2

This is an informal report intended primarily for internal or limited external distribution. The opinions and conclusions stated are those of the author and may or may not be those of the laboratory.

UCID - 16605

LAWRENCE LIVERMORE LABORATORY

University of California/Livermore, California

USER'S MANUAL FOR THE OIL CODES

M. E. Cunningham

October 22, 1974

MASTER

NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Atomic Energy Commission, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

Prepared for U. S. Atomic Energy Commission under contract no. W-7405-Eng-48

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

EB

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

Foreword

This report represents a preliminary version of a user's manual for the OIL family of Eulerian codes presently active at LLL. The intent is to permit users to gain familiarity with each code in the family as soon as possible after the codes become available. As work with the codes progresses, revised versions of this manual will be published. The physical bases for the codes and details on the differencing schemes will be provided in a forthcoming companion document.

Comments and suggestions for improving this manual would be greatly appreciated.

Contents

Abstract	1
Introduction	1
Chapter 1: General Description	1-1
Hydrodynamics	1-1
Equations of State	1-1
Radiation Diffusion	1-1
Strength in DORF9	1-1
Time-Step Control	1-2
Hydrodynamic Δt	1-2
Radiation Δt in RAD9	1-2
Subroutines	1-3
General Rules for Setting Up Problems	1-5
The Grid	1-5
Cell Variables	1-6
The Z-Block	1-7
Zoning and Material Labeling	1-7
Starts and Restarts	1-9
Chapter 2: TCOM	2-1
Generator	2-1
Linking and Generating	2-1
Generating from a Lagrangian Code	2-1
Temperature Map for RAD9	2-4
Generating from Cards	2-4
Input to TCOM for RAD9 and DORF9 (generation from a Lagrangian code)	2-5
Input Data Deck	2-5
Sample Problem	2-5
Output from TCOM for RAD9 and DORF9 (generation from a Lagrangian problem)	2-7
Input to TCOM for RAD9 and DORF9 (card generation)	2-16
Input Data Deck	2-16
Sample Problem	2-19
Output from TCOM for RAD9 and DORF9 (card generation)	2-21
Chapter 3: RAD9	3-1
General Description of Input	3-1
The Z-Block	3-3
The Tillotson Equation of State	3-11
Specific Heat in RAD9	3-13

Contents (Continued)

On-Line Plots and Cell Patches	3-13
PLOTIN	3-14
PATCH	3-16
Output from RAD9	3-16
Chapter 4: DORF9	4-1
Chapter 5: Running the OIL Family Codes (Louise Morris)	5-1
Acknowledgments	5-4
References	6-1

USER'S MANUAL FOR THE OIL CODES

Abstract

Since the OIL family of codes authored by W. E. Johnson is now being used by more than one division at LLL, it has become necessary to formalize information for the various users and to update information on the newer codes as development work is done on them.

This manual provides instructions for setting up problems on the nine-material version of the RADOIL code. It will be revised and expanded to include the DORF code and other codes in the OIL family as appropriate.

Introduction

The OIL codes were written by W. E. Johnson of Computer Code Consultants, Solana Beach, California. The original member of the family was patterned after the LASL PIC code,¹ but was developed to handle continuous mass instead of mass points.

The OIL codes are two-dimensional, Eulerian hydrodynamic, strength-of-materials or radiation-diffusion codes. They have been used in cylindrical geometry but can also be run in Cartesian geometry. At LLL, they are set up to allow 16,007 cells in a problem. The physical parameters are cell-centered. The quantities carried are the masses and specific internal energies of each material in a cell, the pressure and radial and axial velocities common to the cell as a whole, the temperature (in RADOIL), and the stresses (in DORF). There are also associated linking codes, rezoners, and post processors in the family. The units in the codes are grams, jerks ($\times 10^{16}$ erg), centimeters, and shakes ($\times 10^{-8}$ s). Pressures in jerks/cm³ are converted to megabars in the output.

The RADOIL part of the OIL family consists of the following:

- RAD2 – A two-material code with radiation diffusion.
- RAD9 – A nine-material version of the RAD2 code.

These codes are designed to handle two-dimensional problems in radiation hydrodynamics where temperatures are below 1 keV. However, not all parts of the codes now handle temperatures this high equally well. The weak link at present is the Tillotson equation of state (EOS), which is designed to deal with the wide range of pressures encountered in impact problems but not with the range of temperatures encountered in radiation hydrodynamics problems. Despite this EOS difficulty, in comparing problems run with RAD2 or RAD9 with those run using codes with better equations of state, the differences in material motion seem to be extremely small, and the pressure profiles and shock speeds compare adequately.* It should be noted that massless cells cannot be handled by RAD9.

The DORF part of the OIL family consists of the following:

- DORF2 – A two-material code with a rigid-plastic strength model.
- DORF9 – A nine-material version of DORF with an elastic-plastic strength model.

These codes handle hypervelocity impact problems and some other types of problems in the regime where strength of materials becomes important. At present, they use the same paths for loading and unloading; however, this procedure will probably be modified.

Ultimately, this manual will contain instructions for RAD9, DORF9, TCOM (their generator-link-rezoner code), and postprocessors. However, at this time only RAD9 and the generator part of TCOM are included in detail. Revisions to this manual will be published as the codes become available.

*Details concerning the EOS problems and comparisons with other codes will be dealt with in Ref. 2.

Chapter 1: General Description

Hydrodynamics

Overall, the hydrodynamic calculations in the OIL codes are Eulerian. They are performed in two phases which are common to all the two-material and multimaterial* OIL codes. That is, subroutine PH1 solves the Lagrangian equations, and PH2 and associated subroutines make up the coordinate transformation routines that remap the PH1 Lagrangian problem back onto the Eulerian grid. An excellent description of the integral form of the transformation in which many of the approximations can be clearly seen is given in an appendix to the original PIC report.¹ The details of the explicit differencing scheme are explained in several reports by W. E. Johnson³⁻⁵ and will also be included in the forthcoming companion report² to this manual.

Somewhat arbitrary rules in the codes for moving materials out of mixed cells tend to help keep boundaries reasonably well localized and to prevent non-physical jetting of material through the grid. These will be discussed in some detail later as they affect the way in which the code must be zoned. At the present time, only two materials, designated "X" and "dot", may be in a cell. If, in the nine-material codes, more than two get into a cell, alchemy is performed so that only two materials are left. The details again are left to the companion report² and to the report on RADOIL and RAM³. A version of RAD9 which can carry up to four materials in a cell without the need for alchemy is being developed by W. E. Johnson.

To calculate a single pressure for two materials in a cell, the code requires that the pressures in the two materials be equal, and an iteration on the pressures is performed to make this so. The codes will not now handle the combined pressure of two gases in a cell as $P = P_{\text{dot}} + P_X$ (where P_{dot} is the pressure in the dot material and P_X is the pressure in the X material). However, the codes will be changed so that this Dalton's Law pressure sum will be made when two gases are present in the cell.

Equations of State

The present EOS in the OIL family is the Tillotson EOS.⁶ McMaster-Schroeder-Grüneisen⁷ equations of state will be put into the codes as a second option. A high-explosive EOS will soon be put into DORF9; later, other EOS options will be added. The Tillotson EOS and a table of input parameter values are provided in Chapter 3.

Radiation Diffusion

PH4 is the master subroutine for controlling the subroutines for the implicit radiation diffusion calculation. The equations are appropriate for use in problems with temperatures up to about 1 keV. (However, because the Tillotson EOS is not a very good one for temperatures this high, a set of more appropriate tabular equations of state will eventually be added to the code.)

A simple flux limiter is used which does not carry pipe diameter as a geometrical term. Opacities for Fe, Pb, and Al are now available; one for Be is almost ready to go into the code. These four opacities span the periodic table well enough for many problems.

Strength in DORF9

PH3 is the master subroutine for controlling the strength model subroutines in DORF9. The elastic-plastic model in DORF9 is based on a discussion by Prager⁸ and is described by W. Johnson.⁹ The details will be described in Ref. 2.

*The term "multimaterial" will be used to designate "greater than two."

Time-Step Control

The time step can be controlled in any one of three ways:

- A constant Δt may be specified as the time step;
- The code may be allowed to vary between upper and lower limits FFA, FFB (see the Z-block input in Chapter 3); or
- The code may control its time step completely.

We recommended that the code control the time step. When the code controls, a hydrodynamic time step is calculated in subroutine CDT, and in RAD9 a radiation time step is calculated in subroutines AXIAL and RADIAL. In subroutine CDT, the radiation and hydrodynamic time steps are compared, and the lesser one is used in calculating the next cycle. Note that the Δt is that appropriate to the velocity distribution of the cycle just completed. If in the new cycle the Δt proves to be too large, the code does not alter the Δt and recalculate. For example, if the Δt is large enough that more mass would flow out of a cell than the cell contains, the flow is limited but the Δt is not lowered until the code is ready to calculate the following cycle. Thus, the correction to the Δt lags by one cycle. Normally, few or no cells in the grid are concerned, and the results are not affected; however, in an unusual problem this lag might cause running difficulties. The Δt is not allowed to increase at a rate greater than a maximum specified in the input. Details of the hydrodynamic and radiation time-step calculations are given in the following sections.

Hydrodynamic Δt . A hydrodynamic Δt calculation is made in subroutine CDT for all cells whose density is greater than Z(138).^{*} If the density of a cell is less than or equal to Z(138), the cell is bypassed for time-step calculation.

The code finds a minimum Δt by comparing $\frac{C}{\min(DX(I), DY(J))}$, $\frac{U(K) \cdot 2\pi X(I)}{TAU(I)}$, and $\frac{V(K)}{DY(J)}$, where C is the sound speed calculated in subroutine WHATES, U(K) is the radial velocity of the material in cell K, V(K) is the axial velocity, and TAU(I) is the annular area. The quantity UVMAX is set to the largest of these quantities among all the cells of the grid which are tested. The hydrodynamic time step is then set to $\frac{Z(105)}{UVMAX}$, where Z(105) begins as the early-time stability entered in the Z-block. This value is set to 10^{-4} to begin the calculation and is increased every cycle until it reaches the value in Z(139), usually about 0.35 to 0.40. The maximum value it could possibly have is 0.50; a Z(139) greater than 0.5 would allow more mass to flow out of a cell than is in the cell to begin with. It is usually set below 0.5 partly because of the previously mentioned time lag in the Δt correction. The early-time stability is set to a low value at the beginning of a problem to enable the problem to start smoothly. Further discussion will be included in Ref. 2.

Radiation Δt in RAD9. The radiation Δt in RAD9 is calculated in subroutines AXIAL and RADIAL. Cells for which $a\theta^4 < SN$ are checked only if they are cooling. SN is Z(65), an input number, a, is the radiation constant in $\text{jerks/keV}^4 \cdot \text{cm}^3$, and θ is the temperature in keV. Cells for which $a\theta^4 \geq SN$ are always checked. The radiation Δt is set equal to the minimum value of $\frac{FEF \cdot E(K)}{\Delta E(K)}$ where FEF is Z(25), E(K) is the total energy in the cell, and $\Delta E(K)$ is the rate of change in radiation energy in the cell during the cycle just completed. FEF is usually set to 0.15.

Further details of the physics of the time-step control will be discussed in Ref. 2.

^{*}Z(138) represents input parameter 138 in the Z-block array. The Z-block array is described in Chapter 3.

Subroutines

Tables 1-1 and 1-2 list the subroutines included in RAD9 and DORF9, respectively.

Table 1-1. RAD9 subroutines.

Subroutine	Function
MAIN	Main routine for the code.
AMAIN	Principal code controlling routine.
ASSINE	Handles disk and tape linkage.
AXIAL	Axial diffusion routine for radiation.
CARDS	Translation of formats on input cards.
CDT	Calculates the hydrodynamic time step.
CHANGE	Converts $a\theta^4$ to θ .
EDITS	Edits the output to the dump tape and to the tape for either the high-speed printer or microfiche.
ES1-ES9	Mostly unused routines for EOS descriptions (ES1 is the Tillotson EOS).
INPUT	Processes the input before the calculation is begun.
KAP1-KAP9	KAP1 contains that A1 opacity in analytical form. KAP2 contains the Fe opacity in analytical form. KAP3 contains the Pb opacity in analytical form. KAP4 will contain the Be opacity in analytical form. KAP5-KAP9 are available for additional materials.
MASK	Not used at the present time.
OUTCRT	Determines disposition of plot files.
PACK	Packs array NUMF(K) which holds material identification and, for mixed cells, holds the fractional volume of the cell which is occupied by X material.
PATCH	Allows cell-by-cell alteration of variables.
PH1	Does the Lagrangian part of the hydrodynamic calculation.
PH2	With the mass transfer routines TOP, RIGHT, PH22, and PH23, does the coordinate transformation after PH1 to remap onto the Eulerian grid.
PH22	See PH2.
PH23	See PH2.
PH4	Master routine for controlling the radiation flow subroutines.
PHI	Uses a Newton-Raphson scheme to find the new temperature θ by performing the iteration between the specific internal energy and $C_V\theta + a\theta^4/\rho$.
PLOTIN	Optional routine for making on-line graphical plots.
PLOTRD	Subroutine which makes the logic grid plots that go to the high-speed printer at edit time.
PTWO	Artificial viscosity (not used in RAD9).
RADIAL	Radial diffusion routine for radiation.
REZONE	Not used.
RIGHT	See PH2.
SETUP	Not used.
SLITE	Sense light routine.
SOURCE	Routine for handling the radiation boundary conditions.
SPHEAT	Calculates the specific heat.
THETOE	Switches internal energy arrays which have been used in the radiation routines for other quantities back to specific internal energies before return to hydrodynamic routines.

Table 1-1. RAD9 subroutines. (continued)

Subroutine	Function
TOAO4	Converts θ to $a\theta^4$.
TOP	See PH2.
TRACER	Not used in RAD9 at present.
UNDO	Unpacks the array NUMF(K) which holds material identification (see PACK).
WHATES	Routine which examines the state of the material in a cell (pure, mixed), subtracts radiation term from internal energy, calculates partial volumes and iterates pressures for mixed cells, adds one third the radiation energy for the radiation pressure, and calls the appropriate EOS routines [ES1 through ES9].
WHATKA	Routine which examines the state of the material in a cell (pure, mixed), calls the appropriate opacity routines [KAP1 through KAP9], and for mixed cells calculates the combined opacity.

Table 1-2. DORF9 subroutines

Subroutine	Function
MAIN	Main routine for the code.
CARDS	Translation of formats on input cards.
CDT	Calculates the hydrodynamic time step.
EDITS	Edits the output to the dump tape and to the tape for either the high-speed printer or the microfiche.
EPLS	Elastic-plastic strength routine.
ES1-ES9	Mostly unused routines for EOS descriptions (ES1 is the Tillotson EOS).
INPUT	Processes the input before the calculation is begun.
MASK	Not used.
PACK	Packs array NUMF(K) which holds material identification and, for mixed cells, holds the fractional volume of the cell which is occupied by X material.
PH1	Does the Lagrangian part of the hydrodynamic calculation.
PH2	With the mass transfer routines TOP, RIGHT, PH22, and PH23, does the coordinate transformation after PH1 to remap onto the Eulerian grid.
PH22	See PH2.
PH3	Controlling subroutine for strength.
PLOTDR	Subroutine which makes the logic grid plots that go to the high-speed printer at edit time.
RIGHT	See PH2.
SLITE	Sense light routine.
SLITET	Sense light routine.
STRESS	Calculates the strain rates.
TOP	See PH2.
TRACER	Subroutine which handles the tracer particles.
UNDO	Unpacks the array NUMF(K) which holds material identification (see PACK).
WEIGHT	Weights stresses and strains on the basis of where the material was at the previous cycle.

Table 1-2. DORF9 subroutines. (continued)

Subroutine	Function
WHATES	Routine which examines the state of the material in a cell (pure, mixed), subtracts radiation term from internal energy, calculates partial volumes and iterates pressures for mixed cells, adds one third the radiation energy for the radiation pressure, and calls the appropriate EOS routines [ES1 through ES9].

General Rules for Setting Up Problems

The Grid. Figure 1-1 shows a sample grid for the OIL codes. This sample grid is cylindrical about the y-axis. Zones 2, 6, 10, and 14 are solid cylinders with center lines along the y-axis so that the width in the x-direction is the radius of the cylinder. Zones 3, 7, 11, and 15 are annular about the y-axis. The I zonal index runs radially along the x-axis from 1 to its maximum value IMAX. The J zonal index runs axially along the y-axis from 1 to its maximum value JMAX.

Variables carried for each zone, e.g., mass, velocity, and pressure, are carried in a singly dimensioned array by cell number K, where $K = \text{IMAX} \cdot (J-1) + I + 1$, and $K_{\text{MAX}} = \text{IMAX} \cdot (\text{JMAX}) + 1$. The K numbers for the cells in the grid in Fig. 1-1 are printed in the centers of the cells. The I and J values which designate a cell are at the upper right-hand corner of the cell. The shaded cell, cell #8, has an I value of 3 and a J value of 2. Note that the minimum value for K is 2, not 1.

Fig. 1-1. RADOIL grid.

The maximum value for K in a problem is 16,008. Problems may use up to 16,007. (Special versions with larger or smaller KMAX can be compiled if needed. However, 16,000 has been a good working size for most of the problems for which the codes have been used.) The maximum value for I is 201. Problems may use up to 200 (subject to the restriction on K). The maximum value for J is 201. Problems may use up to 200 (subject to the restriction on K).

The DX(I) are the cell widths in the radial direction. The DY(J) are the cell widths in the axial direction.

Then, $X(I) = \sum_{m=1}^I DX(m)$, and $Y(J) = \sum_{n=1}^J DY(n)$. Thus X(I) and Y(J) define the top right-hand corner of the cell I, J in the grid as shown in Fig. 1-1.

Cell Variables. Table 1-3 lists the cell variables.

Table 1-3. Cell variables.

Cell Variables	Definition	Units
AMX(K)	Mass of X material in cell K.	g
AMD(K)	Mass of dot material in cell K.	g
AIX(K)	Specific internal energy of X material in cell K.	jerks/g
AID(K)	Specific internal energy of dot material in cell K.	jerks/g
CVDOT	In RAD9, the specific heat capacity of the dot material.	jerks/g-keV
CVX	In cell K, RAD9, the specific heat capacity of the X material.	jerks/g-keV
P(K)	Pressure in cell K.	jerks/cm ³ in code Mbar in output
RHO	Density in cell (not carried in code but appears in output).	g/cm ³
U(K)	Radial velocity of material in cell K.	cm/shake
V(K)	Axial velocity of material in cell K.	cm/shake
NUMF(K)	Fractional volume of X material in a mixed X-dot cell. ^a Also serves as a material flag. This is a RAD9, DORF9 quantity. Suppose that there are four materials in a problem. Let 1 and 2 be X and 3 and 4 be dot. Typical NUMF(K) values for various cells then are interpreted as follows: -2374 Indicates that the cell contains 2 as X and 3 as dot and the fractional volume of 2 is 0.74. The minus sign catches the eye and indicates a mixed cell. The fraction is carried to four places in the code but is printed out to two places. 100 Indicates that the cell is pure dot and that the dot material is 1. 4000 Indicates that the cell is pure X and that the X material is 4.	
THETA(K)	In RAD9, the temperature in cell K.	keV
SIGRR(K)	In DORF9, the normal stress in the radial direction.	jerks/cm ³
SIGZZ(K)	In DORF9, the normal stress in the axial direction.	jerks/cm ³

Table 3. Cell variables. (continued)

Cell Variables	Definition	Units
SIGRZ(K)	In DORF9, the shear stress.	jerks/cm ³
-SIGZZ(K) - SIGRR(K)	In DORF9, hoop stress.	jerks/cm ³

^aCells with mixed X and X or dot and dot do not occur because the code performs alchemy on them (see discussion of mixed cells on p. 9).

The Z-Block. An array called the Z-block carries the information input to the code. It also carries a number of quantities calculated by the code which may or may not be updated every cycle. The Z-block is printed out on every short or long edit and is a principal diagnostic tool for checking on the health of a problem. The user should understand the quantities in the Z-block and check on the values in it every time he receives output for a problem. Often, the first signs of impending trouble may appear in the Z-block, even though the program may continue for several hundred microseconds in a radiation problem before actually crashing. The quantities in the Z-block, both input and the quantities calculated by the code, are listed in Chapter 3.

Zoning and Material Labeling. It is difficult to write the equations of motion to take care of differences in zone size while still retaining a conservative form. The differencing equations for the OIL family are written assuming equally sized zones. Therefore, changes in zone size should be gradual over a number of zones rather than abrupt from zone to zone. A recommended value for change between adjacent cells is 10%. As with any code, large aspect ratios should also be avoided. If the motion is unidirectional, either radially or axially, this is less important. If the motion is diagonal, differences are noticeable for aspect ratios of 2:1; that is, pressure peaks suffer a loss in resolution commensurate with the long axis of the cell, and U and V velocities behave asymmetrically.

Because of the rules for moving materials out of mixed cells, one should not, in any region where there is to be activity, zone so that there is less than a three-zone width of one material separating regions of the other materials. If there is only a one-zone width, it acts as a "window screen." Figure 1-2 demonstrates how care with zoning will eliminate the window-screen effect.

In Fig. 1-2(a), the dot material is indicated as (•) in cell K-1 and as (Θ) in cell K+1 for ease in following the materials. Although the code makes no such distinction, real problems indeed do have built-in distinctions. For example, the (•) material might be air in a pipe, the (X) might be the pipe and the (Θ) might be tuff. The region shown may be a close-in region where the pipe is about to expand.

The first line in Fig. 1-2(a) shows three zones with a velocity in the left-most cell, K-1, directed to the right. On the first cycle, the code looks at the velocities of cells K-1 and K and finds that there should be (•) material crossing into cell K. This is a low-density material, air, moving into a high-density region of, say, expanded Fe. On the second cycle, a small velocity now exists in the mixed cell K and mass is due to be transferred to cell K+1. The code looks at cell K+1 and sees it is a pure dot cell. The transfer rule in the code is that the mixed cell K must first transfer its dot material because the acceptor cell is a pure dot cell. Then, if not enough mass has been transferred, it will begin to move X material. Thus, in a region of moderate activity dot material will transfer to cell K+1 as shown in the last part of Fig. 1-2(a). Conditions may well be such that the lone X cell will act as a window screen through which (•) will flow into (Θ) unimpeded by the X provided that

- The (•) material to be transferred is not less than the cutoff (in which case none will actually be transferred), and
- The K to K+1 transfer less mass than the total (•) mass of the cell is transferred.

If there are three cells of X material, the window-screen effect does not occur. Thus, in Fig. 1-2(b) dot material will move into cell K-1 as in Fig. 1-2(a). However, any transfer from K-1 to K will be X rather than dot material because the acceptor cell is a pure X cell. Eventually, momentum will be imparted to all the cells and the final configuration may be as shown in Fig. 1-2(b).

Fig. 1-2. Window screen effect.

Note that until all the X material moves out of K-1 into K, no dot can flow into K. Also, until all the (⊙) moves out of K+2 into K+3, no X can move into K+3. There is no window-screen effect and material interfaces are kept reasonably well. When the density of X material left in cell K-1 drops below the cutoff, that cell will become a pure dot cell.

The mixed-cell mass transfer rule exemplified by Fig. 1-2 is not perfect, particularly for gases moving into gases, but it is a fairly reasonable compromise which prevents jetting. However, the zoning must be done with the operation of the transfer rule in mind.

In the nine-material codes, the window-screen effect occurs if the same dot material is on either side of the X material (or vice versa). If the two dot materials are different, the nine-material codes have an additional problem. In mapping two materials, one must be designated as X, the other as dot. Then, when the two materials move into a cell, the code will handle it as a mixed cell.

If a problem will be run with more than two materials, every effort must be made to place X and dot materials alternately and to avoid leaving any boundary of interest with X next to X or dot next to dot.

Figure 1-3 demonstrates a situation in which part of boundary A will cause difficulties between dot materials 2 and 3. Other boundaries will be handled properly. At boundary A, alchemy will be performed when material 2 moves into material 3. The code performs the alchemy on the materials as follows: if there is flow into a cell over any boundary into a dot material and if any of the flows are themselves dot material, the normal densities of the dot materials in donor and acceptor are compared, and the cell is labeled as being the dot material

Numbers are material designations.
"A" indicates portion of boundary where difficulty will occur.

Fig. 1-3. Illustration of a grid geometry which causes material boundary difficulties.

with the largest normal density. The same holds true for X material moving into X material. This alchemy often causes unrealistic flows of a material boundary or impedes the proper flow of that boundary. The window-screen effect would add to the confusion.

Other schemes for handling two dot materials in a cell have been tried but they all have similar disadvantages. One such scheme performs alchemy on two dot materials in a single cell by labeling both materials with the material number of the material having the larger mass. W. E. Johnson is developing a four-material version of the code which will not perform alchemy but will simply carry up to four materials in a single cell if needed.

Starts and Restarts.

The RADOIL and DORF codes are run by picking up information either from the generator to start a new problem or from a previous cycle to restart an already running problem. The executable code may be loaded from a library file, a disk file, or a deck (binary or binary with MAIN and modified subroutines as source decks). The output may be via high-speed printer and/or microfiche. Plots may be CRT or microfiche. Running the codes is further described in Chapter 5.

The data file names the tape to be used, and Z-block and edit information follow. Any information input to the Z-block remains in the problem unless overwritten either by a new data deck on restart or by the code. Z-block entries not made with the input data will remain as they came with the link. Entries not made in data input to the link or to the start or restart decks will be carried as zeroes unless they are variables calculated and entered into the Z-block by the code. When starting a new problem from a TCOM, the code is instructed through the data deck to begin at cycle zero. Thus, at this stage the problem cannot be restarted if it is taken off the machine during production. When restarting, one can choose to instruct the code to pick up at a particular cycle number, N, in which case it is non-restartable if taken off the machine during the run. Should it be restarted, it would again begin calculating at cycle N. The more common way to run on a restart is to instruct the code to start with the last cycle on the tape -- the problem is then restartable.

Subsequent chapters will describe in detail the input for the links and rezoners for all the codes and the input to the codes themselves. Even though some of the information is common to several codes, it will be repeated for each one so that if one wishes to set up a problem, the input instructions can be followed simply line by line.

The instructions for the generator input follow closely those written up by Steve Kurtz in the TOIL Users' Manual which has been used for several years in rough-draft form. His instructions have been updated here to handle the multimaterial version of the code in production on September 1, 1974. Instructions for the plots were adapted from a memo by Erlene Schooler. Following the sections on the detailed input to TCOM, RAD9,

and DORF9 are the sections on the post-processors written by Erlene Schooler (these will be inserted in the next edition of this manual).

The deck file or card deck is ordered as in Fig. 1-4 for both links and codes.

Fig. 1-4. General structure of problem input.

The OIL family of codes runs under the ORDER controller of the Livermore Time-Sharing System (LTSS).

Chapter 2: TCOM

Generator

Linking and Generating. TCOM, the generator for RAD9 and DORF9, can either link from a Lagrangian code or generate a problem from cards. The zonal quantities linked or hand-generated are X and dot masses, specific internal energies, and radial and axial velocities. TCOM will eventually also contain the rezoner and links from RAD9 and DORF9 to Lagrangian codes such as TENSOR and CEL-HEMP.

In the Lagrangian-link mode, the code overlays the Lagrangian grid with an Eulerian grid whose zoning is described in the input data deck. An Eulerian zone contains N^2 particles (N^2 is input) as designated in the deck, and these particles are used to "sample" the Lagrangian grid. Figure 2-1 shows an Eulerian cell with a distribution of 25 particles in the centers of 25 equal areas of the cell, the division between the two Lagrangian cells overlaid by the Eulerian cell, and the division which will be made by the generators in the material mapping.

Fig. 2-1. Illustration of how distribution of material is mapped at a Lagrangian zone boundary.

The generator as used for RAD9 calculates the temperature in each cell from the internal energy and density.

$$\frac{E}{V} = \rho C_V \theta + a\theta^4,$$

where E/V is the internal energy density, C_V is the heat capacity, ρ is the density, and θ is the temperature.

The pressures and, in the case of DORF9, the stress components are not calculated until cycle zero of the RAD9 or DORF9 run. There is no EOS information in the generator.

Generating from a Lagrangian Code. When a problem is generated from a Lagrangian code, a zero-point adjustment must usually be made in the grid map to place the Lagrangian grid at the desired location in the Eulerian grid. This is necessary because the OIL grids cannot have negative coordinates. Figure 2-2 shows the Eulerian overlay of such a grid. The adjustment (ZERP in the code) is the magnitude of the axial distance the origin of the Lagrangian grid must be moved in the overlay to put it at the desired location in the Eulerian grid, whose origin must be at the bottom of its grid. In Fig. 2-2, L is the ZERP, and P is the origin of the Lagrangian problem.

If the problem has been run so that the Z-direction in the Lagrangian grid increases with decreasing K instead of with increasing K, a flag, ICOZ, must be set in the generator. A non-zero value of ICOZ will cause the code to set all Z values in the Lagrangian problem to $-Z$ so that increasing Z will go with increasing K. The map may then be made successfully.

Fig. 2-2. Eulerian grid overlaid on Lagrangian mesh.

The generator conserves mass, momentum, and total energy but performs some interchange between internal and kinetic energy. Remember that any rezoning or linking in Lagrangian or Eulerian codes causes loss and/or distortion of information. Also, the more scrambled the Lagrangian zones are at link time, the poorer the transfer of information. There is no way, for example, to extract valid information from a bow-tie-shaped Lagrangian zone. Garbage in, garbage out.

The generator must also be given information about the Lagrangian code EOS numbers used in the problem. In TCOM, the numbers and assignment of the corresponding materials to material types 1 through 4 are part of the input data to the code.

FUNNY cards indicate to the generator the Lagrangian cells which are occupied. Figure 2-3(a) shows a fanciful Lagrangian grid; Fig. 2-3(b) shows that grid translated into logic space. In this example, occupied cells are designated by the K and L coordinates of the upper right-hand corner of the Lagrangian cells in Fig. 2-3(b). Note, for instance, in Figure 2-3(a), that K=6 and L=3 do not cross but that K=7 and L=3 do. Therefore, in the logic grid, Fig. 2-3(b), an occupied cell is indicated for K=7, L=3, and to the left of and below K=6, L=3 there is a hole.

The FUNNY cards indicate to the generator the lower (LLO) and upper (LHI) K-lines bounding an occupied region. For K=5 in Fig. 2-3(b), the occupied cells as designated by the Lagrangian code are L=4 to L=6. However, in the generator for the Eulerian grid, one designates the bounding L-lines L=3 and L=6. The FUNNY cards

Fig. 2-3. A Lagrangian grid and its corresponding logic space.

designate such bounding L-line pairs for each K-line in the grid. There must be at least two FUNNY cards in the deck: the first lists in order of increasing K all of the corresponding LLO values, and the second lists in order of increasing K all of the corresponding LHI values. If there are more K values than the number of entries which can be made on a single card, they may be continued on cards directly behind. One may, for example, have four LLO cards followed by four LHI cards. There are no LLO or LHI values for K=1 because there are no corresponding cells.

The format for the FUNNY cards is (6X, 2213). For the example shown, the FUNNY card input would look like Fig. 2-4. Note that for K=6, the LLO value corresponds to the lower bounding L value for the occupied cell.

The LEN cards describe the regional packages which make up the Eulerian grid to be generated. LEN cards usually describe the part of the grid outside the region overlaying the Lagrangian grid, but they may also be used to modify part of the Lagrangian region. Anything on the LEN cards which applies to an overlaid Lagrangian region supercedes information picked up from the Lagrangian code.

The LEN packages must be rectangular since they are described by a minimum and maximum I and a minimum and maximum J. In the typical package layout shown in Fig. 2-5, the order of package numbering is arbitrary and is used only to clarify the discussion. If the packages were all tuff, one would need only three: package 1, part of package 4, and a single package for numbers 2 and 3 and the rest of 4 and 5. However, there

[illegible]

Fig. 2-4. Sample input for FUNNY cards describing the Lagrangian grid in Fig. 2-3.

Fig. 2-5. Designation of regions for a typical Eulerian problem.

is a region of different material, package 3, and so one ends up with a total of five packages. Sometimes, where there are small packages involved, it is easier to write LEN cards for several large packages and then stack the cards for small packages behind those for the large ones. In this way, one can cover the whole grid with the large packages and overwrite small parts of these with small packages. Information on any package or part of a package can be overwritten by another package provided the cards describing the overwriting package are stacked in the data deck behind the cards describing the overwritten package.

Note that all zones in a package described by LEN cards must have common values of density, specific internal energy, and velocity. There are no functional fits for quantities as there are for the TCOM routine, which normally generates from cards.

Temperature Map for RAD9. For RAD9, TCOM calculates temperatures from the internal energy mapped over from the Lagrangian code. The code solves for θ by a Newton-Raphson iteration using the equation

$$E = \rho C_V \theta + a\theta^4,$$

where E is the internal energy density, θ is the temperature, C_V is the heat capacity, a is the radiation constant, and ρ is the material density. In the mapping process, the inputs for C_V are constants rather than functions of θ and ρ . The code calculates the functions which are described in Chapter 3.

Generating from Cards.

When a problem is generated by hand, the following cards are used:

- Geometry cards which generate rectangles, triangles, ellipses, or circles in regions or packages* of the problem;

*A package is a geometric region of zones, is generated as a rectangle, triangle, ellipse, or circle, and has either a uniform density, a uniform energy, and a uniform velocity, or specific analytic fits to these quantities. Three cards in the data deck follow the geometry and delete geometry cards of each package. The absence of any or all of these cards indicates that values are to be taken from the previous package.

- Delete geometry cards which do not really delete a geometry generated but rather cause the code not to generate a geometry whose coordinates are specified; and
- Density, energy, and velocity cards which serve a similar function to that of the LEN cards.

Figure 2-6 illustrates the use of a delete geometry card. In Fig. 2-6(a) a circle is generated; a delete card "deletes" the circle in Fig. 2-6(b). The result is the generation of the annulus in Fig. 2-6(c). The map in an actual grid is shown in Fig. 2-6(d).

Fig. 2-6. Illustration of the use of a delete geometry card.

Input to TCOM for RAD9 and DORF9 (generation from a Lagrangian problem).

Input Data Deck. The input for TCOM consists of the data deck and the Lagrangian disk file. TCOM does not have provision for getting the Lagrangian file from tape and one must do this before running so that the desired file will be on disk. TCOM is then run from the teletype and the file name is entered when asked for by the code. This may be done either by the user or by a machine operator to whom instructions have been provided.

The TCOM data deck consists of a header card, geometry cards to describe the grid, EOS cards, FUNNY cards to indicate the Lagrangian K & L line limits to be mapped, LEN cards to describe the regions of the grid outside the Lagrangian region, and the heat capacity card.

The detailed specifications for input data file is provided in Table 2-1. It can be accessed either as a separate disk file TC9D or, if running under ORDER, following a *DATA TC9D.

Sample Problem. A sample problem for linking from a Lagrangian code, including the file linked from, will be kept on Photostore and can be obtained from the author.

Table 2-1. Input to the TCOM code.

Card no.	Column no. ^a	Description of input
1	2-72	Header card, any BCD information.
	75-80	Tape designation, e.g. *LG411 (the asterisk here indicates a blank tape is to be assigned).
2	*1-10	Contain the problem number.
	*11-20	IMAX, the number of cells in the x-direction (maximum of 200).
	*21-30	JMAX, the number of cells in the y-direction (maximum of 200).
	*31-40	QOOOFL = 0. for DORF. = 1.0 for RAD9. Flag indicates which code.
	*41-50	= 2. for tracer particles. = 0. for no tracer particles.
	*51-60	= 0. for cylindrical geometry. >0. for Cartesian geometry.
	*61-70	S9 = $\begin{cases} 0.0 & \text{for all card generation} \\ +1.0 & \text{for rezoner} \\ -1.0 & \text{for generation from a Lagrangian problem} \end{cases}$
	71-72	N7 = binary tape number = 7
3	(two number 3 cards is the minimum)	
	1	= 1 indicates that this is the last DX or DY card to be read in. = 0 indicates that there will be more DX or DY cards.
	2	= 0 indicates DX data will follow on this card. = 1 indicates DY data will follow on this card.
	3-4	The number of zones that will have the same DX or DY value that appears in columns 11-20.
	5-6	The number of zones that will have the same DX or DY value that appears in columns 21-30.
	7-8	The number of zones that will have the same DX or DY value that appears in columns 31-40.
	9-10	The number of zones that will have the same DX or DY value that appears in columns 41-50.
	*11-20	The value of DX or DY.
	*21-30	The value of DX or DY.
	*31-40	The value of DX or DY.
	*41-50	The value of DX or DY.
4	*1-10	Blank.
	*11-20	Blank.
	*21-30	= 80. indicates to the code that an OIL code problem is to be generated rather than a PIC problem.
	*31-40	Blank.
	41-42	Designates material (1) as X if set to 1 or as dot if set to zero.
	43-44	Designates material (2) as X if set to 1 or as dot if set to zero.
	45-46	Designates material (3) as X if set to 1 or as dot if set to zero.
	47-48	Designates material (4) as X if set to 1 or as dot if set to zero.
5a	Format 24I3	Lagrangian EOS designations for materials to become Eulerian material (1)
5b	Format 24I3	Lagrangian EOS designations for materials to become Eulerian material (2).
5c	Format 24I3	Lagrangian EOS designations for materials to become Eulerian material (3).

Table 2-1. Input to the TCOM code. (continued)

Card no.	Column no. ^a	Description of input
5d	Format 24I3	Lagrangian EOS designations for materials to become Eulerian material (4).
6	1-3	Contains $(N)^2$, where N is the number of particles per cell to be generated. $(N)^2$ must be a perfect square, with $1 \leq N \leq 20$. An often used value for $(N)^2$ is 81.
	4-6	Contains the number 9 which designates the tape unit number of the Lagrangian tape.
	7-10	Blank.
	*11-20	Contains the zero-point adjustment for overlaying the Lagrangian and Eulerian grids. This adjustment is necessary because the OIL codes require the lower left-hand corner of the Eulerian grid to be the origin. This is not necessarily the same position as the origin of the Lagrangian grid.
	*21-30	Contains the cycle pickup number.
	*31-40	Contains the ambient density of the backfill (tuff, etc.)
7		FUNNY cards as described in section on general comments concerning the generating from a Lagrangian problem.
7a	1-6	Blank.
	7-72	Values of LLO-format (22I3).
7b	1-6	Blank.
	7-72	Values of LHI-format (22I3).
8		LEN cards — as many 8 cards as there are packages.
	1-5	Contains the smallest value of I for this package.
	6-10	Contains the largest value of I for this package.
	11-15	Contains the smallest value of J for this package.
	16-20	Contains the largest value of J for this package.
		These four numbers describe the Eulerian coordinates of the package.
	21-24	Blank.
	25	= 1 implies X material is contained in this package. = 0 implies dot material is contained in this package.
	*26-35	Contains the density of the material.
	*36-45	Contains the radial velocity component of entire package.
	*46-55	Contains the axial velocity component of entire package.
	*56-65	Contains the specific internal energy for the entire package.
	68	M-type value from 1 to 5 designating the material number for the package.
	72	= 0 indicates more LEN cards to follow. = 1 indicates no more LEN cards to follow.
9(RAD9) only	1-3	Number of values of C_V to follow.
	*4-67	Values of C_V for the N materials of the problem <i>in order of material number</i> . N = 1 to a maximum of 4.

Card 9 is omitted for generation of a DORF9 problem.

^aAn asterisk before the column number signifies that the data are floating-point; otherwise, they are fixed-point data.

Output from TCOM for RAD9 and DORF9 (generated from a Lagrangian problem). Sample page 1 gives at the top the problem number, the time in the problem at which the link to the Lagrangian code was made, the tape on which the TCOM cycle zero was made and the IMAX and JMAX of the Eulerian grid. Following these items is a listing of the locations of the X(I) and Y(J) in centimeters. Following in the printout would be the cell

widths DX(I) in the radial (x or r) direction in centimeters, and DY(J) in the axial (y or z) direction in centimeters for the Eulerian grid. Sample page 3 contains the values of AREA(I) (TAU(I) in the code) which are the annular cell areas taken perpendicular to the z-axis.

"Normal Scheme" refers to the only mapping technique presently done by TCOM.

Next are given the zero-point adjustment for the Lagrangian grid, the pickup cycle from the Lagrangian problem, the density of the backfill in g/cm^3 , a tape unit designation which is not of interest except to the code, the pickup time in shakes, and the number of particles N^2 from the input deck. The numbers on the FUNNY cards follow. The next part of the output consists of edits of variables in the Lagrangian dump. The quantities are labeled as in the Lagrangian code output. Following the information for each K-line, the number of bow-tie zones encountered by the TCOM is indicated.

After the completion of the Lagrangian edit, and after the code has read the LEN cards and created the grid, it provides a summary edit (see sample page 69). TIE is the energy in the part of the Eulerian grid mapped from the Lagrangian code. E is the total energy in the Eulerian grid. It differs from THE by any energy input via the LEN cards and/or by the amount of energy which TCOM inserts. The minimum temperature recognized by the code is 2.5×10^{-8} keV. If a cell has specific internal energy less than $2.5 \times 10^{-8} C_V$, where C_V is the heat capacity, the code puts this amount of energy into the cell. M_X and M_{dot} are the total X and dot masses in the grid.

Sample page 70 shows a part of the material map for the problem. The quantities XMAX and YMAX are the maximum x and y values in the grid in centimeters. Along the left-hand margin of the plot are the J-lines and to the left of these at intervals are values of the cell widths in the y-direction. The plot is a logic plot and the numbers are the material numbers for the cells. The letter M indicates that a cell has more than one material.

Sample page 73 shows the bottom of the material map and the Z-block entries. The Z-block is discussed in detail in Chapter 3. Following the Z-block and the time and cycle(0) are the Eulerian grid quantities. A heading carries the x location of the I=1 cells and the width DX of the I=1 cells. Below are the values for zones in the column for I=1. Table 2-2 lists the Eulerian grid quantities.

Table 2-2. Eulerian grid quantities listed in sample problem printout.

Quantity	Description
I	Cell index for the radial direction.
J	Cell index for the axial direction.
U	Radial velocity in cm/shake.
V	Axial velocity in cm/shake.
F/A	Pressure (not calculated until RAD9 is started).
PVOL	Array specifying the material numbers and the fractional volume of the cell occupied by X material. The fractional volume is determined by the condition $P_X = P_{\text{dot}}$ where P_X is the pressure in the X material in the cell and P_{dot} is the pressure of the dot material. The array is interpreted as follows, using sample page 83:
	<div style="display: flex; align-items: center;"> <div style="margin-right: 20px;">J=29</div> <div>PVOL = 1 0000</div> </div> <div style="display: flex; align-items: center;"> <div style="margin-right: 20px;">J=30</div> <div>PVOL = -21 0000</div> </div> <div style="display: flex; align-items: center;"> <div style="margin-right: 20px;">J=31</div> <div>PVOL = 20 0000</div> </div>
	<p>The four digits to the right will hold the fractional volume of X material after the RAD9 has been started up and has gone into the EOS subroutines to find the pressures. The right-hand digit of the left pair of digits carries the material number for dot material if there is dot material in the cell, and the left digit carries the material number for X material. A minus sign flags a mixed cell. Thus, J=29 is a pure dot cell for which the material number is 1; J=30 is a mixed cell carrying material 2 as its X material and material 1 as its dot material; and J=31 is a pure X cell for which the material number is 2.</p>

Table 2-2. Eulerian grid quantities listed in sample problem printout. (continued)

Quantity	Description
AMX	Mass of X material in the zone in g.
AIX	Specific internal energy of the X material in the zone in jerks/g.
AMD	Mass of dot material in the zone in g.
AID	Specific internal energy of the dot material in the zone in jerks/g.
THETA	Temperature in the zone in keV.
ETA	Density in g/cm ³ .
Z	Location Y in cm of the upper border of the cell.

Sample TCOM output

PAGE 1

RADOL 9619.9 LINK 120 SH

*BN509

(TCIL9 INPUT)

PROB NO. 9619.9C0

I= 80

J= 199

X(I) I=0, 80

2.000000	4.000000	6.000000	8.000000	9.000000
10.000000	11.000000	11.610000	12.220000	13.000000
14.500000	16.000000	19.000000	22.000000	25.000000
28.000000	31.000000	34.000000	37.000000	40.000000
43.000000	46.000000	49.000000	52.000000	55.000000
58.000000	61.000000	63.000000	66.500000	70.000000
75.000000	80.000000	85.000000	90.000000	95.000000
100.000000	105.000000	110.000000	115.000000	120.000000
125.000000	130.000000	135.000000	140.000000	150.000000
160.000000	170.000000	180.000000	190.000000	200.000000
210.000000	220.000000	230.000000	240.000000	250.000000
260.000000	270.000000	280.000000	290.000000	300.000000
315.000000	330.000000	345.000000	360.000000	375.000000
390.000000	405.000000	420.000000	435.000000	450.000000
475.000000	500.000000	525.000000	550.000000	575.000000
600.000000	650.000000	700.000000	750.000000	800.000000

Y(J) J=0, 199

100.000000	150.000000	200.000000	250.000000	300.000000
325.000000	350.000000	375.000000	400.000000	425.000000
450.000000	475.000000	500.000000	525.000000	550.000000
575.000000	600.000000	625.000000	650.000000	675.000000
700.000000	725.000000	750.000000	775.000000	800.000000
825.000000	850.000000	875.000000	900.000000	925.000000
950.000000	975.000000	1000.000000	1020.000000	1040.000000
1060.000000	1080.000000	1100.000000	1115.000000	1130.000000
1145.000000	1160.000000	1175.000000	1190.000000	1205.000000
1220.000000	1235.000000	1250.000000	1260.000000	1270.000000
1280.000000	1290.000000	1300.000000	1310.000000	1320.000000
1330.000000	1340.000000	1350.000000	1360.000000	1370.000000
1380.000000	1390.000000	1400.000000	1410.000000	1420.000000
1430.000000	1440.000000	1450.000000	1460.000000	1470.000000
1480.000000	1490.000000	1500.000000	1504.000000	1508.000000
1512.000000	1516.000000	1520.000000	1524.000000	1528.000000
1532.000000	1536.000000	1540.000000	1544.000000	1548.000000
1552.000000	1556.000000	1560.000000	1564.000000	1568.000000
1572.000000	1576.000000	1580.000000	1582.500000	1585.000000
1589.000000	1593.000000	1597.000000	1601.000000	1605.000000
1609.000000	1613.000000	1616.500000	1620.000000	1625.000000
1630.000000	1635.000000	1640.000000	1645.000000	1650.000000
1655.000000	1660.000000	1665.000000	1670.000000	1675.000000
1680.000000	1685.000000	1690.000000	1695.000000	1700.000000
1705.000000	1710.000000	1715.000000	1720.000000	1725.000000
1730.000000	1735.000000	1740.000000	1745.000000	1750.000000
1755.000000	1760.000000	1765.000000	1770.000000	1775.000000
1780.000000	1785.000000	1790.000000	1795.000000	1800.000000
1810.000000	1820.000000	1830.000000	1840.000000	1850.000000
1860.000000	1870.000000	1880.000000	1890.000000	1900.000000
1910.000000	1920.000000	1930.000000	1940.000000	1950.000000
1960.000000	1970.000000	1980.000000	1990.000000	2000.000000
2020.000000	2040.000000	2060.000000	2080.000000	2100.000000
2120.000000	2140.000000	2160.000000	2180.000000	2200.000000
2220.000000	2240.000000	2260.000000	2280.000000	2300.000000

AREA(1) 1=1, 80

NORMAL SCHEME

2-111

[illegible]

PAGE 69

1

THERE ARE NO MORE PACKAGES----

THE = 4.817720367E+05 E = 4.890465238E+05

M. = 1.23586E+10 MX = 3.24124E+07 M.+MX = 1.23910E+10

0

[illegible]

2-13

[illegible]

TAPE DUMP AT TIME 0. CYCLE 0

```

1 = 1      X(1)=      2.000      DX(1) =      2.000

```

J	U	V	F/A	PVOL	AMX	AIX	AMD	AID	THETA	ETA	Z
198	-0.	-0.	0.	10000	0.	0.	1.257E-01	1.950E-09	2.600E-08	1.000E-04	3.000E+03
198	-0.	-0.	0.	10000	0.	0.	6.283E-02	1.950E-09	2.600E-08	1.000E-04	2.900E+03
197	-0.	-0.	0.	10000	0.	0.	6.283E-02	1.950E-09	2.600E-08	1.000E-04	2.850E+03

66	0.	0.	0.	10000	0.	0.	6.912E-01	1.950E-09	2.600E-08	1.100E-03	1.430E+03
65	0.	0.	0.	10000	0.	0.	6.912E-01	1.950E-09	2.600E-08	1.100E-03	1.420E+03
64	0.	0.	0.	10000	0.	0.	6.912E-01	1.950E-09	2.600E-08	1.100E-03	1.410E+03
63	0.	0.	0.	10000	0.	0.	6.912E-01	1.950E-09	2.600E-08	1.100E-03	1.400E+03
62	0.	0.	0.	10000	0.	0.	6.912E-01	1.950E-09	2.600E-08	1.100E-03	1.390E+03
61	0.	0.	0.	10000	0.	0.	6.912E-01	1.950E-09	2.600E-08	1.100E-03	1.380E+03
60	0.	0.	0.	10000	0.	0.	6.912E-01	1.950E-09	2.600E-08	1.100E-03	1.370E+03
59	-2.690E-07	0.	0.	10000	0.	0.	6.912E-01	1.950E-09	2.600E-08	1.100E-03	1.360E+03
58	-8.751E-07	0.	0.	10000	0.	0.	6.912E-01	1.950E-09	2.600E-08	1.100E-03	1.350E+03
57	-3.315E-03	3.902E-03	0.	-210000	2.242E+03	5.287E-05	6.912E-01	1.950E-09	2.600E-08	9.111E-04	3.568E+00
56	-5.350E-03	9.557E-03	0.	200000	4.180E+02	5.175E-03	6.912E-01	1.950E-09	2.600E-08	7.500E-02	6.652E-01
55	5.634E-02	2.467E-01	0.	200000	6.750E+00	1.405E-01	6.912E-01	1.950E-09	2.600E-08	5.340E-01	1.074E-02
54	6.696E-02	2.727E-01	0.	-210000	1.271E+00	2.032E-01	6.912E-01	1.950E-09	2.600E-08	5.239E-01	2.863E-03
53	8.341E-03	1.482E-01	0.	10000	0.	0.	5.422E-01	8.392E-01	9.184E-01	9.265E-04	1.300E+03
52	8.341E-03	1.482E-01	0.	10000	0.	0.	5.821E-01	1.106E+00	9.184E-01	9.265E-04	1.290E+03
51	8.341E-03	1.482E-01	0.	10000	0.	0.	5.821E-01	1.106E+00	9.184E-01	9.265E-04	1.280E+03
50	8.341E-03	1.482E-01	0.	10000	0.	0.	5.821E-01	1.106E+00	9.184E-01	9.265E-04	1.270E+03
49	8.341E-03	1.482E-01	0.	10000	0.	0.	5.821E-01	1.106E+00	9.184E-01	9.265E-04	1.260E+03
48	5.069E-03	1.049E-01	0.	10000	0.	0.	8.585E-01	1.124E+00	9.109E-04	9.109E-04	1.250E+03
47	1.243E-03	7.534E-02	0.	10000	0.	0.	8.026E-01	1.199E+00	8.516E-04	8.516E-04	1.235E+03
46	8.196E-03	7.534E-02	0.	10000	0.	0.	8.026E-01	1.199E+00	8.516E-04	8.516E-04	1.220E+03
45	8.528E-03	7.534E-02	0.	10000	0.	0.	3.026E-01	1.199E+00	8.516E-04	8.516E-04	1.205E+03
44	6.551E-03	7.534E-02	0.	10000	0.	0.	8.026E-01	1.199E+00	8.516E-04	8.516E-04	1.190E+03
43	1.551E-02	3.471E-01	0.	10000	0.	0.	1.240E+00	8.033E-01	5.206E-01	1.316E-03	1.175E+03
42	1.005E-02	3.592E-01	0.	10000	0.	0.	1.269E+00	7.870E-01	5.207E-01	1.347E-03	1.160E+03
41	-4.012E-04	3.617E-01	0.	10000	0.	0.	1.261E+00	7.920E-01	5.207E-01	1.338E-03	1.145E+03
40	-3.286E-02	5.735E-01	0.	10000	0.	0.	8.830E-01	1.124E+00	5.221E-01	9.378E-04	1.130E+03
39	-2.644E-02	6.187E-01	0.	10000	0.	0.	8.344E-01	1.190E+00	5.224E-01	8.853E-04	1.115E+03
38	8.824E-02	5.420E-01	0.	-210000	2.233E+00	9.492E-02	1.050E+00	1.182E+00	5.276E-01	2.652E-03	1.100E+03
37	5.257E-02	5.079E-01	0.	200000	3.768E+01	9.338E-02	0.	0.	5.851E-01	2.998E-02	1.080E+03
36	5.257E-02	5.085E-01	0.	200000	3.843E+01	9.320E-02	0.	0.	5.861E-01	3.062E-02	1.060E+03
35	1.004E-01	5.077E-01	0.	200000	4.009E+01	9.190E-02	0.	0.	5.881E-01	3.190E-02	1.040E+03
34	2.741E-01	4.133E-01	0.	200000	4.101E+01	9.122E-02	0.	0.	5.892E-01	3.263E-02	1.020E+03
33	2.520E-01	4.313E-01	0.	200000	4.928E+01	9.245E-02	0.	0.	5.873E-01	3.137E-02	1.000E+03
32	9.622E-02	5.217E-01	0.	200000	4.937E+01	9.240E-02	0.	0.	5.874E-01	3.143E-02	9.750E+02
31	9.622E-02	5.217E-01	0.	200000	4.937E+01	9.240E-02	0.	0.	5.874E-01	3.143E-02	9.500E+02
30	9.696E-02	5.254E-01	0.	-210000	1.543E+01	9.240E-02	6.612E-01	1.697E+00	5.480E-01	1.024E-02	9.250E+02
29	1.142E-01	6.118E-01	0.	10000	0.	0.	9.617E-01	1.697E+00	5.224E-01	6.122E-04	9.000E+02
28	6.666E-02	6.677E-01	0.	10000	0.	0.	2.928E+00	5.914E-01	5.235E-01	1.864E-03	8.750E+02
27	1.122E-02	7.519E-02	0.	10000	0.	0.	1.859E+00	8.730E-01	5.192E-01	1.184E-03	8.500E+02
26	2.094E-03	1.489E-02	0.	10000	0.	0.	1.742E+00	9.333E-01	5.192E-01	1.109E-03	8.250E+02
25	1.306E-03	9.743E-03	0.	10000	0.	0.	1.738E+00	9.349E-01	5.192E-01	1.107E-03	8.000E+02
24	2.943E-04	1.223E-03	0.	10000	0.	0.	1.753E+00	9.275E-01	5.192E-01	1.116E-03	7.750E+02
23	3.328E-03	6.639E-02	0.	10000	0.	0.	1.924E+00	8.519E-01	5.193E-01	1.225E-03	7.500E+02
22	3.333E-02	6.098E-01	0.	10000	0.	0.	1.210E+01	1.855E-01	5.348E-01	7.703E-03	7.250E+02
21	6.38E-02	4.107E-01	0.	10000	0.	0.	4.299E+01	9.087E-02	5.592E-01	2.737E-02	7.000E+02
20	5.976E-04	1.363E-02	0.	10000	0.	0.	1.915E+03	3.109E-03	4.145E-02	1.219E+00	6.750E+02
19	0.	-4.193E-04	0.	10000	0.	0.	3.303E+03	1.950E-09	2.600E-08	2.103E+00	6.500E+02
18	0.	0.	0.	10000	0.	0.	3.299E+03	1.950E-09	2.600E-08	2.100E+00	6.250E+02
17	0.	0.	0.	10000	0.	0.	3.299E+03	1.950E-09	2.600E-08	2.100E+00	6.000E+02
16	0.	0.	0.	10000	0.	0.	3.299E+03	1.950E-09	2.600E-08	2.100E+00	5.750E+02
15	0.	0.	0.	10000	0.	0.	3.299E+03	1.950E-09	2.600E-08	2.100E+00	5.500E+02
14	0.	0.	0.	10000	0.	0.	3.299E+03	1.950E-09	2.600E-08	2.100E+00	5.250E+02
13	-0.	-0.	0.	10000	0.	0.	3.299E+03	1.950E-09	2.600E-08	2.100E+00	5.000E+02
12	-0.	-0.	0.	10000	0.	0.	3.299E+03	1.950E-09	2.600E-08	2.100E+00	4.750E+02
11	-0.	-0.	0.	10000	0.	0.	3.299E+03	1.950E-09	2.600E-08	2.100E+00	4.500E+02
10	-0.	-0.	0.	10000	0.	0.	3.299E+03	1.950E-09	2.600E-08	2.100E+00	4.250E+02
9	-0.	-0.	0.	10000	0.	0.	3.299E+03	1.950E-09	2.600E-08	2.100E+00	4.000E+02
8	-0.	-0.	0.	10000	0.	0.	3.299E+03	1.950E-09	2.600E-08	2.100E+00	3.750E+02
7	-0.	-0.	0.	10000	0.	0.	3.299E+03	1.950E-09	2.600E-08	2.100E+00	3.500E+02

Input to TCOM for RAD9 and DORF9 (card generation).

Input Data Deck. In this section, the input is described for problems not linked from another code. All physical quantities and code parameters are entered via the data deck in this case.

Once the Eulerian grid has been described (in the same way as for linking from a Lagrangian code) a series of geometrical packages is generated which delineates materials, geometrical boundaries, changes in density, etc. For a general description see "Generating from Cards" at the beginning of this chapter. All the zones of a package have a common material number and common density, internal energy, and velocity fits. In generating packages, a later package description in the data deck always supersedes an earlier one. Thus, one may generate a package describing a large area and overwrite parts of it with data placed later in the deck.

A package description consists of the following six types of cards:

- General card
- Generate geometry card
- Delete geometry card
- Density card (only one per package)
- Specific internal energy card (only one per package)
- Velocity card (only one per package)

Rectangles, triangles, ellipses, or circles may be with generated and/or deleted with the geometry cards. The entries on the density, specific internal energy, and velocity cards are constants to be used in fitting analytical expressions for the package.

There are now two fits available. Fit one simply designates a uniform value for the quantities ρ , I , U , and V . The other is of the form

$$\begin{array}{lll} \text{Density:} & \rho = A_1 + B_1 R & R = \sqrt{X^2 + Y^2} \\ \text{Specific internal energy:} & I = A_2 + B_2 R & \\ \text{Radial velocity:} & U = (A_3 + B_3 R) \cdot \frac{R}{X} & \\ \text{Axial velocity:} & V = (A_3 + B_3 R) \cdot \frac{R}{Y} & \end{array}$$

Other fits may be inserted in the code as the need arises. Up to six fitting parameters can be entered on a card. Only A_1 and B_1 are used in the analytical fit above. Values of A_1 are used for uniform values in the first scheme.

The specifications for the input data file are provided in Tables 2-3 through 2-6. Note that the last card in the data deck must have a 2 in column 1 to indicate the end of the deck.

Table 2-3. Input to the TCOM code – cards 1 through 4.

Card no.	Column no. ^a	Description of input
1	2-70	Header card, any BCD information
2	*1-10	Contain the problem number.
	*11-20	IMAX, the number of cells in the x-direction (maximum of 200).
	*21-30	JMAX, the number of cells in the y-direction (maximum of 200).

Table 2-3. Input to the TCOM code – cards 1 through 4. (continued)

Card no.	Column no. ^a	Description of input
	*31-40	QOOOFL = 0. for DORF = 1.0 for RAD9
	*41-50	= 2. for tracer particles. = 0. otherwise.
	*51-60	= 0. for cylindrical geometry, > 0. for Cartesian geometry.
	*61-70	S9 = 0. for card generation.
	71-72	N7 = binary tape number = 7
	75-80	Tape number for tape to be written on, e.g. *LG301. The asterisk here indicates indicates a blank tape to be hung.
3	(Two number 3 cards is the minimum)	
	1	= 1 indicates that this is the last DX or DY card to be read in. = 0 indicates that there will be more DX or DY cards.
	2	= 0 indicates DX data. = 1 indicates DY data.
	3-4	The number of zones that will have the same DX or DY value that appears in columns 11-20.
	5-6	The number of zones that will have the same DX or DY value that appears in columns 21-30.
	7-8	The number of zones that will have the same DX or DY value that appears in columns 31-40.
	9-10	The number of zones that will have the same DX or DY value that appears in columns 41-50.
	*11-20	The value of DX or DY.
	*21-30	The value of DX or DY.
	*31-40	The value of DX or DY.
	*41-50	The value of DX or DY.
4	*1-10	Blank.
	*11-20	Blank.
	*21-30	80.
	*31-40	Blank.

^aAn asterisk before the column number signifies that the data are floating-point; otherwise, they are fixed-point data.

Now we begin loading the data to generate a package (Table 2-4). The maximum number of geometries that may be generated or deleted for each package is 72; to increase the maximum requires the changing of dimensions in the code. The five types of cards mentioned on p. 2-16 follow the 5 card of each package. The specifications for these cards are in Tables 2-5 and 2-6.

Table 2-4. Format for package generation.

Card no.	Column no. ^a	Description of input
5	1	Load a 1 here.
	2	= 1 implies that X material will be generated in this package. = 0 implies dot material.

Table 2-4. Format for package generation. (continued)

Card no.	Column no. ^a	Description of input
	5-7	(N ²), the number of particles per cell to be generated, where $1 \leq N \leq 20$.
	*11-20	YC = y-coordinate for the origin of the radius vector used in the density energy and velocity fits.
	*21-30	XC = x-coordinate for the origin of the radius vector used in the density energy and velocity fits.
	*31-40	A number (1 through 6) that specifies the fit number or subroutine to use for this package to calculate the density, velocities, and specific internal energy of the N particles. Only fits 1 and 2 are presently available.
	*41-50	The material number (1 through 4).
	*51-70	Blank.

^a An asterisk before the column number signifies that the data are floating-point; otherwise, they are fixed-point data.

The geometry cards for generating or deleting the various shaped packages are set up for card 6 as shown in Table 2-5.

Table 2-5. Format for geometry cards.

Card no. 6	Column no. ^a	Description of input
A rectangle:	1	= 4
	2-6	Blank.
	7	= 1 means to generate this rectangle. = 0 means to delete this rectangle.
	*11-20	Left x-coordinate of this rectangle.
	*21-30	Right x-coordinate of this rectangle.
	*31-40	Lower y-coordinate of this rectangle.
	*41-50	Upper y-coordinate of this rectangle.
A triangle:	1	= 6
	2-6	Blank.
	7	= 1 means to generate this triangle. = 0 means to delete this triangle.
	*11-20	X1 } The coordinates of one vertex of the triangle.
	*21-30	
	*31-40	X2 } The coordinates of the second vertex.
	*41-50	
	*51-60	X3 } The coordinates of the third vertex.
	*61-70	
		Vertices (1-3) can be in any order.
An ellipse or circle:	1-2	= 41
	3-6	Blank.
	7	= 1 means to generate this ellipse or circle. = 0 means to delete this ellipse or circle.
	*11-20	The semi-axis in the x-direction if an ellipse; the radius if a circle.

Table 2-5. Format for geometry cards. (continued)

Card no.	Column no. ^a	Description of input
	*21-30	The semi-axis in the y-direction if an ellipse; zero for a circle.
	*31-40	The x-coordinate of the center of ellipse or circle.
	*41-50	The y-coordinate of the center of ellipse or circle.

^aAn asterisk before the column number signifies that the data are floating-point; otherwise, they are fixed-point data.

The format of the cards for density, specific internal energy, and velocity follow. If the values for a quantity in a package are the same as in the previous package, the card for that quantity can be omitted.

Table 2-6. Format for density, specific internal energy, and velocity cards.

Card no.	Column no. ^a	Description of input
7 8 9	1-2	= 51 if this is to be a density card = 52 if this is to be a specific internal energy card = 53 if this is to be a velocity card
	*11-20	A_i B_i C_i D_i E_i F_i
	*21-30	
	*31-40	
	*41-50	
	*51-60	
	*61-70	
		fitting constants for quantity as previously described. Only A and B are presently used in fits 1 and 2. Constants are loaded into the arrays TABR(I) for density, TABI(I) for specific internal energy, and TABUV(I) for velocity. I=1,6.
		Include as many sets of cards 5, 6, 7, 8, 9, 10 as there are packages.
10	1	= 2 if this is the last card in the deck = 0 otherwise.
	3	For RAD9, the number of values of C_V to follow.
	*4-67	Values of C_V for the N materials of the problem in order of material number. $N = 1,4$. (The 10 card is omitted if a DORF9 is being generated. A separate card with a 2 in column 1 must be added in this case as the last card in the deck.)

^aAn asterisk before the column number signifies that the data are floating-point; otherwise, they are fixed-point data.

Sample Problem. Consider a small, DORF9, one-material test problem generated with cards. This problem has a spherical aluminum pellet just striking a thick aluminum plate with the motion directed upward along the z-axis of the grid. The pellet has a 0.238-cm radius and is moving at a velocity of 7.35×10^{-3} cm/shake. A copy of the input follows.

Sample DORF9 problem

PAGE 1

1234567890123456789012345678901234567890123456789012345678901234567890

```

*      DATA TC9D
ORIGINAL SPHERE3 DATA FOR TCOM TEST
3.      50.      75.      0.      2.      0.      0.      07 *BN505
0010050505.0476      .05      .055      .06
0005050505.065      .075      .1      .15
0005      .2
0110010301.2      .15      .1      .074
0110050505.0476      .0476      .05      .055
0105050505.06      .065      .075      .1
11050505      .15      .2      .3
0.      0.      80.
11      49      0.      0.      1.
41      1      238      0.      0.      2.762
51      2.7
52      0.
53      7.35      -3
11      1      0.      0.      1.
4      1      0.      4.226      3.      8.518
53      0.
2

```

Output from TCOM for RAD9 and DORF9 (card generation). The sample pages following this discussion are from the output for the pellet problem just described.

Sample page 1 starts with the information from the header card for a title and for identification of the tape on which the cycle zero dump was made. Next are the problem number and IMAX and JMAX. A table of X(I), Y(J), DX(I), DY(J) values follows. Sample page 2 completes the table and gives the annular areas of the zones as a function of I.

Next come the fitting parameters for the two packages making up the problem, one for the pellet, and one for the plate. Sample page 3 gives the energy in the problem and the material masses. THE normally corresponds to the energy in the Lagrangian code part of the grid, and E is the total energy in the grid. In a card generated problem, the numbers are identical.

Sample pages 7 and 8 show the material map of the problem. The Z-block entries are shown next; some of these will be carried over to the DORF9 and many will be overwritten by the DORF9 data input deck. The functions of the Z-block variables in RAD9 input are discussed in Chapter 3 and those for DORF9 will be included in the first revision to this manual.

After this Z-block edit comes the cell-by-cell, long-print edit of quantities. The cell quantities are printed out for each I value. A sample page from the long edit (sample page 83) is shown in the section on the output from TCOM for the problem generated from a Lagrangian code.

Output from sample DORF9 problem

PAGE 1

ORIGINAL SPHERES DATA FOR 100M TEST
(TAILS INPUT)

*BN505

PROB NO. 3.000

I= 50

J= 75

X(I) I=0, 50

0.047600	0.095200	0.142800	0.190400	0.238000
0.285600	0.333200	0.380800	0.428400	0.476000
0.526000	0.576000	0.626000	0.676000	0.726000
0.781000	0.836000	0.891000	0.946000	1.001000
1.061000	1.121000	1.181000	1.241000	1.301000
1.366000	1.431000	1.496000	1.561000	1.626000
1.701000	1.776000	1.851000	1.926000	2.001000
2.101000	2.201000	2.301000	2.401000	2.501000
2.651000	2.801000	2.951000	3.101000	3.251000
3.451000	3.651000	3.851000	4.051000	4.251000

Y(J) J=0, 75

0.200000	0.400000	0.600000	0.800000	1.000000
1.200000	1.400000	1.600000	1.800000	2.000000
2.150000	2.250000	2.350000	2.450000	2.524000
2.571500	2.619200	2.666800	2.714400	2.762000
2.809600	2.857200	2.904800	2.952400	3.000000
3.047600	3.095200	3.142800	3.190400	3.238000
3.285600	3.333200	3.380800	3.428400	3.476000
3.523600	3.571200	3.618800	3.666400	3.714000
3.761600	3.809200	3.856800	3.904400	3.952000
4.000000	4.047600	4.095200	4.142800	4.190400
4.238000	4.285600	4.333200	4.380800	4.428400
4.476000	4.523600	4.571200	4.618800	4.666400
4.714000	4.761600	4.809200	4.856800	4.904400
4.952000	5.000000	5.047600	5.095200	5.142800
5.190400	5.238000	5.285600	5.333200	5.380800
5.428400	5.476000	5.523600	5.571200	5.618800
5.666400	5.714000	5.761600	5.809200	5.856800
5.904400	5.952000	6.000000	6.047600	6.095200
6.142800	6.190400	6.238000	6.285600	6.333200
6.380800	6.428400	6.476000	6.523600	6.571200
6.618800	6.666400	6.714000	6.761600	6.809200
6.856800	6.904400	6.952000	7.000000	7.047600
7.095200	7.142800	7.190400	7.238000	7.285600
7.333200	7.380800	7.428400	7.476000	7.523600
7.571200	7.618800	7.666400	7.714000	7.761600
7.809200	7.856800	7.904400	7.952000	8.000000

DX(I) I=1, 50

0.047600	0.047600	0.047600	0.047600	0.047600
0.047600	0.047600	0.047600	0.047600	0.047600
0.050000	0.050000	0.050000	0.050000	0.050000
0.055000	0.055000	0.055000	0.055000	0.055000
0.060000	0.060000	0.060000	0.060000	0.060000
0.065000	0.065000	0.065000	0.065000	0.065000
0.070000	0.070000	0.070000	0.070000	0.070000
0.075000	0.075000	0.075000	0.075000	0.075000
0.100000	0.100000	0.100000	0.100000	0.100000
0.150000	0.150000	0.150000	0.150000	0.150000
0.200000	0.200000	0.200000	0.200000	0.200000

DY(J) J=1, 75

0.200000	0.200000	0.200000	0.200000	0.200000
0.200000	0.200000	0.200000	0.200000	0.200000
0.150000	0.100000	0.100000	0.100000	0.074000
0.047600	0.047600	0.047600	0.047600	0.047600
0.047600	0.047600	0.047600	0.047600	0.047600
0.047600	0.047600	0.047600	0.047600	0.047600
0.050000	0.050000	0.050000	0.050000	0.050000
0.055000	0.055000	0.055000	0.055000	0.055000
0.060000	0.060000	0.060000	0.060000	0.060000
0.065000	0.065000	0.065000	0.065000	0.065000
0.070000	0.070000	0.070000	0.070000	0.070000
0.100000	0.100000	0.100000	0.100000	0.100000

0.150000	0.150000	0.150000	0.150000	0.150000
0.200000	0.200000	0.200000	0.200000	0.200000
0.300000	0.300000	0.300000	0.300000	0.300000

AREA(1) 1=1, 50

0.007118	0.021354	0.035590	0.049827	0.064063
0.078239	0.092535	0.106771	0.121008	0.135244
0.157394	0.173102	0.188310	0.204513	0.220226
0.260391	0.279336	0.298404	0.317411	0.336417
0.388673	0.411297	0.433917	0.456536	0.479156
0.544611	0.571157	0.597704	0.624250	0.650797
0.783906	0.819249	0.854592	0.889935	0.925278
1.288681	1.351513	1.414345	1.477177	1.540009
2.427823	2.569195	2.710566	2.851938	2.993310
4.210991	4.462318	4.713646	4.964973	5.216301

0

OPACKAGE NO. 1

49 PARTICLES/CELL

	A1	A2	A3	A4	A5	A6
0 DENSITY	2.700000E+00	-0.	-0.	-0.	-0.	-0.
0 ENERGY	0.	-0.	-0.	-0.	-0.	-0.
0 VELOCITY	7.350000E-03	-0.	-0.	-0.	-0.	-0.

0

I(1)= 1 J(1)= 16 I(N)= 6 J(N)= 26

0

0 (X) PARTICLES

PE =4.123533E-06

PM =1.526599E-01

0

OPACKAGE NO. 2

1 PARTICLES/CELL

	A1	A2	A3	A4	A5	A6
0 DENSITY	2.700000E+00	-0.	-0.	-0.	-0.	-0.
0 ENERGY	0.	-0.	-0.	-0.	-0.	-0.
0 VELOCITY	0.	-0.	-0.	-0.	-0.	-0.

0

I(1)= 1 J(1)= 26 I(N)= 50 J(N)= 75

0

0 (X) PARTICLES

PE =0.

PM =8.450528E+02

THERE ARE NO MORE PACKAGES----

THE = 4.123533377E-06

E = 4.123533377E-06

M. = 0.

MX = 6.45205E+02

M. +MX = 8.45205E+02

1PROBLEM 3.0 CYCLE 0. TIME 0. DT 0. DTRAD

XMAX =4.251000E+00

YMAX =8.513000E+00

2-25

Chapter 3: RAD9

General Description of Input

The RAD9 data file is called RAD9D. It can be accessed as a separate disk file or following a *DATA RAD9D when running under ORDER. On the first card of a data deck, the tape card, the names of the pickup and successive cycle dump tapes or disk files to be used are listed in the order in which they are called, up to a maximum of eight. Names designating tapes must be of the form XXNNN or *XXNNN. (e.g., BN409). All other names will be taken to denote disk files. The tape card format is (8A10).

Following the tape card is a header card containing whatever information the user wishes – the format is (8A10). After the header card, come two Z-block cards which complete the set of cards the code reads before reading the pickup tape. The cards in the deck up to this point must be in the order given (see Fig. 3-1). The first of the two Z-block cards contains a 1. in columns 15 and 16. This tells the code that the tape to be read is the first tape on the tape card. The second card, the 151 card, carries the problem number (9619.9) to tell the code that it is to check the problem number on the tape against 9619.9 and if the numbers aren't the same to write out this fact to the high-speed printer. It also carries a 0. in columns 24 and 25 to tell the code that this is a new problem and that it is to look for cycle zero on the pickup tape. If the problem were being restarted, the 0. would be replaced either by a -1. to tell the code to pick up from the last cycle on the tape or by a cycle number to tell the code to hunt through the dumps on the tape for that particular cycle and to start the problem from there. The 1 in column 1 tells the code that this is the last card in the set. The code will then read the input tape and return to look for the rest of the card input. (This much of the data deck plus the last card described below will restart a problem. Only those Z-block variables being changed need be added before the last card.)

The rest of the input consists of Z-block data in any order. The last card in this set must again have a 1 in column 1 to indicate the end of the Z-block data. Usually, the last card carries Z(4), Z(5), Z(6), Z(7) because these change most often during a series of restarts, and it is convenient to have them on the last card. Z(4) is the time interval between short edits, Z(5) is the time interval between long edits, Z(6) is the interval between tape dumps, and Z(7) is the desired stop time for that run. If the problem has to be brought off the machine before the stop time, it should be brought off on a SW1. If you are running on production, a *B card should be inserted among the control cards to indicate to the operator that the code checks SW1 every cycle and comes off the machine with a final tape dump and high-speed tape dump within 2 minutes.

The Z-block format is: (I1, I5, I1, 7E9.4).

- A 1 in column 1 indicates that this is the last card to be read in a set of data cards.
- A 2 in column 1 indicates that the code is to convert the data on the card to integer format.
- The I5 is for the Z-block location where the first data entry on the card is to be stored.
- The following I1 is for the number of data entries to follow. There may be up to seven and they must be for the Z-block location given and for successive Z-block locations. If a location is to be skipped, a new Z-block card must be used for the following entry.

If you wish to prevent the code from writing on the tape it has picked up from and to write instead on the second tape on the tape card, you must overwrite Z(57) in this group of cards. The code does not enter the 1. in the Z-block from the Z(57) card in the first card set but uses this information immediately. The code does not have access to the Z-block until it has read the pickup tape. If there is no Z(57) card in the second set of cards, the code will enter a 1. into the Z-block. The code will write on the first tape unless this 1. is overwritten by a card in the second set. If a 2. is entered in the second set, the code will write on the second tape listed on the tape card and will write on successive tapes thereafter. Note in the sample in Fig. 3-1 there is a Z(57) card in the second set with a 2.

Table 3-1 lists the Z-block quantities for RAD9 along with the values normally used. The latter will eventually become default values written into the code. At the present time, however, all those values not brought over from the TCOM and not generated by RAD9 itself must be put into the cycle zero data deck (the deck used to pick up from the TCOM). The values to be input by the user to start a problem are indicated in the Z-block listing by an x in the Input column. The Location column gives the location of the quantity in the Z-block and is entered in columns 2 through 6 on the data card. The Symbol column gives the name of the quantity in the code (or one of the names). The use of the quantity and nominal values are also given.

Following the Z-block table is a section on the Tillotson EOS and a table of values for the constants for various materials. EOS data are loaded like Z-block quantities and are described in the Z-block table. After that is a description of the input for on-line plots and for "patching" cell variables. PLOTIN is the on-line-plotting routine written by Erlene Schooler,¹⁰ and PATCH allows the alteration of any or all the physical variables associated with a given cell or a number of cells.

Quantities in Table 3-1 whose symbols begin with I, J, K, L, M, N are integers. A 2 must appear in column 1 of Z-block cards containing integer quantities.

Table 3-1. The Z-block.

Input	Location	Symbol	Use of quantity	Nominal value
x	1	PROB	Problem number, loaded in on 151 card (see discussion before Z-block listing).	
	2	CYCLE	Cycle number.	
x	3	DT	Starting time step is input; the time step is then updated by code each cycle.	10^{-4}
x	4	PRINTS	Time for short print edit in shakes.	
x	5	PRINTL	Time for long print edit in shakes.	
x	6	DUMPT7	Time for tape dump in shakes.	
x	7	CSTOP	Time for end of problem in shakes.	
	8	PIDY	π , loaded by TCOM.	
	9	TMZ	Total mass in problem (g); entered by TCOM.	
	10	GAM	FLAG for using tracer particles; enter 2. for tracers, 0. otherwise.	
	11	GAMD	Not used.	
	12	GAMX	Not used.	
	13	ETH	Total energy in problem; loaded by TCOM.	
Not normally used	14	FFA	Upper limit for stability	Normally not used; if used, FFA=1., FFB=0.5.
Not normally used	15	FFB	Lower limit for stability	
	16	RADC	Radiation constant, a , as in $a\theta^4$.	1.37×10^{-2}
	17	CVX	Loaded by TCOM; constant heat capacity of X material above 0.3 keV.	These are no longer used by the code because heat capacity constants are loaded with EOS data.
	18	CVDOT	Constant heat capacity of dot material above 0.3 keV.	
	19	ACO4	$\frac{ac}{4} = 1.0275$	1.0275

Table 3-1. The Z-block. (continued)

Input	Location	Symbol	Use of quantity	Nominal value
x	20	IFRAD	Maximum number of iterations for calculating temperature from $E = \rho C_V \theta + a\theta^4$.	20.
x	21	ALPHA	Set to 1. Coefficient for splitting radiation equations into part explicit, part implicit. Equations are treated totally implicitly at the present time.	1.
	22	BLANK	Velocity of light = 300 cm/shake; loaded by TCOM.	300.
	23	DNN	Stored by code for use in energy check in EDITS — updated every cycle.	
x	24	DMIN	Used for energy check in EDITS.	$10^{-4} - 10^{-6}$
x	25	FEF	Fraction of radiation energy per zone per cycle allowed to leave cell (see discussion under Z(65)).	0.15
	26	DTNA	Δt^{n-1} , (Δt of previous cycle).	
x	27	CVIS	Flag for bottom boundary condition for hydrodynamics.	-1. for transmissive 0. for reflective in sense that momentum (mv) pointed down brings 2mv change.
	28	NPR	Index (working storage for TCOM).	
	29	NPRI	Index (working storage for TCOM).	
	30	NC	Cycle number; at cycle zero NC = -1., at cycle 1 it becomes 1.	
	31	NPC	Not used at present; was number of cycles between short prints.	
	32	NRC	Flag to signal advancing of active grid line L2.	
	33	IMAX	Number of zones in radial direction; loaded by TCOM.	
	34	IMAXA	IMAX + 1.; loaded by TCOM.	
	35	JMAX	Number of zones in the axial direction; loaded by TCOM.	
	36	JMAXA	JMAX + 1.; loaded by TCOM.	
	37	KMAX	Number of cells in problem + 1.; loaded by TCOM.	
	38	KMAXA	KMAX + 1.; loaded by TCOM.	
	39	NMAX	Number of tracer particles (if used); loaded by TCOM.	
	40	ND	Material flag for dot material, (but is edited in Z-block as last such value code looked at; therefore, it is not useful for debug).	

Table 3-1. The Z-block. (continued)

Input	Location	Symbol	Use of quantity	Nominal value
	41	KDT	Flag in CDT which signals edit of Δt , etc.; occurs every cycle between long and/or short edits. Appears after long or short print as: CHANGE DT . . . T = , DT(N) = , DT(N+1) = , I = , J = , STAB = DT(N+1) is Δt , calculated at the beginning of the cycle, which is about to be used by the code. STAB is Z(105).	
	42	IXMAX	IMAX + 2.; loaded by TCOM.	
	43	NOD	Not used.	
Not normally input	44	TP1	Total number of feet of tape code expects to have available = 2000 ft. Set in subroutine INPUT; may be overwritten by input data.	
	45	BD	Not used.	
	46	CD	Not used.	
	47	I1	Not used.	
	48	I2	Not used.	
Not normally used	49	I3	{ 0. for cylindrical geometry 1. for Cartesian geometry	
	50	I4	Not used.	
x	51	N1	Maximum number of iterations to be allowed in the EOS for finding the partial volumes of X and dot materials in mixed cells; determined by the condition $P_X = P_{\text{dot}}$.	30.
x	52	N2	{ = 0. = 1. calls subroutine PATCH. = 2. calls PATCH and reads cards for PLOTIN. = 3. reads cards for PLOTIN.	
	53	N3	Stores original value of ETH from TCOM.	
	54	N4	Not used.	
	55	N5	N5 is set in EDITS; if it is 1., problem is completed.	
	56	N6	N6 is set in EDITS; if it is 1., a short print, plot, or long print is to be executed.	
	57	N7	Tape designator used by code (see discussion at beginning of Z-block section).	
	58	N8	Not used.	
	59	N9	Not used.	

Table 3-1. The Z-block. (continued)

Input	Location	Symbol	Use of quantity	Nominal value
	60	N10	I } I, J values of zone controlling the J } hydrodynamic time step. If values are negative, problem is being controlled by sound speed. If values are positive, problem is being controlled by particle velocity.	
	61	N11		
	62	NRM	Not used.	
	63	TRAD	Time and date.	
	64	XNRG	Not used.	
x	65	SN	Code checks $a\theta^4$ against SN in sub- routines RADIAL and AXIAL. If $a\theta^4 \leq SN$, the amount of radiation flow will be checked only if the cell is cooling. If $a\theta^4 > SN$, the flow will be checked whether the cell is heating or cooling. The Δt will be limited so that the total specific radiation energy change in the cell is never greater than FEF times the specific internal energy in the cell before the flow, divided by the rate of change in radiation energy due to the flow. FEF is normally 0.15 and is entered into Z(25). Value of SN can be increased to 10^{-6} if control is in a region of no interest to the problem. Sometimes this will throw control to the radiation front. Un- less there is this sort of difficulty, smaller values should be used (e.g., 8×10^{-8}).	$8 \times 10^{-8} - 10^{-6}$
	66	DXN	Not used.	
	67	RADER	Not used.	
	68	RADET	Not used.	
	69	RADEB	Not used.	
x	70	DTRAD	Radiation Δt calculated in subroutines AXIAL and RADIAL. Read in for cycle 0. Will be updated by code every cycle.	10^{-4}
	71	REZFCT	Not used.	
	72	AX	Not used.	
	73	BX	Not used.	
	74	CX	Not used.	
	75	TOZONE	Not used.	
	76	ECK	Used in energy check calculation in EDITS subroutine.	
x	77	SBOUND	Artifact-set to 1. Might be removed from code.	1.

Table 3-1. The Z-block. (continued)

Input	Location	Symbol	Use of quantity	Nominal value
x	78	BL	Left boundary indicator for radiation.	-1. for reflective boundary +1. for transmissive boundary BL <i>must</i> be -1.
x	79	BB	Bottom boundary indicator for radiation.	
x	80	BR	Right boundary indicator for radiation.	
x	81	BT	Top boundary indicator for radiation.	
x	82	CABLN	Flag for type of time step control -1. Code controls time step on basis of sound speed, particle velocity, and radiation. 0. Code controls Δt but between upper and lower limits set in Z(14), Z(15). +1. Δt loaded into Z(3) is kept fixed.	-1.
	83	VISC	Used for artificial viscosity calculation; not done in RAD9 at present.	
x	84	T	Time in the problem; usually input at cycle zero as Lagrangian problem pickup time. Starting value is user's option; code will update every cycle.	
	85	GMAX	Not used.	
	86	WSGD	Not used.	
	87	WSGX	Not used.	
	88	GMADR	Not used.	
	89	GMAXR	Not used.	
	90	S1	Not used.	
x	91	L1		These are active grid counters. Set values to cover the area of the problem having temperatures above background (2.5×10^{-8}), velocities above 0. If a rectangular active grid is desired, set L1 = L2 and L3 = L5.
x	92	L2		
x	93	L3		
x	94	L4		
x	95	L5		
	96	S7	Not used.	
	97	S8	Not used.	
	98	S9	Not used.	
x	99	SCALF	For use in ground shock edit. SCALF*VMAX is cutoff value such that if $V(K) < \text{SCALF} * V_{\text{MAX}}$, the cell K will not be included in the edit of energy ahead of ground shock.	.1

Table 3-1. The Z-block. (continued)

Input	Location	Symbol	Use of quantity	Nominal value
	100		Sum of X masses set to zero when the density of X material in cells is less than the cutoff value for density remaining in a cell after mass transfer in PH2. Cutoff value is EQSTC(15) (see EOS constants beginning at Z(186)).	
	101		Sum of dot masses set to zero when the density of dot material in cells is less than the cutoff value for density remaining in a cell after mass transfer in PH2. Cut off value is EQSTC(15) (see EOS constants beginning at Z(186)).	
	102		Sum of total energies of X materials set to zero when the X mass is set to zero as described under Z(100).	
	103		Sum of total energies of dot materials set to zero when the dot mass is set to zero as described under Z(101).	
	104		Sum of Z(102) and Z(103). Z-block values Z(100) through Z(104) are also printed out with captions on the first page of the high-speed edit or fiche.	
x	105		Fraction of stability for early times. If energy is primarily internal at the beginning of the problem, set to 1×10^{-4} . Otherwise set to Z(139). For explanation of quantity see section on time-step control.	1×10^{-4} or Z(139).
x	106		Factor by which Z(105) is increased every cycle until it reaches the value of Z(139) after which it remains fixed.	1.2
	107		Not used.	
	108		Not used.	
	109		Not used.	
x	110		Carries the temperature value which will cause the active grid to advance.	2.8×10^{-8} ($\sim 1.1 \theta_{\min}$)
	111	TP2	Number of feet of tape written by the code on the tape being used. Updated every tape dump. Reset when code calls for new tape.	
	112		For projectile impact problems, provides y component of projectile velocity (not used normally in RAD9).	
	113		Not used.	
	114		Not used.	
	115		I of zone controlling the radiation Δt .	
	116		J of zone controlling the radiation Δt .	
	117--136		Not used.	

Table 3-1. The Z-block. (continued)

Input	Location	Symbol	Use of quantity	Nominal value
x	137		Pressure cutoff; if the pressure in a cell is below this value, it is set to zero in subroutine WHATES.	10^{-10}
x	138		Minimum density a cell must have before the stability check will be done on it in subroutine CDT. For explanation of this and Z(139), see section on time-step control.	$10^{-5} \rho_0^{\min}$ $\rho_0^{\min}$ is the minimum of the normal densities for all the materials in the problem.
x	139		Fraction of stability	0.35
	140-144		Not used	
x	145		Value of internal energy in a cell at the boundary of the active grid which will cause that boundary to be advanced.	$1.2 C_V \theta_{\min}$ C_V is the maximum value of the heat capacity for materials in the problem. $\theta_{\min}$ is the floor temperature = 2.5×10^{-8} keV.
x	146		Value of the sum of the axial and radial velocities in a cell which will cause active grid boundary to be advanced; also, the cutoff value for the axial velocity and the radial velocity.	10^{-6}
	147-150		Not used.	
Next are given EOS data which are not actually stored in the Z-block, but are stored in other locations and are treated exactly the same way. No distinction is made between these values and Z-block values in the input. Mat(1) is material number 1, Mat(2) is material number 2, etc.				
x	166-174	IDEQST(1) IDEQST(9)	IDEQST(1) designates the number of the EOS routine to be called for material 1. At the present time a 1. designating subroutine ES1 is to be used. This is the Tillotson EOS. Other forms will become available in the future. There are as many entries as there are materials.	
x	175	IDEQST(10)	The number of different materials in the problem.	
x	176-184	IDKAP(1)- IDKAP(9)	IDKAP(1) designates which opacity routine is to be called for material 1, etc. $\text{IDKAP}(i) = \begin{cases} 1. & \text{for Al} \\ 2. & \text{for Fe} \\ 3. & \text{for Pb} \\ 4. & \text{for Bc (not yet available)} \end{cases}$ <p>There are as many entries as there are materials in problem.</p>	

Table 3-1. The Z-block. (continued)

Input	Location				Symbol	Use of quantity	Nominal value
	Mat (1)	Mat (2)	Mat (3)	Mat (4)		The first 10 quantities are parameters in the Tillotson Equations given at the end of this section. A table of values for these parameters is given for a number of materials.	
x	186	211	236	261	EQSTC(1)	ρ_0	See Table 3-2.
x	187	212	237	262	EQSTC(2)	a	
x	188	213	238	263	EQSTC(3)	E_0	
x	189	214	239	264	EQSTC(4)	b	
x	190	215	240	265	EQSTC(5)	A	
x	191	216	241	266	EQSTC(6)	E_s	
x	192	217	242	267	EQSTC(7)	E'_s	
x	193	218	243	268	EQSTC(8)	α	
x	194	219	244	269	EQSTC(9)	β	
x	195	220	245	270	EQSTC(10)	B	
x	200	225	250	275	EQSTC(15)	Density cutoff for mass remaining in cell K after transfer. If the density of a given material (1-4) left in cell K after mass transfer has taken place is less than the cutoff value for that material, the mass of that material in cell K is set to 0.	$10^{-5} \rho_{TCOM}^{\min}$ $\rho_{TCOM}^{\min}$ is the minimum density of materials mapped over by TCOM.
x	201	226	251	276	EQSTC(16)	Transfer density cutoff based on the donor cell. If the mass of a material to be transferred out of cell K divided by the volume of cell K is less than this density cutoff, the mass is not transferred.	$10^{-6} \rho_{TCOM}^{\min}$
	202	227	252	277	EQSTC(17)	Not used.	
x	203	228	253	278	EQSTC(18)	If $\rho/\rho_0 < \text{EQSTC}(18)$ and $P < 0$, then P will be set to zero. The quantity ρ is the density of the given material in the cell, ρ_0 is the normal density of that material, and P is the pressure in the cell.	1.
	204	229	254	279	EQSTC(19)–	Not used.	
	209	234	259	284	EQSTC(24)		
x	210	235	260	285	C_V	Specific heat constant in jerks/g·keV. Above 0.3 keV, these are used as constants. Below 0.3 keV, the code fits as described in the section on specific heat.	See Table 3-3.

The Tillotson Equation of State

The following are the Tillotson equations of state for gaseous (PGAS) and solid (PSOL) materials.

$$\text{Let } V = \text{specific volume} = \frac{1}{\rho}$$

$$V_0 = \text{normal specific volume} = \frac{1}{\rho_0}$$

$$\mu = \frac{V_0 - V}{V}$$

E = specific internal energy (with radiation energy subtracted out)

PGAS = pressure of gaseous material

PSOL = pressure of solid material or of material whose specific internal energy is below the vaporization energy.

The Tillotson⁶ equations for the gaseous and solid regions are:

$$PGAS = \frac{aE}{V} + \left\{ \frac{\frac{bE}{V}}{\frac{E}{E_0 \left(\frac{V_0}{V}\right)^2} + 1} + A\mu e^{-\alpha \left(\frac{V}{V_0} - 1\right)} \right\} e^{-\beta \left(\frac{V}{V_0} - 1\right)^2}$$

$$PSOL = \frac{E}{V} \left\{ a + \frac{\frac{bE}{V}}{\frac{E}{E_0 \left(\frac{V_0}{V}\right)^2} + 1} \right\} + A\mu + B\mu^2$$

The quantity A is the bulk modulus ($= \rho_0 C^2$) and B is twice the bulk modulus multiplied by the slope of the shock velocity-particle velocity curve. Also,

$$a + b = G_0$$

where G_0 is the zero pressure Gruneisen coefficient and E_0 , α , and β are fitting constants.

For $\frac{dP}{d\mu} > 0$ in the code, μ is replaced by $-\frac{A}{2B}$, the value of μ at $\frac{dP}{d\mu} = 0$. The parameters α and β in the expression for PGAS are reversed from those in the text of the Tillotson⁶ article but agree with the α and β in his tables.

To avoid discontinuous jumps in the transition between PSOL and PGAS in the code, a smoothing region has been included:

$$PTRANS = \frac{(E - E_s)PGAS + (E'_s - E)PSOL}{E'_s - E_s}$$

As defined in Ref. 11, E_s is the specific internal energy of the material just as it reaches the vaporization temperature, and E'_s is E_s plus the energy needed to vaporize from the liquid state.

Figure 3-2 shows the regions for the three pressure expressions as used in the code. Table 3-2 supplies values of the parameters for the Tillotson EOS. References for the values are given at the bottom of the table.

Table 3-2. Values for Tillotson EOS.

Material	ρ_0	a	E_0	b	A	E_s	E'_s	α	β	B
	g/cm ³	Unitless	jerks/g	Unitless	jerks/cm ³	jerks/g	jerks/g	Unitless	Unitless	jerks/cm ³
Obtained from Ref. 4.										
Be	1.845	0.55	1.75×10^{-5}	0.62	1.173×10^{-4}	1×10^{-5}	4.6×10^{-5}	5.	5.	5.5×10^{-5}
CH ₂	0.92	0.60	7.0×10^{-6}	2.0	7.5×10^{-6}	2.4×10^{-6}	1.8×10^{-5}	10.	5.	2.0×10^{-6}
Al	2.7	0.50	5.0×10^{-6}	1.63	7.52×10^{-6}	3.0×10^{-6}	1.5×10^{-5}	5.	5.	6.5×10^{-6}
Ti	4.51	0.50	7.0×10^{-6}	0.60	1.03×10^{-4}	3.5×10^{-6}	1.25×10^{-5}	5.	5.	5.0×10^{-5}
Fe	7.86	0.50	9.5×10^{-6}	1.50	1.279×10^{-4}	2.44×10^{-6}	1.02×10^{-5}	5.	5.	1.05×10^{-4}
Ni	8.86	0.50	9.0×10^{-6}	1.33	1.912×10^{-4}	2.85×10^{-6}	9.4×10^{-6}	5.	5.	1.5×10^{-4}
Cu	8.90	0.50	3.25×10^{-5}	1.5	1.39×10^{-4}	1.38×10^{-6}	6.9×10^{-6}	5.	5.	1.1×10^{-4}
Mo	10.2	0.50	4.50×10^{-6}	1.02	2.713×10^{-4}	2.8×10^{-6}	9.0×10^{-6}	5.	5.	1.65×10^{-4}
W	19.17	0.50	2.25×10^{-5}	1.04	3.08×10^{-4}	1.135×10^{-6}	5.6×10^{-6}	10.	10.	2.5×10^{-4}
Pb	11.34	0.40	1.5×10^{-6}	2.37	4.664×10^{-5}	2.6×10^{-7}	9.7×10^{-7}	13.	15.	1.5×10^{-5}
Th	11.68	0.40	2.5×10^{-6}	0.86	5.31×10^{-5}	2.0×10^{-6}	8.0×10^{-6}	9.	0.88	5.0×10^{-5}
Obtained from Ref. 11.										
Granite ^a	2.68	0.50	1.6×10^{-5}	1.30	1.8×10^{-5}	3.5×10^{-6}	1.8×10^{-5}	5.	5.	1.8×10^{-5}
Andesite ^a	2.70	0.50	1.6×10^{-5}	1.30	1.8×10^{-5}	3.5×10^{-6}	1.8×10^{-5}	5.	5.	1.8×10^{-5}
Wet tuff	1.97	0.50	1.1×10^{-5}	1.30	1.0×10^{-5}	3.2×10^{-6}	1.6×10^{-5}	5.	5.	6.0×10^{-6}
Dry tuff	1.70	0.50	6.0×10^{-6}	1.30	4.5×10^{-6}	3.5×10^{-6}	1.8×10^{-5}	5.	5.	3.0×10^{-6}
Oil shale	2.3	0.5	1.1×10^{-5}	1.0	2.8×10^{-5}	3.2×10^{-6}	1.6×10^{-5}	5.	5.	1.1×10^{-5}
Dolomite	2.82	0.5	1.0×10^{-5}	0.6	8.5×10^{-5}	2.5×10^{-6}	1.4×10^{-5}	5.	5.	3.0×10^{-5}
Limestone	2.70	0.5	1.0×10^{-5}	0.6	4.0×10^{-5}	2.5×10^{-6}	1.4×10^{-5}	5.	5.	6.7×10^{-5}
Halite	2.16	0.5	5.0×10^{-6}	0.6	2.5×10^{-5}	2.0×10^{-6}	1.5×10^{-5}	5.	5.	3.0×10^{-5}
Alluvium	2.60	0.5	6.0×10^{-6}	0.8	3.0×10^{-5}	3.5×10^{-6}	1.8×10^{-5}	5.	5.	1.0×10^{-5}

^aAlthough the parameters for these quantities are given here, the Tillotson form of the equation really needs to be modified as described in Ref. 2. If users wish to run problems using these materials, a slight modification of the coding needs to be made so that four additional parameters may be added to give a better fit to the data.

Fig. 3-2. Definitions of pressure regions for Tillotson EOS.

In linking from a Lagrangian code, be sure that the normal densities of materials in the Lagrangian problem and in the RAD9 are set so that $\rho_0^{\text{RAD9}} \geq \rho_0^{\text{Lag}}$. If they are smaller in the RAD9 than in the Lagrangian problem, the code at cycle zero will see totally inactive areas as compressed and will assign spurious pressures to such zones. If the pressures are small, they will not affect the running of the problem; however, they can cause difficulty in certain situations. Also, note that one of the disadvantages of treating separate materials, say air and tuff, as a single material is that with $\rho_0 = \rho_{\text{tuff}}$, the air will not be considered as a compressed material until it has reached the density of normal tuff. When the true four-material code is debugged, this will be handled correctly.

Specific Heat in RAD9

The specific heats are fitted below 0.3 keV as a function of temperature. Above 0.3 keV, they are treated as constant. The fitting is described in Ref. 12 and was originally adapted by W. McMaster for the MAITAI code. The table of values for the constants C_V is taken from the MAITAI code. The expression for the specific heat below 0.3 keV is

$$\text{Fit} = 1.82574 C_V \theta^{1/2}$$

$$C_V = 0.1456 \left(\frac{Z+1}{A} \right) \text{jerks/g} \cdot \text{keV} = 3/2 N_0 k \left(\frac{Z+1}{A} \right),$$

where Z is the atomic number, A the atomic weight, N_0 is Avogadro's number, and k is Boltzman's constant. Values of C_V are given in Table 3-3. Actually these are not specific heats in the proper sense i.e., derivatives of the energy with respect to temperature, but are functions connecting energy and temperature.

Table 3-3. Sample table of values of C_V .

Material	C_V (jerks/g·keV)	Material	C_V (jerks/g·keV)
Be	0.0808	Granite	0.0895
Al	0.0755	Sandstone	0.069
Fe	0.0704	Quartz	
Cu	0.0608	Gneiss	
W	0.0593	Alluvium	
Au	0.0591	Tuff	
Pb	0.0583	Limestone	
U	0.0569	Dolomite	
CH ₂	0.089	Basalt	
		Andesite	
		CaCO ₃	

On-line Plots and Cell Patches.

RAD9 has two on-line capabilities as options. Plots of density, pressure, radial and axial velocity, temperature, energy per cell, specific internal energy, and running sum of total energy may be made while the problem is running using the routine PLOTIN¹⁰. One may also alter the physical quantities of individual cells at the beginning of a run by calling subroutine PATCH.

The input for either or both of these options follows the Z-block input. Z(52) carries the flag which indicates whether or not these options are to be called. If Z(52) is not loaded or is loaded as a zero, neither option will be called.

$$Z(52) = \begin{cases} 0. & \text{neither option desired} \\ 1. & \text{PATCH data to be read} \\ 2. & \text{PLOTIN and PATCH data to be read} \\ 3. & \text{PLOTIN data to be read} \end{cases}$$

If data for both options are to be read, the PATCH data must be loaded before the PLOTIN data in the deck. PATCH is called directly from the INPUT routine and the data read in overwrite data read from the input tape. PLOTIN is called directly after the short print in EDITS, and plots are thus made at every cycle where a short print or long print is called for on the last Z-block card.

PLOTIN. The following instructions for using PLOTIN are taken from Ref. 10.

The on-line plots listed in Table 3-4 are available. Requested plots will be printed on microfiche corresponding to short-edit times. The data cards should be placed either after the last Z-block card or after PATCH data cards. No 1 is needed in column 1 of the last card in these sets of cards. However, a 1 is needed in the first column of the last Z-block card as described at the beginning of this chapter.

Table 3-4. Plot numbers for on-line plots available from PLOTIN.

Axial plot	Plot number ^a for		y-axis variable plotted as a function of position	Units of the y-axis variable
		Radial plot		
1		11	Density	g/cm ³
2		12	Pressure	Mbar
3		13	Radial velocity	cm/shake
4		14	Axial velocity	cm/shake
5		15	Temperature	keV
6		16	Energy per cell	jerks
7		17	Specific internal energy	jerks/g
8			Running sum of total energy	jerks

^aFor semilog scaling, add 20 to listed plot number. For log-log scaling, add 40 to listed plot number. Thus: for an axial plot of pressure on a log-log scale, plot number = 2 + 40 = 42; for a radial plot of density on a semilog scale, plot number = 11 + 20 = 32.

The input format for PLOTIN is as follows:

Card 1: NT, [plot set 1], [plot set 2], [plot set 3]
(15, 1515)

Card 2 . . . N: [plot set 4] , . . . , [plot set NT]
(5x, 1515)

A plot set consists of the five input parameters, PLT, ILO, IHI, JLO, and JHI, in that order. All cards have a maximum of three plot sets. Only card one has NT, where $NT \leq 102$. Input formats are listed in Table 3-5.

Table 3-5. Input formats for on-line plots.

Column	Parameter
1-5	NT: Total no. of plots (card 1 only; on cards 2 . . . N, columns 1-5 are blank)
6-10	PLT: Identifying plot number
11-15	ILO: Minimum I value (axial plots: ILO=I line)
16-20	IHI: Maximum I value (axial plots: IHI=0)
21-25	JLO: Minimum J value (radial plots: JLO=J line)
26-30	JHI: Maximum J value (radial plots: JHI=0)
31-35	PLT: Identifying plot number for second plot
36-40	ILO: Same as columns 11-15
41-45	IHI: Same as columns 16-20
46-50	JLO: Same as columns 21-25
51-55	JHI: Same as columns 26-30
56-60	PLT: Identifying plot number for third plot
61-65	ILO: Same as columns 11-15
66-70	IHI: Same as columns 16-20
71-75	JLO: Same as columns 21-25
76-80	JHI: Same as columns 26-30

Several output options are available for PLOTIN. To have plots printed on something other than microfiche, an additional card is required. This card should follow the last plot card. The card format for plot print is IDEVICE, ICAMERA (format 2I5). Table 3-6 lists the options.

Table 3-6. Input for output options.

IDEVICE		ICAMERA	
Input	Option	Input	Option
1	DD80	1 ^a	Fiche
2 ^a	FR80	2	35 mm
3	DD80 & FR80	3	35 mm + Xerox
4	SAVE file on disk	4	16 mm
5	DD80 & SAVE file		
6	FR80 & SAVE file		

^aDefault case, plots go to microfiche.

PATCH. The PATCH subroutine allows the overwriting of the physical variables of cells. Because it has a cell-by-cell input it is not useful for changing whole regions; however, it can be used to overwrite troublesome cells or to change characteristics in a small region. The overwrite takes place at cycle zero or at the restart cycle.

The first card following the Z-block tells the code the number of cells to be altered is NUMB. The format is 115. The number of cards to follow is equal to NUMB. The quantities to be specified for a cell are listed in Table 3-7.

Table 3-7. Quantities specified in PATCH subroutines.

Quantity	Description
I	Cell index for the radial direction
J	Cell index for the axial direction
UP	Radial velocity
VP	Axial velocity
RHOX	The density of X material = $\frac{AMX(K)}{TAU(I) \cdot DY(J)} = \frac{X \text{ mass}}{\text{cell volume}}$
RHOD	The density of dot material = $\frac{AMD(K)}{TAU(I) \cdot DY(J)} = \frac{\text{dot mass}}{\text{cell volume}}$
AX	The specific internal energy for X material = AIX(K)
AD	The specific internal energy for dot material = AID(K)

Quantities not specified are set to zero. The quantities are in the order given in Table 3-7, and the format is (215, 6E10.3).

Ideally, the code should be restarted from the teletype when using PATCH so that the quantities overwritten can be checked. They will be written out cell-by-cell on the teletype and can be checked before the problem uses significant machine time.

Output from RAD9.

Output pages at the beginning of the edit provide information on the input which generated the problem. Sample output from the cycle zero edit are shown in the next few pages.

Sample pages 5 and 6 show the first part of the edit. Entries AI, AK, and AM are the total internal energy, the total kinetic energy, and the total mass for the X and dot materials in the problem. Sums of X and dot quantities are also given.

Next are printed the cumulative energy check, and the ground-shock edit if called for by the calculation (see section on ground-shock edit). UVMAX, ETH, and REL ERROR come next. UVMAX is a quantity from subroutine CDT (see section on time-step control), and ETH is a corrected energy value. The REL ERROR is a bookkeeping number. The code evaluates the total energy in the grid in two ways. ETH is the energy in the grid at cycle zero and is updated whenever energy is set to zero because of the cutoffs or whenever energy flows off the end of the grid. E is the sum over all the cells of the internal and kinetic energy. A bookkeeping fraction WSA is constructed from these two.

$$WSA = \frac{ETH - E}{ETH}$$

The REL ERROR (ECK in the code) is the quantity WSA compared at cycle N and N-1:

$$ECK = WSA_N - WSA_{N-1}$$

Following these variables is a list of the sums of quantities set to zero by the code. These values also occur in the Z-block and are Z(100), Z(101), Z(102), Z(103), and Z(104). Next are the I and J of the zone controlling the hydrodynamic time step as calculated in CDT. Negative values of I and J imply that the time step is being controlled by the sound speed rather than by the particle velocity during the cycle at which the edit was made. The I or J values for the active grid boundaries follow, then the radiation time step, and then the I and J controlling the radiation time step.

A table of Z-block (and Z-block-like) values is printed out for entries through Z(185). IDEQST is the list of the numbers indicating the type of EOS to be called for each of the materials in the code. IDEQST(10) is the number of materials in the problem.

On sample page 6 is a similar list of the identifying numbers of the opacities called for each material in order of MTYPE number. Next, the EOS parameters for the materials in order of MTYPE number are listed.

Sample pages 32 and 35 follow. These again are parts of a material map as described in the chapter on the generator. Other maps follow. The density map on sample page 36 is a map filled with numbers approximating the zone densities. A number 7 indicates densities from 7 to 8, etc. The I or J of the cell with the maximum density in the grid is printed out at the top of the map. Similar maps of energy, pressure, axial and radial velocities, and X and dot specific internal energies and temperature follow the density map. In these plots, the numbers indicate the value of the quantity in each zone as a fraction of the maximum value of that quantity in the grid; e.g., a 9 represents 90% to 100% of the maximum value.

When a short print is called, the edit described to this point is the total edit. When a long print is called for, an edit of cell quantities for all cells in the largest rectangle defined by the active grid lines follows the short edit. Sample page 74 shows part of such a long edit. The quantities for all J zones in a column of zones defined by each I are grouped together. The sample page shows the beginning of the edit for I=1. The quantities are listed in Table 3-8.

Table 3-8. Quantities output from RAD9.

Quantity	Description
U	Radial velocity in cm/shake
V	Axial velocity in cm/shake
F/A	Pressure in Mbar
PVOL	Indicates materials present in the cell and the fractional volume occupied by X material Example: J=29 PVOL = 100 Material is pure dot. Material number is 1. J=30 PVOL = -2179 (-) indicates the cell is mixed 2 indicates the X material is material number 2 1 indicates the dot material is material number 1 79 indicates the partial volume of X material is 79%. The partial volume is calculated by iterating until $P_X = P_{\text{dot}}$ in the cell J=31 PVOL = 2000 Material is pure X Material number is 2
AMX	The X mass in g
AIX	The specific internal energy of the X material in jerks/g

Table 3-8. Quantities output from RAD9. (continued)

Quantity	Description
AMD	The dot mass in g
AID	The specific internal energy of the dot material in jerks/g
THETA	The temperature in keV
RHO	Density in g/cm ³ . For a mixed cell, it is the combined density, (AMX+AMD)/VOLUME.
Z	The location of upper boundary of the cell in cm
ESUM	$\sum_{j=1}^J E_j$; the running sum at each J of the total energies (internal plus kinetic)

At the end of the long print is a very short edit which is printed out every cycle. Subroutine CDT prints out the message "CHANGE DT" followed by the time, the time step for the cycle just completed (DT(N)); the time step for the cycle just beginning (DT(N+1)), the I and J of the zone controlling the hydrodynamic time step, and Z(105) which is labeled STAB. Following this is a message from the radiation subroutines RADIAL and AXIAL. It gives the I and J of the zone controlling the radiation time step, the magnitude of the radiation time step, DTRAD, and the subroutine in which it was calculated. The time step may be different for RADIAL and AXIAL. If the problem is controlled by radiation, the time step for the next cycle will be the lesser of the two radiation time steps calculated.

Other edits may be done by the code as required. For example, if the iteration in subroutine WHATES fails to produce identical pressures in X and dot materials, the code prints out the message CELL HAS FAILED IN PRESSURE ITERATION followed by the values of I, J, K, cycle number, and two flags which identify paths taken by the code in WHATES (NUB and LUB). It also prints the last try at X and dot pressures (PX and PD), the last value of the partial volume of X material (EPSI), the X and dot masses in the cell (AMX and AMD), and the X and dot specific internal energies (AIX and AID).

The code will not exit because often the failure either is very slight or occurs in zones of very low activity. The user should look at the values, the location in the grid, etc. and decide whether to rerun allowing more iterations or to ignore the situation because it will have no significant effect. Possibly, the failure to iterate is symptomatic of serious trouble with the problem.

The code also prints out a message if the internal energy in a cell goes negative (and has to be set to zero by the code). The message is NEGATIVE DOT INTERNAL ENERGY or NEGATIVE X INTERNAL ENERGY followed by the values of I and J and the values of the mass and the offending internal energy. Other error messages printed out by the code will be self-explanatory.

Note that RAD9 prints a cycle zero edit but there is no cycle zero tape dump except that of the generator.

Output from RAD9

1PROBLEM	CYCLE	TIME	DT	TRAD	DTRAD	NR	N1	PAGE	5
9619.9	0	1.2000000E+02	1.7429386E-04	0.	1.0000000E-04	0	40	N2 L	N3 0
									N4 0

0

		A1	AK	A1+AK	AM
DOT	1	3.2330194E+05	1.3567177E+05	4.5897371E+05	1.2358758E+10
X	2	1.1744112E+04	1.3445373E+04	2.5189485E+04	3.2415705E+07
TOTALS		3.3504605E+05	1.4911714E+05	4.8416319E+05	1.2391174E+10

0

0.	RADEB	0.	RADER	0.	RADET	MAX VEL	THE	REL ERROR
						1.2000000E-04	4.8413914E+05	-4.9676366E-05

0.	0.	0.	0.	0.	0.	0.
X MASS SET TO 0	MASS SET TO 0	X TOTAL E SET TO 0	TOTAL E SET TO 0	TOTAL E SET TO 0	TOTAL E SET TO 0	
0.	0.	0.	0.	0.	0.	

1 0.	1.00000E-08	1.00000E-09	0.	1.00000E+00	0.	1.22177E+00
2 0.	1.00000E-08	1.00000E-09	0.	1.00000E+00	0.	1.22177E+00

I(DTHYDR0)	J(DTHYDR0)	I1	I2
9	34	80	0
L1	L2	L3	L4
59	59	90	15
			L5
			90

DTRAD	I(DTRAD)	J(DTRAD)
1.0000000E-04	0	0

Z-BLOCK									
1	9.61990E+03	0.	1.74294E-04	1.00000E+01	1.00000E+01	1.00000E+01	1.40000E+02	3.14159E+00	1.23912E+10
10	0.	0.	0.	4.84139E+05	0.	0.	1.37000E-02	3.24338E+07	8.00000E+02
19	1.02750E+00	0.	1.00000E+00	3.00000E+02	-4.96754E-05	1.20000E-01	1.50000E-01	1.74294E-04	-1.00000E+00
28	0.	0.	0.	0.	33976	80	81	199	200
37	15921	15922	0	0	0	82	1105	2.00000E+03	0.
46	0.	0.	0.	0.	-0	40	L	0	0
55	0	0	0	0	0	9	34	0	0
64	0.	1.00000E-07	0.	0.	0.	0.	1.00000E-04	0.	0.
73	0.	0.	2.00000E-05	-4.96764E-05	1.00000E+00	-1.00000E+00	1.00000E+00	1.00000E+00	1.00000E+00
82	-1.00000E+00	0.	1.20000E+02	1.67000E+00	1.67000E+00	1.67000E+00	2.49254E+00	2.49254E+00	0.
91	0.	0.	0.	0.	0.	0.	-0.	-1.00000E+00	1.00000E-01
100	0.	0.	0.	0.	0.	0.	0.	0.	0.
109	0.	3.00000E-08	1.52206E+02	1.00000E+12	0.	1.20000E-04	1.20000E+00	0.	0.
118	0.	0.	0.	0.	0.	0.	0.	0.	0.
127	0.	0.	0.	0.	0.	0.	0.	0.	0.
136	0.	0.	0.	0.	0.	0.	0.	0.	0.
145	0.	1.00000E-10	2.00000E-05	3.50000E-01	0.	0.	0.	0.	0.
154	4.00000E-09	1.00000E-06	0.	0.	0.	0.	9.61990E+03	0.	-1.00000E+00
163	0.	0.	0.	0.	0.	0.	0.	0.	0.
172	0.	0.	0.	0.	0.	0.	0.	0.	0.

181	0.	0.	0.	0.	0.	0.	0.	0.	2.10000E+00
IDEQST	1	1	0	0	0	0	0	0	2
IDKAP	1	3	0	0	0	0	0	0	0
186	2.10000E+00	5.00000E-01	1.10000E-05	1.30000E+00	1.00000E-05	3.20000E-06	1.80000E-05	5.00000E+00	5.00000E+00
195	6.00000E-06	4.04000E+00	3.40000E+00	4.20000E-01	0.	1.00000E-08	1.00000E-09	0.	1.00000E+00
204	0.	1.22177E+00	0.	0.	0.	0.	7.50000E-02	1.13400E+01	4.00000E-01
211	1.13400E+01	4.00000E-01	2.00000E-06	2.40000E+00	4.60000E-05	2.60000E-07	9.70000E-05	1.00000E+01	2.00000E+00
220	3.60000E-07	4.04000E+00	3.40000E+00	4.20000E-01	0.	1.00000E-06	1.00000E-09	0.	1.00000E+00
229	0.	2.96965E+00	0.	0.	0.	0.	6.90000E-02	0.	0.

```

N1      N2      N3      N4
40      L      0      0

YMAX = 3.000000E+03

```

[illegible]

3-22

63

0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100

[illegible]

3-23

PROBLEM
9619.9

CYCLE
0

TIME
1.2000000E+02

DT
1.7429386E-04

0.

TRAD

DTRAD
1.0000000E-04

NR
0

N1
40

N2
L

N3
0

N4
0

PAGE 74

RAD9 I = 1 X(1) = 2.000 DX(1) = 2.000

J	U	V	F/A	PVOL	AMX	A1X	AMD	A1D	THETA	RHO	Z	ESUM
1	-0.	-0.	0.	100 0.	0.	0.	2.639E+03	1.950E-09	2.600E-08	2.100E+00	1.000E+02	5.146E-06
2	-0.	-0.	0.	100 0.	0.	0.	1.319E+03	1.950E-09	2.600E-08	2.100E+00	1.500E+02	7.719E-06
3	-0.	-0.	0.	100 0.	0.	0.	1.319E+03	1.950E-09	2.600E-08	2.100E+00	2.000E+02	1.029E-05
4	-0.	-0.	0.	100 0.	0.	0.	1.319E+03	1.950E-09	2.600E-08	2.100E+00	2.500E+02	1.286E-05
5	-0.	-0.	0.	100 0.	0.	0.	1.319E+03	1.950E-09	2.600E-08	2.100E+00	3.000E+02	1.544E-05
6	-0.	-0.	0.	100 0.	0.	0.	6.597E+02	1.950E-09	2.600E-08	2.100E+00	3.500E+02	1.672E-05
7	-0.	-0.	0.	100 0.	0.	0.	6.597E+02	1.950E-09	2.600E-08	2.100E+00	4.000E+02	1.801E-05
8	-0.	-0.	0.	100 0.	0.	0.	6.597E+02	1.950E-09	2.600E-08	2.100E+00	4.500E+02	1.930E-05
9	-0.	-0.	0.	100 0.	0.	0.	6.597E+02	1.950E-09	2.600E-08	2.100E+00	5.000E+02	2.058E-05
10	-0.	-0.	0.	100 0.	0.	0.	6.597E+02	1.950E-09	2.600E-08	2.100E+00	5.500E+02	2.187E-05
11	-0.	-0.	0.	100 0.	0.	0.	6.597E+02	1.950E-09	2.600E-08	2.100E+00	6.000E+02	2.316E-05
12	-0.	-0.	0.	100 0.	0.	0.	6.597E+02	1.950E-09	2.600E-08	2.100E+00	6.500E+02	2.444E-05
13	-0.	-0.	0.	100 0.	0.	0.	6.597E+02	1.950E-09	2.600E-08	2.100E+00	7.000E+02	2.573E-05
14	-0.	-0.	0.	100 0.	0.	0.	6.597E+02	1.950E-09	2.600E-08	2.100E+00	7.500E+02	2.702E-05
15	-0.	-0.	0.	100 0.	0.	0.	6.597E+02	1.950E-09	2.600E-08	2.100E+00	8.000E+02	2.830E-05
16	-0.	-0.	0.	100 0.	0.	0.	6.597E+02	1.950E-09	2.600E-08	2.100E+00	8.500E+02	2.959E-05
17	-0.	-0.	0.	100 0.	0.	0.	6.597E+02	1.950E-09	2.600E-08	2.100E+00	9.000E+02	3.088E-05
18	-0.	-0.	0.	100 0.	0.	0.	6.597E+02	1.950E-09	2.600E-08	2.100E+00	9.500E+02	3.216E-05
19	-0.	-0.	0.	100 0.	0.	0.	6.597E+02	1.950E-09	2.600E-08	2.100E+00	1.000E+03	3.345E-05
20	5.96E-04	-1.368E-02	1.896E+01	100 0.	0.	0.	8.813E+00	8.994E-02	3.598E-01	2.219E+00	6.500E+02	9.152E-05
21	-2.560E-02	4.022E-01	1.037E+01	100 0.	0.	0.	3.849E-01	8.519E-01	5.193E-01	1.225E-03	7.500E+02	3.967E+00
22	-5.333E-02	6.098E-01	5.279E+00	100 0.	0.	0.	3.507E-01	9.275E-01	5.192E-01	1.116E-03	7.500E+02	4.292E+00
23	-5.328E-03	6.639E-02	3.557E+00	100 0.	0.	0.	3.477E-01	9.349E-01	5.192E-01	1.107E-03	8.000E+02	4.617E+00
24	2.943E-04	1.226E-03	3.518E+00	100 0.	0.	0.	3.484E-01	9.333E-01	5.192E-01	1.109E-03	8.250E+02	4.943E+00
25	1.306E-03	9.743E-03	3.514E+00	100 0.	0.	0.	3.718E-01	8.790E-01	5.192E-01	1.184E-03	8.500E+02	5.270E+00
26	2.094E-03	-1.439E-02	3.515E+00	100 0.	0.	0.	4.610E-01	7.380E-01	5.230E-01	1.467E-03	8.750E+02	5.640E+00
27	1.122E-02	-7.519E-02	3.543E+00	100 0.	0.	0.	1.923E-01	1.697E+00	5.224E-01	6.122E-04	9.000E+02	6.003E+00
28	6.225E-02	-3.482E-01	3.455E+00	100 0.	0.	0.	3.22E-01	1.697E+00	5.480E-01	1.024E-02	9.250E+02	6.972E+00
29	1.142E-01	-6.116E-01	3.818E+00	2154 3.086E+00	9.240E-02	0.	0.	0.	5.874E-01	3.143E-02	9.500E+02	9.274E+00
30	9.695E-02	-5.254E-01	5.818E+00	2000 9.875E+00	9.240E-02	0.	0.	0.	5.874E-01	3.143E-02	9.750E+02	1.158E+01
31	9.622E-02	-5.217E-01	1.053E+01	2000 9.875E+00	9.240E-02	0.	0.	0.	5.874E-01	3.143E-02	1.000E+03	1.381E+01
32	9.622E-02	-5.217E-01	1.053E+01	2000 9.875E+00	9.240E-02	0.	0.	0.	5.874E-01	3.143E-02	1.020E+03	1.581E+01
33	1.365E-01	-4.999E-01	1.053E+01	2000 9.871E+00	9.241E-02	0.	0.	0.	5.874E-01	3.143E-02	1.040E+03	1.708E+01
34	1.266E-01	4.831E-01	1.044E+01	2000 7.810E+00	9.273E-02	0.	0.	0.	5.868E-01	3.108E-02	1.060E+03	1.861E+01
35	3.439E-02	5.053E-01	9.635E+00	2000 6.992E+00	9.644E-02	0.	0.	0.	5.817E-01	2.782E-02	1.080E+03	2.014E+01
36	2.707E-02	5.042E-01	9.503E+00	2000 6.795E+00	9.746E-02	0.	0.	0.	5.805E-01	2.704E-02	1.100E+03	2.045E+01
37	2.707E-02	5.042E-01	9.503E+00	2000 6.795E+00	9.746E-02	0.	0.	0.	5.805E-01	2.704E-02	1.115E+03	2.069E+01
38	1.239E-02	6.144E-01	3.604E+00	100 0.	0.	0.	2.491E-01	1.071E+00	5.228E-01	9.913E-04	1.130E+03	2.092E+01
39	-3.094E-02	6.144E-01	3.604E+00	100 0.	0.	0.	1.869E-01	1.071E+00	5.228E-01	9.913E-04	1.145E+03	2.114E+01
40	-2.824E-02	5.557E-01	3.607E+00	100 0.	0.	0.	1.989E-01	1.006E+00	5.224E-01	1.055E-03	1.160E+03	2.135E+01
41	4.376E-03	3.588E-01	3.620E+00	100 0.	0.	0.	2.540E-01	7.864E-01	5.207E-01	1.348E-03	1.175E+03	2.157E+01
42	1.807E-02	3.588E-01	3.620E+00	100 0.	0.	0.	2.540E-01	7.864E-01	5.207E-01	1.348E-03	1.190E+03	2.176E+01
43	1.807E-02	3.588E-01	3.620E+00	100 0.	0.	0.	1.805E-01	1.075E+00	5.185E-01	8.516E-04	1.205E+03	2.196E+01
44	1.025E-02	1.607E-01	3.493E+00	100 0.	0.	0.	1.605E-01	1.199E+00	5.185E-01	8.516E-04	1.220E+03	2.215E+01
45	-5.130E-03	7.534E-02	3.455E+00	100 0.	0.	0.	1.605E-01	1.199E+00	5.185E-01	8.516E-04	1.235E+03	2.234E+01
46	-8.526E-03	7.534E-02	3.455E+00	100 0.	0.	0.	1.632E-01	1.180E+00	5.184E-01	8.660E-04	1.250E+03	2.254E+01
47	-8.526E-03	7.534E-02	3.455E+00	100 0.	0.	0.	1.164E-01	1.106E+00	5.184E-01	9.265E-04	1.260E+03	2.267E+01
48	-5.069E-03	2.950E-02	3.459E+00	100 0.	0.	0.	1.164E-01	1.106E+00	5.184E-01	9.265E-04	1.270E+03	2.280E+01
49	8.341E-03	-1.482E-01	3.475E+00	100 0.	0.	0.	1.164E-01	1.106E+00	5.184E-01	9.265E-04	1.280E+03	2.293E+01
50	8.341E-03	-1.482E-01	3.475E+00	100 0.	0.	0.	1.164E-01	1.106E+00	5.184E-01	9.265E-04	1.280E+03	2.293E+01
51	8.341E-03	-1.482E-01	3.475E+00	100 0.	0.	0.	1.164E-01	1.106E+00	5.184E-01	9.265E-04	1.280E+03	2.293E+01

Chapter 4: DORF9

(To be added later.)

Chapter 5: Running the OIL Family Codes (Louise Morris)

The RAD9 branch of the OIL family codes consists of two separate codes: TCOM, the generator (and coming rezoner), and the RAD9 code itself. With the current grid size of 16008, TCOM occupies 133k SCM/665k LCM and RAD9 117k SCM/725k LCM. (Where SCM and LCM are the CDC 7600 small-core and large-core octal memory sizes, respectively.)

Current versions of the codes and libraries will be maintained on the photostore with magnetic tape backup. The codes are stored by subroutine in a LIX¹³ compatible file, and the library is simply a collection of compiled binary decks (including MAIN) assembled using the routine ALTER.¹⁴ Bit counts (checksums) of the file will be available to verify code files if problems are suspected. The data file for the sample problem described earlier in this report in Chapters 2 and 3 are also available from the author.

The running code responds to sense switches, making it advisable to run under a controller (e.g., ORDER¹⁵). The executable controllee can be loaded from its library using LOD¹⁶ or, preferably, under ORDER by using the *LOD card to force-load the entire library and necessary routines from the system library ORDERLIB.¹⁷

For example, if the RAD9 library on disk were called RADLIB, the ORDER control cards shown in Fig. 5-1 would load the library into an executable file, and with the *XEQ card begin execution of the controllee using the data file RAD9D.

PROGRAMMER		EXT.		DATE		PAGE	
PROBLEM		EXT.		DATE		PAGE	
FORTRAN							
FORTRAN STATEMENT							
1	2	3	4	5	6	7	8
9	10	11	12	13	14	15	16
17	18	19	20	21	22	23	24
25	26	27	28	29	30	31	32
33	34	35	36	37	38	39	40
41	42	43	44	45	46	47	48
49	50	51	52	53	54	55	56
57	58	59	60	61	62	63	64
65	66	67	68	69	70	71	72
*ID NNNAAA ROUTINE NAME YOUR NAME BOX ANW							
* LOD 130000; RADLIB; ORDERLIB, 1							
* XEQ							
* DATA RAD9D							
DATA CARDS							

Fig. 5-1. Example ORDER control cards using entire library.

If modifications to the library subroutines are necessary, get MAIN and the required subroutines from the source LIX file. Any file-editing routine, e.g., TRIX,¹⁸ can be used to change the files and merge them into a source file. Basic ORDER control cards will be included with MAIN, the routine which also defines the cliché RAD9C. An example of the new file is shown in Fig. 5-2.

PROGRAMMER		EXT.		DATE	
PROBLEM		EXT.		PAGE	
FORTRAN					
FORTRAN STATEMENT					
1	2	3	4	5	6
*ID	NNNAAA	ROUTINE NAME		YOUR NAME	BOX ANN
*LIB	RADLIB				
*LOD	1300000; ↑				
*XEQ					
*CARDS	DEBUG ↑				
*FORTRAN		FORTRAN SOURCE AND SPECIAL BINARIES			
*DATA	RAD9D	DATA DECK			

Fig. 5-2. Example ORDER control cards using modified subroutines and binaries.

Note in the two examples shown in Figs. 5-1 and 5-2 that the differences between the uses of both the *LOD and *LIB and the *LOD control cards alone. Where the *LOD is used alone, the entire library, MAIN, and subroutines are being loaded from the library. The second method, where both *LOD and *LIB are used, uses the MAIN deck and special subroutines, source or binary, and loads only the missing subroutines from the library file RADLIB and implied system library ORDERLIB.

The user must furnish his own *ID card and is likewise free to modify the ORDER control cards to suit his own needs. We have only attempted to show a basic example, not a complete description of ORDER. Again, as in the first example, the library RADLIB must be in the user's private files.

To read the library from tape, the vault name and exact library name must appear on the *LIB card. Library files on tape are necessary for running under production accounts.

One comment should be made about the ↑ on *LOD and *CARDS cards. The ↑ causes the routines to be compiled and loaded with symbol tables which may or may not be of interest to the user. The symbol tables add to the length of the disk files and complicate punching binary decks, but are necessary if debugging tools such as DEBUG¹⁹ or DOD²⁰ are to be used.

The running conditions differ for TCOM and RAD9. Soon after the TCOM goes into execution, the code requests user to type in the Lagrangian file name. For our 16000-zone problem, the code runs about 5 minutes (CDC7600 time) and writes its cycle zero dump on tape assigned at the end of the run just before writing the . . . 0002 BCD OUT high-speed print (HSP) file. A sometimes encountered error I/O . . . OOOZBCD OUT means a parity error was encountered in writing the HSP file. Since the tape has already been written, this error means part of the HSP file may be lost, although the essential output, the cycle zero tape, has probably been written correctly.

Sample IBM 1800 tape census

FILE	RECORD	MODE	DENS	WORDS	CHAR ERROR	FIRST 84 CHARACTERS OR FIRST FEW WORDS	PAGE
1	1	BIN	800	150	1500	17354544763146314631 000000000000000000 000000000000000000 000000000000000000	1
1	2	BIN	800	2814 48/60	8148	000000000000000000 777777777777777777 777777777777777777 777777777777777777	
1	3	BIN	800	2814 48/60	8148	000000000000000000 777777777777777777 777777777777777777 777777777777777777	
1	4	BIN	800	2814 48/60	8148	000000000000000000 17335116740140360976 17347566320220550134 17356342530170454115	
1	5	BIN	800	2814 48/60	8148	000000000000000000 000000000000000000 000000000000000000 000000000000000000	
1	6	BIN	800	2814 48/60	8148	000000000000000000 16634015453123221510 16634015453123221510 16634015453123221510	
1	7	BIN	800	2814 48/60	8148	000000000000000000 000000000000000000 000000000000000000 000000000000000000	
1	8	BIN	800	2814 48/60	8148	000000000000000000 000000000000000000 000000000000000000 000000000000000000	
1	9	BIN	800	2814 48/60	8148	000000000000000000 000000000000000000 000000000000000000 000000000000000000	
1	10	BIN	800	2814 48/60	8148	12341234123412341234 16666553762465362572 16666553762465362572 16666553762465362572	
1	11	BIN	800	80	800	172140000000000000 172240000000000000 172240000000000000 172340000000000000	
1	12	BIN	800	80	800	17236220773264773214 17254554574407574351 17257665172142172057 17265376673736273672	
1	13	BIN	800	159	1990	172662000000000000 172745400000000000 172762000000000000 172776400000000000	
1	14	BIN	800	10	100	000000000000000000 000000000000000000 000000000000000000 000000000000000000	
1	15	BIN	800	10	100	000000000000000000 000000000000000000 000000000000000000 000000000000000000	
1	16	BIN	800	250	2500	000000000000000000 000000000000000000 000000000000000000 000000000000000000	
END OF FILE 1, 16 RECORDS							
2	1	BIN	800	150	1500	173151500000000000 000000000000000000 000000000000000000 000000000000000000	

RAD9 picks up cycle zero, or on a restart, cycle N from tape. When RAD9 goes into execution, the required tape is assigned and remains assigned during the entire run, unloading only for the assignment of a new tape as requested by the code. Thus, if the system goes down, the tape connection could be lost and the problem would have to be restarted from a previous tape dump.

During execution, (ctrl-O) SW2. causes the code to print the current cycle, problem time, time step for new cycle (DT), and previous cycle time step (DTNA). For a grid size of 16000, 3-1/2 to 4 cycles run per minute of machine time.

Termination of a run is usually either with a SW1. or as directed by the input. The code checks SW1. and SW2. every cycle. Allow 2 minutes for the code to complete its cycle calculation after SW1. has been set and to write a final tape dump and HSP edit.

The dump tapes can be read independently from the code to verify one's current status or help diagnose problems. A tape census can be made on either the CDC 7600 or IBM 1800 if different computer hardware is needed. A sample IBM 1800 tape census is given. ATE²¹ is useful for obtaining a decimal dump of the tape or selected portions of selected files.

A typical problem may have a grid size defined by IMAX=80, and JMAX=199. The code then sets KMAXA=JMAX *IMAX + 2 = 15922. MZ is always set to 150 (Z-block proper, not including EOS constants). The dump arrays in order are Z(MZ), U(KMAXA), V(KMAXA), AMD(KMAXA), AMX(KMAXA), AID(KMAXA), AIX(KMAXA), P(KMAXA), NUMF(KMAXA), THETA(KMAXA), X(IMAX), TAU(IMAX), Y(JMAX), IDEQST(10), IDKAP(10), and EQSTC(250).

The tape is terminated by a Z-block whose first value is 666. (octal 17315 15000 00000 00000) Dumps marking the end of a physical tape have Z(1) = 666. and Z(2) = 666.6. Ten dumps usually fill a standard 2000-foot magnetic tape.

ACKNOWLEDGMENTS

The author wishes to thank Wallace Johnson, Barbara Crowley, and Jon Bryan for critiquing this manual, Louise Morris for contributing Chapter 5 and for help in working over the several drafts, and Coralyn McGregor for editing the manuscript. She also wishes to thank Diane Tassevigen for typing the various drafts and Joanne Campbell for assisting her with the last draft.

REFERENCES

1. M. Evans and F. Harlow, *The Particle in Cell Method for Hydrodynamics Calculations*, LASL, Rept. LA-2139 (1957) (see Appendix II).
2. M. E. Cunningham, *The Physics of the OIL Family of Codes*, Lawrence Livermore Laboratory, Rept. in preparation (Title U; Report SRD).
3. W. E. Johnson, *RADOIL and RAM*, Systems, Science and Software, La Jolla, CA, Rept. 3SR-104, DASA 2649 (1971).
4. W. E. Johnson, *Development and Application of Computer Programs Related to Hypervelocity Impact*, Systems, Science and Software, La Jolla, CA, Rept. 3SR-353 (1970).
5. W. E. Johnson, *Development and Application of Computer Programs Related to Hypervelocity Impact*, Systems, Science and Software, La Jolla, CA, Rept. 3SR-749 (1971).
6. J. H. Tillotson, *Metallic Equations of State for Hypervelocity Impact*, General Atomic, San Diego, CA, Rept. GA-3216 (1964).
7. R. C. Schroeder and W. H. McMaster, *Compilation of Shock Hugoniot Data & Hugoniot Melting Points for the Elements*, Lawrence Livermore Laboratory, Rept. UCRL-51253 (1972).
8. W. Prager, *Introduction to Mechanics of Continua*, Ginn & Co.
9. W. E. Johnson, *Code Correlation Study*, Air Force Weapons Lab., Abq. Rept. AFWL-TR-70-144 (1971).
10. E. Schooler, Lawrence Livermore Laboratory, Internal Document UOPBA 73-97 (1973). Readers outside the Laboratory who desire further information on LLL internal documents should address their inquiries to the Technical Information Department, Lawrence Livermore Laboratory, Livermore, California 94550.
11. R. T. Allen, K. Pyatt, and R. N. Schlang, *Coupling of Energy with the Ground for Near Surface Nuclear Explosions*, Gulf General Atomic, San Diego, CA, Rept. GA-8910, DASA 2110 (1968).
12. Ya. B. Zel'dovich and Yu. P. Raisir, *Physics of Shock Waves and High Temperature Hydrodynamic Phenomena*, Vol. 2, W. D. Hayes and R. F. Probstein, Eds. (Academic Press, New York, 1967), p. 695.
13. J. E. Ramus, *Utility Routine LIX*, Lawrence Livermore Laboratory, Rept. UR-321 (1973).
14. R. A. Hughes, *6600 ALTER Routine*, Lawrence Livermore Laboratory, CIC Rept. O2-012 (1968).
15. R. Potter and T. Fallon, *Livermore Time-Sharing System, Part III, Chapter 202: The ORDER System*, Lawrence Livermore Laboratory, Rept. LTSS-202 (Edition 3, 1973).
16. S. F. Mendicino, *LOD, A Relocatable Loader*, Lawrence Livermore Laboratory, CIC Rept. LS-003 (1968).
17. E. Carpenter and S. V. Solbeck, *Livermore Time-Sharing System, Part IV, Chapter 304: ORDERLIB Subroutine Library*, Lawrence Livermore Laboratory, Rept. LTSS-304 (Edition 1, June 1, 1973; Revision 2, May 21, 1974).
18. A. B. Cecil, H. F. Moll, and J. Rinde, *File Editing with TRIX*, Lawrence Livermore Laboratory, Rept. UCID-30040 (1972).
19. D. W. Thompson, R. W. Kuhn, *Utility Routine DBUG*, Lawrence Livermore Laboratory, Rept. UR-108 (1973).
20. W. Derby, *Utility Routine DOD*, Lawrence Livermore Laboratory, Rept. UR-114 (1974).
21. W. Derby, *Utility Routine ATE*, Lawrence Livermore Laboratory, Rept. UR-105 (1974).