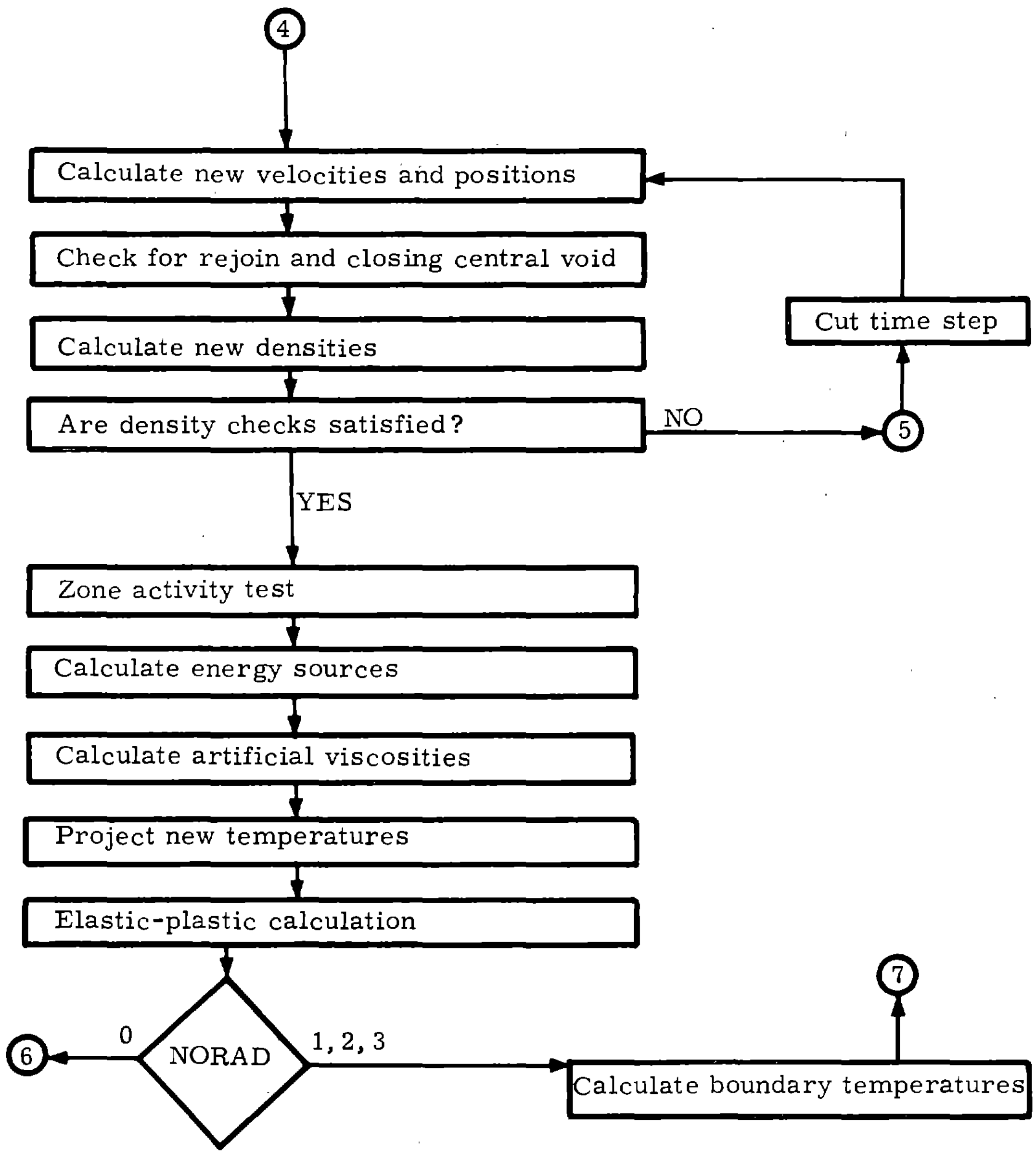
Appendix F

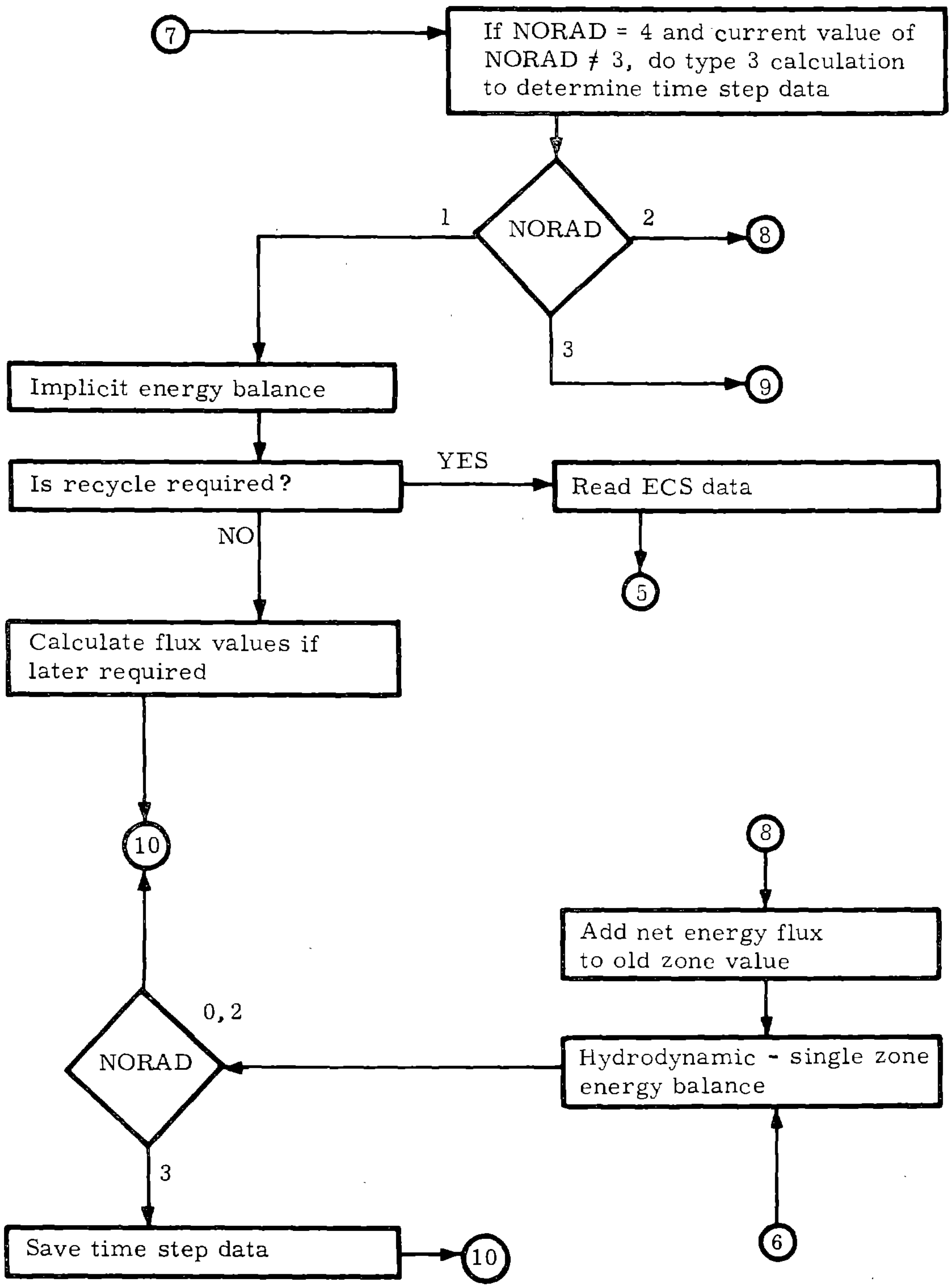
FLOW CHART OF MAIN PROGRAM

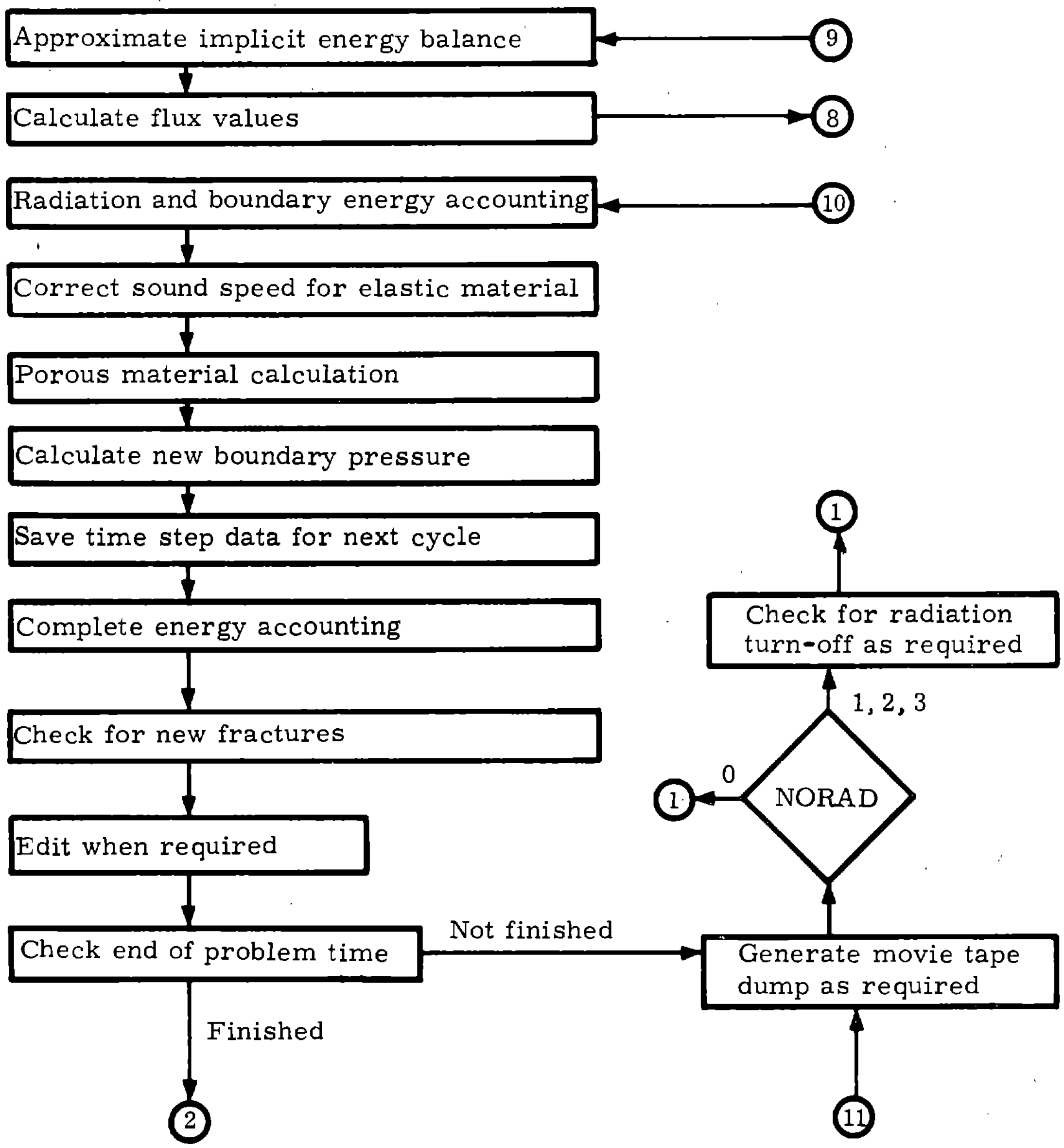


Preceding page blank 129, 130


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
Reset variables
Exit
3
0
NORAD
1, 3
2
Store ECS arrays
3
Calculate boundary mean free paths
Select time step
Apply flux limiters
NORAD
0, 1, 2, 3
4
NORAD
1, 3
3
4
2
Select fastest radiation calculation. When required, set NORAD = 1, 2 or 3
Explicit flux calculation


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
0
6
NORAD
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
NORAD
0, 2
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
1
Complete energy accounting
Check for radiation turn-off as required
1, 2, 3
Check for new fractures
0
1
NORAD
Edit when required
Check end of problem time
Not finished
Generate movie tape dump as required
Finished
2
11

Appendix G

FORTRAN LISTING

```
C   * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C   *                 ISSUED BY SANDIA CORPORATION.
C   *                   A PRIME CONTRACTOR TO 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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```

```
      PROGRAM CHARTD (INPUT,OUTPUT,TAPE1=OUTPUT,TAPE3,TAPE2=TAPE3,TAPE7,CHD
     1TAPE10,TAPE11,TAPE12,TAPE17=INPUT)                               CHD
C                                                                      CHD
C     SEPTEMBER,1971    THIS DECK LOADED 9/1/71                        CHD
C     WARNING  - - -  ECS VERSION                                      CHD
C     FOR MACHINES WITHOUT EXTENDED CORE STORAGE MORE TAPES ARE REQUIREDCHD
C     AND THE DUMMY ECS SUBROUTINE MUST BE ADDED                       CHD
C                                                                      CHD
C     S.L.THOMPSON  SANDIA  ALBUQUERQUE,N.M.  5162                     CHD
C     SC-RR-710713, SC-RR-710714 AND SC-TM-710715                      CHD
C     RADIATION DIFFUSION HYDRO CODE                                   CHD
C     PLANE,CYLINDERICAL,OR SPHERICAL GEOMETRY                         CHD
C     ELASTIC-PLASTIC AND DISTENDED MATERIAL ROUTINES                  CHD
C     TEMPERATURE AND DENSITY ARE INDEPENDENT VARIABLES                CHD
C     TAPE 1 IS STANDARD EDIT OUTPUT TAPE                              CHD
C     TAPE 2 IS OPTIONAL EDIT OUTPUT TAPE                              CHD
C     TAPE 3 IS MOVIE TAPE                                             CHD
C     TAPE 10 IS STANDARD RESTART OUTPUT AND INPUT TAPE                CHD
C     TAPE 11 IS OPTIONAL RESTART OUTPUT TAPE                          CHD
C     TAPE 12 IS EOS INPUT TAPE - READ ONLY                            CHD
C     TAPE 7 IS STANDARD DEPOSITION INPUT TAPE - READ ONLY             CHD
C     TAPE 17 IS OPTIONAL DEPOSITION INPUT TAPE                        CHD
      COMMON /A/ JBND(21),ITRIED(400),IZPTL(400),IZPRL(400),KPHASE(400),CHD
     1KACT(401),ISPALL(400),NSPALL,OBS,IBS,ICYCLE,IDTMAX,IDTMIN,JPRIN,NCCHD
     2OUNT,NMTRLS,NZN,NZ,NZP,NDUMP,NBPRES,NOSOUR,NACTION,NORAD,IGM,NRADCCHD
     3K,MOVIE,IMPEXP,IMPA,KRO4,NOHYD                                   CHD
      COMMON D(400),DO(400),T(400),TO(400),P(400),XM(400),XM2(401),X(401CHD
     1),XO(401),V(401),VO(401),XL(400),XLO(400),VL(400),VLO(401),CSOD(40CHD
     20),Q(400),SXD(400),SZD(400),FPATH(400),FLUX(401),E(400),PPPT(400),CHD
     3PEPTIN(400),PSPALL(400),SD(400),TEMP(400),TSAVE(400),PSAVE(400),ESCHD
     4AVE(400),TEMPR(401),TMSPALL(20),DT,DTMAX,DTMIN,DTTEMP,DTRAD,TIME,TCHD
     5PN,TEND,DTRADT,BL,BQ,DTIMEP(25),DLTTMX(25),DTMINN(25),TIMEP(25),TDCHD
     6TMINN(25),TIMES(25),WORKF,WORKB,ENO,ESOURS,TBPRES(25),PINNER(25),PCHD
     7OUTER(25),XMATUP(21),DTCS,DTP,TITH(25),TEINTH(25),TEOUTH(25),FLINFCHD
     8,FLINFO,FLINB,FLINBO,FLOUF,FLOUFO,FLOUB,FLOUBO,RADEB,RADEF,SCRADF,CHD
     9SCRADB,SPLA(20),SPLB(20),SPLC(20),SPLD(20),ENTSV(400),TMOV(10),DTMCHD
     $OV(10),TRADOFF,SWEP,YIELD(20,8),DRATIO(400),SWPOR               CHD
      COMMON /C/ TEMPA,TEMPB,TEMPC,TEMPD,TEMPE,TEMPF,TEMPG,TEMPH,TEMPI,TCHD
     1EMPJ,TEMPK,TEMPL,TEMPM,TEMPN,TEMPAB,TBPU,PBORYO,PBORYI,TRADMIN,RADCHD
     2K1,RADK2,RADK3,RADK4,RADK5,RADK6,TEBOUT,TEBIN,TTHIU              CHD
      COMMON /D/ IS,IS1,ICALL,ITLOW,JTLOW,INES                         CHD
      COMMON /E/ IZETL(21),IZERL(21),ITL(21),IRL(21),IEOS(400),IEOSS(20)CHD
     1,KTP(21),NRDS(21),NUMTEM(20),IGAS(20),NOANEOS,NISEOS             CHD
      COMMON /NAME/ ANAME(13),MAXZONE,NTS1,NTS2,NTS3,ITTMP,CYMESH       CHD
      COMMON /TAPES/ I,IIN,IOUT,IEOSTP,ITWO                            CHD
      DIMENSION SD2(1), SD3(1), TSOUR1(1), TSOUR2(1), TSOUR3(1), TSOUR4(CHD
     11), THESE(1)                                                     CHD
      EQUIVALENCE (SD2(1),SD(1)), (SD3(1),TEMP(1)), (TSOUR1(1),TSAVE(1))CHD
     1, (TSOUR2(1),PSAVE(1)), (TSOUR3(1),ESAVE(1)), (TSOUR4(1),TEMPR(1))CHD
     2, (THESE(1),DRATIO(1))                                           CHD
      DIMENSION GG(1), GGA(1), GGB(1), GGC(1), GGE(1), GGF(1)          CHD
      EQUIVALENCE (GG(1),TEMP(1)), (GGA(1),GGF(1),FLUX(1))             CHD
      EQUIVALENCE (GGB(1),TSAVE(1)), (GGC(1),GGE(1),PSAVE(1))          CHD
      INTEGER OBS                                                      CHD
C     THESE VARIABLES ARE DIMENSION OF ABOVE COMMONS AND VARIABLES     CHD
```

```
      DATA KOMMONA,KOMMONB,MAXZONE,MAXNMT/2446,13841,400,20/
      DATA MAXTHI,MAXNPRI,MAXDTMA,MAXDTMI,MAXBPR/5*24/
C     TAPE NUMBERS
      DATA IIN,IOUT,IEOSTF,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,FRACDT,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)
      TBPRES(1)=0.
      TBPRES(NBPRES+1)=1.E100
      PINNER(NBPRES+1)=PINNER(NBPRES)
      POUTER(NBPRES+1)=POUTER(NBPRES)
      J=NBPRES+1
      PRINT 5830, (I,TBPRES(I),PINNER(I),POUTER(I),I=1,J)
  230 CONTINUE
      IF (NORAD.EQ.0) GO TO 250
      IF (NTHIST.LE.0) GO TO 240
      READ 5820, (TITH(I),TEINTH(I),TEOUTH(I),I=1,NTHIST)
      TITH(1)=0.
      J=NTHIST+1
      TITH(J)=1.E100
      TEINTH(J)=TEINTH(J-1)
      TEOUTH(J)=TEOUTH(J-1)
      PRINT 5840, (I,TITH(I),TEINTH(I),TEOUTH(I),I=1,J)
      GO TO 250
  240 TITH(2)=1.E100
      TEINTH(1)=TEINTH(2)=TEOUTH(1)=TEOUTH(2)=TITH(1)=0.
  250 CONTINUE
      BL=0.5*BL
      BQ=.5*BQ**2
      DTMAX=DLTTMX(1)
      DTMIN=DTMINN(1)
      TPN=DTIMEP(1)
      TIMEP(NPRIN+1)=TIMES(NDTMAX+1)=TDTMINN(NDTMINN+1)=1.E300
      DTIMEP(NPRIN+1)=DTIMEP(NPRIN)
      DTMINN(NDTMINN+1)=DTMINN(NDTMINN)
      DLTTMX(NDTMAX+1)=DLTTMX(NDTMAX)
      IDTMIN=IDTMAX=1
      DT=DLTTMX(1)
      IM1=MAXZONE+1
      DO 260 I=1,IM1
  260 KACT(I)=1
C
C     ZONING AND PROBLEM SET UP
      JBAD=0
      PRINT 5850, NMTRLS
      IA=NMTRLS+1
      READ 5770, (XMATUP(I),I=1,IA)
      PRINT 5860, (I,XMATUP(I),I=1,IA)
      J=1
      JJ=2
      DO 880 I=1,NRZC
      IS=10H * * * * *
      PRINT 5880, I,(IS,L=1,8)
      READ 5870, ITYPE,TEMPD,TEMPE,TEMPA,TEMPB,TEMPC,IES
      IF (TEMPB.LE.0.) TEMPB=.02567785
      PRINT 5890, ITYPE,TEMPD,TEMPE,TEMPA,TEMPB,TEMPC,IES
      READ 5770, (TEMP(L),L=1,8)
      IF (TEMP(6).LE.0..AND.TEMP(3).GE.0.) TEMP(6)=.8
      IF (TEMP(4).LE.0..AND.TEMP(3).GE.0.) TEMP(4)=TEMPA
      PRINT 5910, (L,TEMP(L),L=1,8)
      READ 5770, (TEMP(L),L=9,16)
```

```
      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)
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  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*(RATIC-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
```

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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)
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      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=-CSOO(JJ)
      TSAVE(JJJ)=-TEMPA
      YIELD(JJJ,3)=TEMPA/CSOO(JJ)
      IF (YIELD(JJJ,3).GE.0.) STOP 7405
      TEMPE=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((TEMP
     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,TEMPO,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 3100 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
```

```
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)+BG*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
```

```
      DTRAD=TEMPI
      NTS2=ZUP
 2400 TEMPA=2.
      IMPEXP=1
 2410 IMPA=0
 2420 PRINT 6140, ICYCLE,TIME,TEMPA
      GO TO 2730
C     IMPLICIT SELECTED
 2430 IMPEXP=0
      TEMPA=1.
      GO TO 2410
 2440 IF (TEMPA.LT.TEMPB) GO TO 2430
C     APPROXIMATE IMPLICIT SELECTED
      IMPEXP=0
      IMPA=1
      TEMPA=3.
      DTRAD=TEMPJ
      NTS2=ZLOW
      GO TO 2420
 2450 IF (IMPEXP) 2460,2470,2590
 2460 DTRAD=1.E50
      GO TO 2730
 2470 IF (IMPA) 2480,2480,2580
C     IMPLICIT DIFFUSION
 2480 DTRAD=1.E-50
      TEMPG=6.
      TEMPC=TO(1)**3
      IF (IGM-2) 2490,2500,2510
 2490 TEMPA=1.
      GO TO 2520
 2500 TEMPA=XO(1)
      TEMPG=TWOPIE*TEMPG
      GO TO 2520
 2510 TEMPA=XO(1)**2
      TEMPG=FOURPIE*TEMPG
 2520 TEMPD=-TEMPG*TEMPA*TEMPR(1)*TEMPC
      DO 2570 I=1,NZN
      IP1=I+1
      TEMPB=TEMPC
      TEMPC=TO(IP1)**3
      TEMPE=TEMPD
      IF (IGM-2) 2550,2530,2540
 2530 TEMPA=XO(IP1)
      GO TO 2550
 2540 TEMPA=XO(IP1)**2
 2550 TEMPD=TEMPG*TEMPA*TEMPR(IP1)*(TEMPB-TEMPC)
      IF (KACT(I)) 2570,2560,2570
 2560 TEMPF=PEFTIN(I)*(TEMPE-TEMPD)/XM(I)
      IF (TEMPF.LE.DTRAD) GO TO 2570
      NTS2=I
      DTRAD=TEMPF
 2570 CONTINUE
      DTRAD=1./CTRAD
      IF (NCKR) 2730,2730,2390
C     APPROXIMATE IMPLICIT DIFFUSION
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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
      TEMPC=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=TEMPC-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 KSHG, (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                                                   CHD 1431
      IF (ISPALL(I).EQ.0) GO TO 3350                                    CHD 1432
      IF (XL(I).GT.X(I+1)) GO TO 3350                                   CHD 1433
      IF (X(I+1).GT.(.9*XL(I)+.1*X(I))) GO TO 3330                      CHD 1434
      TEMPAB=X(I+2)                                                     CHD 1435
      IF (ISPALL(I+1).EQ.1) TEMPAB=XL(I+1)                              CHD 1436
      IF (XL(I).LT.(.9*X(I+1)+.1*TEMPAB)) GO TO 3330                    CHD 1437
      TEMPE=TIME+DT                                                     CHD 1438
      IEDREJ=I+1                                                        CHD 1439
      IF (NEDREJ.NE.0) PRINT 6440, IEDREJ,ICYCLE,TEMPE                  CHD 1440
      IEDREJ=1                                                          CHD 1441
      ISPALL(I)=0                                                       CHD 1442
      NSPALL=NSPALL-1                                                   CHD 1443
      TEMPE=V(I+1)                                                      CHD 1444
      V(I+1)=(XM(I)*VL(I)+XM(I+1)*V(I+1))/(XM(I)+XM(I+1))               CHD 1445
      TEMPJ=.25*(XM(I)*VL(I)**2+XM(I+1)*TEMPE**2-(XM(I)+XM(I+1))*V(I+1)*CHD 1446
     1*2)                                                               CHD 1447
      X(I+1)=.5*(XL(I)+X(I+1))                                          CHD 1448
      SD(I)=.5*TEMPJ/(XM(I)*DT)                                         CHD 1449
      SD(I+1)=.5*TEMPJ/(XM(I+1)*DT)                                     CHD 1450
      GO TO NGM9, (3300,3310,3320)                                      CHD 1451
 3300 D(I)=XM(I)/(X(I)-X(I+1))                                          CHD 1452
      D(I+1)=XM(I+1)/(X(I+1)-TEMPAB)                                    CHD 1453
      GO TO 3350                                                        CHD 1454
 3310 D(I)=XM(I)/((X(I)-X(I+1))*(X(I)+X(I+1))*PIE)                      CHD 1455
      D(I+1)=XM(I+1)/((X(I+1)-TEMPAB)*(X(I+1)+TEMPAB)*PIE)              CHD 1456
      GO TO 3350                                                        CHD 1457
 3320 D(I)=XM(I)/((X(I)-X(I+1))*(X(I)**2+X(I)*X(I+1)+X(I+1)**2)*PIE43)  CHD 1458
      D(I+1)=XM(I+1)/((X(I+1)-TEMPAB)*(X(I+1)**2+X(I+1)*TEMPAB+TEMPAB**2CHD 1459
     1)*PIE43)                                                          CHD 1460
      GO TO 3350                                                        CHD 1461
 3330 PRINT 6450                                                        CHD 1462
      DO 3340 KKK=1,NZ                                                  CHD 1463
 3340 SD(KKK)=0.                                                        CHD 1464
      GO TO 3020                                                        CHD 1465
 3350 CONTINUE                                                          CHD 1466
 3360 CONTINUE                                                          CHD 1467
C     CHECK FOR ZONE ACTIVATION                                         CHD 1468
      IF (NACTION.EQ.0) GO TO 3470                                      CHD 1469
      IF (KCUTM.GT.0) GO TO 3470                                        CHD 1470
      IF (V(1)) 3390,3370,3390                                          CHD 1471
 3370 IF (NORAD) 3400,3400,3380                                         CHD 1472
 3380 IF (ABS(FLUX(1))-FLUXMIN) 3400,3400,3390                          CHD 1473
 3390 KACT(1)=KACT(2)=0                                                 CHD 1474
 3400 NACTION=IM1=0                                                     CHD 1475
      IP1=2                                                             CHD 1476
      DO 3460 I=2,NZ                                                    CHD 1477
      IM1=IM1+1                                                         CHD 1478
      IP1=IP1+1                                                         CHD 1479
      IF (V(I)) 3440,3410,3440                                          CHD 1480
 3410 IF (NORAD) 3450,3450,3420                                         CHD 1481
 3420 IF (ABS(FLUX(I))-FLUXMIN) 3450,3450,3430                          CHD 1482
 3430 IF (I.GT.2) KACT(I-2)=0                                           CHD 1483
 3440 KACT(IM1)=KACT(I)=KACT(IP1)=0                                     CHD 1484
 3450 IF (KACT(IM1).EQ.0) NACTION=NACTION+1                             CHD 1485
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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)+(SO(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
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      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 390C
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=TEMPB
      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
      GO TO 4300
 4260 IP1=5291
      GO TO 4300
 4270 IP1=5292
      GO TO 4300
 4280 IP1=5293
      GO TO 4300
 4290 IP1=5294
C     FOR RECYCLE PRINT CHANGE NEXT CARD
 4300 JJ=0
      IF (NCKR.GT.1.AND.IMPA.EQ.1) GO TO 4770
      IF (JJ) 4310,4320,4310
 4310 PRINT 5570, ICYCLE,TIME,DT,I,IP1,TEMPG,TEMPA,TEMPJ,TEMPC,TEMPD,TEMC
     1PH,TEMPB,TEMFL,ITTMP
      PRINT 5580, (I,TEMP(I),FLUX(I),TSAVE(I),PSAVE(I),T(I),TO(I),D(I),D
     1O(I),SD(I),E(I),I=1,NZ)
 4320 KCUTM=KCUTM+1
      IF (KCUTM.GT.5) STOP 5210
      DT=0.5*DT
      DO 4330 I=1,NZ
      D(I)=TEMPA=DO(I)
      T(I)=TEMPB=TO(I)
      CALL EOS
      E(I)=TEMPC
      P(I)=TEMPD
      PPPT(I)=TEMPH
 4330 PEPTIN(I)=1./TEMPG
      CALL READEC (CSOD,6*MAXZONE,4*MAXZONE)
      CALL READEC (ISPALL,10*MAXZONE,MAXZONE+3)
      GO TO 2760
 4340 DO 4360 I=1,NZ
      IF (KACT(I)) 4360,4350,4360
 4350 PEPTIN(I)=1./PEPTIN(I)
 4360 CONTINUE
C     CALCULATE FLUX IF LATER REQUIRED
      IF (ICYCLE.EQ.50*(ICYCLE/50)) GO TO 4370
      IF (NCOUNT+1.NE.10*((NCOUNT+1)/10)) GO TO 4470
 4370 TEMPB=1.
      DO 4460 I=1,NZP
      TEMPL=TEMPM
      IF (NZP-I) 4380,4390,4380
 4380 TEMPM=(T(I)+TO(I))**4
      GO TO 4400
 4390 TEMPM=TEMPN
 4400 IF (TEMPR(I)) 4420,4410,4420
 4410 FLUX(I)=0.
      GO TO 4460
 4420 IF (IGM-2) 4450,4430,4440
 4430 TEMPB=TWOPIE*XO(I)
      GO TO 4450
 4440 TEMPB=FOURPIE*XO(I)*X(I)
 4450 FLUX(I)=TEMPR(I)*(TEMPM-TEMPL)/(DT*TEMPB)
 4460 CONTINUE
 4470 CONTINUE
```

```
      IF (NCKR-1) 4920,4920,4900
C     APPROXIMATE IMPLICIT DIFFUSION FIRST PASS TEMPERATURES
 4480 IF (IGM-2) 4490,4500,4510
 4490 TEMPB=DT
      GO TO 4520
 4500 TEMPA=TWOPIE*DT
      GO TO 4520
 4510 TEMPA=FOURPIE*DT
 4520 DO 4580 I=2,NZ
      IF (TEMPR(I)) 4540,4530,4540
 4530 PSAVE(I)=0.
      GO TO 4580
 4540 TEMPR(I)=.25*TEMPR(I)*(TO(I)+TO(I-1))**3
      IF (IGM-2) 4570,4550,4560
 4550 TEMPE=TEMPA*XO(I)
      GO TO 4570
 4560 TEMPB=TEMPA*XO(I)*X(I)
 4570 PSAVE(I)=TEMPB*TEMPR(I)
 4580 CONTINUE
      DO 4700 I=1,NZ
      IF (KACT(I)) 4590,4600,4590
 4590 ESAVE(I)=-TO(I)
      GGB(I)=1.
      GGA(I)=GGC(I)=0.
      GO TO 4700
 4600 TEMPJ=T(I)
      TEMPA=D(I)
      CALL EOS
      TEMPB=.5*TEMP(I)*TEMPH
      ESAVE(I)=TEMPC-E(I)-TEMPG*TEMPJ-SD(I)*DT+TEMP(I)*(Q(I)+.5*(TEMPD+P
     1(I)-TEMPH*TEMPJ))
      GGB(I)=TEMPG+TEMPB
      IF (I.EQ.1) GO TO 4620
      IF (I.EQ.NZ) GO TO 4630
      GGA(I)=PSAVE(I)/XM(I)
      GGC(I)=PSAVE(I+1)/XM(I)
      ESAVE(I)=ESAVE(I)+(GGA(I)*(TO(I)-TO(I-1))-GGC(I)*(TO(I+1)-TO(I)))
 4610 GGB(I)=GGB(I)+GGA(I)+GGC(I)
      GO TO 4700
 4620 IP1=1
      GO TO 4640
 4630 IP1=NZP
 4640 IF (IGM-2) 4650,4660,4670
 4650 TEMPB=1.
      GO TO 4680
 4660 TEMPB=TWOPIE*XO(IP1)
      GO TO 4680
 4670 TEMPB=FOURPIE*XO(IP1)*X(IP1)
 4680 TEMPB=TEMPB*TEMPR(IP1)*DT
      IF (I.EQ.NZ) GO TO 4690
      GGA(1)=0.
      GGC(1)=PSAVE(2)/XM(1)
      GGB(1)=GGB(1)+.5*TEMPB*TO(1)**3/XM(1)
      ESAVE(1)=ESAVE(1)+(.5*TO(1)**4-SCRADF*(ZEBOUT+TEBOUT)**4/16.)*TEMPC
     1B/XM(1)-GGC(1)*(TO(2)-TO(1))
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      GO TO 4610                                                        CHD 1871
 4690 GGA(NZ)=PSAVE(NZ)/XM(NZ)                                          CHD 1872
      GGC(NZ)=0.                                                        CHD 1873
      GGB(NZ)=GGB(NZ)+.5*TEMPB*TO(NZ)**3/XM(NZ)                         CHD 1874
      ESAVE(NZ)=ESAVE(NZ)+GGA(NZ)*(TO(NZ)-TO(NZN))-(.5*TO(NZ)**4-SCRADB*CHD 1875
     1(ZEBIN+TEBIN)**4/16.)*TEMPB/XM(NZ)                                CHD 1876
      GO TO 4610                                                        CHD 1877
 4700 CONTINUE                                                          CHD 1878
C     BACKWARD-FORWARD SOLUTION                                         CHD 1879
      GGE(1)=GGC(1)/GGB(1)                                              CHD 1880
      GGF(1)=-ESAVE(1)/GGB(1)                                           CHD 1881
      DO 4730 I=2,NZ                                                    CHD 1882
      IP1=I-1                                                           CHD 1883
      TEMPG=GGB(I)-GGA(I)*GGE(IP1)                                      CHD 1884
      IF (TEMPG) 4720,4710,4720                                         CHD 1885
 4710 IP1=5386                                                          CHD 1886
      GO TO 4300                                                        CHD 1887
 4720 GGE(I)=GGC(I)/TEMPG                                               CHD 1888
      IF (ABS(GGE(I)).LT.1.E5) GO TO 4730                               CHD 1889
      IP1=5387                                                          CHD 1890
      GO TO 4300                                                        CHD 1891
 4730 GGF(I)=(GGA(I)*GGF(IP1)-ESAVE(I))/TEMPG                           CHD 1892
      TSAVE(NZ)=GGF(NZ)                                                 CHD 1893
      DO 4740 IP1=1,NZN                                                 CHD 1894
      I=NZ-IP1                                                          CHD 1895
 4740 TSAVE(I)=GGE(I)*TSAVE(I+1)+GGF(I)                                 CHD 1896
      IF (NCKR.LE.1) GO TO 4790                                         CHD 1897
C     TYPE 4 RACIATION RETURN                                           CHD 1898
      DO 4760 I=1,NZ                                                    CHD 1899
      IF (KACT(I)) 4750,4760,4750                                       CHD 1900
 4750 TSAVE(I)=TO(I)                                                    CHD 1901
 4760 CONTINUE                                                          CHD 1902
      GO TO 3630                                                        CHD 1903
 4770 TSAVE(1)=1.E100                                                   CHD 1904
      DO 4780 I=2,NZ                                                    CHD 1905
 4780 TSAVE(I)=1.                                                       CHD 1906
      GO TO 3630                                                        CHD 1907
 4790 DO 4820 I=1,NZ                                                    CHD 1908
      IF (KACT(I)) 4800,4810,4800                                       CHD 1909
 4800 TSAVE(I)=TO(I)                                                    CHD 1910
      GO TO 4820                                                        CHD 1911
 4810 T(I)=TSAVE(I)                                                     CHD 1912
      IF (T(I).GT.0.) GO TO 4820                                        CHD 1913
      IP1=5394                                                          CHD 1914
      GO TO 4300                                                        CHD 1915
 4820 CONTINUE                                                          CHD 1916
C     FLUX                                                              CHD 1917
      TEMPA=TO(1)+T(1)                                                  CHD 1918
      FLOUF=TEMPR(1)*.5*TEMPA*TO(1)**3                                  CHD 1919
      FLINF=SCRADF*TEMPR(1)*(ZEBOUT+TEBOUT)**4/16.                      CHD 1920
      FLUX(1)=FLOUF-FLINF                                               CHD 1921
      DO 4830 I=2,NZ                                                    CHD 1922
      TEMPB=TEMPA                                                       CHD 1923
      TEMPA=TO(I)+T(I)                                                  CHD 1924
 4830 FLUX(I)=TEMPR(I)*(TEMPA-TEMPB)                                    CHD 1925
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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=PBDRYI=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.                                                    CHO 2036
 5300 CONTINUE                                                            CHO 2037
C     CHECK FOR FRACTURE                                                  CHO 2038
      IF (NSPALL.LT.0) GO TO 5360                                         CHO 2039
      TEMPM=IEDREJ                                                        CHO 2040
      TEMPN=NEDREJ                                                        CHO 2041
      IF (SWEP) 5310,5330,5310                                            CHO 2042
 5310 DO 5320 I=1,NZ                                                      CHO 2043
      TEMPR(I)=P(I)                                                       CHO 2044
 5320 P(I)=P(I)-SXD(I)                                                    CHO 2045
 5330 CALL FRACT                                                          CHO 2046
      IEDREJ=TEMPM                                                        CHO 2047
      IF (SWEP) 5340,5360,5340                                            CHO 2048
 5340 DO 5350 I=1,NZ                                                      CHO 2049
 5350 P(I)=TEMPR(I)                                                       CHO 2050
 5360 IF (NEDREJ.LE.0) GO TO 5370                                         CHO 2051
      IF (IEDREJ.EQ.1) GO TO 5400                                         CHO 2052
 5370 IF (TIME.LT.TEND) GO TO 5380                                        CHO 2053
C     END OF PROBLEM                                                      CHO 2054
      ITIMEL=0                                                            CHO 2055
 5380 IF (IFLPR.EQ.1) GO TO 5400                                          CHO 2056
      TEMP=TIME+DT*.5                                                     CHO 2057
C     CHECK EDIT TIME                                                     CHO 2058
      IF (TEMP.LT.TIMEP(JPRIN+1)) GO TO 5390                              CHO 2059
      JPRIN=JPRIN+1                                                       CHO 2060
      CALL EDIT                                                           CHO 2061
      TPN=TIMEP(JPRIN)+DTIMEP(JPRIN)                                      CHO 2062
      GO TO 5410                                                          CHO 2063
 5390 CONTINUE                                                            CHO 2064
      IF (TEMP.LT.TPN) GO TO 5410                                         CHO 2065
      TPN=TPN+DTIMEP(JPRIN)                                               CHO 2066
 5400 CALL EDIT                                                           CHO 2067
 5410 IF (MOVIE.LE.0) GO TO 5450                                          CHO 2068
C     GENERATE MOVIE TAPE                                                 CHO 2069
      TEMPA=TIME+.5*DT                                                    CHO 2070
      IF (TEMPA-TTCMOV) 5440,5430,5430                                    CHO 2071
 5420 WRITE (3) (ANAME(I),I=1,13)                                         CHO 2072
 5430 MOVFRM=MOVFRM+1                                                     CHO 2073
      TTOMOV=TIME+DTMOV(JMOV)                                             CHO 2074
      PRINT 5730, MOVFRM,ICYCLE,TIME                                      CHO 2075
      WRITE (3) NZ,NZP,ICYCLE,MOVFRM,TIME,X(NZP),V(NZP),(X(I),V(I),XL(I)CHO 2076
     1,VL(I),ISPALL(I),T(I),D(I),P(I),Q(I),E(I),ENTSV(I),SXD(I),SZD(I),DCHO 2077
     2RATIO(I),I=1,NZ)                                                    CHO 2078
 5440 IF (TIME.LT.TMOV(JMOV+1)) GO TO 5450                                CHO 2079
      JMOV=JMOV+1                                                         CHO 2080
      TTOMOV=TMOV(JMOV)+DTMOV(JMOV)                                       CHO 2081
      GO TO 5440                                                          CHO 2082
 5450 CONTINUE                                                            CHO 2083
      IF (IEDREJ.NE.1) GO TO 5470                                         CHO 2084
      DO 5460 KKK=1,NZ                                                    CHO 2085
 5460 SD(KKK)=0.                                                          CHO 2086
C     CHECK RADIATION FOR POSSIBLE TURN OFF                               CHO 2087
 5470 IF (NORAD.EQ.0) GO TO 2040                                          CHO 2088
      IF (TIME.LT.TRADOFF) GO TO 2040                                     CHO 2089
      IF (ICYCLE.NE.50*(ICYCLE/50)) GO TO 2040                            CHO 2090
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      IF (ICYCLE.LT.200) GO TO 2040
      IF (TIME.LT.1.05*TSOURM) GO TO 2040
      TEMPA=1.
      DO 5510 I=1,NZ
      IF (IGM-2) 5500,5480,5490
 5480 TEMPA=TWOPIE*X(I)
      GO TO 5500
 5490 TEMPA=FOURPIE*X(I)**2
 5500 IF (DT*(ABS(FLUX(I))+ABS(FLUX(I+1)))*TEMPA.GT.1.E-5*XM(I)*E(I)) GO
     1 TO 2040
      IF (RADK4*T(I)**4.GT.1.E-4*E(I)*D(I)) GO TO 2040
 5510 CONTINUE
C     APPEARS THAT RADIATION MAY BE TURNED OFF
      NORAD=-666
      DO 5520 I=1,NZP
 5520 FLUX(I)=FPATH(I)=0.
      FLINF=FLOUF=FLINFO=FLOUFO=FLINB=FLOUB=FLINBO=FLOUBO=0.
      KRD4=NCKR=0
      IF (NOHYD.NE.0) ITIMEL=0
      IMPEXP=-1
      IMPA=0
      PRINT 5740, ICYCLE,TIME
      GO TO 1780
C
 5530 FORMAT (13H0HYDRODYNAMIC,A9)
 5540 FORMAT (16H0ELASTIC-PLASTIC,A9)
 5550 FORMAT (7H0POROUS,A9)
 5560 FORMAT (22H0 ENERGY BALANCE ERROR,2I6,4E13.5)
 5570 FORMAT (23H0ENERGY BALANCE RECYCLE,I8,2E13.5,2I10,/,8E13.5,I8)
 5580 FORMAT (I5,10E12.4)
 5590 FORMAT (9H1 CHART D,75X,14HSEPTEMBER,1971,//,20H  EXECUTION BEGAN
     1AT,E10.3,8H SECONDS,8X,5HDATE ,A10,5X,5HTIME ,A10,//)
 5600 FORMAT (13A6)
 5610 FORMAT (1H1)
 5620 FORMAT (5X,13A6)
 5630 FORMAT (6I5,5E10.3)
 5640 FORMAT (8I10)
 5650 FORMAT (8H0ITIMEL=,I6,36X,3HNG=,I6/,7H NDUMP=,I6,37X,4HIIN=,I6/,6H
     1 IOUT=,I6,38X,7HIEOSTP=,I6,/,6H ITWO=,I6,38X,7HNEDREJ=,I6,/,8H FRA
     2CDT=,E15.7,27X,7HDTINCR=,E15.7,/,6H TEND=,E15.7)
 5660 FORMAT (28H RESTARTED THE WRONG PROBLEM)
 5670 FORMAT (19H EOF FOUND ON INPUT,I10,3H OF,I5,8H RESTART)
 5680 FORMAT (8H RESTART,I4,4H OF ,I4,14H HAS BEEN READ,I6)
 5690 FORMAT (16I5)
 5700 FORMAT (5H0IGM=,I4,41X,6HNORAD=,I4)
 5710 FORMAT (6H0NRZC=,I4,40X,7HNMTRLS=,I4,/,7H NPRIN=,I4,39X,7HNDTMAX=,
     1I4,/,9H NCTMINN=,I4,37X,7HNBPRES=,I4,/,8H NOSOUR=,I4,38X,4HIBS=,I4
     2,/,5H OBS=,I4,41X,7HNSPALL=,I5,/,9H NACTION=,I4,37X,7HNTHIST=,I5,/
     3,8H NRADCK=,I5,37X,6HMOVIE=,I5)
 5720 FORMAT (6H0    I,4X,7HTMOV(I),14X,8HDTMOV(I),//,(I6,E17.7,E16.7))
 5730 FORMAT (13H0 MOVIE FRAME,I8,13H WRITTEN     CYCLE=,I8,9H    TIME=,
     1E12.4)
 5740 FORMAT (31H1 RADIATION HAS BEEN TURNED OFF,3X,7HICYCLE=,I7,5X,5HTI
     1ME=,E12.5)
 5750 FORMAT (17H0THERE IS NO TYPE,I6,9H GEOMETRY)
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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,9H0ENSITY =,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)   CHD 2201
6140 FORMAT (///,16H  STARTING CYCLE,I7,7H  TIME=,E12.5,18H  RADIATION CHD 2202
    1OPTION,F3.0,14H  WILL BE USED)                                   CHD 2203
6150 FORMAT (90H1       X(I)     M(I)/M(I-1)  I        M(I)      PPPT(I)   CHD 2204
    1  CV(I)     NUMEOS  IEOS IZPTL IZPRL,/)                          CHD 2205
6160 FORMAT (17H0 END OF MATERIAL,I3,19H  START OF MATERIAL,I3,/)      CHD 2206
6170 FORMAT (E12.4,12X,I4,3E12.4,4I6)                                 CHD 2207
6180 FORMAT (2E12.4,I4,3E12.4,4I6)                                    CHD 2208
6190 FORMAT (6H1 TYPE,I3,16H INTERNAL SOURCE)                         CHD 2209
6200 FORMAT (I5,6E10.3)                                               CHD 2210
6210 FORMAT (26H INCORRECT INPUT IN SOURCE,3I6,/,6E17.8)              CHD 2211
6220 FORMAT (113H1    TSOUR1(I)      TSOUR2(I)      TSOUR3(I)     TSOUR4(ICHD 2212
    1)      SDOT2(I)       SDOT3(I) ZONE(I)  E ZONE(I)       SUM E)   CHD 2213
6230 FORMAT (6E14.6,I5,2E14.6)                                        CHD 2214
6240 FORMAT (16H ERROR IN SOURCE,I4,4E18.7)                           CHD 2215
6250 FORMAT (14H SOURCE REGION,I3,40H HAS UPPER AND LOWER BOUNDARIES RECHD 2216
    1VERSED)                                                          CHD 2217
6260 FORMAT (19H SOURCE INPUT ERROR,/,I5,5E15.7)                      CHD 2218
6270 FORMAT (13H SOURCE ERROR,2I10)                                   CHD 2219
6280 FORMAT (47H0 THERE IS AN OVERLAPPING SOURCE REGION IN ZONE,I5,27H CHD 2220
    1 SOME ENERGY HAS BEEN LOST,/)                                    CHD 2221
6290 FORMAT (27H0 SOURCE STRENGTH IN REGION,I3,17H,CONTAINING ZONES,I5,CHD 2222
    18H THROUGH,I5,3H IS,E15.7,5H ERGS)                               CHD 2223
6300 FORMAT (11H1 HE SOURCE,//,21H POINT OF INITIATION=,E15.7,14X,16HDECHD 2224
    1TONATION TIME=,E15.7,/,16H RIGHT BOUNDARY=,E15.7,19X,14HLEFT BOUNDCHD 2225
    2ARY=,E15.7,/,21H DETONATION VELOCITY=,E15.7,14X,24HCHEMICAL ENERGYCHD 2226
    3 RELEASE=,E15.7,/,29H ZONE DETONATION FRONT WIDTH=,E15.7,6X,19HLASCHD 2227
    4T REGION SWITCH=,E15.7,/,19H FIRST REGION ZONE=,I5,26X,17HLAST REGCHD 2228
    5ION ZONE=,I5)                                                    CHD 2229
6310 FORMAT (/,9H DENSITY=,E15.7,26X,12HTEMPERATURE=,E15.7,/,10H PRESSUCHD 2230
    1RE=,E15.7,25X,12HSOUND SPEED=,E15.7)                             CHD 2231
6320 FORMAT (//,37H0LARGE TIME STEP CUT ATTEMPTED CYCLE=,I7,8X,5HTIME=,CHD 2232
    1E12.5,/,4H0DT=,E12.5,9X,4HDTP=,E12.5,9X,5HDTPP=,E12.5,8X,7HDTTEMP=CHD 2233
    2,E12.5,/,6H0DTCS=,E12.5,7X,6HDTRAD=,E12.5,7X,6HDTMAX=,E12.5,7X,6HDCHD 2234
    3TMIN=,E12.5,/,19H0DTTEMP(CORRECTED)=,E12.5)                      CHD 2235
6330 FORMAT (10H0THERE ARE,I4,26H REGIONS OF INITIAL ACTION,(/,7H REGIOCHD 2236
    1N,I4,22H HAS LOWER BOUNDARY AT,E12.4,22H AND UPPER BOUNDARY AT,E12CHD 2237
    2.4))                                                             CHD 2238
6340 FORMAT (10H0INITIALLY,I5,17H ZONES ARE ACTIVE)                   CHD 2239
6350 FORMAT (51H0REZONE FOR VOID CAN ONLY BE USED IN PLANE GEOMETRY)   CHD 2240
6360 FORMAT (I5,E15.7)                                                CHD 2241
6370 FORMAT (34H0A VOID HAS BEEN ZONED AT BOUNDARY,I4,9H  SPACE =,E15.7CHD 2242
    1,3H CM)                                                          CHD 2243
6380 FORMAT (16H0 RESTART NUMBER,I5,21H IS WRITTEN     TIME =,E14.7,11H CHD 2244
    1  ICYCLE =,I6)                                                   CHD 2245
6390 FORMAT (47H0 THE TIME STEP IS BECOMING VERY SMALL.  CYCLE=,I7,6H TCHD 2246
    1IME=,E17.9,/,5H  DT=,E12.5,7H KCUTM=,I4,7H DTMIN=,E12.5,7H DTMAX=,CHD 2247
    2E12.5,6H DTCS=,E12.5,8H DTTEMP=,E12.5)                           CHD 2248
6400 FORMAT (31H TIME STEP CUT FOR DENSITY, DT=,E13.6,7H CYCLE=,I6,6H TCHD 2249
    1IME=,E13.6,13H ZONE NUMBER=,I5,9H NEW DEN=,E12.5,9H OLD DEN=,E12.5CHD 2250
    2)                                                                CHD 2251
6410 FORMAT (30H0CENTRAL VOID CLOSED ON CYCLE=,I6,7H  TIME=,E13.5)     CHD 2252
6420 FORMAT (24H0 RIGHT BOUNDARY OF ZONE,I5,18H  FRACTURE OF ZONE,I5,/,CHD 2253
    110X,2HD=,E15.7,7X,3HD0=,E15.7,/,4H  X=,E15.7,6X,3HX0=,E15.7,7X,3HXCHD 2254
    2L=,E15.7,7X,4HXL0=,E15.7,/,4H  V=,E15.7,6X,3HV0=,E15.7,7X,3HVL=,E1CHD 2255
    35.7,7X,4HVL0=,E15.7)                                             CHD 2256
6430 FORMAT (23H0 LEFT BOUNDARY OF ZONE,I5,18H  FRACTURE OF ZONE,I5,/,4CHD 2257
    1X,2HD=,E15.7,15X,3HD0=,E15.7,/,4H  X=,E15.7,6X,3HX0=,E15.7,7X,3HXLCHD 2258
    2=,E15.7,7X,4HXL0=,E15.7,/,4H  V=,E15.7,6X,3HV0=,E15.7,7X,3HVL=,E15CHD 2259
    3.7,7X,4HVL0=,E15.7)                                              CHD 2260
6440 FORMAT (19H0REJOIN AT BOUNDARY,I6,8H  CYCLE=,I6,7H  TIME=,E14.7)  CHD 2261
6450 FORMAT (25H0TIME STEP CUT FOR REJOIN)                            CHD 2262
6460 FORMAT (28H1 ALL ZONES ACTIVATED  TIME=,E14.7,8H  CYCLE=,I6)      CHD 2263
     END                                                              CHD 2264
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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,END,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,PBORYO,PBORYI,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) ENO=TEMPC
      WRITE (1,440) TEMPD,PBDRYI,WORKB,PBDRYO,WORKF
      WRITE (1,450) TEMPC,TEMPA,TEMPB,ENO,ESOURS
      TEMPA=WORKF+WORKB+ENO+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)                                                CHD 2532
      TEMPG=TEMPC*TEMPF                                                 CHD 2533
      TEMPH=1.-TEMPF                                                    CHD 2534
      TEMPI=TEMPA*(1.-TEMPB)                                            CHD 2535
      TEMPB=TEMPA*TEMPB*TEMPD                                           CHD 2536
      JJJ=JJJ+1                                                         CHD 2537
C     Y=TEMPA AND POISSON RATIO=TEMPD                                   CHD 2538
  110 IF (KACT(I)) 290,120,290                                          CHD 2539
  120 IF (E(I)-TEMPC) 130,280,280                                       CHD 2540
  130 IF (KPHASE(I)-1) 280,140,280                                      CHD 2541
  140 TEMPA=TEMPI+TEMPB*D(I)                                            CHD 2542
      IF (E(I)-TEMPG) 150,150,160                                       CHD 2543
  150 TEMPD=TEMPE                                                       CHD 2544
      GO TO 170                                                         CHD 2545
  160 TEMPD=E(I)/TEMPC                                                  CHD 2546
      TEMPA=TEMPA*(1.-TEMPD)/TEMPH                                      CHD 2547
      TEMPD=(TEMPE*(1.-TEMPD)+0.5*(TEMPD-TEMPF))/TEMPH                  CHD 2548
C     G=TEMPN                                                           CHD 2549
  170 TEMPN=0.25*(DO(I)+D(I))*CSOD(I)**2*(1.-2.*TEMPD)/(1.-TEMPD)       CHD 2550
C     COMPUTE DEVIATORS                                                 CHD 2551
      SXDO=SXD(I)                                                       CHD 2552
      TEMPJ=(D(I)-DO(I))/(1.5*DT*(D(I)+DO(I)))                          CHD 2553
C     TEMPK IS X STRETCH DEVIATOR                                       CHD 2554
C     TEMPJ IS Z STRETCH DEVIATOR                                       CHD 2555
      IF (ISPALL(I)) 190,180,190                                        CHD 2556
  180 IS=I+1                                                            CHD 2557
      TEMPK=2.*(V(I)-V(IS))/(X(I)+XO(I)-X(IS)-XO(IS))+TEMPJ             CHD 2558
      GO TO 200                                                         CHD 2559
  190 TEMPK=2.*(V(I)-VL(I))/(X(I)+XO(I)-XL(I)-XLO(I))+TEMPJ             CHD 2560
  200 SXD(I)=SXDO+2.*DT*TEMPN*TEMPK                                     CHD 2561
      TEMPL=.6666666666*TEMPA**2                                        CHD 2562
      IF (IGM-2) 210,240,210                                            CHD 2563
C     PLANE AND SPHERICAL                                               CHD 2564
  210 TEMPD=1.5*SXD(I)**2                                               CHD 2565
      IF (TEMPD-TEMPL) 230,230,220                                      CHD 2566
  220 SXD(I)=TEMPA*(SXD(I)/(1.5*ABS(SXD(I))))                           CHD 2567
C     TEMPD IS DEVIATOR STRESS WORK                                     CHD 2568
  230 TEMPD=1.5*DT*TEMPK*(SXD(I)-SXDO)/(D(I)+DO(I))                     CHD 2569
      SZD(I)=-0.5*SXD(I)                                                CHD 2570
      GO TO 270                                                         CHD 2571
C     CYLINDRICAL                                                       CHD 2572
  240 SZDO=SZD(I)                                                       CHD 2573
      SZD(I)=SZDO+2.*DT*TEMPN*TEMPJ                                     CHD 2574
      TEMPD=2.*(SXD(I)*(SXD(I)+SZD(I))+SZD(I)**2)                       CHD 2575
      IF (TEMPD-TEMPL) 260,260,250                                      CHD 2576
  250 TEMPD=SQRT(TEMPL/TEMPD)                                           CHD 2577
      SXD(I)=TEMPD*SXD(I)                                               CHD 2578
      SZD(I)=TEMPD*SZD(I)                                               CHD 2579
  260 TEMPD=DT*((SXD(I)+SXDO)*(2.*TEMPK+TEMPJ)+(SZD(I)-SZDO)*(2.*TEMPJ+TCHD 2580
     1EMPK))/(D(I)+DO(I))                                               CHD 2581
  270 E(I)=E(I)+TEMPD                                                   CHD 2582
      GO TO 290                                                         CHD 2583
C     CAME HERE BECAUSE MATERIAL HAS NO STRENGTH                        CHD 2584
  280 SXD(I)=SZD(I)=0.                                                  CHD 2585
  290 CONTINUE                                                          CHD 2586

      RETURN                                                            CHD 2587
      END                                                               CHD 2588
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      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,END,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 /ANDPOR/ 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
      ABETO=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)*ABETO                                            CHD 2643
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      GO TO 70                                                          CHD 2644
   60 PALPL=Z4-Z5*ABETL                                                 CHD 2645
   70 IF (KACT(I)) 660,80,660                                           CHD 2646
   80 IF (DRATIO(I)-1.) 660,660,90                                      CHD 2647
   90 DISTR=DRATIO(I)                                                   CHD 2648
      DRATIO(I)=1.                                                      CHD 2649
      DV2=.5*(D(I)-DO(I))/(D(I)*DO(I))                                  CHD 2650
      IF (E(I).LT.Z8) GO TO 310                                         CHD 2651
C     ABOVE MELT                                                        CHD 2652
  100 IS1=0                                                             CHD 2653
      GEM=GEMEU                                                         CHD 2654
      GO TO 120                                                         CHD 2655
C     ABOVE OR BELOW MELT                                               CHD 2656
  110 IS1=-1                                                            CHD 2657
  120 TEMPA=D(I)                                                        CHD 2658
      TLOW=Z7                                                           CHD 2659
      IF (TEMPA.LT.Z6) GO TO 140                                        CHD 2660
  130 TLOW=.001                                                         CHD 2661
  140 IS=0                                                              CHD 2662
      TEMPJ=T(I)                                                        CHD 2663
      IF (IS1) 170,150,160                                              CHD 2664
  150 IF (TEMPJ.LT.GEMTU) TEMPJ=GEMTU                                   CHD 2665
      GO TO 170                                                         CHD 2666
  160 IF (TEMPJ.GT.GEMTL) TEMPJ=GEMTL                                   CHD 2667
  170 CALL EOS                                                          CHD 2668
C     TEMPN IS THE CORRECTED ENERGY                                     CHD 2669
      TEMPN=E(I)-DV2*(P(I)-TEMPD)                                       CHD 2670
      IF (IS1) 200,180,190                                              CHD 2671
  180 IF (TEMPN-GEM) 210,200,200                                        CHD 2672
  190 IF (TEMPN-GEM) 200,200,210                                        CHD 2673
  200 TEMPAB=(TEMPN-TEMPC)/(TEMPG-DV2*TEMPH)                            CHD 2674
      GO TO 220                                                         CHD 2675
  210 TEMPAB=(GEM-TEMPC)/TEMPG                                          CHD 2676
  220 TEMPN=ABS(TEMPAB)                                                 CHD 2677
      TEMPK=1.E-6                                                       CHD 2678
      IF (IS.GT.190) TEMPK=1.E-3                                        CHD 2679
      IF (TEMPN.LE.TEMPK*TEMPJ) GO TO 280                               CHD 2680
      IF (TEMPN.GT..05*TEMPJ) TEMPAB=.05*TEMPJ*TEMPAB/TEMPN             CHD 2681
      TEMPK=TEMPJ+TEMPAB                                                CHD 2682
      IF (TEMPK.LE.TLOW) TEMPK=.5*(TLOW+TEMPJ)                          CHD 2683
      IF (IS1-1) 240,230,240                                            CHD 2684
  230 IF (TEMPK.GE.Z7) TEMPK=.5*(Z7+TEMPJ)                              CHD 2685
  240 IS=IS+1                                                           CHD 2686
      IF (IS-200) 270,250,260                                           CHD 2687
  250 PRINT 700, IS1,ICYCLE,T(I),E(I),P(I),GEM,DV2,TEMPA,DISTR,TLOW,IS1,CHD 2688
     1ICYCLE,D(I),TEMPE                                                 CHD 2689
  260 PRINT 700, I,IS,TEMPJ,TEMPK,TEMPAB,TEMPC,TEMPD,TEMPG,TEMPH        CHD 2690
      IF (IS.GE.400) STOP 12                                            CHD 2691
  270 TEMPJ=TEMPK                                                       CHD 2692
      GO TO 170                                                         CHD 2693
  280 P(I)=TEMPD                                                        CHD 2694
      IF (IS1) 290,290,340                                              CHD 2695
  290 T(I)=TEMPJ                                                        CHD 2696
  300 E(I)=TEMPC                                                        CHD 2697
      PPPT(I)=TEMPH                                                     CHD 2698
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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*(TLOW*(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
```

```
      GO TO 100
C     CALCULATE NEW SOLID DENSITY AND TEMPERATURE
  450 TEMPJ=T(I)
      TEMPA=D(I)*DISTR
      IS=0
      PNC=PHAT
      DIS=DISTR
  460 CRUSHP=DIS-1.
      IF (Z5.LT.0.) GO TO 480
      IF (DIS.LT.ALPL) GO TO 470
      CRUSH=(Z4-Z5)*SQRT(CRUSHP/DISN1)
      CRUSHP=CRUSH/(2.*CRUSHP)
      CRUSH=Z5+CRUSH
      GO TO 500
  470 CRUSH=(PALPL*CRUSHP+Z5*(ALPL-DIS))/ALPN
      CRUSHP=(PALPL-Z5)/ALPN
      GO TO 500
  480 IF (DIS.LT.ALPL) GO TO 490
      CRUSH=Z4+Z5*ALOG(CRUSHP/DISN1)
      CRUSHP=Z5/CRUSHP
      GO TO 500
  490 CRUSH=PALPL-Z5*(ALPL-DIS)/ALPN
      CRUSHP=Z5/ALPN
  500 CRUSH=CRUSH*FKOFE
      IF (CRUSH.GT.1.E6) GO TO 510
      CRUSH=1.E6
      CRUSHP=0.
      GO TO 520
  510 CRUSHP=CRUSHP*FKOFE
  520 E(I)=TEMPK-DV2*(PNC-CRUSH)
      IF (E(I).GT.GEM) GO TO 440
      IF (IEOS(I)) 530,530,540
C     ANALYTIC
  530 CALL EOS
      PHAT=C82
      EHAT=(TEMPD-TEMPJ*TEMPH)/TEMPA**2
      GO TO 550
C     TABLE
  540 TEMPM=TEMPA
      TEMPA=1.0001*TEMPA
      CALL EOS
      PHAT=TEMPD
      EHAT=TEMPC
      TEMPA=TEMPM
      CALL EOS
      PHAT=(PHAT-TEMPD)/(.0001*TEMPA)
      EHAT=(EHAT-TEMPC)/(.0001*TEMPA)
  550 TEMPI=CRUSHP/D(I)
      TEMPAB=PHAT-TEMPI
      TEMPI=EHAT-DV2*TEMPI
      TLOW=TEMPAB*TEMPG-TEMPH*TEMPI
      IF (TLOW.EQ.0.) GO TO 600
      TEMPN=((TEMPC-E(I))*TEMPH-(TEMPD-CRUSH)*TEMPG)/TLOW
      TEMPM=((TEMPD-CRUSH)*TEMPI-(TEMPC-E(I))*TEMPAB)/TLOW
      TEMPAB=ABS(TEMPN)
```

```
      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.Z5) 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) 660,660,650
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
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      SUBROUTINE EDGE                                                   CHD 2861
C     CALCULATES BOUNDARY PRESSURES AND TEMPERATURES                    CHD 2862
      COMMON /A/ JBND(21),ITRIED(400),IZPTL(400),IZPRL(400),KPHASE(400),CHD 2863
     1KACT(401),ISPALL(400),NSPALL,OBS,IBS,ICYCLE,IDTMAX,IDTMIN,JPRIN,NCCHD 2864
     2OUNT,NMTRLS,NZN,NZ,NZP,NDUMP,NBPRES,NOSOUR,NACTION,NORAD,IGM,NRADCCHD 2865
     3K,MOVIE,IMPEXP,IMPA,KRD4,NOHYD                                    CHD 2866
      COMMON D(400),DO(400),T(400),TO(400),P(400),XM(400),XM2(401),X(401CHD 2867
     1),XO(401),V(401),VO(401),XL(400),XLO(400),VL(400),VLO(401),CSOO(40CHD 2868
     20),Q(400),SXD(400),SZD(400),FPATH(400),FLUX(401),E(400),PPPT(400),CHD 2869
     3PEPTIN(400),PSPALL(400),SD(400),TEMP(400),TSAVE(400),PSAVE(400),ESCHD 2870
     4AVE(400),TEMPR(401),TMSPALL(20),DT,DTMAX,DTMIN,DTTEMP,DTRAD,TIME,TCHD 2871
     5PN,TEND,DTRACT,BL,BQ,DTIMEP(25),DLTTMX(25),DTMINN(25),TIMEP(25),TDCHD 2872
     6TMINN(25),TIMES(25),WORKF,WORKB,ENO,ESOURS,TBPRES(25),PINNER(25),PCHD 2873
     7OUTER(25),XMATUP(21),DTCS,DTP,TITH(25),TEINTH(25),TEOUTH(25),FLINFCHD 2874
     8,FLINFO,FLINB,FLINBO,FLOUF,FLOUFO,FLOUB,FLOUBO,RADEB,RADEF,SCRADF,CHD 2875
     9SCRADB,SPLA(20),SPLB(20),SPLC(20),SPLD(20),ENTSV(400),TMOV(10),DTMCHD 2876
     $OV(10),TRADOFF,SWEP,YIELD(20,8),DRATIO(400),SWPOR                 CHD 2877
      COMMON /C/ TEMPA,TEMPB,TEMPC,TEMPD,TEMPE,TEMPF,TEMPG,TEMPH,TEMPI,TCHD 2878
     1EMPJ,TEMPK,TEMPL,TEMPM,TEMPN,TEMPAB,TBPU,PBDRYO,PBDRYI,TRADMIN,RADCHD 2879
     2K1,RADK2,RADK3,RADK4,RADK5,RADK6,TEBOUT,TEBIN,TTHIU               CHD 2880
      COMMON /D/ IS,IS1,ICALL,ITLOW,JTLOW,INES                          CHD 2881
   10 IF (TEMPJ-TBPU) 30,20,20                                          CHD 2882
   20 ITLOW=ITLOW+1                                                     CHD 2883
      TBPL=TBPRES(ITLOW)                                                CHD 2884
      TBPU=TBPRES(ITLOW+1)                                              CHD 2885
      IF (TBPU.EQ.TBPL) GO TO 20                                        CHD 2886
      DTTT=1./(TBPU-TBPL)                                               CHD 2887
      TBIN1=PINNER(ITLOW)                                               CHD 2888
      TBIN2=PINNER(ITLOW+1)-TBIN1                                       CHD 2889
      TBOUT1=POUTER(ITLOW)                                              CHD 2890
      TBOUT2=POUTER(ITLOW+1)-TBOUT1                                     CHD 2891
      GO TO 10                                                          CHD 2892
   30 PBDRYO=(TEMPJ-TBPL)*DTTT                                          CHD 2893
      PBDRYI=TBIN1+TBIN2*PBDRYO                                         CHD 2894
      PBDRYO=TBOUT1+TBOUT2*PBDRYO                                       CHD 2895
      RETURN                                                            CHD 2896
      ENTRY TEDGE                                                       CHD 2897
   40 IF (TEMPJ-TTHIU) 60,50,50                                         CHD 2898
   50 JTLOW=JTLOW+1                                                     CHD 2899
      TTHIL=TITH(JTLOW)                                                 CHD 2900
      TTHIU=TITH(JTLOW+1)                                               CHD 2901
      IF (TTHIU.EQ.TTHIL) GO TO 50                                      CHD 2902
      QTTT=1./(TTHIU-TTHIL)                                             CHD 2903
      QBIN1=TEINTH(JTLOW)                                               CHD 2904
      QBIN2=TEINTH(JTLOW+1)-QBIN1                                       CHD 2905
      QBOUT1=TEOUTH(JTLOW)                                              CHD 2906
      QBOUT2=TEOUTH(JTLOW+1)-QBOUT1                                     CHD 2907
      GO TO 40                                                          CHD 2908
   60 TEBOUT=(TEMPJ-TTHIL)*QTTT                                         CHD 2909
      TEBIN=QBIN1+QBIN2*TEBOUT                                          CHD 2910
      TEBOUT=QBOUT1+QBOUT2*TEBOUT                                       CHD 2911
      RETURN                                                            CHD 2912
      END                                                               CHD 2913
```

```
      SUBROUTINE SOURCE
C     CALCULATES INTERNAL ENERGY SOURCE STRENGTHS
      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,KRO4,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),CRATIO(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
```

```
      SUBROUTINE FRACT
C     SPALL CALCULATION BASED ON EITHER THE
C     MAXIMUM TENSILE STRENGTH
C     STRESS GRADIENT METHOD OF THURSTON AND MUDD
C     OR
C     THE CUMULATIVE DAMAGE METHOD OF TULER AND BUTCHER
C
      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
C     ENTER WITH STRESS IN P ARRAY
      IF (ICYCLE.EQ.1) GO TO 100
   10 JJJ=1
      DO 90 I=1,NZN
      TEMPI=P(I)
      IP1=I+1
      P(I)=.5*(TEMPI+P(IP1))
      IF (I.LT.JBND(JJJ)) GO TO 20
      JJ=JJJ
      JJJ=JJJ+1
      TEMPA=SPLA(JJ)
      TEMPB=SPLB(JJ)
      TEMPC=SPLC(JJ)
      TEMPD=SPLD(JJ)
      TEMPE=TMSPALL(JJ)
      TEMPF=1./(TEMPE-.025678)
      TEMPAB=YIELD(JJ,7)
   20 IF (P(I).GT.-1.E6) GO TO 90
      IF (T(I).GT.TEMPAB) GO TO 90
      IF (ISPALL(I).EQ.1) GO TO 90
      IF (TEMPC.LT.0.) GO TO 70
C     STRESS GRADIENT
      IF (T(I).GE.TEMPE) GO TO 50
      IF (TEMPA.GT.0.) GO TO 30
      TEMPG=PSPALL(I)
      GO TO 40
   30 TEMPK=2.*ABS(TEMPI-P(IP1))/(XM(I)/D(I)+XM(IP1)/D(IP1))
      IF (IGM.GT.1) TEMPK=3.1415926536*TEMPK*(2.*X(IP1))**(IGM-1)
      TEMPG=TEMPD+TEMPA*TEMPK**TEMPB
      IF (TEMPG.GT.PSPALL(I)) TEMPG=PSPALL(I)
```

```
   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).GE.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.JBNC(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
```

```
      SUBROUTINE EOS
C     EQUATION OF STATE ROUTINE WITH ECS
      COMMON /A/ JBNO(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,NORAO,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),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 /ANDPOR/ C82
      DATA ATHIRD,ROWAO,LTIES,LASTES/.333333333333,0.,0,0/
      DATA MAXNOT,MAXNOD,MAXTPH,MAXSIZE/37,35,29,1295/
      DATA NNNIZE,NNNITB,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     CSOO(I)=SOUND SPEED
C
```

```
   10 IES=IEOS(I)
      IF (DRATIO(I).LE.1.) GO TO 20
      TEMPAS=TEMPA
      TEMPA=DRATIO(I)*TEMPA
   20 CONTINUE
      IF (IES.LT.0) GO TO 900
      IES2=IES+1
      IF (NISEOS) 30,30,40
   30 ITLO=ITL(IES)
      ITHI=ITL(IES2)-1
      IRLO=IRL(IES)
      IRHI=IRL(IES2)-1
      KTPIES=KTP(IES)
      KTPIET=KTP(IES2)
      NRSIES=NROS(IES)
      GO TO 50
C     ECS PATH
   40 ITLO=IRLO=KTPIES=NRSIES=1
      ITHI=ITL(IES2)-ITL(IES)
      IRHI=IRL(IES2)-IRL(IES)
      KTPIET=KTP(IES2)-KTP(IES)+1
      IF (IES.EQ.LASTES) GO TO 50
      IA=NECSA*(IES-1)+NECSB
      CALL READEC (TTBL,IA,NECSA)
      LASTES=IES
C     SEARCH T MESH
   50 ITOFF=0
      IT=IZPTL(I)
      IF (TTBL(IT)-TEMPJ) 90,110,60
   60 IT=IT-1
      IF (IT.GE.ITLO) GO TO 80
      ITOFF=-1
      IF (TEMPJ.GT.0.) GO TO 70
      IBACK=5
      PRINT 1690, I,ICYCLE,TEMPJ,TEMPA,IBACK
      STOP
   70 IT=IT+1
      XT=XTTBL(ITLO)
      TPOINT=TTBL(ITLO)
      GO TO 120
   80 IF (TTBL(IT)-TEMPJ) 110,110,60
   90 IT=IT+1
      IF (IT.LE.ITHI) GO TO 100
      IT=IT-2
      ITOFF=1
      XT=XTTBL(ITHI)
      TPOINT=TTBL(ITHI)
      GO TO 120
  100 IF (TTBL(IT).LE.TEMPJ) GO TO 90
      IT=IT-1
  110 XT=ALOG(TEMPJ)
      TPOINT=TEMPJ
  120 XT1=XTTBL(IT)
      XT2=XTTBL(IT+1)
C     DETERMINE  NUMBER OF PHASES
```

```
      IF (TEMPA.GE.RTRIP(IES)) GO TO 210
      IF (TEMPJ.GT..999*TCRIT(IES)) GO TO 210
      IF (TEMPJ.GT.TTRIP(IES)) GO TO 130
      IF (TEMPA.GT.RSMIN(IES)) GO TO 210
  130 KT=IT-ITLO+KTPIES
      IF (KT.GE.KTPIET) GO TO 200
      IF (ITOFF.GE.0) GO TO 140
      RHLIQ=RHOOO(IES)+BETA9(IES)*TEMPJ
      IF (TEMPA.GE.RHLIQ) GO TO 210
      RHVAP=BETA11(IES)*TEMPJ
      IF (TEMPA.LE.RHVAP) GO TO 210
      RHLIQP=BETA9(IES)
      RHVAPP=BETA11(IES)
      GO TO 230
  140 C85=XTTBL(IT)
      C86=XTTBL(IT+1)
      C82=.5*(C85+C86)
      IF (XT.GT.C82) GO TO 170
      C81=.75*C85+.25*C86
      IF (XT.GT.C81) GO TO 160
      C82=C81
      C81=C85
      C86=BETA5(KT)
      C84=BETA1(KT)
      IF (IT.EQ.ITLO) GO TO 150
      C85=BETA8(KT-1)
      C83=BETA4(KT-1)
      GO TO 190
  150 C83=ALOG(TTBL(ITLO)*BETA9(IES)+RHOOO(IES))
      C85=ALOG(TTBL(ITLO)*BETA11(IES))
      GO TO 190
  160 C83=BETA1(KT)
      C84=BETA2(KT)
      C85=BETA5(KT)
      C86=BETA6(KT)
      GO TO 190
  170 C85=.75*C86+.25*C85
      IF (XT.GT.C85) GO TO 180
      C81=C82
      C82=C85
      C83=BETA2(KT)
      C84=BETA3(KT)
      C85=BETA6(KT)
      C86=BETA7(KT)
      GO TO 190
  180 C81=C85
      C82=C86
      C83=BETA3(KT)
      C84=BETA4(KT)
      C85=BETA7(KT)
      C86=BETA8(KT)
  190 C84=(C84-C83)/(C82-C81)
      RHLIQ=EXP(C83+C84*(XT-C81))
      IF (TEMPA.GE.RHLIQ) GO TO 210
      C86=(C86-C85)/(C82-C81)
```

```
      RHVAP=EXP(C85+C86*(XT-C81))
      IF (TEMPA.LE.RHVAP) GO TO 210
      RHLIQP=RHLIQ*C84/TEMPJ
      RHVAPP=RHVAP*C86/TEMPJ
      GO TO 230
  200 C81=(TCRIT(IES)-TEMPJ)
      C82=C81**ATHIRD
      RHLIQ=RCRIT(IES)+BETA10(IES)*C82
      IF (TEMPA.GE.RHLIQ) GO TO 210
      RHVAP=RCRIT(IES)-BETA12(IES)*C82
      IF (TEMPA.LE.RHVAP) GO TO 210
      C81=C82/(3.*C81)
      RHLIQP=-BETA10(IES)*C81
      RHVAPP=BETA12(IES)*C81
      GO TO 230
C
C     ONE-PHASE REGION
  210 KPHASE(I)=1
      IR=IZPRL(I)
      ROWA=TEMPA
      IBACK=0
      GO TO 370
  220 TEMPC=EEVAL
      TEMPD=PPVAL
      TEMPG=CVVAL
      TEMPH=DPVAL
      ENTSV(I)=SSVAL
      CSOD(I)=CSDVAL
      IZPTL(I)=IT
      IZPRL(I)=IR
      GO TO 930
C
C     TWO-PHASE REGION
  230 KPHASE(I)=2
C     LIQUID SIDE OF REGION
      IR=IZPRL(I)
      ROWA=RHLIQ
      IBACK=1
      GO TO 370
  240 EELIQ=EEVAL
      PPLIQ=PPVAL
      CVLIQ=CVVAL
      DPLIQ=DPVAL
      ROSLIQ=ROSLAN
      SSLIQ=SSVAL
      IZPRL(I)=IR
C     VAPOR SIDE OF REGION
      ROWA=RHVAP
      IF (RHVAP.GE.RTBL(IRLO)) GO TO 250
      IF (ITOFF) 250,330,250
  250 IR=IRLO
      IBACK=-1
      GO TO 370
C     CALCULATE MIXED FUNCTIONS
  260 C81=RHLIQ-RHVAP
```

```
      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 TEMPC=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                                                        CHD 3352
      GO TO 430                                                      CHD 3353
  400 IF (RTBL(IR)-ROWA) 430,430,380                                 CHD 3354
  410 IR=IR+1                                                        CHD 3355
      IF (IR.LE.IRHI) GO TO 420                                      CHD 3356
      IROFF=1                                                        CHD 3357
      IR=IR-2                                                        CHD 3358
      GO TO 430                                                      CHD 3359
  420 IF (RTBL(IR).LE.ROWA) GO TO 410                                CHD 3360
      IR=IR-1                                                        CHD 3361
  430 CONTINUE                                                       CHD 3362
C     DETERMINE IF IN MESH        IF NOT  WHERE                      CHD 3363
      YR1=YRTBL(IR)                                                  CHD 3364
      YR2=YRTBL(IR+1)                                                CHD 3365
      NPT11=NRSIES+IT-ITLO+(IR-IRLO)*NUMTEM(IES)                     CHD 3366
      NPT21=NPT11+1                                                  CHD 3367
      NPT12=NPT11+NUMTEM(IES)                                        CHD 3368
      NPT22=NPT12+1                                                  CHD 3369
      IF (ITOFF) 510,440,550                                         CHD 3370
  440 IF (IROFF) 450,470,490                                         CHD 3371
  450 NOFRG=1                                                        CHD 3372
  460 YR=YR1                                                         CHD 3373
      GO TO 590                                                      CHD 3374
  470 NOFRG=0                                                        CHD 3375
  480 YR=ALOG(ROWA)                                                  CHD 3376
      GO TO 590                                                      CHD 3377
  490 NOFRG=3                                                        CHD 3378
  500 YR=YR2                                                         CHD 3379
      GO TO 590                                                      CHD 3380
  510 IF (IROFF) 520,530,540                                         CHD 3381
  520 NOFRG=5                                                        CHD 3382
      GO TO 460                                                      CHD 3383
  530 NOFRG=4                                                        CHD 3384
      GO TO 480                                                      CHD 3385
  540 NOFRG=8                                                        CHD 3386
      GO TO 500                                                      CHD 3387
  550 IF (IROFF) 560,570,580                                         CHD 3388
  560 NOFRG=6                                                        CHD 3389
      GO TO 460                                                      CHD 3390
  570 NOFRG=2                                                        CHD 3391
      GO TO 480                                                      CHD 3392
  580 NOFRG=7                                                        CHD 3393
      GO TO 500                                                      CHD 3394
C     INTERPOLATE IN MESH FOR TEMPERATURE DEPENDENT PARTS            CHD 3395
C     OF THERMODYNAMIC FUNCTIONS                                     CHD 3396
  590 DELX=XT2-XT1                                                   CHD 3397
      DXX1=XT-XT1                                                    CHD 3398
      DXX2=XT2-XT                                                    CHD 3399
      DELY=YR2-YR1                                                   CHD 3400
      DYY1=YR-YR1                                                    CHD 3401
      DYY2=YR2-YR                                                    CHD 3402
      DXDY=DELX*DELY                                                 CHD 3403
      DXY11=DXX1*DYY1                                                CHD 3404
      DXY12=DXX1*DYY2                                                CHD 3405
      DXY21=DXX2*DYY1                                                CHD 3406
```

```
      DXY22=DXX2*DYY2
C     ENERGY ANC CV
      EEVAL=EXP((DXY11*ETBL(NPT22)+DXY21*ETBL(NPT12)+DXY12*ETBL(NPT21)+D
     1XY22*ETBL(NPT11))/DXDY)
      CVVAL=(((ETBL(NPT21)-ETBL(NPT11))*DYY2+(ETBL(NPT22)-ETBL(NPT12))*D
     1YY1)/DXDY)*EEVAL/TPOINT
C     PRESSURE AND DERIVATIVES
      PPVAL=EXP((DXY11*PTBL(NPT22)+DXY21*PTBL(NPT12)+DXY12*PTBL(NPT21)+D
     1XY22*PTBL(NPT11))/DXDY)
      DPVAL=(((PTBL(NPT21)-PTBL(NPT11))*DYY2+(PTBL(NPT22)-PTBL(NPT12))*D
     1YY1)/DXDY)*PPVAL/TPOINT
      DPRAL=(((PTBL(NPT12)-PTBL(NPT11))*DXX2+(PTBL(NPT22)-PTBL(NPT21))*D
     1XX1)/DXDY)*PPVAL/ROHA
C     ENTROPY
      SSVAL=(DXY11*STBL(NPT22)+DXY21*STBL(NPT12)+DXY12*STBL(NPT21)+DXY22
     1*STBL(NPT11))/DXDY
      GO TO LEMOVB, (610,600)
  600 EEVAL=EEVAL-AMISS(12*IES-8)
  610 IF (IBACK) 630,620,630
C     SOUNC SPEED
  620 CSDVAL=EXP((DXY11*SOUNSP(NPT22)+DXY21*SOUNSP(NPT12)+DXY12*SOUNSP(N
     1PT21)+DXY22*SOUNSP(NPT11))/DXDY)
C     ROSSELAND MEAN
  630 IF (NORAD.EQ.0) GO TO 640
      ROSLAN=EXP((CXY11*ROSTAB(NPT22)+DXY21*ROSTAB(NPT12)+DXY12*ROSTAB(N
     1PT21)+DXY22*ROSTAB(NPT11))/DXDY)
  640 CONTINUE
C     ZERO-TEMPERATURE PART OF THERMODYNAMICS
      IF (IGAS(IES)) 650,660,650
C     GAS PATH
  650 COLDE=COLDP=0.
      GO TO 73C
C     SOLID PATH
  660 ICOME=0
      IF (IES.NE.LTIES) GO TO 670
      IF (ROWA.EQ.ROWAO) GO TO 720
  670 KA=22*(IES-1)
      ETA=ROWA/RHOOO(IES)
      IF (ETA.GT.1.E-20) GO TO 680
C     VERY LOW DENSITY
      COLDP=0.
      COLDE=AAAT(KA+17)*AAAT(KA+15)-AAAT(KA+16)*AAAT(KA+14)
      GO TO 710
  680 ETA13=ETA**ATHIRD
      ETA23=ETA/ETA13
      ETA2=AAAT(KA+13)
      IF (ETA.LE.ETA2) GO TO 690
      C81=AAAT(KA+2)/ETA13
      C82=EXP(-C81)
      C83=AAAT(KA+1)*ETA23
      C84=AAAT(KA+4)*ETA13
      C85=AAAT(KA+5)*ETA23
      COLDF=ETA*C83*C82-(AAAT(KA+3)+C84+C85+AAAT(KA+19)*ETA)
      CALL EPINT3 (C81,C82,C86)
      COLDE=AAAT(KA+6)+(3.*C83*C86+(AAAT(KA+3)+1.5*C84+3.*C85)/ETA-AAAT(
```

```
     1KA+19)*ALOG(ETA))/RHOOO(IES)                                      CHD 3462
      GO TO 710                                                         CHD 3463
  690 ETA1=AAAT(KA+12)                                                  CHD 3464
      C81=EXP(-AAAT(KA+8)/ETA13)                                        CHD 3465
      C82=EXP(-AAAT(KA+10)/ETA13)                                       CHD 3466
      COLDP=ETA23*(AAAT(KA+7)*C81-AAAT(KA+9)*C82)                       CHD 3467
      COLDE=AAAT(KA+16)*(C81-AAAT(KA+14))-AAAT(KA+17)*(C82-AAAT(KA+15)) CHD 3468
      IF (ETA.GE.ETA1) GO TO 710                                        CHD 3469
      IF (AAAT(KA+11)) 700,710,700                                      CHD 3470
  700 C81=ETA/ETA1                                                      CHD 3471
      C82=(1.-C81)                                                      CHD 3472
      C83=C82**3                                                        CHD 3473
      COLDP=COLDP+AAAT(KA+11)*C83*(C81-0.2)*ETA**2                      CHD 3474
      COLDE=COLDE-AAAT(KA+18)*ETA*C82*C83                               CHD 3475
  710 LTIES=IES                                                         CHD 3476
      ROWAO=ROWA                                                        CHD 3477
  720 IF (ICOME) 360,730,360                                            CHD 3478
  730 IF (NOFRG.GT.0) GO TO 750                                         CHD 3479
C     IN TABLE                                                          CHD 3480
  740 EEVAL=EEVAL+COLDE                                                 CHD 3481
      PPVAL=PPVAL+COLDP                                                 CHD 3482
      IF (IBACK) 260,220,240                                            CHD 3483
C     OFF TABLE                                                         CHD 3484
  750 GO TO (760,770,780,790,800,810,820,830), NOFRG                    CHD 3485
  760 C81=ROWA/RTBL(IRLO)                                               CHD 3486
      PPVAL=PPVAL*C81                                                   CHD 3487
      DPVAL=DPVAL*C81                                                   CHD 3488
      SSVAL=SSVAL-FPVAL*ALOG(C81)/(TEMPJ*ROWA)                          CHD 3489
      GO TO 890                                                         CHD 3490
  770 C81=TEMPJ-TTBL(ITHI)                                              CHD 3491
      CVVAL=CVHIGH(IES)                                                 CHD 3492
      EEVAL=EEVAL+CVVAL*C81                                             CHD 3493
      DPVAL=2.*CVVAL*ROWA/3.                                            CHD 3494
      PPVAL=PPVAL+DPVAL*C81                                             CHD 3495
      SSVAL=SSVAL+CVVAL*ALOG(TEMPJ/TTBL(ITHI))                          CHD 3496
      GO TO 840                                                         CHD 3497
  780 C81=ROWA/RTBL(IRHI)                                               CHD 3498
      PPVAL=PPVAL*C81                                                   CHD 3499
      DPVAL=DPVAL*C81                                                   CHD 3500
      SSVAL=SSVAL-FPVAL*ALOG(C81)/(TEMPJ*ROWA)                          CHD 3501
      GO TO 890                                                         CHD 3502
  790 C81=TEMPJ/TTBL(ITLO)                                              CHD 3503
      EEVAL=EEVAL*C81                                                   CHD 3504
      CVVAL=EEVAL/TEMPJ                                                 CHD 3505
      PPVAL=PPVAL*C81                                                   CHD 3506
      DPVAL=PPVAL/TEMPJ                                                 CHD 3507
      SSVAL=SSVAL+CVVAL*ALOG(C81)                                       CHD 3508
      GO TO 890                                                         CHD 3509
  800 C81=TEMPJ/TTBL(ITLO)                                              CHD 3510
      C82=ROWA/RTBL(IRLO)                                               CHD 3511
      EEVAL=EEVAL*C81                                                   CHD 3512
      CVVAL=EEVAL/TEMPJ                                                 CHD 3513
      PPVAL=PPVAL*C81*C82                                               CHD 3514
      DPVAL=PPVAL/TEMPJ                                                 CHD 3515
      SSVAL=SSVAL-DPVAL*ALOG(C82)/ROWA+CVVAL*ALOG(C81)                  CHD 3516
```

```
      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 CALCULATION
  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
      TEMPH=TEMPH+RADK1*C81
      TEMPG=TEMPG+RADK2*C81/TEMPA
      ENTSV(I)=ENTSV(I)+RADK1*C81/TEMPA
      C81=RADK3*C81*TEMPJ
      TEMPD=TEMPD+C81
      C81=3.*C81/TEMPA
      IF (1.E-5*TEMPC.GT.C81) GO TO 960
      CSOD(I)=SQRT(CSOD(I)**2+.45*C81)
  960 TEMPC=TEMPC+C81
      RETURN
C
C     SET UP EQUATION OF STATE
C     READ EOS INPUT TAPE
  970 CONTINUE
C     NECSB IS FIRST ECS LOCATION FOR EOS
      NECSB=12*MAXZONE+4
      IINN=IIN
      IIN=IEOSTP
      DO 980 IJ=1,NMTRLS
      IF (IEOSS(IJ).GT.0.) GO TO 990
  980 CONTINUE
      GO TO 1000
  990 READ (IIN,1860) (IZETL(IJ),IJ=1,10)
      PRINT 1840, (IZETL(IJ),IJ=1,10)
C     PUTS EOS IN NUMERICAL ASCENDING ORDER, IZERL STORES THE SEQUENCE
 1000 DO 1010 JJ=1,NMTRLS
 1010 IZETL(JJ)=IEOSS(JJ)
      DO 1030 JJ=1,NMTRLS
      IS=99999
      DO 1020 JK=1,NMTRLS
      IF (IS.LE.IZETL(JK)) GO TO 1020
      IS=IZETL(JK)
      JL=JK
 1020 CONTINUE
      IZERL(JJ)=IS
      IZETL(JL)=99999
 1030 CONTINUE
      IS=1
      ISS=1
      IZETL(1)=IZERL(1)
 1040 CONTINUE
      IF (IS.GE.NMTRLS) GO TO 1060
      IF (IZERL(IS).LT.IZERL(IS+1)) GO TO 1050
      IS=IS+1
      GO TO 1040
 1050 CONTINUE
      IS=IS+1
      ISS=ISS+1
      IZETL(ISS)=IZERL(IS)
      GO TO 1040
 1060 CONTINUE
C     ISS = NUMBER OF DIFFERENT EOS
C     IZETL STORES DIFFERENT EOS NUMBERS IN ASCENDING ORDER
C     PUT ANALYTICAL EOS NUMBERS LAST
```

```
      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)
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```
      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
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```
      DO 1290 I=1,JL                                                    CHD 3737
      JK=JK+1                                                           CHD 3738
      PTBL(JK)=ALOG(PTBL(JK))                                           CHD 3739
      ETBL(JK)=ALOG(ETBL(JK))                                           CHD 3740
      IF (SOUNSP(JK).GE.0.0001) GO TO 1270                              CHD 3741
      SOUNSP(JK)=0.0001                                                 CHD 3742
 1270 SOUNSP(JK)=ALOG(SOUNSP(JK))                                       CHD 3743
      IF (ROSTAB(JK).GT.0.) GO TO 1280                                  CHD 3744
      ROSTAB(JK)=.2                                                     CHD 3745
 1280 ROSTAB(JK)=ALOG(ROSTAB(JK))                                       CHD 3746
 1290 CONTINUE                                                          CHD 3747
      IF (JK.GT.MAXSIZE) GO TO 1360                                     CHD 3748
      IA=KTP(J)                                                         CHD 3749
      IG=KTP(J+1)-1                                                     CHD 3750
      IF (IG.GT.MAXTPH) GO TO 1370                                      CHD 3751
      DO 1300 I=IA,IG                                                   CHD 3752
 1300 READ (IIN,1720) BETA1(I),BETA2(I),BETA3(I),BETA4(I),BETA5(I),BETA6CHD 3753
     1(I),BETA7(I),BETA8(I)                                             CHD 3754
      IF (IGAS(J).NE.0) GO TO 1320                                      CHD 3755
      DO 1310 JK=1,8                                                    CHD 3756
      JI=MAXTPH*(JK-1)                                                  CHD 3757
      DO 1310 I=IA,IG                                                   CHD 3758
 1310 BETA1(I+JI)=ALOG(BETA1(I+JI))                                     CHD 3759
C     NEXT RECORD SET IS MELTING TEMPERATURES AT MESH DENSITIES         CHD 3760
 1320 READ (IIN,1720) (TSAVE(I),I=1,MQR)                                CHD 3761
      IF (NISEOS) 1390,1390,1330                                        CHD 3762
C     ECS PATH                                                          CHD 3763
 1330 IA=NECSA*(J-1)+NECSB                                              CHD 3764
      CALL WRITEC (TTBL,IA,NECSA)                                       CHD 3765
      PSAVE(J+1)=ITL(J+1)                                               CHD 3766
      PSAVE(J+26)=IRL(J+1)                                              CHD 3767
      PSAVE(J+51)=KTP(J+1)                                              CHD 3768
      PSAVE(J+76)=NROS(J+1)                                             CHD 3769
      ITL(J+1)=IRL(J+1)=KTP(J+1)=NROS(J+1)=1                            CHD 3770
      GO TO 1390                                                        CHD 3771
C     SET FLAG FOR TABLE OVERFLOW                                       CHD 3772
 1340 I=1                                                               CHD 3773
      GO TO 1380                                                        CHD 3774
 1350 I=2                                                               CHD 3775
      GO TO 1380                                                        CHD 3776
 1360 I=3                                                               CHD 3777
      IG=JK                                                             CHD 3778
      GO TO 1380                                                        CHD 3779
 1370 I=4                                                               CHD 3780
 1380 PRINT 1760, I,IG,IES,J,ISS,MAXNOD,MAXNOT,MAXSIZE,MAXTPH           CHD 3781
      STOP                                                              CHD 3782
 1390 CONTINUE                                                          CHD 3783
      IES=ISS+1                                                         CHD 3784
      IF (NISEOS) 1420,1420,1400                                        CHD 3785
C     ECS PATH                                                          CHD 3786
 1400 DO 1410 J=2,IES                                                   CHD 3787
      IF (IZETL(J-1).LT.0) GO TO 1420                                   CHD 3788
      NISEOS=J-1                                                        CHD 3789
      ITL(J)=PSAVE(J)                                                   CHD 3790
      IRL(J)=PSAVE(J+25)                                                CHD 3791
```

```
      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                                               CHD 3847
 1550 CALL WRITEC (TTBL,IA,NECSA)                                        CHD 3848
      IA=IA+NECSA                                                        CHD 3849
 1560 IF (NOANE(S.EQ.1) CALL ANEOS2 (3,ISS,IIN,IZETL)                    CHD 3850
      GO TO 1610                                                         CHD 3851
C                                                                        CHD 3852
C     WRITE EOS DATA FOR RESTART                                         CHD 3853
 1570 WRITE (IOUT) (IZETL(I),I=1,NNNIZE)                                 CHD 3854
      WRITE (IOUT) (TTBL(I),I=1,NNNTTB)                                  CHD 3855
      IA=NECSB                                                           CHD 3856
      IF (NISEOS) 1600,1600,1580                                         CHD 3857
C     ECS PATH                                                           CHD 3858
 1580 DO 1590 I=1,NISEOS                                                 CHD 3859
      IA=NECSA*(I-1)+NECSB                                               CHD 3860
      CALL READEC (TTBL,IA,NECSA)                                        CHD 3861
 1590 WRITE (IOUT) (TTBL(J),J=1,NECSA)                                   CHD 3862
      IA=IA+NECSA                                                        CHD 3863
 1600 IF (NOANE(S.EQ.1) CALL ANEOS2 (2,ISS,IOUT,IZETL)                   CHD 3864
 1610 PRINT 1680, IA,NISEOS                                              CHD 3865
      ASSIGN 350 TO LEMOVA                                               CHD 3866
      ASSIGN 610 TO LEMOVE                                               CHD 3867
      DO 1640 I=1,MAXZONE                                                CHD 3868
      IF (IEOS(I)) 1640,1650,1620                                        CHD 3869
 1620 IES=IEOS(I)                                                        CHD 3870
      IF (AMISS(12*IES-8)) 1630,1640,1630                                CHD 3871
 1630 ASSIGN 340 TO LEMOVA                                               CHD 3872
      ASSIGN 600 TO LEMOVB                                               CHD 3873
      GO TO 1650                                                         CHD 3874
 1640 CONTINUE                                                           CHD 3875
 1650 RETURN                                                             CHD 3876
 1660 STOP 305                                                           CHD 3877
C                                                                        CHD 3878
 1670 FORMAT (26H0 ECS SWITCH IS OFF IN EOS)                             CHD 3879
 1680 FORMAT (29H1 LAST ECS LOCATION IN USE IS,I10,//,I5,22H EOS TABLES CHD 3880
     1ARE STORED)                                                        CHD 3881
 1690 FORMAT (48H1 ZERO OR NEGATIVE DENSITY OR TEMPERATURE   ZONE,I5,5HCCHD 3882
     1YCLE,I8,/,4H  T=,E13.6,20X,4HRHO=,E13.6,15X,6HIBACK=,I7)           CHD 3883
 1700 FORMAT (I6,7A10,A4)                                                CHD 3884
 1710 FORMAT (4I5,3E20.10)                                               CHD 3885
 1720 FORMAT (4E20.10)                                                   CHD 3886
 1730 FORMAT (5E16.8)                                                    CHD 3887
 1740 FORMAT (E20.10)                                                    CHD 3888
 1750 FORMAT (E16.8)                                                     CHD 3889
 1760 FORMAT (25H EOS TABLES ARE TOO LARGE,5I7)                          CHD 3890
 1770 FORMAT (17H1 TABULAR EOS ARE)                                      CHD 3891
 1780 FORMAT (34H0 END OF EOS TAPE HAS BEEN REACHED,2I7)                 CHD 3892
 1790 FORMAT (18H0 FOUND EOS NUMBER,I7,18H  WHEN LOOKING FOR,I7)         CHD 3893
 1800 FORMAT (8H0 NUMBER,I7,5X,7A10,A4,/,21H  REFERENCE  DENSITY=,E14.7,CHD 3894
     115H   TEMPERATURE=,E14.7)                                          CHD 3895
 1810 FORMAT (//,20H  TABLE STORAGE DATA)                                CHD 3896
 1820 FORMAT (7H0 NROS(,I2,2H)=,I6,1H/,I6,1X,4HITL(,I2,2H)=,I4,1H/,I4,6XCHD 3897
     1,4HIRL(,I2,2H)=,I4,1H/,I4,6X,4HKPT(,I2,2H)=,I5,1H/,I5)             CHD 3898
 1830 FORMAT (7H0 NROS(,I2,2H)=,I6,8X,4HITL(,I2,2H)=,I4,11X,4HIRL(,I2,2HCHD 3899
     1)=,I4,11X,4HKTP(,I2,2H)=,I5,8X,7HNUMTEM(,I2,2H)=,I4)               CHD 3900
 1840 FORMAT (25H1 HEADING ON EOS TAPE IS ,10A8)                         CHD 3901

 1850 FORMAT (//,I5,25H EOS TABLES ARE REQUESTED,/,(17I7))               CHD 3902
 1860 FORMAT (10A8)                                                      CHD 3903
 1870 FORMAT (13H1ERROR IN EOS)                                          CHD 3904
      END                                                                CHD 3905
```

```
      SUBROUTINE TPLINE (NES,RM,TM,EM)
C     DETERMINES TRIPLE LINE AND CRITICAL POINT PROPERTIES
      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 /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 /ISE/ ISEND,ENTCR(20),ENTTPL(20)
      DATA ISEND/1/
      DATA II/0/
      DATA RSOL,TTWO/2000*0./
      IF (ISEND) 10,20,20
   10 IF (ISEND+1) 200,40,40
   20 IF (II) 40,30,40
   30 PRINT 260
   40 IF (NES) 60,60,50
   50 RM=RTRIP(NES)
      TM=TTRIP(NES)
      II=12*(NES-1)+1
      EM=AMISS(II)
      GO TO 190
   60 II=-NES
      JJ=LOCSV(II)+18
      TM=ACK(JJ)
      IF (TM) 70,70,80
   70 RM=EM=0.
      GO TO 190
   80 K1=LOCKP(II)
      K2=LOCKPL(II)
      IF (K1-K2) 150,90,90
   90 JJ=JJ+12
      IF (ACK(JJ).LE.1.) GO TO 100
      TM=0.
      GO TO 70
  100 D8=.999999*TM
      GU=ACK(JJ-19)
      GL=ACK(JJ-7)
  110 RM=.5*(GU+GL)
      CALL ANEOS (D8,RM,D1,EM,D2,D3,D4,D5,D6,D7,K2,II)
      IF (GU-GL.LE.1.E-9*RM) GO TO 140
      IF (D1) 120,130,130
  120 GL=RM
      GO TO 110
  130 GU=RM
      GO TO 110
  140 IF (ABS(D1).LE.100.) GO TO 180
      IF (ISEND.GE.0) PRINT 230, ACK(JJ),NES
      RM=ACK(JJ-19)
      GO TO 180
  150 DO 170 I=K1,K2
      IF (TM-TTWO(I)) 170,160,170
  160 RM=RSOL(I)
```

```
      GO TO 180
  170 CONTINUE
      PRINT 250, NES,TM
      GO TO 90
  180 CALL ANEOS (TM,RM,D1,EM,D2,D3,D4,D5,D6,D7,JJ,II)
  190 IF (ISEND.GE.0) PRINT 240, NES,TM,RM,EM
      RETURN
  200 IF (NES) 210,210,220
  210 II=-NES
      RM=RCT(II)
      TM=TCT(II)
      RETURN
  220 RM=RCRIT(NES)
      TM=TCRIT(NES)
      RETURN
C
  230 FORMAT (16H0 WARNING - TYPE,F3.0,22H EOS USED FOR MATERIAL,I4,45H
     1DOES NOT HAVE CORRECT TRIPLE LINE PROPERTIES,/)
  240 FORMAT (/,5H0EOS=,I6,5X,3HTM=,E12.5,5X,5HRHOM=,E12.5,5X,3HEM=,E12.
     15)
  250 FORMAT (//,13H0TPLINE ERROR,I10,E14.5)
  260 FORMAT (17H1TRIPLE LINE DATA)
      END
```

```
      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 TENSION SUPPRESSION
  110 IF (P.GE.0.) GO TO 130
      IF (T.GE.ACK(LOC+18)) GO TO 120
      IF (RHO.GT.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) GO 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 50
   10 IF (RHO.GT.1.E-10) GO TO 20
      DPDR=FTT
      P=RHO*FTT
      E=ACK(L+10)+1.5*FTT
      GO TO 50
   20 CONTINUE
      RHOO=ACK(L+11)
      X1=RHO**.3333333333
      RHOOO=ACK(L+19)
      X2=RHO/RHOOO
      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*RHOOO)
      E=3.*ACK(L+4)*((X7-1.)/ACK(L+5)-(X8-1.)/ACK(L+6))/RHOOO
      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.*RHOOO)
      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.RHOO) 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
```

```
      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
      LOCKF(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.
```

```
      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
```

```
      COT(I)=COT(I)/S                                                   CHD 4328
      DZB(26)=DZB(26)+ZZS(I)*COT(I)                                     CHD 4329
      IKK=ZZS(I)                                                        CHD 4330
      IKJ=IKK+(IKK*(IKK+1))/2                                           CHD 4331
      IF (IKK.GE.1.AND.IKK.LE.92) GO TO 190                             CHD 4332
      PRINT 1490, IKK                                                   CHD 4333
      STOP 1017                                                         CHD 4334
  190 DZB(29)=DZB(29)+COT(I)*EIP(IKJ-IKK)                               CHD 4335
  200 S1=S1+COT(I)*EIP(IKJ-IKK)*1.66026E-24                             CHD 4336
      DZB(27)=0.                                                        CHD 4337
      DO 210 I=IZ,IZI                                                   CHD 4338
      FNI(I)=COT(I)/S1                                                  CHD 4339
  210 DZB(27)=DZB(27)+FNI(I)                                            CHD 4340
      IF (DZB(30).EQ.2.) GO TO 240                                      CHD 4341
      IF (BOOT.LE.0.) GO TO 240                                         CHD 4342
      S1=3.*DZB(27)*BOLTS*DZB(12)*DZB(15)**2                            CHD 4343
      DZB(21)=DZB(11)*(BOOT**2-S1)                                      CHD 4344
      S2=DZB(11)*BOOT**2/DZB(21)                                        CHD 4345
      S2=S2*(2.*GAM-1.-(DZB(15)-2.)*(.5-.5/S2))                         CHD 4346
      S3=S1*DZB(11)/DZB(15)                                             CHD 4347
      S4=S3*(1.+2.*S2)+DZB(21)                                          CHD 4348
      S5=S4**2-8.*S2*S3**2                                              CHD 4349
      IF (S5.LE.0.) GO TO 220                                           CHD 4350
      S6=.5*(S4+SQRT(S5))                                               CHD 4351
      S6=DZB(21)*S6/(S6-S3)**2                                          CHD 4352
      S5=1.-S6                                                          CHD 4353
      IF (ABS(S5).LE.0.1) GO TO 230                                     CHD 4354
      S6=1.-.1*S5/ABS(S5)                                               CHD 4355
      GO TO 230                                                         CHD 4356
  220 S6=1.                                                             CHD 4357
  230 TGAM=3.*(S6*S2-DZB(15))                                           CHD 4358
  240 S1=0.                                                             CHD 4359
      DO 250 I=IZ,IZI                                                   CHD 4360
      IKK=ZZS(I)                                                        CHD 4361
      IKK=(IKK*(IKK+1))/2                                               CHD 4362
      S=EIP(IKK)*1.66026E-24                                            CHD 4363
  250 S1=S1+ALOG(FNI(I)/(DZB(27)*(DZB(27)*S)**1.5))*FNI(I)/DZB(27)      CHD 4364
      DZB(13)=4.36050E-42*DZB(27)**(5./3.)*EXP(2.*S1/3.)                CHD 4365
      IKK=0                                                             CHD 4366
      GAM=DZB(15)+TGAM/3.                                               CHD 4367
      IF (DZB(30).EQ.2) GO TO 410                                       CHD 4368
      DZB(14)=DZB(25)*EXP(1.5-2.*DZB(15))/DZB(11)                       CHD 4369
      DZB(16)=(1.-2.*DZB(15))/DZB(11)**2                                CHD 4370
      DZB(17)=(3.*DZB(15)-2.)/DZB(11)                                   CHD 4371
      I=0                                                               CHD 4372
      S3=GAM                                                            CHD 4373
      SPS=1.E6                                                          CHD 4374
C     SPS LIMITS POTENTIAL RANGE IF POSSIBLE                            CHD 4375
  260 S=1.-DZB(21)/(DZB(11)*DZB(10)*GAM**2)                             CHD 4376
      IF (S.LE.0.) GO TO 280                                            CHD 4377
      S=SQRT(S)                                                         CHD 4378
      S1=ALOG(DZB(21)/(200.*SPS*GAM*S))                                 CHD 4379
      S2=27.*GAM*(1.-S)                                                 CHD 4380
      IF (S2.GE.S1) GO TO 280                                           CHD 4381
      I=I+1                                                             CHD 4382
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```
      IF (I.GT.400) GO TO 270
      GAM=0.99*GAM
      GO TO 260
  270 GAM=S3
  280 DFB1=GAM
  290 S=DZB(13)*DZB(12)*(DZB(11)**(1./3.)/DZB(25))**2
      SPS=S
      I=0
      S1=DZB(20)-DZB(11)*((3.*DZB(15)+S)/(1.+S))*DZB(27)*DZB(12)*BOLTS
      IKK=IKK+1
      IF (IKK.EQ.2) GO TO 310
      IF (DZB(15).EQ.1.) GO TO 300
      S=1.+((2.*DZB(15)-1.)**2-2.)*S1/DZB(21)
      DZB(3)=DZB(21)*(SQRT(S**2+4.*DZB(15)*(DZB(15)-1.)*(1.-2.*S1/DZB(21
     1))**2)-S)*.5/(DZB(15)-1.)
      GO TO 320
  300 DZB(3)=((DZB(21)-2.*S1)**2)/(DZB(21)-S1)
      GO TO 320
  310 CALL ANEOS1 (DZB(12),DZB(11),S,S2,S3,S4,S5,S6,IT)
      DZB(3)=DZB(3)*DZB(21)/(DZB(11)*S6)
  320 GAM=DFB1
  330 S2=DZB(3)/(DZB(11)*DZB(10)*GAM**2)
      IF (S2.LT.1.) GO TO 350
      GAM=GAM*SQRT(1.00001*S2)
      IF (I.GT.15) GAM=GAM*1.005
      I=I+1
      IF (I.GT.40) STOP 20
      IF (IKK.GE.2) GO TO 330
      S1=DZB(20)-DZB(11)*((3.*DZB(15)+SPS)/(1.+SPS))*DZB(27)*DZB(12)*BOL
     1TS
      IF (GAM.EQ.1.) GO TO 340
      S=1.+((2.*GAM-1.)**2-2.)*S1/DZB(21)
      DZB(3)=DZB(21)*(SQRT(S**2+4.*GAM*(GAM-1.)*(1.-2.*S1/DZB(21))**2)-S
     1)*.5/(GAM-1.)
      GO TO 330
  340 DZB(3)=((DZB(21)-2.*S1)**2)/(DZB(21)-S1)
      GO TO 330
  350 S3=1.
      S4=.8
  360 S5=.5*(S3+S4)
      S6=SQRT(1.-S2*S5)
      DZB(5)=3.*GAM*(1.+S6)
      DZB(6)=3.*GAM*(1.-S6)
      S6=6.*GAM*S6
      DZB(4)=S5**(-1./3.)
      IF (S3-S4.LE.1.E-9) GO TO 390
      S6=1.-3.*DZB(3)*(EXP(DZB(5)*(1.-DZB(4)))-EXP(DZB(6)*(1.-DZB(4))))/
     1(DZB(4)**2*S1*S6)
      IF (S6) 370,390,380
  370 S4=S5
      GO TO 360
  380 S3=S5
      GO TO 360
  390 DZB(19)=DZB(11)/S5
      DZB(4)=S1/(S5**(2./3.)*(EXP(DZB(5)*(1.-DZB(4)))-EXP(DZB(6)*(1.-DZB
```

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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                                          CHD 4493
      DFB2=(S3*DFN2-S7*DFN1)/S                                          CHD 4494
      IF (ABS(DFB1).GT.0.002*S1) DFB1=0.002*S1*DFB1/ABS(DFB1)           CHD 4495
      IF (ABS(DFB2).GT.0.002*S2) DFB2=0.002*S2*DFB2/ABS(DFB2)           CHD 4496
      IF (S3.LT.0..AND.IKK.GT.-200) GO TO 490                           CHD 4497
      IF (ABS(DFB1).GT.1.E-10*S1) GO TO 490                             CHD 4498
      IF (ABS(DFB2).LE.1.E-10*S2) GO TO 530                             CHD 4499
  490 S1=S1+DFB1                                                        CHD 4500
      S2=S2+DFB2                                                        CHD 4501
      GO TO 450                                                         CHD 4502
  500 S4=1.-BOOT*ETAOT/(DZB(11)*DZB(10)*GAM**2)                         CHD 4503
      IF (S4) 510,510,520                                               CHD 4504
  510 GAM=SQRT(1.00001*BOOT*ETAOT/(DZB(11)*DZB(10)))                    CHD 4505
      GO TO 450                                                         CHD 4506
  520 S4=SQRT(S4)                                                       CHD 4507
      S5=3.*GAM*(1.+S4)                                                 CHD 4508
      S6=3.*GAM*(1.-S4)                                                 CHD 4509
      S4=BOOT/(2.*GAM*S4)                                               CHD 4510
      DFN1=ETAOT**.3333333333                                           CHD 4511
      DFN2=EXP(S5*(1.-1./DFN1))                                         CHD 4512
      DFB1=EXP(S6*(1.-1./DFN1))                                         CHD 4513
      DFB2=DFN1**2                                                      CHD 4514
      S3=S4*(DFN2-DFB1)*(ETAOT/DFN1)                                    CHD 4515
      S7=S4*((2.*DFN1+S5)*DFN2-(2.*DFN1+S6)*DFB1)/(3.*DFB2)             CHD 4516
      IF (S) 460,470,480                                                CHD 4517
  530 DZB(3)=S2                                                         CHD 4518
      DZB(19)=DZB(11)/S1                                                CHD 4519
      DZB(4)=S4                                                         CHD 4520
      DZB(5)=S5                                                         CHD 4521
      DZB(6)=S6                                                         CHD 4522
      GO TO 400                                                         CHD 4523
  540 CONTINUE                                                          CHD 4524
      IF (ABS(DZB(15)+TGAM/3.-GAM).LT.1.E-4) GO TO 550                  CHD 4525
      S1=3.*(GAM-DZB(15))                                               CHD 4526
      PRINT 1500, TGAM,S1                                               CHD 4527
  550 CALL ANPHTR (DZB,MAT,TGAM)                                        CHD 4528
      DO 560 I=1,40                                                     CHD 4529
  560 ACK(IT+I)=DZB(I)                                                  CHD 4530
      IF (DZB(18).GT.0.) GO TO 630                                      CHD 4531
      IF (DZB(30).EQ.2.) GO TO 630                                      CHD 4532
      S7=1.                                                             CHD 4533
  570 SPS=DZB(12)                                                       CHD 4534
      S=DZB(11)                                                         CHD 4535
      CALL ANEOS1 (SPS,S,S1,S2,S3,S4,S5,S6,IT)                          CHD 4536
      S9=S7*S2-DZB(18)                                                  CHD 4537
      IF (S9) 610,580,580                                               CHD 4538
  580 SPS=SPS+.01                                                       CHD 4539
      S8=S2                                                             CHD 4540
      IF (SPS.GT.1.) GO TO 610                                          CHD 4541
      JJ=0                                                              CHD 4542
  590 JJ=JJ+1                                                           CHD 4543
      IF (JJ.GT.1000) GO TO 610                                         CHD 4544
      CALL ANEOS1 (SPS,S,S1,S2,S3,S4,S5,S6,IT)                          CHD 4545
      IF (ABS(S1).LE.10.) GO TO 600                                     CHD 4546
      S5=S1/S6                                                          CHD 4547
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      IF (ABS(S5).GT.0.01*S) S5=0.01*S*S5/ABS(S5)                   CHD 4548
      S=S-S5                                                          CHD 4549
      GO TO 590                                                       CHD 4550
  600 IF (S2-S9) 580,620,620                                          CHD 4551
  610 PRINT 1390, SPS,S,S9,S2,S1,JJ                                   CHD 4552
      STOP                                                            CHD 4553
  620 ACK(IT+18)=DZB(18)=((S9-S8)*SPS+(S2-S9)*(SPS-.01))/(S2-S8)     CHD 4554
  630 IF (ACK(IT+30).EQ.2.) ACK(IT+43)=0.                             CHD 4555
      IF (ACK(IT+43)) 640,830,650                                     CHD 4556
  640 ACK(IT+43)=ACK(IT+18)*1.117E12/ACK(IT+29)                       CHD 4557
  650 IF (ACK(IT+44).EQ.0.) ACK(IT+44)=.95                            CHD 4558
  660 S1=S2=ACK(IT+49)=I1=0                                           CHD 4559
      ACK(IT+47)=1.E50                                                CHD 4560
      IF (ACK(IT+30).LT.2.) S2=-1.                                    CHD 4561
      S=ACK(IT+18)                                                    CHD 4562
      GAM=ACK(IT+43)                                                  CHD 4563
      RCT(MAT)=.2*ACK(IT+19)                                          CHD 4564
      CALL ANMAXW (S,S1,S2,IT,MAT,I1)                                 CHD 4565
      IF (ACK(IT+43).EQ.0.) GO TO 850                                 CHD 4566
      PCO2=CMLT(8)                                                    CHD 4567
      CMLT(8)=1.                                                      CHD 4568
      IF (I1.GE.0) GO TO 680                                          CHD 4569
  670 PRINT 1270                                                      CHD 4570
      CMLT(8)=PCO2                                                    CHD 4571
      ACK(IT+46)=ACK(IT+43)=IKK=0                                     CHD 4572
      S2=-1                                                           CHD 4573
      CALL ANMAXW (S,S1,S2,IT,MAT,IKK)                                CHD 4574
      IF (IKK.LT.0) GO TO 830                                         CHD 4575
      CALL ANEOS1 (S,S1,S4,S5,S6,S7,S8,S9,IT)                         CHD 4576
      PRINT 1280, S                                                   CHD 4577
      DZB(18)=-S5-GAM                                                 CHD 4578
      S7=0.                                                           CHD 4579
      GO TO 570                                                       CHD 4580
  680 IF (ACK(IT+44).LT.0.) ACK(IT+44)=-ACK(IT+44)/S1                 CHD 4581
      S2=ACK(IT+44)*S1                                                CHD 4582
      IF (S2.LT.S1) GO TO 690                                         CHD 4583
      PRINT 1290, S2,S1                                               CHD 4584
      GO TO 670                                                       CHD 4585
  690 CALL ANEOS1 (S,S1,S4,S5,S6,S7,S8,S9,IT)                         CHD 4586
      CALL ANEOS1 (S,S2,DFB1,DFB2,BOOT,S7,S8,S9,IT)                   CHD 4587
      S5=ACK(IT+43)+S5-DFB2                                           CHD 4588
      S6=S6-BOOT+(ACK(IT+43)+S4*(1./S2-1./S1))/S                      CHD 4589
      S4=S4-DFB1                                                      CHD 4590
      ACK(IT+46)=S1                                                   CHD 4591
      ACK(IT+47)=S2                                                   CHD 4592
      S1=S4/S2                                                        CHD 4593
      S8=S6*S                                                         CHD 4594
      S9=(S1+(2.*CMLT(1)-CMLT(2))*S8-CMLT(2)*S5)/(CMLT(3)-CMLT(2))    CHD 4595
      S8=S5+S8-S9                                                     CHD 4596
      ACK(IT+44)=S8/S2**CMLT(2)                                       CHD 4597
      ACK(IT+45)=S9/S2**CMLT(3)                                       CHD 4598
      ACK(IT+43)=-2.*SQRT(S)*S6/S2**CMLT(1)                           CHD 4599
      ACK(IT+48)=ACK(IT+50)=ACK(IT+51)=1.E50                          CHD 4600
      ACK(IT+52)=DFN1=ETAOT=I1=0                                      CHD 4601
      PCO1=10.*S                                                      CHD 4602
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```
      IF (PCO1.GT..8) PCO1=.8
      S3=S
  700 S3=1.02*S3
      IKK=1
      CALL ANLS (S3,S2,S1,BOOT,IT,MAT,IKK)
      IF (IKK.LT.0) GO TO 670
      DFN2=(S3-S)/(S1-S2)
      IF (DFN2.GT.DFN1) DFN1=DFN2
      IF (S3.GT.PCO1) GO TO 710
      IF (BOOT.LE.ACK(IT+11)) GO TO 710
      S7=(S3-S)/(BOOT-ACK(IT+11))
      IF (S7.LT.ACK(IT+51)) ACK(IT+51)=S7
      ETAOT=S3
  710 IF (BOOT/S1-1..LE.5.E-5) GO TO 720
      IF (S1.LE.100.*ACK(IT+11)) GO TO 730
  720 ACK(IT+48)=S3
      GO TO 750
  730 I1=I+1
      IF (I1-500) 700,700,740
  740 PRINT 1300, S3,S1,BOOT
      GO TO 670
  750 ACK(IT+50)=1.05*DFN1
      IF (ETAOT.LE.0.) GO TO 760
      ACK(IT+52)=ETAOT
      ACK(IT+51)=.9999*ACK(IT+51)
  760 S1=1.E50
      I1=0
      S3=S
  770 S3=.990*S3
      IKK=1
      S8=S1
      IF (S8.LT.ACK(IT+47)) IKK=3
      CALL ANLS (S3,S2,BOOT,S1,IT,MAT,IKK)
      IF (IKK.LT.0) GO TO 790
      IF (S1.GT.ACK(IT+23)) GO TO 800
  780 ACK(IT+49)=S3
      GO TO 820
  790 IF (IKK.NE.-3) GO TO 670
      PRINT 1310, ACK(IT+23),S8
      ACK(IT+23)=S8
      S3=DFN1
      GO TO 780
  800 I1=I1+1
      DFN1=S3
      IF (I1-500) 770,770,810
  810 PRINT 1320, S3,S1,BOOT
      GO TO 670
  820 CONTINUE
      CMLT(8)=PCO2
      GO TO 870
  830 DO 840 I=43,52
  840 ACK(IT+I)=0.
      IF (ACK(IT+30)-2.) 870,870,660
  850 IF (I1.LT.0) GO TO 860
      ACK(IT+47)=S1
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      GO TO 870                                                          CHD 4658
  860 ACK(IT+47)=ACK(IT+11)                                             CHD 4659
  870 DO 880 I=1,18                                                     CHD 4660
  880 PRINT 1510, (I1,ACK(IT+I1),I1=I,54,18)                            CHD 4661
      PRINT 1480                                                        CHD 4662
      I1=ACK(IT+31)                                                     CHD 4663
      I2=ACK(IT+28)                                                     CHD 4664
      DO 890 I=1,I2                                                     CHD 4665
      PRINT 1520, I,ZZS(I1),I,COT(I1),I,FNI(I1)                         CHD 4666
  890 I1=I1+1                                                           CHD 4667
      IF (ACK(IT+12).LE.0.) GO TO 900                                   CHD 4668
      IF (ACK(IT+11).LE.0.) GO TO 900                                   CHD 4669
      CALL ANEOS (ACK(IT+12),ACK(IT+11),S1,S2,S3,S4,S5,S6,DZB(1),DZB(2),CHD 4670
     1I,MAT)                                                            CHD 4671
      DZB(3)=ACK(IT+11)*S6                                              CHD 4672
      PRINT 1530, ACK(IT+12),ACK(IT+11),S1,S2,S3,S4,S5,S6,DZB(3),DZB(2) CHD 4673
  900 SPS=ACK(IT+30)                                                    CHD 4674
      CALL ANPHASE (MAT,IT,IKPN)                                        CHD 4675
      IF (SPS-ACK(IT+30)) 910,920,910                                   CHD 4676
  910 IF (ACK(IT+46).LE.0.) GO TO 920                                   CHD 4677
      PRINT 1330, MAT                                                   CHD 4678
      ZB(2)=ACK(IT+30)                                                  CHD 4679
      GO TO 50                                                          CHD 4680
  920 LOCKPL(MAT)=IKPN-1                                                CHD 4681
      PRINT 1540, MAT,LOCKP(MAT),MAT,LOCKPL(MAT)                        CHD 4682
      IF (ACK(IT+46).LE.0.) GO TO 1190                                  CHD 4683
      DFN1=CMLT(8)                                                      CHD 4684
      CMLT(7)=PCP1=DFN2=I1=0                                            CHD 4685
      CMLT(8)=1.                                                        CHD 4686
      PRINT 1350                                                        CHD 4687
      BOOT=ACK(IT+49)                                                   CHD 4688
  930 I2=2                                                              CHD 4689
      S7=1.E10                                                          CHD 4690
      CALL ANLS (BOOT,S7,S1,S2,IT,MAT,I2)                               CHD 4691
      IF (I2.GE.0) GO TO 940                                            CHD 4692
      I1=1                                                              CHD 4693
      GO TO 1110                                                        CHD 4694
  940 CMLT(7)=-1.                                                       CHD 4695
      CALL ANEOS1 (BOOT,S2,S3,S4,S5,S6,S7,S8,IT)                        CHD 4696
      S9=S4-BOOT*S5+S3/S2                                               CHD 4697
      CMLT(7)=0.                                                        CHD 4698
      PRINT 1360, BOOT,S2,S3,S4,S5,S9                                   CHD 4699
      CALL ANEOS1 (BOOT,S1,S3,S4,S5,S6,S7,S8,IT)                        CHD 4700
      S9=S4-BOOT*S5+S3/S1                                               CHD 4701
      PRINT 1370, I2,S1,S3,S4,S5,S9                                     CHD 4702
C     CHECK FAST ITERATION                                              CHD 4703
      CMLT(8)=0.                                                        CHD 4704
      DO 1100 I2=1,3                                                    CHD 4705
      IF (I2-2) 950,980,990                                             CHD 4706
  950 PCO1=ACK(IT+47)+(BOOT-ACK(IT+18))/ACK(IT+50)                      CHD 4707
      IF (BOOT-ACK(IT+18)) 960,1100,970                                 CHD 4708
  960 PCO1=ACK(IT+23)                                                   CHD 4709
  970 PCO2=S1                                                           CHD 4710
      GO TO 1000                                                        CHD 4711
  980 PCO1=S1                                                           CHD 4712
```

```
      PCO2=S2
      GO TO 1000
  990 PCO1=S2
      PCO2=S2+10.
 1000 IF (1.0001*PCO1.GE.PCO2) GO TO 1100
      DO 1090 IKJ=1,3
      IF (IKJ-2) 1010,1020,1030
 1010 PCP2=.99
      GO TO 1040
 1020 PCP2=.5
      GO TO 1040
 1030 PCP2=.01
 1040 PCP2=PCP2*PCO1+(1.-PCP2)*PCO2
      IF (PCP2.LE.ACK(IT+23)) GO TO 1090
      CALL ANEOS (BOOT,PCP2,S3,S4,S5,S6,S7,S8,S9,SPS,JJ,MAT)
      IF (I2-2) 1050,1060,1070
 1050 IF (JJ-6) 1080,1090,1080
 1060 IF (JJ-5) 1080,1090,1080
 1070 IF (JJ-4) 1080,1090,1080
 1080 PRINT 1340, MAT,PCP2,BOOT,JJ
      PCP1=MAT
 1090 CONTINUE
 1100 CONTINUE
      CMLT(8)=1.
 1110 DFN2=DFN2+1.
      IF (DFN2-3.) 1120,1130,1140
 1120 BOOT=BOOT+(ACK(IT+18)-ACK(IT+49))/3.
      GO TO 1150
 1130 BOOT=ACK(IT+18)
      GO TO 1150
 1140 BOOT=BOOT*(ACK(IT+48)/ACK(IT+18))**.06
 1150 IF (BOOT.LT.ACK(IT+48)) GO TO 930
      IF (PCP1) 1160,1170,1160
 1160 CMLT(8)=MAT
      GO TO 1180
 1170 CMLT(8)=DFN1
 1180 IF (I1.EQ.1) PRINT 1380
 1190 CMLT(7)=0.
      IF (ACK(IT+30).EQ.2.) GO TO 1210
      IF (ACK(IT+1).GT.1.E50) GO TO 1210
      PRINT 1410
      S3=ACK(IT+11)
      IF (ACK(IT+1).GE.1.E50) S3=.05*S3
      IF (ACK(IT+1).GE.1.E50) S2=S3
      IF (ACK(IT+1).LT.1.E50) S2=(ACK(IT+2)*ACK(IT+19)-S3)/25.
      DO 1200 I=1,50
      CMLT(7)=-1.
      CALL ANEOS1 (1.E-6,S3,S4,S5,S6,S7,S8,GAM,IT)
      S6=S3/ACK(IT+19)
      PRINT 1420, S3,S4,GAM,S5,S6
 1200 S3=S3+S2
 1210 IT=IT+54
      IZ=IZI+1
      CMLT(7)=0.
      IF (THUG.LT.0.) THUG=DZB(12)
```

```
      IF (RHUG.LT.0.) RHUG=DZB(11)
      CALL ANHUG (MAT,RHUG,THUG)
 1220 CONTINUE
      IF (IZ.GT.100) GO TO 1230
      IF (IT.GT.1080) GO TO 1230
      IF (IKPN.GT.1000) GO TO 1230
      RETURN
 1230 PRINT 1550, IZ,IT,IKPN
      STOP 1016
C
C     WRITE RESTART DATA
 1240 WRITE (ITAPE) (ACK(I),I=1,NACK),(LOCSV(I),I=1,NLOCSV)
      RETURN
C
C     READ RESTART DATA
 1250 READ (ITAPE) (ACK(I),I=1,NACK),(LOCSV(I),I=1,NLOCSV)
      RETURN
C
 1260 FORMAT (27H1 CHART D ANALYTIC EOS DATA,10X,12HVERSION 8/71)
 1270 FORMAT (//,35H  UNABLE TO INCLUDE MELT TRANSITION,5X,21HWILL CONTI
     1NUE WITHOUT)
 1280 FORMAT (34H0 MELT TEMPERATURE INCREASED FROM ,E12.5,/)
 1290 FORMAT (//,7H  RHOL=,E13.6,4X,5HRHOS=,E13.6)
 1300 FORMAT (//,29H  HIGH TEMPERATURE MELT ERROR,3E15.6)
 1310 FORMAT (/,42H0 WARNING - ZB(17) HAS BEEN INCREASED FROM,E12.5,3H T
     1O,E12.5,24H FOR THE MELT TRANSITION,/)
 1320 FORMAT (//,28H  LOW TEMPERATURE MELT ERROR,3E15.6)
 1330 FORMAT (29H1 RECALCULATION OF EOS NUMBER,I5)
 1340 FORMAT (34H  FAST ANLS ITERATION FAILURE MAT=,I5,/,6H  RHO=,E12.5,
     13X,2HT=,E12.5,2X,7HKPHASE=,I5)
 1350 FORMAT (13H1   MELT CURVE,//,7X,1HT,10X,2HRS,10X,2HPS,10X,2HES,10X,
     12HSS,10X,2HGS,/,18X,2HRL,10X,2HPL,10X,2HEL,10X,2HSL,10X,2HGL)
 1360 FORMAT (/,6E12.4)
 1370 FORMAT (I10,2X,5E12.4)
 1380 FORMAT (///,27H  DO NOT USE THIS EOS......)
 1390 FORMAT (24H0 MELT TEMPERATURE ERROR,/,5E13.4,I6)
 1400 FORMAT (18H0 THERE IS NO TYPE,E12.5,4H EOS,/,(8E13.6))
 1410 FORMAT (27H1 ZERO-TEMPERATURE ISOTHERM,//,8X,3HRHO,10X,1HP,9X,4HDP
     1DR,10X,1HE,10X,3HETA)
 1420 FORMAT (2X,5E12.4)
 1430 FORMAT (I3,I5,I2,5A10,2E10.3)
 1440 FORMAT (34H1 EOS DATA FOR ANALYTIC EOS NUMBER,I6,5X,14HLIBRARY NUM
     1BER,I5,5X,4HTYPE,I3,//,2X,5A10,//,7H  RHUG=,E12.4,9X,5HTHUG=,E12.4
     2,/)
 1450 FORMAT (7H1 ISE =,I6)
 1460 FORMAT (8E10.3)
 1470 FORMAT (3(5H  ZB(,I2,2H)=,E16.9))
 1480 FORMAT (1X)
 1490 FORMAT (34H1 THE IONIZATION POTENTIALS FOR Z=,I4,17H ARE NOT IN TA
     1BLE)
 1500 FORMAT (48H0 TGAM FOR EXPANDED STATES HAS BEEN CHANGED FROM,E13.5,
     13H TO,E13.5,/)
 1510 FORMAT (3(4H  C(,I2,2H)=,E16.9))
 1520 FORMAT (4H  Z(,I2,2H)=,F4.0,7H   COT(,I2,2H)=,E12.5,7H    FNI(,I2,2
     1H)=,E12.5)

 1530 FORMAT (28H0 REFERENCE POINT CONDITIONS,/,4H  T=,E14.6,7X,4HRHO=,E
     114.6,/,4H  P=,E14.6,7X,2HE=,E14.6,/,4H  S=,E14.6,7X,3HCV=,E14.6,/,
     27H  DPDT=,E14.6,4X,5HDPDR=,E14.6,/,5H  B0=,E14.6,6X,3HCS=,E14.6)
 1540 FORMAT (8H0 LOCKP(,I2,2H)=,I4,11H    LOCKPL(,I2,2H)=,I4)
 1550 FORMAT (25H1 ARRAY OVERFLOW IN ANEOS,10X,3HIZ=,I5,5H  IT=,I5,7H  I
     1KPN=,I6)
 1560 FORMAT (5(F5.0,E10.3))
      END
```

```
      SUBROUTINE ANION1 (T,RHO,Z,FN,P,E,S,CV,DPDT,DPDR,ZBAR,TTT)          CHD 4831
C     ANEOS PACKAGE                                                       CHD 4832
C     SINGLE-ELEMENT IONIZATION CALCULATION                               CHD 4833
      COMMON /ANES/ ACK(1080),ZZS(100),COT(100),FNI(100),RCT(21),TCT(21)CHD 4834
     1,RSOL(1000),RVAP(1000),TTWO(1000),SAVER(92),CMLT(8),ZB(92),DZB(40)CHD 4835
     2,BOLTS,EIP(4370),LOCSV(21),LOCKP(21),LOCKPL(21)                    CHD 4836
      T32=6.E21*TTT/(RHO*FN)                                              CHD 4837
      IZ=Z                                                                CHD 4838
      I1=(IZ*(IZ+1))/2+1                                                  CHD 4839
      FLT=ALOG(T32)                                                       CHD 4840
      EIU=EIP(I1)                                                         CHD 4841
      EIL=EIU/T                                                           CHD 4842
      FK1=T32*EXP(-EIL)                                                   CHD 4843
      IF (FK1.GT.0.5) GO TO 20                                            CHD 4844
      K=0                                                                 CHD 4845
      ZBAR=.5*(SQRT(FK1*(FK1+4.))-FK1)                                    CHD 4846
      IF (ZBAR.GT.1.E-6) GO TO 10                                         CHD 4847
      ZBAR=P=E=S=CV=DPDT=DPDR=0.                                          CHD 4848
      GO TO 130                                                           CHD 4849
   10 DZBT=FK1*(1.-ZBAR)/(2.*ZBAR+FK1)                                    CHD 4850
      DZBR=-DZBT/RHO                                                      CHD 4851
      DZBT=DZBT*(1.5+EIL)/T                                               CHD 4852
      GO TO 100                                                           CHD 4853
   20 I2=I1+IZ-1                                                          CHD 4854
      EIU=EIP(I2)                                                         CHD 4855
      EIL=EIU/T                                                           CHD 4856
      FK2=T32*EXP(-EIL)                                                   CHD 4857
      IF (FK2.LT.Z-0.5) GO TO 30                                          CHD 4858
      K=IZ-1                                                              CHD 4859
      FK1=FK2-Z+1.                                                        CHD 4860
      ZBAR=.5*(SQRT(FK1**2+4.*Z*FK2)-FK1)                                 CHD 4861
      IF (FK1.GT.1.E7) ZBAR=Z                                             CHD 4862
      DZBT=FK2*(Z-ZBAR)/(2.*ZBAR+FK1)                                     CHD 4863
      DZBR=-DZBT/RHO                                                      CHD 4864
      DZBT=DZBT*(1.5+EIL)/T                                               CHD 4865
      GO TO 100                                                           CHD 4866
   30 DO 40 I=1,IZ                                                        CHD 4867
      K=I-1                                                               CHD 4868
      ZBAR=I                                                              CHD 4869
      ZBAR=ZBAR+0.5                                                       CHD 4870
      EIU=EIP(I1+I)                                                       CHD 4871
      FI=EIU/T+SAVER(I)-FLT                                               CHD 4872
      IF (FI.GE.0.) GO TO 50                                              CHD 4873
   40 CONTINUE                                                            CHD 4874
      STOP 4040                                                           CHD 4875
   50 EIL=EIP(I1+K)                                                       CHD 4876
      DLL=(EIU-EIL)/T                                                     CHD 4877
      FIBAR=EIU                                                           CHD 4878
      ZBARU=ZBAR                                                          CHD 4879
      ZBARL=ZBAR-1.                                                       CHD 4880
      K=0                                                                 CHD 4881
   60 FIP=1./ZBAR+DLL                                                     CHD 4882
      DZBAR=-FI/FIP                                                       CHD 4883
      ZZBAR=ZBAR                                                          CHD 4884
      ZBAR=ZBAR+DZBAR                                                     CHD 4885
```

```
      IF (ABS(DZBAR).LE.1.E-6*ZZBAR) GO TO 90
   70 K=K+1
      IF (K.GT.100) STOP 4041
      IF (ZBAR.GT.0.) GO TO 80
      ZBAR=ZBAR-.5*DZBAR
      GO TO 70
   80 FIBAR=EIL*(ZBARU-ZBAR)+EIU*(ZBAR-ZBARL)
      FI=FIBAR/T+ALOG(ZBAR)-FLT
      GO TO 60
   90 DZBT=ZBAR/(T+ZBAR*(EIU-EIL))
      DZBR=-T*DZBT/RHO
      DZBT=DZBT*(1.5+FIBAR/T)
      K=ZBAR
  100 ZBARL=FN*BOLTS
      P=ZBAR*ZBARL*RHO*T
      DPDT=RHO*ZBARL*(ZBAR+T*DZBT)
      DPDR=ZBARL*T*(ZBAR+RHO*DZBR)
      E=0.
      IF (K.EQ.0) GO TO 120
      DO 110 I=1,K
  110 E=E+EIP(I1+I-1)
  120 EIL=K
      EIU=EIP(I1+K)
      E=ZBARL*(1.5*ZBAR*T+E+(ZBAR-EIL)*EIU)
      CV=ZBARL*(1.5*(ZBAR+T*DZBT)+EIU*DZBT)
      S=ZBAR*ZBARL*(FLT+2.5-ALOG(ZBAR))
  130 RETURN
      END
```

```
      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/(RHO*FN)
      ZBAR=ZRAT*XX
      IF (ZBAR.LT.1.E-6) GO TO 30
      IF (ZBAR.GT.ZBARM) ZBAR=.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)
      E=0.
      DO 120 I=1,NMATS
      IZ=ISK+I
      C=FNI(IZ)
      I1=ZZS(IZ)
      I1=(I1*(I1+1))/2
      KK=ZB(I)
      IF (KK.EQ.0) GO TO 110
      DO 100 J=1,KK
  100 E=E+C*EIP(I1+J)
  110 S=KK
  120 E=E+C*(ZB(I)-S)*EIP(I1+KK+1)
      E=1.5*ZBAR*ZC1*T+E*BOLTS
      S=ZBAR*ZC1*(FLXX/T+2.5)
      XX=ZBAR/XX
      IF (XX.GT.1.E-10) ZRAT=XX
      RETURN
      END
```

```
      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(1060),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                                                              CHD 5116
    E1=EM                                                              CHD 5117
    S1=SM                                                              CHD 5118
    CV1=CVM                                                            CHD 5119
    DPDT1=DPDTM                                                        CHD 5120
    DPDR1=DPDRM                                                        CHD 5121
    GO TO 120                                                          CHD 5122
110 CALL ANEOS1 (T,R1,P1,E1,S1,CV1,DPDT1,DPDR1,LOC)                    CHD 5123
120 X3=R1-R2                                                           CHD 5124
    X1=(R1-R)/X3                                                       CHD 5125
    X2=(R-R2)/X3                                                       CHD 5126
    FM1=R1*X2/R                                                        CHD 5127
    FM2=R2*X1/R                                                        CHD 5128
    E=FM1*E1+FM2*E2                                                    CHD 5129
    S=FM1*S1+FM2*S2                                                    CHD 5130
    IF (P1.LE.P2) GO TO 130                                            CHD 5131
    DPDR=0.995*R1+0.005*R2                                             CHD 5132
    IF (R.LE.CPDR) GO TO 130                                           CHD 5133
    X4=R1-DPDR                                                         CHD 5134
    P=(P1*(R-DPDR)+P2*(R1-R))/X4                                       CHD 5135
    DPDR=(P1-P2)/X4                                                    CHD 5136
    GO TO 140                                                          CHD 5137
130 P=P2                                                               CHD 5138
    DPDR=0.                                                            CHD 5139
140 DPDT=(S2-S1)*R1*R2/X3                                              CHD 5140
    IF (KK.EQ.K1) GO TO 150                                            CHD 5141
    X4=(RVAP(KK)-RVAP(KJ))/DT                                          CHD 5142
    X5=(RSOL(KK)-RSOL(KJ))/DT                                          CHD 5143
    GO TO 160                                                          CHD 5144
150 X4=R2P                                                             CHD 5145
    X5=R1P                                                             CHD 5146
160 CONTINUE                                                           CHD 5147
    X3=-(R1*X1*X4+R2*X2*X5)/(R*X3)                                     CHD 5148
    X1=CV1+(P1-T*DPDT1)*X5/R1**2                                       CHD 5149
    X2=CV2+(P2-T*DPDT2)*X4/R2**2                                       CHD 5150
    CV=X3*(E1-E2)+FM1*X1+FM2*X2                                        CHD 5151
    RETURN                                                             CHD 5152
    END                                                                CHD 5153
```

```
      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.EQ.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
  360 IF (R1.LT.ACK(IT+23)) PRINT 480, ACK(IT+23),R1
      GO TO 380
  370 IF (JJJ.EQ.2.AND.I.EQ.1.AND.ACK(IT+46).GT.0.) GO TO 380
      IF (5*(I/5).NE.I) GO TO 390
  380 PRINT 490, T,R1,P1,E1,S1,G1,NTY,R2,P2,E2,S2,G2
  390 CONTINUE
  400 RSOL(IK)=ACK(IT+19)
      RVAP(IK)=0.
      TTWO(IK)=0.
      IKPN=IK+1
      RETURN
C
  410 FORMAT (23H  WILL LEAVE POINT OUT.)
  420 FORMAT (26H  WILL CHANGE FORM OF EOS.)
  430 FORMAT (62H  WARNING - NEGATIVE EXPANSION COEFFICIENT IN THE LIQUI
     1D PHASE,/,2X,2HT=,E12.5,2X,4HRHO=,E12.5,5X,29HIMPROPER BEHAVIOR WI
     2LL RESULT)
  440 FORMAT (68H0 THE CRITICAL POINT ITERATION WILL NOT CONVERGE FOR MA
     1TERIAL NUMBER,I5,26H. WILL CHANGE FORM OF EOS.)
  450 FORMAT (36H1 TWO-PHASE CALCULATION FOR MATERIAL,I5,/,16H  CRITICAL
     1 POINT,/,6H  RHO=,E15.7,7X,2HT=,E15.7,9X,2HP=,E15.7,/,2X,2HE=,E15.
     27,9X,2HS=,E15.7,9X,4HNTY=,I5,/)
  460 FORMAT (26H0 THE MELTING TEMPERATURE(,E15.7,64H) IS GREATER THAN C
     1RITICAL TEMPERATURE. WILL CHANGE FORM OF EOS.)
  470 FORMAT (22H0 TWO-PHASE BOUNDARIES,/,7X,1HT,9X,6HRHOLIQ,8X,4HPLIQ,9
     1X,4HELIQ,9X,4HSLIQ,9X,4HGLIQ,/,17X,6HRHOVAP,8X,4HPVAP,9X,4HEVAP,9X
     2,4HSVAP,9X,4HGVAP)
  480 FORMAT (40H0 WARNING - - THE MINIMUM SOLID DENSITY(,E12.5,43H) IS
     1GREATER THAN THE TRIPLE POINT DENSITY(,E12.5,2H).,/,68H  IMPROPER
     2SOLID BEHAVIOR WILL RESULT. TO CORRECT USE SMALLER VALUE.,/)
  490 FORMAT (/,6E13.5,/,I13,5E13.5)
      END
```

```
      SUBROUTINE ANMAXW (T,RL,RV,L,MAT,IERR)
C     ANEOS PACKAGE
C     LIQUID-VAPOR AND SOLID-VAPOR MAXWELL CONSTRUCTION
      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 /CNES/ P1,E1,S1,G1,P2,E2,S2,G2
      N=NP=0
      CM7=CMLT(7)
      IF (IERR.LT.0) NP=1
      IF (RV.LT.0.) GO TO 230
      RVO=RLO=RCT(MAT)
      RV=ACK(L+25)**3*EXP(3.*ACK(L+15)-1.-ACK(L+10)/(ACK(L+27)*BOLTS*T))
     1/(ACK(L+13)*T)**1.5
      IF (RL) 10,20,30
   10 RL=-RL
      AL=0.
      GO TO 40
   20 RL=ACK(L+19)
   30 AL=1.
   40 RLM=RL
      DP2=1.E-3*RL
      IF (RV.GT.DP2) RV=DP2
      IF (RV.LT.1.E-100) RV=1.E-100
   50 IERR=0
   60 CALL ANEOS1 (T,RV,P2,E2,S2,D1,D2,DP2,L)
      IF (DP2.GT.0.) GO TO 80
      RVO=RV
      RV=.99*RV
      IF (IERR.GT.30) RV=.5*RV
      IERR=IERR+1
      IF (IERR-900) 60,60,70
   70 IERR=-1
      GO TO 220
   80 G2=E2-T*S2+P2/RV
      IERR=0
   90 IF (T.LT.ACK(L+18)) CMLT(7)=-1.
      CALL ANEOS1 (T,RL,P1,E1,S1,D1,D2,DP1,L)
      CMLT(7)=CM7
      IF (DP1.GT.0.) GO TO 110
      RLO=RL
      RL=1.005*RL
      IERR=IERR+1
      IF (IERR-900) 90,90,100
  100 IERR=-2
      GO TO 220
  110 G1=E1-T*S1+P1/RL
      SP=P1-P2
      SG=G1-G2
      DRL=AL*RL*(SP-RV*SG)/(DP1*(RV-RL))
      DRV=RV*(SP-RL*SG)/(DP2*(RV-RL))
      IF (ABS(DRL).GT.1.E-6*RL) GO TO 120
      IF (ABS(DRV).LE.1.E-6*RV) GO TO 200
  120 IF (N.GT.40) DRL=.5*DRL
      IF (N.LT.60) GO TO 130
```

```
      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 ANMAXW 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
  150 IF (1.04*RS-RHO) 160,210,180
  160 IF (DRL) 170,210,210
  170 IF (DRS) 250,210,210
  180 IF (RL-1.04*RHO) 210,210,190
  190 IF (DRL) 210,210,200
  200 IF (DRS) 210,210,260
  210 ADRS=ABS(DRS)
      ADRL=ABS(DRL)
      IF (ADRS.GT.1.E-7*RS) GO TO 220
      IF (ADRL.LE.1.E-7*RL) GO TO 240
  220 IF (IERR.LT.400) GO TO 230
      DRS=.1*DRS
      DRL=.1*DRL
      IF (IERR.GT.500) GO TO 280
  230 GL=GSX*RS
      IF (ADRS.GT.GL) DRS=GL*DRS/ADRS
      GL=GSX*RL
      IF (ADRL.GT.GL) DRL=GL*DRL/ADRL
      RS=RS+DRS
      RL=RL+DRL
      IF (RS.LE.RL) RS=1.00001*RL
      IERR=IERR+1
      GO TO 140
  240 NERR=IERR
      IF (RHO.LE.RL) GO TO 260
      IF (RHO.GE.RS) GO TO 250
      IERR=2
      GO TO 310
  250 IERR=1
      GO TO 320
  260 IERR=3
      GO TO 320
  270 IERR=-1
      GO TO 290
  280 IERR=-2
  290 PRINT 330, T,RHO,IERR,RS,RL,DRS,DRL
      IF (NP.GE.1) RETURN
      STOP
  300 IERR=-4
      IF (NP.LE.2) GO TO 290
      IERR=-3
      RETURN
C     IN LIQUID-SOLID REGION HERE
  310 X2=RHO*(RS-RL)
      DRS=RS*(RHO-RL)/X2
      DRL=RL*(RS-RHO)/X2
      DPDTM=(SL-SS)*((RS*RL)/(RS-RL))
      DRLDT=(DPDTM-DPDTL)/DPDRL
      DRSDT=(DPDTM-DPDTS)/DPDRS
      X1=-RHO*(RL*(RHO-RL)*DRSDT+RS*(RS-RHO)*DRLDT)/X2**2
      EM=DRS*ES+DRL*EL
      SM=DRS*SS+DRL*SL
      CVM=X1*(ES-EL)+DRS*(CVS+(PS-T*DPDTS)*DRSDT/RS**2)+DRL*(CVL+(PL-T*D
     1PDTL)*DRLDT/RL**2)

      DPDRM=0.
      PM=DRS*PS+DRL*PL
  320 IF (NP.EQ.2) IERR=NERR
      RETURN
C
  330 FORMAT (///,21H0 FATAL ERROR IN ANLS,2E12.5,I5,4E13.5)
      END
```

```
      SUBROUTINE ANHUG (M,RO,TO)                                         CHD 5580
C     ANEOS PACKAGE                                                      CHD 5581
C     HUGONIOT CALCULATION                                               CHD 5582
      DIMENSION TS(48), CD(8)                                            CHD 5583
      COMMON /BIG/ B(1)                                                  CHD 5584
      EQUIVALENCE (PO,B(1)), (EO,B(2)), (SO,B(3)), (D1,B(4)), (D2,B(5)),CHD 5585
     1 (D3,B(6)), (D4,B(7)), (VO,B(8)), (T,B(9)), (R,B(10)), (P,B(11)), CHD 5586
     2(E,B(12)), (S,B(13)), (CV,B(14)), (PT,B(15)), (PR,B(16)), (F,B(17)CHD 5587
     3), (DF,B(18)), (DR,B(19)), (V,B(20)), (U,B(21)), (TS(1),B(22))    CHD 5588
      EQUIVALENCE (CD(1),B(75))                                          CHD 5589
      DATA (TS(I),I=1,48)/.026,.0265,.0275,.0285,.03,.035,.04,.05,.06,.0CHD 5590
     18,.1,.12,.14,.16,.18,.2,.25,.3,.35,.4,.45,.5,.55,.6,.65,.7,.75,.8,CHD 5591
     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.,CHD 5592
     310./                                                               CHD 5593
      IF (RO.LE.0.) RETURN                                               CHD 5594
      IF (TO.LE.0.) RETURN                                               CHD 5595
      PRINT 40                                                           CHD 5596
      CALL ANEOS (1.E-6,RO,CD(1),CD(2),CD(3),CD(4),CD(5),CD(6),CD(7),CD(CHD 5597
     18),KP,M)                                                           CHD 5598
      CALL ANEOS (TO,RO,PO,EO,SO,D1,D2,D3,D4,VO,KP,M)                    CHD 5599
      D1=0.                                                              CHD 5600
      D2=1.                                                              CHD 5601
      PRINT 60                                                           CHD 5602
      PRINT 50, RO,TO,PO,CD(1),EO,SO,VO,D1,D2                            CHD 5603
      N=51                                                               CHD 5604
      DO 30 I=1,48                                                       CHD 5605
      T=TS(I)                                                            CHD 5606
      IF (T.LE.TO) GO TO 30                                              CHD 5607
      IF (N.GT.50) R=RO                                                  CHD 5608
      N=0                                                                CHD 5609
   10 CALL ANEOS (T,R,P,E,S,CV,PT,PR,D1,D2,KP,M)                         CHD 5610
      F=E-EO+.5*(PO+P)*(RO-R)/(R*RO)                                     CHD 5611
      DF=(P-T*PT)/R**2+.5*PR*(RO-R)/(RO*R)-.5*(PO+P)/R**2                CHD 5612
      IF (DF.EQ.0.) GO TO 30                                             CHD 5613
      DR=-F/DF                                                           CHD 5614
      IF (ABS(DR).LE.1.E-8*R) GO TO 20                                   CHD 5615
      D1=1.                                                              CHD 5616
      IF (DR.LT.0.) D1=-1.                                               CHD 5617
      IF (ABS(DR).GT..5*R) DR=.5*R*D1                                    CHD 5618
      R=R+DR                                                             CHD 5619
      N=N+1                                                              CHD 5620
      IF (N-50) 10,10,30                                                 CHD 5621
   20 V=SQRT((P-PO)/(RO*(1.-RO/R)))                                      CHD 5622
      U=V*(1.-RO/R)                                                      CHD 5623
      D1=R/RO                                                            CHD 5624
      DF=1H                                                              CHD 5625
      IF (KP.EQ.4) DF=5HSOLID                                            CHD 5626
      IF (KP.EQ.5) DF=4HMELT                                             CHD 5627
      IF (KP.EQ.6) DF=6HLIQUID                                           CHD 5628
      CALL ANEOS (1.E-6,R,CD(1),CD(2),CD(3),CD(4),CD(5),CD(6),CD(7),CD(8CHD 5629
     1),KP,M)                                                            CHD 5630
      PRINT 50, R,T,P,CD(1),E,S,V,U,D1,N,DF                              CHD 5631
   30 CONTINUE                                                           CHD 5632
      RETURN                                                             CHD 5633
C                                                                        CHD 5634

   40 FORMAT (10H1 HUGONIOT)                                             CHD 5635
   50 FORMAT (9E12.4,I3,2X,A6)                                           CHD 5636
   60 FORMAT (9H0      RHO,10X,1HT,11X,1HP,10X,2HPC,11X,1HE,11X,1HS,11X,1CHD 5637
     1HV,11X,1HU,7X,8HRHO/RHOO)                                          CHD 5638
      END                                                                CHD 5639
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      SUBROUTINE ANPHTR (C,MAT,TGAM)                                    CHD 5640
C     ANEOS PACKAGE                                                     CHD 5641
C     MODIFIES THE ZERO-TEMPERATURE ISOTHERM OF THE ANALYTICAL EOS      CHD 5642
C     FOR A TEMPERATURE INDEPENDENT PHASE TRANSITION                    CHD 5643
      DIMENSION C(1)                                                    CHD 5644
      IF (C(30).EQ.2.) RETURN                                           CHD 5645
      IF (C(1).GT.C(19)) GO TO 20                                       CHD 5646
   10 C(1)=1.E100                                                       CHD 5647
      C(2)=C(7)=C(8)=C(9)=C(38)=C(39)=C(40)=0.                          CHD 5648
      RETURN                                                            CHD 5649
   20 S3=C(15)+TGAM/3.                                                  CHD 5650
      S1=S3-2.5                                                         CHD 5651
      S2=S3+2.5                                                         CHD 5652
      S4=EXP(-C(33))*C(32)                                              CHD 5653
      S5=(15.+7.*C(33)+C(33)**2)*S4                                     CHD 5654
      S6=(10.+4.*C(33)+.5*C(33)**2)*S4                                  CHD 5655
      S4=(6.+3.*C(33)+.5*C(33)**2)*S4                                   CHD 5656
      ETA1=C(1)/C(19)                                                   CHD 5657
      S7=ETA1**.3333333333                                              CHD 5658
      S8=C(32)*ETA1*S7**2*EXP(-C(33)/S7)                                CHD 5659
   30 C34=S4-9.*S3*C(3)                                                 CHD 5660
      C35=3.*C(3)*(6.*S3+1.)-S5                                         CHD 5661
      C36=S6-3.*C(3)*(3.*S3+1.)                                         CHD 5662
      PTR=S8-(C34+C35*S7+C36*S7**2)                                     CHD 5663
      IF (C(7).EQ.0.) GO TO 70                                          CHD 5664
      IF (ABS(PTR-C(7)).LE.1.E-4*(PTR+C(7))) GO TO 70                   CHD 5665
      IF (S2-S1.LT.1.E-7) GO TO 70                                      CHD 5666
      IF (PTR-C(7)) 50,70,40                                            CHD 5667
   40 S2=S3                                                             CHD 5668
      GO TO 60                                                          CHD 5669
   50 S1=S3                                                             CHD 5670
   60 S3=.5*(S1+S2)                                                     CHD 5671
      GO TO 30                                                          CHD 5672
   70 IF (C(2).LT.C(1)) C(2)=C(1)                                       CHD 5673
      ETA2=C(2)/C(19)                                                   CHD 5674
      C37=C(37)-C(34)+C34-1.5*(C(35)-C35)-3.*(C(36)-C36)                CHD 5675
      S1=C(33)/S7                                                       CHD 5676
      S2=EXP(-S1)                                                       CHD 5677
      CALL EPINT3 (S1,S2,S4)                                            CHD 5678
      C8=(3.*C(32)*S4*S7**2+C34/ETA1+1.5*C35*S7/ETA1+3.*C36/S7-C37)/C(19CHD 5679
     1)                                                                 CHD 5680
      DP1=C(32)*S7*(5.*S7+C(33))*EXP(-C(33)/S7)/3.-(C35/S7+2.*C36)/(3.*SCHD 5681
     17)                                                                CHD 5682
      DP2=C(32)*((10.+6.*C(33)/S7)/S7+C(33)**2/ETA1)*EXP(-C(33)/S7)/9.+2CHD 5683
     1.*(C35/S7+C36)/(9.*ETA1*S7)                                       CHD 5684
      IF (C(39)) 80,90,100                                              CHD 5685
   80 DP3=-DP1*C(39)                                                    CHD 5686
      GO TO 110                                                         CHD 5687
   90 DP3=DP1*ETA2/ETA1                                                 CHD 5688
      GO TO 110                                                         CHD 5689
  100 DP3=C(39)                                                         CHD 5690
  110 IF (C(40)) 120,130,140                                            CHD 5691
  120 DP4=-DP2*C(40)                                                    CHD 5692
      GO TO 150                                                         CHD 5693
  130 DP4=DP2*(ETA2/ETA1)**2                                            CHD 5694
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      GO TO 150                                                         CHD 5695
  140 DP4=C(40)                                                         CHD 5696
  150 S1=ETA2**.3333333333                                              CHD 5697
      S2=EXP(-C(33)/S1)                                                 CHD 5698
      S4=C(32)*S1*(5.*S1+C(33))*S2-3.*DP3                               CHD 5699
      S5=9.*ETA2*DP4-C(32)*(10.*S1**2+6.*C(33)*S1+C(33)**2)*S2          CHD 5700
      C39=S1*S1*(S5-S4)                                                 CHD 5701
      C40=S1*(S4-.5*S5)                                                 CHD 5702
      C38=C(32)*S1**2*ETA2*S2-PTR-(C39+C40*S1)*S1                       CHD 5703
      EN2=C8+PTR*(ETA2-ETA1)/(C(19)*ETA1*ETA2)                          CHD 5704
      S4=C(33)/S1                                                       CHD 5705
      CALL EPINT3 (S4,S2,S5)                                            CHD 5706
      C9=EN2-(3.*C(32)*S5*S1**2+C38/ETA2+(1.5*C39/S1+3.*C40)/S1)/C(19)  CHD 5707
      S4=3.*(S3-C(15))                                                  CHD 5708
      PRINT 180, PTR,C(7),DP1,DP3,DP2,DP4,C8,EN2,S4,TGAM                CHD 5709
      IF (C(7).GT.C.) GO TO 160                                         CHD 5710
      IF (ETA2.GT.ETA1) GO TO 170                                       CHD 5711
      IF (C(39).NE.0.) GO TO 170                                        CHD 5712
      IF (C(40).NE.0.) GO TO 170                                        CHD 5713
      PRINT 190                                                         CHD 5714
      GO TO 10                                                          CHD 5715
  160 IF (ABS(PTR-C(7)).LE.1.E-3*(PTR+C(7))) GO TO 170                  CHD 5716
      PRINT 200                                                         CHD 5717
  170 PRINT 210                                                         CHD 5718
      C(1)=ETA1                                                         CHD 5719
      C(2)=ETA2                                                         CHD 5720
      C(7)=PTR                                                          CHD 5721
      C(8)=C8                                                           CHD 5722
      C(9)=C9                                                           CHD 5723
      C(34)=C34                                                         CHD 5724
      C(35)=C35                                                         CHD 5725
      C(36)=C36                                                         CHD 5726
      C(37)=C37                                                         CHD 5727
      C(38)=C38                                                         CHD 5728
      C(39)=C39                                                         CHD 5729
      C(40)=C40                                                         CHD 5730
      RETURN                                                            CHD 5731
C                                                                       CHD 5732
  180 FORMAT (//,74H  ZERO-TEMPERATURE ISOTHERM HAS BEEN MODIFIED FOR A CHD 5733
     1SOLID PHASE TRANSITION,//,12H  PCTR(CAL)=,E13.6,10X,12HPCTR(INPUT)CHD 5734
     2=,E13.6,/,15H  DPDETA(ETA1)=,E13.6,7X,13HDPDETA(ETA2)=,E13.6,/,17HCHD 5735
     3  D2PDETA2(ETA1)=,E13.6,5X,15HD2PDETA2(ETA2)=,E13.6,/,11H  EC(ETA1CHD 5736
     4)=,E13.6,11X,9HEC(ETA2)=,E13.6,/,11H  TGAMSTAR=,E13.6,11X,5HTGAM=,CHD 5737
     5E13.6)                                                            CHD 5738
  190 FORMAT (64H0 ALL DEFAULT OPTIONS WERE USED.  NO TRANSITION WILL BECHD 5739
     1 INCLUDED,/,1H1)                                                  CHD 5740
  200 FORMAT (38H0 SOMETHING IS WRONG - CHECK CAREFULLY)                CHD 5741
  210 FORMAT (1H1)                                                      CHD 5742
      END                                                               CHD 5743
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      SUBROUTINE ANDATA (IT,IZ,ISETAB)                                  CHD 5744
C     ANEOS PACKAGE                                                     CHD 5745
C     DATA STATEMENTS                                                   CHD 5746
C     ATOMIC WEIGHT OF ELEMENT Z IS (Z*(Z+1))/2                         CHD 5747
C     FIRST IONIZATION POTENTIAL OF ELEMENT Z IS (Z*(Z+1))/2+1          CHD 5748
C     LAST IONIZATION POTENTIAL OF ELEMENT Z IS (Z*(Z+1))/2+Z           CHD 5749
      COMMON /ANES/ ACK(1080),ZZS(100),COT(100),FNI(100),RCT(21),TCT(21)CHD 5750
     1,RSOL(1000),RVAP(1000),TTWO(1000),SAVER(92),CMLT(8),ZB(92),DZB(40)CHD 5751
     2,BOLTS,EIP(4370),LOCSV(21),LOCKP(21),LOCKPL(21)                   CHD 5752
      COMMON /BIG/ BIGDUM(1)                                            CHD 5753
      DIMENSION TABLE(200), TABPL(200), DTAB(5000)                      CHD 5754
      DATA CMLT/.3,.1,.2,5*0./                                          CHD 5755
      DATA ACK,ZZS/1180*0./                                             CHD 5756
      DATA BOLTS/1.60207E-12/                                           CHD 5757
C     Z =  1                                                            CHD 5758
      DATA (EIP(I),I=1,2)/1.00801,1.3595E+01/                           CHD 5759
C     Z =  2                                                            CHD 5760
      DATA (EIP(I),I=3,5)/4.00280,2.4581E+01,5.4403E+01/                CHD 5761
C     Z =  3                                                            CHD 5762
      DATA (EIP(I),I=6,9)/6.93900,5.3900E+00,7.5619E+01,1.2242E+02/     CHD 5763
C     Z =  4                                                            CHD 5764
      DATA (EIP(I),I=10,14)/9.01300,9.3200E+00,1.8206E+01,1.5385E+02,2.1CHD 5765
     1766E+02/                                                          CHD 5766
C     Z =  5                                                            CHD 5767
      DATA (EIP(I),I=15,20)/10.81200,8.2960E+00,2.5149E+01,3.7920E+01,2.CHD 5768
     15930E+02,3.4013E+02/                                              CHD 5769
C     Z =  6                                                            CHD 5770
      DATA (EIP(I),I=21,27)/12.01161,1.1256E+01,2.4376E+01,4.7871E+01,6.CHD 5771
     14476E+01,3.9199E+02,4.8984E+02/                                   CHD 5772
C     Z =  7                                                            CHD 5773
      DATA (EIP(I),I=28,35)/14.00730,1.4530E+01,2.9593E+01,4.7426E+01,7.CHD 5774
     17450E+01,9.7863E+01,5.5192E+02,6.6683E+02/                        CHD 5775
C     Z =  8                                                            CHD 5776
      DATA (EIP(I),I=36,44)/16.00000,1.3614E+01,3.5108E+01,5.4886E+01,7.CHD 5777
     17394E+01,1.1387E+02,1.3808E+02,7.3911E+02,8.7112E+02/             CHD 5778
C     Z =  9                                                            CHD 5779
      DATA (EIP(I),I=45,54)/18.99920,1.7418E+01,3.4980E+01,6.2646E+01,8.CHD 5780
     17140E+01,1.1421E+02,1.5712E+02,1.8514E+02,9.5360E+02,1.1020E+03/  CHD 5781
C     Z = 10                                                            CHD 5782
      DATA (EIP(I),I=55,65)/20.18400,2.1559E+01,4.1070E+01,6.3500E+01,9.CHD 5783
     17020E+01,1.2630E+02,1.5791E+02,2.0720E+02,2.3910E+02,1.1956E+03,1.CHD 5784
     23604E+03/                                                         CHD 5785
C     Z = 11                                                            CHD 5786
      DATA (EIP(I),I=66,77)/22.99100,5.1380E+00,4.7290E+01,7.1650E+01,9.CHD 5787
     18880E+01,1.3837E+02,1.7209E+02,2.0844E+02,2.6416E+02,2.9978E+02,1.CHD 5788
     24648E+03,1.6461E+03/                                              CHD 5789
C     Z = 12                                                            CHD 5790
      DATA (EIP(I),I=78,90)/24.31300,7.6440E+00,1.5031E+01,8.0120E+01,1.CHD 5791
     10929E+02,1.4123E+02,1.8649E+02,2.2490E+02,2.6596E+02,3.2790E+02,3.CHD 5792
     26736E+02,1.7612E+03,1.9590E+03/                                   CHD 5793
C     Z = 13                                                            CHD 5794
      DATA (EIP(I),I=91,104)/26.98200,5.9840E+00,1.8823E+01,2.8440E+01,1CHD 5795
     1.1996E+02,1.5377E+02,1.9042E+02,2.4138E+02,2.8453E+02,3.3010E+02,3CHD 5796
     2.9850E+02,4.4190E+02,2.0855E+03,2.2990E+03/                       CHD 5797
C     Z = 14                                                            CHD 5798
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      DATA (EIP(I),I=105,119)/28.09000,8.1490E+00,1.6340E+01,3.3460E+01,CHD 5799
     14.5130E+01,1.6673E+02,2.0511E+02,2.4641E+02,3.0307E+02,3.5096E+02,CHD 5800
     24.0130E+02,4.7600E+02,5.2320E+02,2.4360E+03,2.6660E+03/           CHD 5801
C     Z = 15                                                            CHD 5802
      DATA (EIP(I),I=120,135)/30.97500,1.0484E+01,1.9720E+01,3.0156E+01,CHD 5803
     15.1354E+01,6.5007E+01,2.2041E+02,2.6331E+02,3.0926E+02,3.7160E+02,CHD 5804
     24.2430E+02,4.7940E+02,5.6030E+02,6.1140E+02,2.8150E+03,3.0610E+03/CHD 5805
C     Z = 16                                                            CHD 5806
      DATA (EIP(I),I=136,152)/32.06600,1.0357E+01,2.3400E+01,3.5000E+01,CHD 5807
     14.7290E+01,7.2500E+01,8.8029E+01,2.8099E+02,3.2880E+02,3.7895E+02,CHD 5808
     24.4700E+02,5.0580E+02,5.6600E+02,6.5100E+02,7.0600E+02,3.2200E+03,CHD 5809
     33.4820E+03/                                                       CHD 5810
C     Z = 17                                                            CHD 5811
      DATA (EIP(I),I=153,170)/35.45400,1.3010E+01,2.3800E+01,3.9900E+01,CHD 5812
     15.3500E+01,6.7800E+01,9.6700E+01,1.1427E+02,3.4830E+02,4.0070E+02,CHD 5813
     24.5530E+02,5.3090E+02,5.9300E+02,6.6300E+02,7.4900E+02,8.0700E+02,CHD 5814
     33.6540E+03,3.9310E+03/                                            CHD 5815
C     Z = 18                                                            CHD 5816
      DATA (EIP(I),I=171,189)/39.94900,1.5755E+01,2.7620E+01,4.0900E+01,CHD 5817
     15.9790E+01,7.5000E+01,9.1300E+01,1.2400E+02,1.4346E+02,4.2260E+02,CHD 5818
     24.7940E+02,5.3890E+02,6.2100E+02,6.8700E+02,7.5500E+02,8.5400E+02,CHD 5819
     39.1600E+02,4.1150E+03,4.4070E+03/                                 CHD 5820
C     Z = 19                                                            CHD 5821
      DATA (EIP(I),I=190,209)/39.10300,4.3390E+00,3.1810E+01,4.6000E+01,CHD 5822
     16.0900E+01,8.2600E+01,9.9700E+01,1.1800E+02,1.5500E+02,1.7594E+02,CHD 5823
     25.0380E+02,5.6400E+02,6.2900E+02,7.1700E+02,7.8800E+02,8.7000E+02,CHD 5824
     39.6600E+02,1.0310E+03,4.6030E+03,4.9100E+03/                      CHD 5825
C     Z = 20                                                            CHD 5826
      DATA (EIP(I),I=210,230)/40.08000,6.1110E+00,1.1868E+01,5.1210E+01,CHD 5827
     16.7000E+01,8.4390E+01,1.0900E+02,1.2800E+02,1.4330E+02,1.8800E+02,CHD 5828
     22.1130E+02,5.9180E+02,6.5500E+02,7.2700E+02,8.2000E+02,8.9600E+02,CHD 5829
     39.9000E+02,1.0840E+03,1.1530E+03,5.1190E+03,5.4710E+03/           CHD 5830
C     Z = 21                                                            CHD 5831
      DATA (EIP(I),I=231,252)/44.95800,6.5400E+00,1.2800E+01,2.4750E+01,CHD 5832
     17.3900E+01,9.2000E+01,1.1100E+02,1.3900E+02,1.5900E+02,1.8000E+02,CHD 5833
     22.2600E+02,2.5000E+02,6.8700E+02,7.5800E+02,8.3000E+02,9.3000E+02,CHD 5834
     31.0100E+03,1.1150E+03,1.2100E+03,1.2820E+03,5.4833E+03,6.0354E+03/CHD 5835
C     Z = 22                                                            CHD 5836
      DATA (EIP(I),I=253,275)/47.90000,6.8200E+00,1.3570E+01,2.7470E+01,CHD 5837
     14.3240E+01,9.9800E+01,1.2000E+02,1.4100E+02,1.7200E+02,1.9300E+02,CHD 5838
     22.1700E+02,2.6600E+02,2.9100E+02,7.8800E+02,8.6400E+02,9.4100E+02,CHD 5839
     31.0460E+03,1.1320E+03,1.2450E+03,1.3410E+03,1.4178E+03,6.0493E+03,CHD 5840
     46.6277E+03/                                                       CHD 5841
C     Z = 23                                                            CHD 5842
      DATA (EIP(I),I=276,299)/50.94400,6.7400E+00,1.4650E+01,2.9400E+01,CHD 5843
     14.8000E+01,6.5000E+01,1.2900E+02,1.5100E+02,1.7400E+02,2.0600E+02,CHD 5844
     22.3050E+02,2.5800E+02,3.0900E+02,3.3600E+02,8.9700E+02,9.7600E+02,CHD 5845
     31.0570E+03,1.1700E+03,1.2600E+03,1.3800E+03,1.4805E+03,1.5603E+03,CHD 5846
     46.6438E+03,7.2484E+03/                                            CHD 5847
C     Z = 24                                                            CHD 5848
      DATA (EIP(I),I=300,324)/52.00000,6.7640E+00,1.6490E+01,3.0950E+01,CHD 5849
     15.0000E+01,7.3000E+01,9.1000E+01,1.6100E+02,1.8500E+02,2.1000E+02,CHD 5850
     22.4900E+02,2.7200E+02,2.9900E+02,3.5500E+02,3.8400E+02,1.0130E+03,CHD 5851
     31.0950E+03,1.1820E+03,1.3010E+03,1.3950E+03,1.5252E+03,1.6263E+03,CHD 5852
     41.7097E+03,7.2667E+03,7.8974E+03/                                 CHD 5853
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C     Z = 25
      DATA (EIP(I),I=325,350)/54.94000,7.4330E+00,1.5636E+01,3.3690E+01,
     15.3000E+01,7.6000E+01,1.0000E+02,1.1900E+02,1.9600E+02,2.2200E+02,
     22.4800E+02,2.8800E+02,3.1500E+02,3.5000E+02,4.0400E+02,4.3500E+02,
     31.1360E+03,1.2220E+03,1.3130E+03,1.4380E+03,1.5380E+03,1.6780E+03,
     41.7790E+03,1.8660E+03,7.9180E+03,8.5750E+03/
C     Z = 26
      DATA (EIP(I),I=351,377)/55.84900,7.8700E+00,1.6180E+01,3.0643E+01,
     15.7000E+01,7.9000E+01,1.0300E+02,1.3000E+02,1.5100E+02,2.3500E+02,
     22.6200E+02,2.9000E+02,3.3000E+02,3.5500E+02,3.9000E+02,4.5700E+02,
     34.8900E+02,1.2660E+03,1.3540E+03,1.4500E+03,1.5830E+03,1.6870E+03,
     41.8370E+03,1.9380E+03,2.0290E+03,8.5990E+03,9.2810E+03/
C     Z = 27
      DATA (EIP(I),I=378,405)/58.93560,7.8600E+00,1.7050E+01,3.3490E+01,
     15.3000E+01,8.3000E+01,1.0800E+02,1.3400E+02,1.6400E+02,1.9000E+02,
     22.9000E+02,3.0500E+02,3.3700E+02,3.8000E+02,4.1200E+02,4.4400E+02,
     35.1200E+02,5.4700E+02,1.4030E+03,1.4950E+03,1.5949E+03,1.7342E+03,
     41.8429E+03,2.0045E+03,2.1045E+03,2.1989E+03,9.3098E+03,1.0018E+04/
C     Z = 28
      DATA (EIP(I),I=406,434)/58.71000,7.6330E+00,1.8150E+01,3.5160E+01,
     15.6000E+01,7.9000E+01,1.1200E+02,1.4000E+02,1.6900E+02,2.0200E+02,
     22.3000E+02,3.2100E+02,3.5000E+02,3.8500E+02,4.3000E+02,4.5500E+02,
     35.0000E+02,5.3000E+02,6.0700E+02,1.5410E+03,1.6421E+03,1.7465E+03,
     41.8922E+03,2.0055E+03,2.1789E+03,2.2779E+03,2.3755E+03,1.0048E+04,
     51.0782E+04/
C     Z = 29
      DATA (EIP(I),I=435,464)/63.55000,7.7240E+00,2.0290E+01,3.6830E+01,
     15.9000E+01,8.2000E+01,1.1000E+02,1.4000E+02,1.7000E+02,2.0600E+02,
     22.4100E+02,2.6500E+02,3.7000E+02,4.0000E+02,4.4000E+02,4.8000E+02,
     35.2000E+02,5.6000E+02,6.3000E+02,6.7100E+02,1.6940E+03,1.7960E+03,
     41.9050E+03,2.0570E+03,2.1750E+03,2.3600E+03,2.4580E+03,2.5590E+03,
     51.0813E+04,1.1573E+04/
C     Z = 30
      DATA (EIP(I),I=465,495)/65.37000,9.3910E+00,1.7960E+01,3.9700E+01,
     16.2000E+01,8.6000E+01,1.1500E+02,1.4500E+02,1.8000E+02,2.1000E+02,
     22.5000E+02,2.7935E+02,3.1100E+02,4.2000E+02,4.5000E+02,4.9000E+02,
     35.4000E+02,5.8000E+02,6.2000E+02,7.0000E+02,7.4111E+02,1.8500E+03,
     41.9555E+03,2.0680E+03,2.2225E+03,2.3593E+03,2.5473E+03,2.6592E+03,
     52.7671E+03,1.1665E+04,1.2441E+04/
C     Z = 31
      DATA (EIP(I),I=496,527)/69.72000,6.0000E+00,2.0510E+01,3.0700E+01,
     16.4200E+01,9.0000E+01,1.1800E+02,1.4400E+02,1.7400E+02,2.1800E+02,
     22.5500E+02,2.8922E+02,3.2071E+02,3.6584E+02,4.7072E+02,5.0313E+02,
     35.4522E+02,5.9701E+02,6.4272E+02,6.8534E+02,7.7042E+02,8.1423E+02,
     42.0127E+03,2.1217E+03,2.2379E+03,2.3948E+03,2.5503E+03,2.7414E+03,
     52.8673E+03,2.9821E+03,1.2543E+04,1.3336E+04/
C     Z = 32
      DATA (EIP(I),I=528,560)/72.60000,7.8800E+00,1.5930E+01,3.4210E+01,
     14.5700E+01,9.3400E+01,1.1300E+02,1.4800E+02,1.7700E+02,2.1200E+02,
     22.6200E+02,2.9525E+02,3.3145E+02,3.6510E+02,4.2370E+02,5.2445E+02,
     35.5929E+02,6.0345E+02,6.5704E+02,7.0845E+02,7.5370E+02,8.4387E+02,
     48.9038E+02,2.1822E+03,2.2948E+03,2.4145E+03,2.5739E+03,2.7482E+03,
     52.9423E+03,3.0821E+03,3.2038E+03,1.3449E+04,1.4259E+04/
C     Z = 33
      DATA (EIP(I),I=561,594)/74.92420,9.8100E+00,1.8630E+01,2.8340E+01,
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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/                                                       CHD 5970
C      Z = 41                                                           CHD 5971
      DATA (EIP(I),I=861,902)/92.91000,6.8800E+00,1.4320E+01,2.5040E+01,CHD 5972
     13.8300E+01,5.0000E+01,1.0300E+02,1.2500E+02,1.4300E+02,1.6700E+02,CHD 5973
     21.8500E+02,2.0300E+02,2.4888E+02,2.8281E+02,4.8379E+02,5.3443E+02,CHD 5974
     35.8270E+02,6.3074E+02,6.7838E+02,7.3654E+02,7.9341E+02,8.4753E+02,CHD 5975
     49.0055E+02,1.0804E+03,1.1440E+03,1.2006E+03,1.2635E+03,1.3332E+03,CHD 5976
     51.4360E+03,1.5049E+03,1.6408E+03,1.7117E+03,4.0140E+03,4.1583E+03,CHD 5977
     64.3100E+03,4.4918E+03,4.8349E+03,5.0564E+03,5.3214E+03,5.5054E+03,CHD 5978
     72.2827E+04,2.3784E+04/                                            CHD 5979
C      Z = 42                                                           CHD 5980
      DATA (EIP(I),I=903,945)/95.95000,7.1000E+00,1.6150E+01,2.7130E+01,CHD 5981
     14.6400E+01,6.1200E+01,6.8000E+01,1.2600E+02,1.5300E+02,1.6900E+02,CHD 5982
     21.9700E+02,2.1000E+02,2.3334E+02,2.7746E+02,3.1732E+02,5.4561E+02,CHD 5983
     35.9689E+02,6.4606E+02,6.9579E+02,7.4515E+02,8.0437E+02,8.6387E+02,CHD 5984
     49.1998E+02,9.7515E+02,1.1685E+03,1.2280E+03,1.2870E+03,1.3520E+03,CHD 5985
     51.4235E+03,1.5320E+03,1.6035E+03,1.7445E+03,1.8180E+03,4.2516E+03,CHD 5986
     64.3993E+03,4.5546E+03,4.7388E+03,5.1007E+03,5.3252E+03,5.6042E+03,CHD 5987
     75.7952E+03,2.4005E+04,2.4978E+04/                                 CHD 5988
C      Z = 43                                                           CHD 5989
      DATA (EIP(I),I=946,989)/99.00000,7.2800E+00,1.5260E+01,3.1000E+01,CHD 5990
     14.3000E+01,5.9000E+01,7.6000E+01,9.4000E+01,1.6100E+02,1.8300E+02,CHD 5991
     21.9900E+02,2.2400E+02,2.4072E+02,2.6538E+02,3.0775E+02,3.5353E+02,CHD 5992
     36.1044E+02,6.6237E+02,7.1244E+02,7.6385E+02,8.1493E+02,8.7522E+02,CHD 5993
     49.3735E+02,9.9545E+02,1.0528E+03,1.2596E+03,1.3149E+03,1.3764E+03,CHD 5994
     51.4434E+03,1.5167E+03,1.6309E+03,1.7051E+03,1.8512E+03,1.9274E+03,CHD 5995
     64.4959E+03,4.6472E+03,4.8060E+03,4.9927E+03,5.3734E+03,5.6009E+03,CHD 5996
     75.8938E+03,6.0917E+03,2.5210E+04,2.6199E+04/                      CHD 5997
C      Z = 44                                                           CHD 5998
      DATA (EIP(I),I=990,1034)/101.07000,7.3640E+00,1.6760E+01,2.8460E+0CHD 5999
     11,4.6000E+01,6.3000E+01,8.1000E+01,1.0000E+02,1.1900E+02,1.9300E+0CHD 6000
     22,2.1600E+02,2.2500E+02,2.5295E+02,2.7314E+02,2.9912E+02,3.3973E+0CHD 6001
     32,3.9144E+02,6.7830E+02,7.3086E+02,7.8184E+02,8.3494E+02,8.8774E+0CHD 6002
     42,9.4910E+02,1.0138E+03,1.0739E+03,1.1334E+03,1.3537E+03,1.4049E+0CHD 6003
     53,1.4688E+03,1.5379E+03,1.6130E+03,1.7329E+03,1.8097E+03,1.9609E+0CHD 6004
     63,2.0398E+03,4.7470E+03,4.9018E+03,5.0642E+03,5.2534E+03,5.6528E+0CHD 6005
     73,5.8834E+03,6.1902E+03,6.3950E+03,2.6442E+04,2.7448E+04/         CHD 6006
C      Z = 45                                                           CHD 6007
      DATA (EIP(I),I=1035,1080)/102.91000,7.4600E+00,1.8070E+01,3.1050E+CHD 6008
     101,4.6000E+01,6.7000E+01,8.5000E+01,1.0500E+02,1.2600E+02,1.4700E+CHD 6009
     202,2.2600E+02,2.5000E+02,2.6700E+02,2.8360E+02,3.0726E+02,3.3457E+CHD 6010
     302,3.7341E+02,4.3105E+02,7.4918E+02,8.0238E+02,8.5426E+02,9.0906E+CHD 6011
     402,9.6357E+02,1.0260E+03,1.0934E+03,1.1554E+03,1.2171E+03,1.4508E+CHD 6012
     503,1.4979E+03,1.5642E+03,1.6354E+03,1.7123E+03,1.8379E+03,1.9173E+CHD 6013
     603,2.0736E+03,2.1552E+03,5.0049E+03,5.1632E+03,5.3292E+03,5.5209E+CHD 6014
     703,5.9390E+03,6.1727E+03,6.4934E+03,6.7051E+03,2.7701E+04,2.8724E+CHD 6015
     804/                                                               CHD 6016
C      Z = 46                                                           CHD 6017
      DATA (EIP(I),I=1081,1127)/106.40000,8.3300E+00,1.9420E+01,3.2920E+CHD 6018
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     15.0100E+01,6.2600E+01,1.2750E+02,1.5000E+02,1.8200E+02,2.1800E+02,
     22.5300E+02,3.0264E+02,3.3851E+02,3.7671E+02,4.1251E+02,4.8458E+02,
     35.8121E+02,6.1846E+02,6.6471E+02,7.2008E+02,7.7721E+02,8.2508E+02,
     49.2033E+02,9.6955E+02,2.3586E+03,2.4747E+03,2.5979E+03,2.7598E+03,
     52.9529E+03,3.1500E+03,3.3037E+03,3.4324E+03,1.4383E+04,1.5208E+04/
C      Z = 34
      DATA (EIP(I),I=595,629)/78.96000,9.7500E+00,2.1500E+01,3.2000E+01,
     14.3000E+01,6.8000E+01,8.2000E+01,1.5500E+02,1.8700E+02,2.2300E+02,
     22.6000E+02,2.9560E+02,3.4631E+02,3.8480E+02,4.2499E+02,4.6294E+02,
     35.4849E+02,6.4099E+02,6.8066E+02,7.2899E+02,7.8616E+02,8.4899E+02,
     48.9949E+02,9.9982E+02,1.0517E+03,2.5417E+03,2.6613E+03,2.7881E+03,
     52.9525E+03,3.1643E+03,3.3645E+03,3.5321E+03,3.6677E+03,1.5343E+04,
     61.6185E+04/
C      Z = 35
      DATA (EIP(I),I=630,665)/79.91200,1.1840E+01,2.1600E+01,3.5900E+01,
     14.7300E+01,5.9700E+01,8.8600E+01,1.0300E+02,1.9300E+02,2.2800E+02,
     22.6600E+02,3.0390E+02,3.4122E+02,3.9299E+02,4.3411E+02,4.7629E+02,
     35.1640E+02,6.1541E+02,7.0379E+02,7.4587E+02,7.9629E+02,8.5525E+02,
     49.2379E+02,9.7691E+02,1.0823E+03,1.1370E+03,2.7317E+03,2.8548E+03,
     52.9851E+03,3.1520E+03,3.3826E+03,3.5858E+03,3.7673E+03,3.9099E+03,
     61.6330E+04,1.7189E+04/
C      Z = 36
      DATA (EIP(I),I=666,702)/83.80000,1.3996E+01,2.4560E+01,3.6900E+01,
     15.2000E+01,6.5000E+01,7.9000E+01,1.1000E+02,1.2600E+02,2.3400E+02,
     22.7000E+02,3.1123E+02,3.5082E+02,3.8986E+02,4.4269E+02,4.8644E+02,
     35.3061E+02,5.7287E+02,6.8536E+02,7.6961E+02,8.1411E+02,8.6661E+02,
     49.2736E+02,1.0016E+03,1.0574E+03,1.1679E+03,1.2252E+03,2.9284E+03,
     53.0550E+03,3.1890E+03,3.3583E+03,3.6076E+03,3.8139E+03,4.0094E+03,
     64.1588E+03,1.7345E+04,1.8220E+04/
C      Z = 37
      DATA (EIP(I),I=703,740)/85.48000,4.1760E+00,2.7500E+01,4.0000E+01,
     15.2000E+01,7.1000E+01,8.5000E+01,1.0000E+02,1.3500E+02,1.5100E+02,
     22.7700E+02,3.1672E+02,3.5948E+02,4.0076E+02,4.4152E+02,4.9542E+02,
     35.4179E+02,5.8795E+02,6.3236E+02,7.5833E+02,8.3845E+02,8.8537E+02,
     49.3995E+02,1.0025E+03,1.0825E+03,1.1408E+03,1.2564E+03,1.3164E+03,
     53.1319E+03,3.2621E+03,3.3996E+03,3.5714E+03,3.8395E+03,4.0488E+03,
     64.2582E+03,4.4145E+03,1.8387E+04,1.9278E+04/
C      Z = 38
      DATA (EIP(I),I=741,779)/87.63000,5.6920E+00,1.1027E+01,4.3000E+01,
     15.7000E+01,7.2000E+01,9.2000E+01,1.0700E+02,1.2400E+02,1.6200E+02,
     21.7900E+02,3.2400E+02,3.6646E+02,4.1076E+02,4.5372E+02,4.9620E+02,
     35.5117E+02,6.0017E+02,6.4832E+02,6.9488E+02,8.3432E+02,9.1032E+02,
     49.5965E+02,1.0163E+03,1.0806E+03,1.1663E+03,1.2273E+03,1.3480E+03,
     51.4107E+03,3.3423E+03,3.4759E+03,3.6170E+03,3.7913E+03,4.0781E+03,
     64.2905E+03,4.5138E+03,4.6771E+03,1.9456E+04,2.0364E+04/
C      Z = 39
      DATA (EIP(I),I=780,819)/88.90800,6.3800E+00,1.2230E+01,2.0500E+01,
     16.2000E+01,7.7000E+01,9.3000E+01,1.1600E+02,1.3100E+02,1.4800E+02,
     21.9100E+02,2.0600E+02,3.7299E+02,4.1922E+02,4.6505E+02,5.0971E+02,
     35.5391E+02,6.0994E+02,6.6156E+02,7.1170E+02,7.6042E+02,9.1332E+02,
     49.8520E+02,1.0369E+03,1.0957E+03,1.1618E+03,1.2532E+03,1.3168E+03,
     51.4426E+03,1.5080E+03,3.5594E+03,3.6966E+03,3.8412E+03,4.0180E+03,
     64.3236E+03,4.5390E+03,4.7762E+03,4.9464E+03,2.0553E+04,2.1477E+04/
C      Z = 40
      DATA (EIP(I),I=820,860)/91.22000,6.8400E+00,1.3130E+01,2.2980E+01,
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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+
     703,2.8209E+03,2.9154E+03,3.0130E+03,3.2225E+03,3.3305E+03,3.5442E+
     803,3.6550E+03,8.3009E+03,8.4990E+03,8.7065E+03,8.9308E+03,9.6374E+
     903,9.9111E+03,1.0380E+04,1.0667E+04,4.3682E+04,4.4898E+04/
C     Z = 57
      DATA (EIP(I),I=1653,1710)/138.92000,5.6100E+00,1.1430E+01,1.9170E+
     101,5.2000E+01,6.6000E+01,8.0000E+01,1.0000E+02,1.1400E+02,1.4400E+
     202,1.6500E+02,2.0400E+02,2.5910E+02,2.8739E+02,3.1378E+02,3.4142E+
     302,3.7056E+02,4.0078E+02,4.3678E+02,4.6983E+02,5.0411E+02,5.3942E+
     402,5.9743E+02,7.0860E+02,7.4799E+02,7.8848E+02,8.5900E+02,9.0237E+
     502,9.4667E+02,1.0514E+03,1.8206E+03,1.8876E+03,1.9544E+03,2.0301E+
     603,2.1062E+03,2.1851E+03,2.2913E+03,2.3779E+03,2.4661E+03,2.7753E+
     703,2.8618E+03,2.9564E+03,3.0532E+03,3.1531E+03,3.3788E+03,3.4893E+
     803,3.7089E+03,3.8221E+03,8.6456E+03,8.8478E+03,9.0600E+03,9.2895E+
     903,1.0056E+04,1.0336E+04,1.0817E+04,1.1110E+04,4.5434E+04,4.6674E+
     $04/
C     Z = 58
      DATA (EIP(I),I=1711,1769)/140.13000,6.9000E+00,1.2300E+01,2.0000E+
     101,3.5000E+01,7.0000E+01,8.5000E+01,1.0000E+02,1.2200E+02,1.3700E+
     202,1.6500E+02,1.8900E+02,2.2523E+02,2.8870E+02,3.2118E+02,3.4890E+
     302,3.7786E+02,4.0834E+02,4.3990E+02,4.7790E+02,5.1230E+02,5.4798E+
     402,5.8462E+02,6.5210E+02,7.6026E+02,8.0098E+02,8.4274E+02,9.1846E+
     502,9.6322E+02,1.0146E+03,1.1172E+03,1.9265E+03,1.9955E+03,2.0645E+
     603,2.1421E+03,2.2203E+03,2.3015E+03,2.4127E+03,2.5015E+03,2.5921E+
     703,2.8862E+03,2.9981E+03,3.0949E+03,3.1939E+03,3.2961E+03,3.5381E+
     803,3.6511E+03,3.8765E+03,3.9921E+03,8.9971E+03,9.2033E+03,9.4203E+
     903,9.6549E+03,1.0481E+04,1.0767E+04,1.1260E+04,1.1560E+04,4.7213E+
     $04,4.8476E+04/
C     Z = 59
      DATA (EIP(I),I=1770,1829)/140.91300,5.8000E+00,1.6786E+01,2.3848E+
     101,3.3130E+01,4.9317E+01,8.9000E+01,1.0600E+02,1.2200E+02,1.4600E+
     202,1.6200E+02,1.9700E+02,2.1132E+02,2.4816E+02,3.2000E+02,3.5667E+
     302,3.8572E+02,4.1600E+02,4.4782E+02,4.8072E+02,5.2072E+02,5.5647E+
     402,5.9355E+02,6.3152E+02,7.0847E+02,8.1362E+02,8.5567E+02,8.9870E+
     502,9.7962E+02,1.0258E+03,1.0843E+03,1.1848E+03,2.0355E+03,2.1065E+
     603,2.1777E+03,2.2572E+03,2.3375E+03,2.4210E+03,2.5372E+03,2.6282E+
     703,2.7212E+03,3.0000E+03,3.1375E+03,3.2365E+03,3.3377E+03,3.4422E+
     803,3.7005E+03,3.8160E+03,4.0472E+03,4.1652E+03,9.3553E+03,9.5656E+
     903,9.7873E+03,1.0027E+04,1.0913E+04,1.1206E+04,1.1710E+04,1.2017E+
     $04,4.9020E+04,5.0305E+04/
C     Z = 60
      DATA (EIP(I),I=1830,1890)/144.25000,6.3000E+00,1.6051E+01,2.8371E+
     101,3.7096E+01,4.7959E+01,6.5334E+01,1.1000E+02,1.2800E+02,1.4700E+
     202,1.7100E+02,1.8357E+02,2.1904E+02,2.3533E+02,2.7278E+02,3.5644E+
     302,3.9387E+02,4.2425E+02,4.5584E+02,4.8901E+02,5.2325E+02,5.6525E+
     402,6.0235E+02,6.4082E+02,6.8013E+02,7.6655E+02,8.6869E+02,9.1207E+
     502,9.5636E+02,1.0425E+03,1.0900E+03,1.1556E+03,1.2540E+03,2.1474E+
     603,2.2204E+03,2.2939E+03,2.3753E+03,2.4576E+03,2.5434E+03,2.6647E+
     703,2.7579E+03,2.8533E+03,3.1424E+03,3.2798E+03,3.3810E+03,3.4845E+
     803,3.5913E+03,3.8658E+03,3.9838E+03,4.2209E+03,4.3413E+03,9.7204E+
     903,9.9347E+03,1.0161E+04,1.0406E+04,1.1352E+04,1.1651E+04,1.2167E+
     $04,1.2480E+04,5.0853E+04,5.2162E+04/
C     Z = 61
      DATA (EIP(I),I=1891,1952)/147.00000,6.0000E+00,1.8016E+01,2.8001E+
     101,4.1656E+01,5.2043E+01,6.4487E+01,8.3050E+01,1.3500E+02,1.5400E+
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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+CHD 6294
      $04,1.5607E+04,1.5963E+04,1.6583E+04,1.6956E+04,6.8578E+04,7.0095E+CHD 6295
      $04/                                                               CHD 6296
C      Z = 70                                                            CHD 6297
       DATA (EIP(I),I=2485,2555)/173.04000,6.2000E+00,1.2100E+01,3.7750E+CHD 6298
      101,5.3132E+01,6.9249E+01,8.5435E+01,1.0941E+02,1.2495E+02,1.6448E+CHD 6299
      202,1.8637E+02,1.9563E+02,2.1203E+02,2.3769E+02,2.6304E+02,2.8971E+CHD 6300
      302,3.1897E+02,3.6494E+02,3.9381E+02,4.2626E+02,4.5987E+02,4.9275E+CHD 6301
      402,5.3288E+02,5.6897E+02,6.1252E+02,8.1428E+02,8.5926E+02,9.0294E+CHD 6302
      502,9.4768E+02,9.9430E+02,1.0419E+03,1.1039E+03,1.1545E+03,1.2070E+CHD 6303
      603,1.2596E+03,1.4407E+03,1.5128E+03,1.5695E+03,1.6264E+03,1.7646E+CHD 6304
      703,1.8260E+03,1.9626E+03,2.0400E+03,3.4331E+03,3.5261E+03,3.6221E+CHD 6305
      803,3.7225E+03,3.8253E+03,3.9341E+03,4.1059E+03,4.2211E+03,4.3405E+CHD 6306
      903,4.7359E+03,4.8695E+03,4.9927E+03,5.1187E+03,5.2485E+03,5.6855E+CHD 6307
      $03,5.8285E+03,6.1241E+03,6.2685E+03,1.3745E+04,1.4000E+04,1.4274E+CHD 6308
      $04,1.4570E+04,1.6114E+04,1.6476E+04,1.7108E+04,1.7487E+04,7.0684E+CHD 6309
      $04,7.2223E+04/                                                    CHD 6310
C      Z = 71                                                            CHD 6311
       DATA (EIP(I),I=2556,2627)/174.98000,6.1000E+00,1.5000E+01,1.9000E+CHD 6312
      101,5.5256E+01,7.1017E+01,8.7581E+01,1.0444E+02,1.3043E+02,1.4758E+CHD 6313
      202,1.9073E+02,2.1314E+02,2.2197E+02,2.4097E+02,2.6797E+02,2.9498E+CHD 6314
      302,3.2324E+02,3.5367E+02,3.9715E+02,4.2806E+02,4.6289E+02,4.9810E+CHD 6315
      402,5.3301E+02,5.7361E+02,6.1167E+02,6.5584E+02,8.6941E+02,9.1515E+CHD 6316
      502,9.6016E+02,1.0062E+03,1.0542E+03,1.1032E+03,1.1672E+03,1.2191E+CHD 6317
      603,1.2729E+03,1.3269E+03,1.5175E+03,1.5865E+03,1.6445E+03,1.7028E+CHD 6318
      703,1.8461E+03,1.9090E+03,2.0527E+03,2.1280E+03,3.5783E+03,3.6733E+CHD 6319
      803,3.7716E+03,3.8739E+03,3.9787E+03,4.0898E+03,4.2667E+03,4.3841E+CHD 6320
      903,4.5059E+03,4.9121E+03,5.0451E+03,5.1705E+03,5.2988E+03,5.4309E+CHD 6321
      $03,5.8841E+03,6.0296E+03,6.3311E+03,6.4779E+03,1.4185E+04,1.4444E+CHD 6322
      $04,1.4722E+04,1.5024E+04,1.6627E+04,1.6996E+04,1.7640E+04,1.8025E+CHD 6323
      $04,7.2816E+04,7.4379E+04/                                         CHD 6324
C      Z = 72                                                            CHD 6325
       DATA (EIP(I),I=2628,2700)/178.50000,7.0000E+00,1.4900E+01,2.1000E+CHD 6326
      101,3.1000E+01,7.3850E+01,8.9991E+01,1.0700E+02,1.2454E+02,1.5253E+CHD 6327
      202,1.7130E+02,2.1807E+02,2.4101E+02,2.5000E+02,2.7161E+02,2.9995E+CHD 6328
      302,3.2862E+02,3.5846E+02,3.9008E+02,4.3107E+02,4.6401E+02,5.0123E+CHD 6329
      402,5.3804E+02,5.7497E+02,6.1604E+02,6.5608E+02,7.0086E+02,9.2624E+CHD 6330
      502,9.7273E+02,1.0191E+03,1.0664E+03,1.1158E+03,1.1661E+03,1.2321E+CHD 6331
      603,1.2854E+03,1.3406E+03,1.3959E+03,1.5960E+03,1.6620E+03,1.7213E+CHD 6332
      703,1.7808E+03,1.9294E+03,1.9936E+03,2.1444E+03,2.2176E+03,3.7265E+CHD 6333
      803,3.8235E+03,3.9240E+03,4.0282E+03,4.1351E+03,4.2485E+03,4.4304E+CHD 6334
      903,4.5500E+03,4.6742E+03,5.0914E+03,5.2237E+03,5.3513E+03,5.4818E+CHD 6335
      $03,5.6162E+03,6.0857E+03,6.2337E+03,6.5410E+03,6.6902E+03,1.4631E+CHD 6336
      $04,1.4894E+04,1.5178E+04,1.5484E+04,1.7148E+04,1.7523E+04,1.8178E+CHD 6337
      $04,1.8570E+04,7.4976E+04,7.6562E+04/                              CHD 6338
C      Z = 73                                                            CHD 6339
       DATA (EIP(I),I=2701,2774)/180.95500,7.8800E+00,1.6200E+01,2.2000E+CHD 6340
      101,3.3000E+01,4.5000E+01,9.3531E+01,1.1005E+02,1.2751E+02,1.4573E+CHD 6341
      202,1.7572E+02,1.9611E+02,2.4649E+02,2.6996E+02,2.7865E+02,3.0396E+CHD 6342
      302,3.3362E+02,3.6396E+02,3.9538E+02,4.2819E+02,4.6668E+02,5.0165E+CHD 6343
      402,5.4127E+02,5.7967E+02,6.1864E+02,6.6017E+02,7.0219E+02,7.4758E+CHD 6344
      502,9.8477E+02,1.0320E+03,1.0797E+03,1.1284E+03,1.1790E+03,1.2307E+CHD 6345
      603,1.2987E+03,1.3533E+03,1.4099E+03,1.4666E+03,1.6761E+03,1.7391E+CHD 6346
      703,1.7998E+03,1.8606E+03,2.0143E+03,2.0800E+03,2.2379E+03,2.3090E+CHD 6347
      803,3.8777E+03,3.9767E+03,4.0795E+03,4.1856E+03,4.2945E+03,4.4102E+CHD 6348
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     903,4.5972E+03,4.7190E+03,4.8456E+03,5.2737E+03,5.4053E+03,5.5351E+CHD 6349
     $03,5.6679E+03,5.8046E+03,6.2903E+03,6.4408E+03,6.7540E+03,6.9056E+CHD 6350
     $03,1.5085E+04,1.5352E+04,1.5640E+04,1.5952E+04,1.7675E+04,1.8057E+CHD 6351
     $04,1.8723E+04,1.9122E+04,7.7163E+04,7.8772E+04/                    CHD 6352
C      Z = 74                                                            CHD 6353
      DATA (EIP(I),I=2775,2849)/183.86000,7.9800E+00,1.7700E+01,2.4000E+CHD 6354
     101,3.5000E+01,4.8000E+01,6.1000E+01,1.1430E+02,1.3120E+02,1.4910E+CHD 6355
     202,1.6800E+02,2.0000E+02,2.2200E+02,2.7600E+02,3.0000E+02,3.0900E+CHD 6356
     302,3.3800E+02,3.6900E+02,4.0100E+02,4.3400E+02,4.6800E+02,5.0400E+CHD 6357
     402,5.4100E+02,5.8300E+02,6.2300E+02,6.6400E+02,7.0600E+02,7.5000E+CHD 6358
     502,7.9600E+02,1.0450E+03,1.0930E+03,1.1420E+03,1.1920E+03,1.2440E+CHD 6359
     603,1.2970E+03,1.3670E+03,1.4230E+03,1.4810E+03,1.5390E+03,1.7580E+CHD 6360
     703,1.8180E+03,1.8800E+03,1.9420E+03,2.1010E+03,2.1680E+03,2.3330E+CHD 6361
     803,2.4020E+03,4.0320E+03,4.1330E+03,4.2380E+03,4.3460E+03,4.4570E+CHD 6362
     903,4.5750E+03,4.7670E+03,4.8910E+03,5.0200E+03,5.4590E+03,5.5900E+CHD 6363
     $03,5.7220E+03,5.8570E+03,5.9960E+03,6.4980E+03,6.6510E+03,6.9700E+CHD 6364
     $03,7.1240E+03,1.5545E+04,1.5816E+04,1.6109E+04,1.6426E+04,1.8209E+CHD 6365
     $04,1.8597E+04,1.9275E+04,1.9680E+04,7.9377E+04,8.1009E+04/         CHD 6366
C      Z = 75                                                            CHD 6367
      DATA (EIP(I),I=2850,2925)/186.30000,7.8700E+00,1.6600E+01,2.6000E+CHD 6368
     101,3.8000E+01,5.1000E+01,6.4000E+01,7.9000E+01,1.4108E+02,1.5874E+CHD 6369
     202,1.7753E+02,1.9719E+02,2.2869E+02,2.5169E+02,3.1019E+02,3.3594E+CHD 6370
     302,3.8743E+02,4.1693E+02,4.4830E+02,4.8068E+02,5.1418E+02,5.4868E+CHD 6371
     402,5.8505E+02,6.2243E+02,6.6443E+02,7.0480E+02,7.4618E+02,7.8868E+CHD 6372
     502,8.3305E+02,8.7930E+02,1.1339E+03,1.1822E+03,1.2314E+03,1.2818E+CHD 6373
     603,1.3342E+03,1.3874E+03,1.4558E+03,1.5122E+03,1.5704E+03,1.6288E+CHD 6374
     703,1.8494E+03,1.9098E+03,1.9722E+03,2.0347E+03,2.1822E+03,2.2494E+CHD 6375
     803,2.4138E+03,2.4831E+03,4.2363E+03,4.3369E+03,4.4414E+03,4.5491E+CHD 6376
     903,4.6597E+03,4.7769E+03,4.9593E+03,5.0828E+03,5.2113E+03,5.6116E+CHD 6377
     $03,5.7787E+03,5.9106E+03,6.0457E+03,6.1848E+03,6.6422E+03,6.7948E+CHD 6378
     $03,7.1104E+03,7.2643E+03,1.5930E+04,1.6228E+04,1.6547E+04,1.6886E+CHD 6379
     $04,1.8807E+04,1.9217E+04,1.9882E+04,2.0308E+04,8.1834E+04,8.3485E+CHD 6380
     $04/                                                                CHD 6381
C      Z = 76                                                            CHD 6382
      DATA (EIP(I),I=2926,3002)/190.20000,8.7000E+00,1.7000E+01,2.5000E+CHD 6383
     101,4.0000E+01,5.4000E+01,6.8000E+01,8.3000E+01,9.9000E+01,1.6895E+CHD 6384
     202,1.8737E+02,2.0705E+02,2.2747E+02,2.5847E+02,2.8247E+02,3.4547E+CHD 6385
     302,3.7297E+02,4.6755E+02,4.9755E+02,5.2930E+02,5.6205E+02,5.9605E+CHD 6386
     402,6.3105E+02,6.6780E+02,7.0555E+02,7.4755E+02,7.8830E+02,8.3005E+CHD 6387
     502,8.7305E+02,9.1780E+02,9.6430E+02,1.2246E+03,1.2731E+03,1.3226E+CHD 6388
     603,1.3733E+03,1.4261E+03,1.4796E+03,1.5463E+03,1.6031E+03,1.6616E+CHD 6389
     703,1.7203E+03,1.9426E+03,2.0033E+03,2.0661E+03,2.1291E+03,2.2651E+CHD 6390
     803,2.3326E+03,2.4963E+03,2.5658E+03,4.4436E+03,4.5439E+03,4.6479E+CHD 6391
     903,4.7551E+03,4.8654E+03,4.9819E+03,5.1546E+03,5.2776E+03,5.4056E+CHD 6392
     $03,5.7671E+03,5.9704E+03,6.1021E+03,6.2374E+03,6.3766E+03,6.7894E+CHD 6393
     $03,6.9416E+03,7.2539E+03,7.4076E+03,1.6322E+04,1.6647E+04,1.6991E+CHD 6394
     $04,1.7354E+04,1.9412E+04,1.9844E+04,2.0495E+04,2.0943E+04,8.4318E+CHD 6395
     $04,8.5989E+04/                                                     CHD 6396
C      Z = 77                                                            CHD 6397
      DATA (EIP(I),I=3003,3080)/192.20000,9.0000E+00,1.7000E+01,2.7000E+CHD 6398
     101,3.9000E+01,5.7000E+01,7.2000E+01,8.8000E+01,1.0400E+02,1.2100E+CHD 6399
     202,1.9791E+02,2.1709E+02,2.3766E+02,2.5884E+02,2.8934E+02,3.1434E+CHD 6400
     302,3.8184E+02,4.1109E+02,5.4938E+02,5.7988E+02,6.1200E+02,6.4513E+CHD 6401
     402,6.7963E+02,7.1513E+02,7.5225E+02,7.9038E+02,8.3238E+02,8.7350E+CHD 6402
     502,9.1563E+02,9.5913E+02,1.0043E+03,1.0510E+03,1.3169E+03,1.3656E+CHD 6403
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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 5432
     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+CHD 6459
     202,1.6600E+02,1.9596E+02,2.3058E+02,2.6887E+02,3.2461E+02,3.4684E+CHD 6460
     302,3.7096E+02,3.9519E+02,4.2369E+02,4.5269E+02,5.3819E+02,5.7444E+CHD 6461
     402,8.9368E+02,9.2618E+02,9.5980E+02,9.9443E+02,1.0309E+03,1.0684E+CHD 6462
     503,1.1071E+03,1.1467E+03,1.1887E+03,1.2313E+03,1.2749E+03,1.3204E+CHD 6463
     603,1.3671E+03,1.4148E+03,1.7032E+03,1.7529E+03,1.8037E+03,1.8563E+CHD 6464
     703,1.9109E+03,1.9657E+03,2.0243E+03,2.0829E+03,2.1427E+03,2.2033E+CHD 6465
     803,2.4337E+03,2.4963E+03,2.5609E+03,2.6264E+03,2.7049E+03,2.7737E+CHD 6466
     903,2.9343E+03,3.0051E+03,5.5256E+03,5.6239E+03,5.7254E+03,5.8308E+CHD 6467
     $03,5.9392E+03,6.0519E+03,6.1766E+03,6.2971E+03,6.4226E+03,6.5903E+CHD 6468
     $03,6.9742E+03,7.1053E+03,7.2412E+03,7.3811E+03,7.5707E+03,7.7211E+CHD 6469
     $03,8.0164E+03,8.1696E+03,1.8382E+04,1.8845E+04,1.9315E+04,1.9792E+CHD 6470
     $04,2.2540E+04,2.3082E+04,2.3666E+04,2.4219E+04,9.7146E+04,9.8914E+CHD 6471
     $04/                                                               CHD 6472
C      Z = 82                                                           CHD 6473
      DATA (EIP(I),I=3403,3485)/207.20000,7.4150E+00,1.5028E+01,3.1930E+CHD 6474
     101,4.2310E+01,6.8800E+01,8.4000E+01,1.0300E+02,1.2200E+02,1.4200E+CHD 6475
     202,1.7300E+02,2.0100E+02,2.3400E+02,2.7100E+02,3.1200E+02,3.5900E+CHD 6476
     302,3.8200E+02,4.0700E+02,4.3200E+02,4.6000E+02,4.9000E+02,5.8000E+CHD 6477
     402,6.1800E+02,9.8400E+02,1.0170E+03,1.0510E+03,1.0860E+03,1.1230E+CHD 6478
     503,1.1610E+03,1.2000E+03,1.2400E+03,1.2820E+03,1.3250E+03,1.3690E+CHD 6479
     603,1.4150E+03,1.4620E+03,1.5100E+03,1.8040E+03,1.8540E+03,1.9050E+CHD 6480
     703,1.9580E+03,2.0130E+03,2.0680E+03,2.1250E+03,2.1840E+03,2.2440E+CHD 6481
     803,2.3050E+03,2.5370E+03,2.6000E+03,2.6650E+03,2.7310E+03,2.7980E+CHD 6482
     903,2.8670E+03,3.0270E+03,3.0980E+03,5.7510E+03,5.8490E+03,5.9500E+CHD 6483
     $03,6.0550E+03,6.1630E+03,6.2750E+03,6.3900E+03,6.5100E+03,6.6350E+CHD 6484
     $03,6.7640E+03,7.1840E+03,7.3150E+03,7.4510E+03,7.5910E+03,7.7360E+CHD 6485
     $03,7.8860E+03,8.1780E+03,8.3310E+03,1.8815E+04,1.9305E+04,1.9800E+CHD 6486
     $04,2.0300E+04,2.3186E+04,2.3750E+04,2.4320E+04,2.4895E+04,9.9793E+CHD 6487
     $04,1.0158E+05/                                                    CHD 6488
C      Z = 83                                                           CHD 6489
      DATA (EIP(I),I=3486,3569)/208.98800,7.2870E+00,1.6680E+01,2.5560E+CHD 6490
     101,4.5300E+01,5.6000E+01,8.8300E+01,1.0700E+02,1.2700E+02,1.4800E+CHD 6491
     202,1.6900E+02,2.0356E+02,2.3283E+02,2.6524E+02,3.0127E+02,3.4084E+CHD 6492
     302,3.9803E+02,4.2211E+02,4.4813E+02,4.7407E+02,5.1209E+02,5.4289E+CHD 6493
     402,6.2559E+02,6.7219E+02,1.0171E+03,1.0519E+03,1.0877E+03,1.1247E+CHD 6494
     503,1.1636E+03,1.2034E+03,1.2444E+03,1.2863E+03,1.3321E+03,1.3771E+CHD 6495
     603,1.4231E+03,1.4711E+03,1.5199E+03,1.5701E+03,1.8732E+03,1.9251E+CHD 6496
     703,1.9781E+03,2.0328E+03,2.0898E+03,2.1468E+03,2.2127E+03,2.2736E+CHD 6497
     803,2.3356E+03,2.3987E+03,2.6392E+03,2.7042E+03,2.7709E+03,2.8387E+CHD 6498
     903,2.9454E+03,3.0171E+03,3.1853E+03,3.2586E+03,5.9099E+03,6.0119E+CHD 6499
     $03,6.1169E+03,6.2259E+03,6.3379E+03,6.4546E+03,6.5989E+03,6.7233E+CHD 6500
     $03,6.8528E+03,6.9864E+03,7.4229E+03,7.5581E+03,7.6978E+03,7.8421E+CHD 6501
     $03,8.1184E+03,8.2734E+03,8.5802E+03,8.7403E+03,1.9469E+04,1.9939E+CHD 6502
     $04,2.0416E+04,2.0901E+04,2.3968E+04,2.4521E+04,2.5131E+04,2.5697E+CHD 6503
     $04,1.0270E+05,1.0479E+05/                                         CHD 6504
C      Z = 84                                                           CHD 6505
      DATA (EIP(I),I=3570,3654)/210.00000,8.4300E+00,1.9000E+01,2.7000E+CHD 6506
     101,3.8000E+01,6.1000E+01,7.3000E+01,1.1200E+02,1.3200E+02,1.5400E+CHD 6507
     202,1.7600E+02,2.0181E+02,2.3520E+02,2.6575E+02,2.9757E+02,3.3262E+CHD 6508
     302,3.7077E+02,4.3815E+02,4.6330E+02,4.9035E+02,5.1722E+02,5.6527E+CHD 6509
     402,5.9687E+02,6.7227E+02,7.2747E+02,1.0518E+03,1.0886E+03,1.1261E+CHD 6510
     503,1.1651E+03,1.2058E+03,1.2476E+03,1.2906E+03,1.3343E+03,1.3838E+CHD 6511
     603,1.4308E+03,1.4788E+03,1.5288E+03,1.5796E+03,1.6318E+03,1.9441E+CHD 6512
     703,1.9978E+03,2.0528E+03,2.1093E+03,2.1683E+03,2.2273E+03,2.3021E+CHD 6513
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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./
      DATA (DTAB(I),I=86,112)/9HBERYLLIUM,1.,4.,1.845,0.,0.,-7.97E5,1.17
     1,.09995,1.091,2.,3.69E11,.134,12*0.,4.,1./
C     IRON  130 KBAR PHASE TRANSITION   SC-RR-70-28
      DATA TABLE(5),TABPL(5)/5.,113./
      DATA (DTAB(I),I=113,139)/10HIRON 130PT,1.,4.,7.85,0.,0.,1.93E12,1.
     175,0.,0.,2.,7.3E10,.282,5*0.,8.36,8.75,1.12E11,2.3E12,5.E12,2*0.,2
     26.,1./
C     ALUMINUM WITH MELT TRANSITION AND CONDUCTION
      DATA TABLE(6),TABPL(6)/6.,140./
      DATA (DTAB(I),I=140,166)/10HALUMINUM/M,1.,4.,2.7,0.,0.,7.63E11,2.0
     16,.0343,-1.,2.,1.2E11,-6.639E9,3.5E12,.8,2.7E11,0.,2.305,5*0.,3.98
     2E9,.924,13.,1./
C     LEAD WITH MELT TRANSITION AND CONDUCTION
      DATA TABLE(7),TABPL(7)/7.,167./
      DATA (DTAB(I),I=167,193)/6HLEAD/M,1.,4.,11.35,0.,0.,-2.051E5,2.77,
     1.0076,1.46,2.,9.5E9,-4.08E8,2.E12,0.,4.E10,0.,9.94,5*0.,2.30E8,.96
     27,82.,1./
C     BERYLLIUM WITH MELT TRANSITION AND CONDUCTION
      DATA TABLE(8),TABPL(8)/8.,194./
      DATA (DTAB(I),I=194,220)/4HBE/M,1.,4.,1.851,0.,0.,-7.998E5,1.16,.0
     19995,1.124,2.,3.69E11,-3.68E10,0.,0.,2.9E10,-.54347,6*0.,1.3E10,0.
     2,4.,1./
C     COPPER WITH MELT TRANSITION AND CONDUCTION
      DATA TABLE(9),TABPL(9)/9.,221./
      DATA (DTAB(I),I=221,247)/8HCOPPER/M,1.,4.,8.94,0.,0.,-3.94E5,1.99,
     1.0271,1.489,2.,5.25E10,-4.637E9,6.E12,.7,4.4E11,7*0.,2.055E9,-8.21
     27,29.,1./
C
C     SELECT EOS FROM TABLE
      TAB=ISETAB
      DO 10 I=1,NUMTAB
      IF (TAB.NE.TABLE(I)) GO TO 10
      IS=TABPL(I)
      GO TO 20
   10 CONTINUE
      PRINT 50, ISETAB
      STOP
   20 PRINT 60, ISETAB,DTAB(IS)
      DO 30 I=1,24
      IS=IS+1
   30 ZB(I)=DTAB(IS)
      J1=ZB(1)
      JK=IZ-1
      DO 40 I=1,J1
      JK=JK+1
      ZZS(JK)=DTAB(IS+1)
      COT(JK)=DTAB(IS+2)
   40 IS=IS+2
      RETURN
C
   50 FORMAT (19H1 THERE IS NO TABLE,I6,13H IN DATA LIST)
   60 FORMAT (20H0 LIBRARY EOS NUMBER,I6,3H ( ,A10,15H ) IS REQUESTED,/)
      END
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      SUBROUTINE ZAPPER
C     READS DTF OR BUCKL TAPE AND SETS UP CHART SOURCES.
      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,FLINBC,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
      DIMENSION SD2(1), SD3(1), TSOUR1(1), TSOUR2(1), TSOUR3(1), TSOUR4(
     11)
      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))
      DIMENSION NBDTF(1)
      EQUIVALENCE (NBDTF(1),VLO(1))
      READ 440, TEMPAB,TEMPB,TEMPC,TEMPD,TEMPF,TEMPG,IS,IS1
      JJ=7
      IF (IS.EQ.1) JJ=17
      IS=JJ
      IF (TEMPAB.GE.0.) GO TO 10
      TEMPA=-TEMPAB
      TEMPAB=4.185E7*TEMPA
      GO TO 20
   10 TEMPA=TEMPAB/4.185E7
   20 READ (IS,450) (XO(I),I=1,9),ICALL
      IF (ICALL.GT.0) GO TO 30
      PRINT 460, (XO(I),I=1,9)
      GO TO 40
   30 PRINT 470, (XO(I),I=1,9)
   40 PRINT 480, TEMPA,TEMPAB
      IF (IS1.EQ.1) PRINT 490
      IF (ICALL.GT.0) GO TO 170
      READ (IS,500) NZDTF,NMATDTF
      PRINT 510, NZDTF,NMATDTF
      JJ=NMATDTF+1
      NZDTFP=NZDTF+1
      READ (IS,500) (NBDTF(I),I=1,JJ)
      NBDTF(JJ+1)=10000
      READ (IS,520) (DO(I),VO(I),I=1,NZDTF)
      XO(1)=X(1)
      DO 50 I=1,NZDTF
   50 XO(I+1)=XO(I)-DO(I)/D(I)
      PRINT 530
```

```
      JL=1
      TEMPA=0.
      DO 90 I=1,NZDTFP
      DO 60 J=1,NZP
      IF (ABS(XO(I)-X(J)).GT.1.E-5*ABS(XO(I)+X(J))) GO TO 60
      XO(I)=X(J)
      GO TO 70
   60 CONTINUE
   70 IF (I.NE.NBDTF(JL+1)) GO TO 80
      IF (I.EQ.NZDTFP) GO TO 80
      JJ=JL+1
      PRINT 540, JL,JJ
      JL=JJ
   80 XX=XO(1)-XO(I)
      IF (I.EQ.NZDTFP) GO TO 90
      TEMPA=TEMPA+DO(I)
      PRINT 550, XO(I),XX,I,TEMPA,VO(I),JL
   90 CONTINUE
      PRINT 550, XO(NZDTFP),XX,NZDTFP
      JL=1
      XX=X(1)
      FR=0.
      DO 150 I=1,NZ
      I1=I+1
      SD3(I)=0.
  100 JJ=JL+1
      IF (JJ.GT.NZDTFP) GO TO 160
      IF (X(I1)-XO(JJ)) 110,120,140
  110 JK=0
      GO TO 130
  120 JK=1
  130 SD3(I)=SD3(I)+(1.-FR)*VO(JL)
      FR=0.
      JL=JJ
      XX=XO(JJ)
      IF (JK.EQ.0) GO TO 100
      GO TO 150
  140 F1=(XX-X(I1))/(XO(JL)-XO(JJ))
      SD3(I)=SD3(I)+F1*VO(JL)
      FR=FR+F1
      XX=X(I1)
  150 SD2(I)=TEMPAB*SD3(I)/XM(I)
  160 JL=1
      GO TO 350
  170 READ (IS,560) JL,TEMPH,JJ
C     JL IS THE LAYER NUMBER, JL IS NEGATIVE FOR LAST LAYER
      NZDTFP=IABS(JL)
      IF (NZDTFF.GT.1) GO TO 180
      PRINT 570
      TEMPL=0.
      GO TO 190
  180 IIK=NZDTFP-1
      PRINT 540, IIK,NZDTFP
  190 JK1=JBND(NZDTFP)
      JK2=JBND(NZDTFP+1)
```

```
      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
     1O(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)=TEMPAE*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)
C     ZONING ROUTINE
      DIMENSION X(1), Y(1), Z(1)
      IF (RA.GT.0.) GO TO 50
      IF (D.LE.0.OR.DLEFT.LE.0.) STOP 2020
      RAP=RR-RL
      RAU=RR-D
      RAL=RL+DLEFT
      IF (IG-2) 10,20,30
   10 FM1=D/RAP
      FM2=DLEFT/RAP
      GO TO 40
   20 FM1=(D*(RR+RAU))/(RAP*(RR+RL))
      FM2=(DLEFT*(RL+RAL))/(RAP*(RR+RL))
      GO TO 40
   30 FM1=(D*(RR**2+RR*RAU+RAU**2))/(RAP*(RR**2+RR*RL+RL**2))
      FM2=(DLEFT*(RL**2+RL*RAL+RAL**2))/(RAP*(RR**2+RR*RL+RL**2))
   40 RA=(1.-FM1)/(1.-FM2)
      IFQ=1
      IRL=0
      GO TO 60
   50 IFQ=0
      IRL=0
      IF (DLEFT.LE.0.) GO TO 60
      IRL=1
      D=DLEFT
   60 IF (ER.LT..001) ER=.001
      IMN=IM-IR+1
      RAU=(1.+ER)*RA
      RAL=(1.-ER)*RA
      SRA=RA
      ANUM=1./3.
      IT=IST=ISQ=JKS=0
      IF (IRL.EQ.0) GO TO 260
      CC=.001*RA
C     ZONE IN INCREASING POSITION DIRECTION
      IMM=IM-IMN
      I=IM-1
      Y(IM)=RL
      Y(I)=RL+D
   70 I1=I
      I2=I+1
      I=I-1
      XX=Y(I2)/Y(I1)
      IF (IG-2) 80,90,100
   80 Y(I)=Y(I1)*(1.+RA*(1.-XX))
      GO TO 110
   90 Y(I)=Y(I1)*SQRT(1.+RA*(1.-XX)*(1.+XX))
      GO TO 110
  100 Y(I)=Y(I1)*(1.+RA*(1.-XX)*(1.+XX*(1.+XX)))**ANUM
  110 IF (Y(I)-RR) 120,140,130
  120 IF (I-IMM) 330,330,70
  130 IF (IT.EQ.1) GO TO 160
      IT=1
      IF (Y(I)-RR.LT.RR-Y(I1)) GO TO 140
```

```
      IOP=I1                                                            CHD 7024
      KSW=1                                                             CHD 7025
      GO TO 150                                                         CHD 7026
  140 IOP=I                                                             CHD 7027
      KSW=-1                                                            CHD 7028
      CC=-CC                                                            CHD 7029
  150 ION=IOP+1                                                         CHD 7030
  160 IF (I.GT.IOP) GO TO 120                                           CHD 7031
      FM1=Y(IOP)-Y(ION)                                                 CHD 7032
      FM2=RR-Y(ION)                                                     CHD 7033
      IF (IG-2) 190,170,180                                             CHD 7034
  170 FM1=FM1*(Y(IOP)+Y(ION))                                           CHD 7035
      FM2=FM2*(RR+Y(ION))                                               CHD 7036
      GO TO 190                                                         CHD 7037
  180 FM1=FM1*(Y(IOP)**2+Y(ION)*(Y(IOP)+Y(ION)))                        CHD 7038
      FM2=FM2*(RR**2+Y(ION)*(RR+Y(ION)))                                CHD 7039
  190 IF (ABS(FM1-FM2).LE.1.E-4*(FM1+FM2)) GO TO 240                    CHD 7040
      IF (KSW) 200,200,210                                              CHD 7041
  200 IF (Y(IOP)-RR) 220,240,230                                        CHD 7042
  210 IF (RR-Y(IOP)) 220,240,230                                        CHD 7043
  220 RA=RA-CC                                                          CHD 7044
      CC=.1*CC                                                          CHD 7045
      IST=IST+1                                                         CHD 7046
      IF (IST-9) 230,230,500                                            CHD 7047
  230 RA=RA+CC                                                          CHD 7048
      ISQ=ISQ+1                                                         CHD 7049
      IF (ISQ.GT.1000) GO TO 500                                        CHD 7050
      IF (RA.GT.RAU) GO TO 520                                          CHD 7051
      IF (RA.LT.RAL) GO TO 520                                          CHD 7052
      I=IM-1                                                            CHD 7053
      GO TO 70                                                          CHD 7054
  240 DO 250 I=ION,IM                                                   CHD 7055
      I1=IR-ION+I+1                                                     CHD 7056
  250 X(I1)=Y(I)                                                        CHD 7057
      IL=I1                                                             CHD 7058
      RETURN                                                            CHD 7059
  260 I=2                                                               CHD 7060
C     ZONE IN DECREASING POSITION DIRECTION                             CHD 7061
      CC=.001*RA                                                        CHD 7062
      Y(1)=RR                                                           CHD 7063
      Y(2)=RR-D                                                         CHD 7064
  270 I1=I                                                              CHD 7065
      I2=I-1                                                            CHD 7066
      I=I+1                                                             CHD 7067
      XX=Y(I2)/Y(I1)                                                    CHD 7068
      IF (IG-2) 280,290,300                                             CHD 7069
  280 Y(I)=Y(I1)*(1.-RA*(XX-1.))                                        CHD 7070
      GO TO 310                                                         CHD 7071
  290 XX=1.-RA*(XX-1.)*(XX+1.)                                          CHD 7072
      IF (XX.LT.0.) GO TO 350                                           CHD 7073
      Y(I)=Y(I1)*SQRT(XX)                                               CHD 7074
      GO TO 310                                                         CHD 7075
  300 XX=1.-RA*(XX-1.)*(XX*(1.+XX)+1.)                                  CHD 7076
      IF (XX.LT.0.) GO TO 350                                           CHD 7077
      Y(I)=Y(I1)*XX**ANUM                                               CHD 7078
```

```
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(ICN)+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
640 PRINT 960, RL,RR
    PRINT 1030
    GO TO 950
650 IF (I.LT.4) GO TO 590
    FM2=Y(3)-Y(4)
    FM3=Y(3)-Z(3)
    IF (IG-2) 680,660,670
660 FM2=FM2*(Y(3)+Y(4))
    FM3=FM3*(Y(3)+Z(3))
    GO TO 680
670 FM2=FM2*(Y(3)**2+Y(3)*Y(4)+Y(4)**2)
    FM3=FM3*(Y(3)**2+Y(3)*Z(3)+Z(3)**2)
680 IF (Y(4).LT.Z(4)) GO TO 640
    RAP=(1.-FM1/FM3)/(1.-FM2/FM3)
    IF (RAP.EQ.1.) XX=FM3/FM1
    IF (RAP.NE.1.) XX=1.+ALOG(FM2/FM1)/ALOG(RAP)
    NUM=XX+.5
    IF (NUM.GT.IMN) GO TO 330
    XS=ALOG(RAP)
    XX=NUM
    IF (RAP.NE.1.) FM1=FM3*(1.-RAP)/(1.-EXP(XX*XS))
    IF (RAP.EQ.1.) FM1=FM3/XX
    I=3
    KLL=NUM-1
    DO 730 KN=1,KLL
    XX=KN
    IF (RAP.EQ.1) GO TO 690
    FM4=FM1*(1.-EXP(XX*XS))/(1.-RAP)
    GO TO 700
690 FM4=XX*FM1
700 I=I+1
    Z(I)=Z(3)**IG+FM4
    IF (IG-2) 730,710,720
710 Z(I)=SQRT(Z(I))
    GO TO 730
720 Z(I)=Z(I)**ANUM
730 CONTINUE
    X(IR+1)=Y(2)
    X(IR+2)=Y(3)
    IOP=IR+2
    DO 740 I1=2,I
    IOP=IOP+1
    I2=I-I1+2
740 X(IOP)=Z(I2)
    IL=IOP+1
    X(IL)=RL
    IF (IL-IR.LT.24) GO TO 850
    K=11
    N=12
    J1=IR
750 FM1=X(J1+K)-X(J1+N)
    FM2=X(J1+1)-X(J1+2)
    FM3=X(J1+2)-X(J1+K)
    IF (IG-2) 780,760,770
```

```
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 WICTH)                                                 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.

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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.

<u>Card 3 Format (16I5)</u>

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 ($V \equiv 0$).

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 ($V \equiv 0$).

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 $T_o \le 0$, 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.

$-20 \le$ IES ≤ -1 for analytic EOS (see card set 12).

For Type 7 zoning, variables 4 to 7 are ignored.

Region Information Card 2. Format (8E10.3)

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 ($\mathcal{E}_m$) 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. (31-40) λ.

Variable 5. (41-50) $(-C)$ (must be negative).

Variable 6. (51-60) K_s.

Variable 7. (61-70) Blank

Variable 8. (71-80) Blank

IV. Tensile Strength Limit (see Section VII for notation).

Variable 1. (1-10) σ_s - Maximum tensile strength ($\sigma_s > 0$).

Variable 2. (11-20) T_s - Strength vanishing temperature.

If $T_s \leq 0$, code sets $T_s = 10$.

Variable 3. (21-30) Blank

Variable 4. (31-40) Blank

Variable 5. (41-50) C.

If $C = 0$, code sets $C = 1$.

Variable 6. (51-60) Blank

Variable 7. (61-70) Blank

Variable 8. (71-80) Blank

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) $\mathscr{S}_2$ for Zone I.

Variable 7. (56-65) $\mathscr{S}_3$ 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)	$\dot{\mathscr{I}}_2 / \dot{\mathscr{I}}_3$ (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., $2 \le JJ \le NMTRLS$.

Appendix I

INPUT CARDS FOR THE ANALYTIC EQUATION OF STATE

Appendix I

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.

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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.

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R. Morales, GMX-11
F. T. Seibel, W-8
B. P. Shafer, W-1
J. P. Shannon, T-3
G. R. Spillman, TD-3
J. N. Stewart, J-9
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