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NUCLEAR EXPLOSION INTERACTION STUDIES

Volume III

The OUTPUT Code

J. R. Triplett et al.

Gulf General Atomic Incorporated
San Diego, California 92112

Contract No. F29601-67-C-0014

TECHNICAL REPORT NO. AFWL-TR-67-131, Vol III

April 1968

AIR FORCE WEAPONS LABORATORY
Air Force Systems Command
Kirtland Air Force Base
New Mexico

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FOREWORD

This report was prepared by Gulf General Atomic Incorporated, San Diego, California, under Contract F29601-67-C-0014. The research was funded by DASA under Project 5710, Subtask 07.017, Program Element 6.16.46.01H, and by ARPA Order 313, Program Element 6.25.03.01R.

Inclusive dates of research were 29 September 1966 to 27 October 1967. The report was submitted 13 March 1968 by the Air Force Weapons Laboratory Project Officer, Major John Bode (WLRT).

This report is published in four volumes: Volume I, Laser Phenomenology (classified CONFIDENTIAL); Volume II, Two-Dimensional Code Development; Volume III, The OUTPUT Code; and Volume IV, Material Property Codes. The first volume contains a classified report on interaction of laser radiation with solid targets and a brief description of calculations done in conjunction with experiments at the Air Force Weapons Laboratory. The remaining three volumes contain reports of code development efforts in the areas of radiative transfer, hydrodynamics, radiative absorption coefficients, and equations of state.

The projects described in this report are for the most part in an incomplete state of development. This is due in part to the nature of the existing computer programs themselves, which continue in a state of development as long as they are in use, and in part to the time scale involved in bringing new programs to a state of capability for solving real problems.

Gulf General Atomic staff personnel responsible for the direction of the research include J. H. Alexander, R. Brightman, R. S. Englemore, B. E. Freeman, W. B. Lindley, L. Norris, J. T. Palmer, L. M. Schalit, J. R. Triplett, and Mrs. Chris Imes. Contractor's report number is GA-7764, Vol III.

The cooperation of Dr. P. V. Avizonis, Major J. Bode, Capt C. C. David, Major G. Spillman, and Lt L. Stoessel of AFWL is gratefully acknowledged.

Other documents produced under this contract are: GAMD-7592, " A Numerical Scheme for First-Order Compton Scattering," J. T. Palmer, December 13, 1966; GAMD-7846, "Difference Equations for Heat Flow in Two Dimensions," J. R. Triplett, March 2, 1967; GAMD-7879, "A Modified Characteristic Method for Radiative Transfer," J. R. Triplett, March 17, 1967; GAMD-7889, "R D C D. A FORTRAN Input Routine," J. H. Alexander, March 24, 1967; GAMD-8333, "Hydrodynamic Equations

for Multidimensional Problems," J. R. Triplett, October 24, 1967; GAMD-8379, "A Brief Study of the Thermodynamic Properties of Several Low Z Elements at Low Temperature," L. M. Schalit, November 22, 1967.

This technical report has been reviewed and is approved.

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ABSTRACT

(Distribution Limitation Statement No. 2)

The OUTPUT code is designed for the analysis of early-time nuclear explosions. The equations for radiative transfer (characteristic method) and conservation of total (fluid and radiation) momentum and energy are solved in one-dimensional (plane or spherical) geometry. The radiation equations include first-order Compton scattering, and the hydrodynamic equations are treated in explicit Lagrangian form. The code is undergoing continuing development; the formulation, flow charts, glossary, and listings presented represent its status as of 27 October 1967.

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SECTION I

INTRODUCTION

PURPOSE OF CODE

The OUTPUT code, a version of the SPUTTER code, is a one-dimensional, Lagrangian, radiative hydrodynamics program written in the FORTRAN IV language. The purpose of this code is to calculate and to predict the radiative spectrum and the early-time evolution of nuclear devices. The code has been applied to several devices; the results of these applications are reported in reference 1.

PHYSICAL MODEL

The solution to the radiation transport equation is similar to that in the standard SPUTTER program (Ref. 2) in that the characteristic ray approach is employed for grey or multifrequency problems with mixed diffusion and transport regimes. However, OUTPUT includes as options Thomson scattering (conservative scattering) and first-order Compton scattering (nonconservative). The physics of the hydrodynamics routine have also been improved by including the radiation pressure as a tensor. This improvement has the effect of adding a term to the momentum equation and a corresponding work term to the energy equation. The energy equation also now uses the radiation pressure as calculated in the radiation routines rather than the usual equilibrium diffusion assumption $P_r = (1/3)\, a\, \theta^4$, where $\theta = kT$ is the local material temperature multiplied by the Boltzmann constant, in electron volts, and $a = 137$ ergs/cm^3/eV^4 is the Stefan radiation constant in appropriate units.

LOGIC OF CONSTRUCTION

The logic followed in constructing OUTPUT has been that the SPUTTER format and bookkeeping subroutines should be employed as fully as possible so as to achieve the following benefits: (1) opacities and material properties developed for SPUTTER would be immediately usable; (2) problems run with SPUTTER could be picked up (i. e., off a tape) and continued with OUTPUT or vice versa, using at most a simple transcription program; (3) the job of redeveloping the auxiliary subroutines could be avoided; and (4) personnel familiar with SPUTTER and its derivatives could easily learn the differences between the codes. The differences between the current SPUTTER program and the OUTPUT code are described in Appendix I. It should be noted that the OUTPUT code was designed for a particular class of problems; consequently, the capability of the SPUTTER program to handle certain problems, e. g., conduction, boiling, etc., has been eliminated. This has increased the efficiency of the code and released needed core storage and common variables. The user is cautioned that variables used solely in deleted sections of the SPUTTER code are now employed differently.

This report is not a complete documentation of the OUTPUT code but rather a documentation of those portions of the SPUTTER code that have been substantially altered. The SPUTTER code has been documented in reference 3. As an aid to gaining experience in using the OUTPUT code, a list of the cards used in making the successful comparison between the Gulf General Atomic and Air Force Weapons Laboratory versions of the OUTPUT code is included in Appendix II.

SECTION II

THEORETICAL MODEL

The equations presented in this section represent the theoretical model employed in the OUTPUT code. In general, the constraints stated with the equations limit the applicability of the model to low-temperature devices, with one-dimensional (plane or spherical) symmetry.

RADIATION EQUATIONS

The derivation of the transport equation for the intensity $I(\nu, \vec{\Omega}, r, t)$, i.e., the radiant energy per unit frequency ν, per unit solid angle $d\Omega$, about the direction (unit vector) $\vec{\Omega}$ per unit time dt, per unit area, including the effects of Compton scattering, is presented in reference 4. A summary of this derivation is presented below.

The contributions to the rate of change of the intensity, or to $1/c\,(\partial I/\partial t) + \vec{\Omega} \cdot \nabla I$, are assumed to be absorption, emission, and the scattering of photons by free electrons. The absorption coefficient includes all significant processes by which photons are absorbed subject to the local-thermodynamic-equilibrium (LTE) assumption. The scattering coefficient and the differential cross section for scattering are determined from the Klein-Nishina formula (Ref. 5). A series of further approximations are required to complete the hypothesis. They are:

1. The electron states before and after scattering are nondegenerate.
2. Doppler effects can be ignored.
3. Polarization is unimportant.
4. $h\nu/m_o c^2 \leq 0.2$, $m_o c^2$ = rest energy of an electron.
5. Stimulated scattering is negligible.

6. Retardation effects are omitted.

7. The spectrum is a smooth function of ν.

With these assumptions, the following transport equation in plane geometry is obtained for the quantity $I(\mu) \equiv \frac{2\pi}{c} I(\vec{\Omega})$:

$$\mu \frac{dI}{dx} = \mu_a' (B_\nu - I) + S \tag{1}$$

where $\mu = \vec{\Omega} \cdot \hat{x}$ is the normal direction cosine;

$$\mu_a' = \mu_a (1 - e^{-h\nu/\theta}) \tag{2}$$

is the linear absorption coefficient corrected for induced emission;

$$B_\nu = \frac{4\pi h\nu^3}{c^3} (e^{h\nu/\theta} - 1)^{-1} \tag{3}$$

is the Planck distribution function for radiation from a blackbody at temperature θ eV, multiplied by $\frac{2\pi}{c}$;

$$S = -\mu_s \Bigg[I - \frac{3}{16} \int_{-1}^{1} d\mu' I(\mu')[3 - \mu^2 + (3\mu^2 - 1)(\mu')^2]$$
$$+ \gamma \Bigg\{ -2I + \frac{3}{16} \int_{-1}^{1} d\mu' \left(I(\mu') - \gamma \frac{dI(\mu')}{d\gamma} \right) [3 - \mu^2 + \mu'\mu(3\mu^2 - 5)$$
$$+ (3\mu^2 - 1)(\mu')^2 + \mu(3 - 5\mu^2)(\mu')^3] \Bigg\} \Bigg] + 0(\gamma^2) \tag{4}$$

where

$$\mu_s = \frac{8}{3} \pi r_o^2 N_e \tag{5}$$

is the Thomson scattering coefficient valid for $h\nu \ll m_o c^2$, in which $r_o = e^2/(m_o c^2)$ is the classical electron radius and N_e is the number of electrons per cm^3; and

$$\gamma = \frac{h\nu}{m_o c^2} \tag{6}$$

Examination of the form of the scattering source term reveals that the low-energy limit, i.e., $\gamma \to 0$, gives the Thomson scattering law. To determine the material heating due to Compton scattering, it is necessary to integrate over all solid angles and over the entire frequency range. The result, with sign reversed, is

$$-\nabla \cdot \vec{F} = -c \int_0^\infty \mu_a' (2B_\nu - E_\nu)\, d\nu + \mu_s \frac{hc}{m_o c^2} \int_0^\infty \nu E_\nu \, d\nu \tag{7}$$

where

$$\vec{F} = \int_0^\infty d\nu \int_{4\pi} I(\nu, \vec{\Omega})\vec{\Omega}\, d\Omega$$

is the total flux and

$$E_\nu = \frac{1}{c} \int_{4\pi} I(\nu, \vec{\Omega})\, d\Omega$$

is the radiant energy density spectrum. The first term on the right is the usual heating term due to absorption or emission, whereas the second term is the heating rate due to Compton scattering.

NUMERICAL INTEGRATION OF THE TRANSPORT EQUATION

The development of a scheme to integrate the transport equation along a ray requires that several numerical approximations be made. Rewrite the source term S by rearranging and by employing the notation

$$I_n = \int_{-1}^{1} I(\mu)(\mu)^n \, d\mu \tag{8}$$

Thus, I_o, I_1, and I_2 are proportional to the radiation energy density, the flux, and the radiation pressure, respectively. Now,

$$S = -\mu_s \Big\{ I(1 - 2\gamma) - \frac{3}{16} [(3 - \mu^2) I_o + (3\mu^2 - 1) I_2]$$

$$+ \frac{3}{16} \gamma [(3 - \mu^2) I_o + \mu(3\mu^2 - 5) I_1 + (3\mu^2 - 1) I_2 + \mu(3 - 5\mu^2) I_3]$$

$$- \frac{3}{16} \gamma^2 \frac{\partial}{\partial \gamma} [(3 - \mu^2) I_o + \mu(3\mu^2 - 5) I_1 + (3\mu^2 - 1) I_2 + \mu(3 - 5\mu^2) I_3] \Big\} \tag{9}$$

It is convenient to expand the last term as follows:

$$\gamma^2 \frac{\partial f(\gamma)}{\partial \gamma} = \frac{\partial [\gamma^2 f(\gamma)]}{\partial \gamma} - 2\gamma f(\gamma) \tag{10}$$

Using this substitution, one finds

$$S = -\mu_s \Big\{ I(1 - 2\gamma) - \frac{3}{16} [(3 - \mu^2) I_o + (3\mu^2 - 1) I_2]$$

$$+ \frac{9}{16} \gamma [(3 - \mu^2) I_o + \mu(3\mu^2 - 5) I_1 + (3\mu^2 - 1) I_2 + \mu(3 - 5\mu^2) I_3]$$

$$- \frac{3}{16} \frac{\partial \gamma^2}{\partial \gamma} [(3 - \mu^2) I_o + \mu(3\mu^2 - 5) I_1 + (3\mu^2 - 1) I_2 + \mu(3 - 5\mu^2) I_3] \Big\} \tag{11}$$

In Eq. (1), the intensity $I(\mu, \nu)$ is the monochromatic intensity. In most computer codes employing radiation transport, the quantity being calculated is the integral of the intensity over some frequency band (ν_j, ν_{j+1}), for which one finds

$$\mu \frac{dI_j}{dx} = \mu_{a_j} (B_j - I_j) + S_j \tag{12}$$

where

$$S_j = \int_{\nu_j}^{\nu_{j+1}} S(\nu)\, d\nu \tag{13}$$

$$I_j = \int_{\nu_j}^{\nu_{j+1}} I(\nu)\, d\nu \tag{14}$$

The notation I_j must not be confused with I_n as previously defined. However, the distinction between symbols is fairly clear. Note that single subscripts denote intensities and double subscripts represent moment quantities. Continuing, one finds

$$S_j = -\mu_s \Big\{ I_j(1 - 2\overline{\gamma}_j) - \frac{3}{16}\left[(3 - \mu^2) I_{o_j} + (3\mu^2 - 1) I_{2_j}\right]$$

$$+ \frac{9}{16}\overline{\gamma}_j \left[(3 - \mu^2) I_{o_j} + \mu(3\mu^2 - 5) I_{1_j} + (3\mu^2 - 1) I_{2_j} + \mu(3 - 5\mu^2) I_{3_j}\right]$$

$$- \frac{3}{16}\frac{h}{m_o c^2}\nu_{j+1}^2 \left[(3 - \mu^2) I_o(\nu_{j+1}) + \mu(3\mu^2 - 5) I_1(\nu_{j+1})\right.$$

$$\left. + (3\mu^2 - 1) I_2(\nu_{j+1}) + \mu(3 - 5\mu^2) I_3(\nu_{j+1})\right]$$

$$+ \frac{3}{16}\frac{h}{m_o c^2}\nu_j^2 \left[(3 - \mu^2) I_o(\nu_j) + \mu(3\mu^2 - 5) I_1(\nu_j) + \mu(3 - 5\mu^2) I_3(\nu_j)\right.$$

$$\left. + (3\mu^2 - 1) I_2(\nu_j)\right]\Big\} \tag{15}$$

where the assumption has been made that $\overline{\gamma}_j = (1/2)(\gamma_j + \gamma_{j+1})$ and

$$I_{x_j} = \int_{\nu_j}^{\nu_{j+1}} I_x(\nu)\, d\nu \tag{16}$$

Moreover,

$$\overline{\gamma}_j I_{x_j} = \int_{\nu_j}^{\nu_{j+1}} \gamma I_x(\nu)\, d\nu \tag{17}$$

One should note that in Eq. (15) the quantities $I_o(\nu_j)$, $I_1(\nu_j)$, etc., are the moment quantities evaluated at the boundaries of the frequency group of interest, i.e., ν_j and ν_{j+1}. At this point, an approximation must be made relating the boundary quantities and the frequency average quantities. If

the spectrum is flat over the various frequency groups, then

$$I_{x_j} \cong I_x(\nu_j)(\nu_{j+1} - \nu_j) \tag{18}$$

Thus,

$$\begin{aligned} S_j = -\mu_s \Big\{ & I_j(1 - 2\bar{\gamma}_j) - \frac{3}{16}\left[(3 - \mu^2) I_{o_j} + (3\mu^2 - 1) I_{2_j}\right] \\ & + \frac{9}{16}\bar{\gamma}_j\left[(3 - \mu^2) I_{o_j} + \mu(3\mu^2 - 5) I_{1_j} + (3\mu^2 - 1) I_{2_j} + \mu(3 - 5\mu^2) I_{3_j}\right] \\ & - \frac{3}{16}\frac{h}{m_o c^2}\frac{\nu_{j+1}^2}{(\nu_{j+2} - \nu_{j+1})}\left[(3 - \mu^2) I_{o_{j+1}} + \mu(3\mu^2 - 5) I_{1_{j+1}} + (3\mu^2 - 1) I_{2_{j+1}}\right. \\ & \qquad \left. + \mu(3 - 5\mu^2) I_{3_{j+1}}\right] \\ & + \frac{3}{16}\frac{h}{m_o c^2}\frac{\nu_j^2}{\nu_{j+1} - \nu_j}\left[(3 - \mu^2) I_{o_j} + \mu(3\mu^2 - 5) I_{1_j} + (3\mu^2 - 1) I_{2_j}\right. \\ & \qquad \left. + \mu(3 - 5\mu^2) I_{3_j}\right] \Big\} \end{aligned} \tag{19}$$

Reorganizing the source term with $\Delta\nu_j = \nu_{j+1} - \nu_j$, one obtains

$$\begin{aligned} S_j = -\mu_s \Big\{ & I_j(1 - 2\bar{\gamma}_j) - \frac{3}{16} A_2\left[(3 - \mu^2) I_{o_j} + (3\mu^2 - 1) I_{2_j}\right] \\ & + \frac{3}{16} A_1 \mu\left[(3\mu^2 - 5) I_{1_j} + (3 - 5\mu^2) I_{3_j}\right] \\ & - \frac{3}{16} A_3\left[(3 - \mu^2) I_{o_{j+1}} + (3\mu^2 - 1) I_{2_{j+1}}\right] \\ & - \frac{3}{16} A_3 \mu\left[(3\mu^2 - 5) I_{1_{j+1}} + (3 - 5\mu^2) I_{3_{j+1}}\right] \Big\} \end{aligned} \tag{20}$$

where

$$A_1 = 3\overline{\gamma}_j + \frac{h}{m_o c^2} \frac{\nu_j^2}{\Delta\nu_j} \tag{21}$$

$$A_2 = 1 - A_1, \tag{22}$$

$$A_3 = \frac{h}{m_o c^2} \frac{\nu_{j+1}^2}{\Delta\nu_{j+1}} \tag{23}$$

At this point, the integration of the transport equation can be performed as follows:

$$\mu \frac{dI_j}{dx} = \mu_{a_j} (B_j - I_j) - \mu_s I_j (1 - 2\overline{\gamma}_j) + \mu_s \{ \ \} \tag{24}$$

where

$$\{ \ \} = \frac{S_j}{\mu_s} + I_j (1 - 2\overline{\gamma}_j) \tag{25}$$

Using

$$e^{(x/\mu) [\mu_{a_j} + \mu_s (1 - 2\overline{\gamma}_j)]} \tag{26}$$

as an integrating factor, one finds

$$I_j(x_2) = I_j(x_1) e^{-\alpha_j(x_2 - x_1)} + \frac{\mu_{a_j}}{\mu} \int_{x_1}^{x_2} B_j(x') e^{-\alpha_j(x_2 - x')} dx'$$

$$+ \frac{\mu_s}{\mu} \int_{x_1}^{x_2} \{ \ \} e^{-\alpha_j(x_2 - x')} dx' \tag{27}$$

where

$$\alpha_j = \frac{1}{\mu} [\mu_{a_j} + \mu_s (1 - 2\overline{\gamma}_j)] \tag{28}$$

The first two terms on the right-hand side have already been evaluated in radiation-transport routines currently employed by SPUTTER (Ref. 2). Here, the integral in the third term will be evaluated. The term in braces [Eq. (25)] contains such terms as I_{o_j}, $I_{o_{j+1}}$, etc. At this point, some approximation must be made concerning the spatial dependence of these quantities. Following the assumption used in developing the Thomson scattering code, assume that all functions vary linearly in geometric space. Performing the required integration, one then finds

$$\frac{\mu_s}{\mu}\int_{x_1}^{x_2}\{\ \}\, e^{-\alpha_j(x_2-x')}\,dx'$$

$$= \frac{\mu_s}{\mu}\,\frac{3}{16}\,A_2\left[\left(\frac{1-e^{-\alpha_j\Delta}}{\alpha_j}\right)A + B\left(\frac{x_2 - x_1 e^{-\alpha_j\Delta}}{\alpha_j} - \frac{1-e^{-\alpha_j\Delta}}{\alpha_j^2}\right)\right]$$

$$- \frac{\mu_s}{\mu}\,\frac{3}{16}\,\mu A_1\left[\left(\frac{1-e^{-\alpha_j\Delta}}{\alpha_j}\right)C + D\left(\frac{x_2 - x_1 e^{-\alpha_j\Delta}}{\alpha_j} - \frac{1-e^{-\alpha_j\Delta}}{\alpha_j^2}\right)\right]$$

$$+ \frac{\mu_s}{\mu}\,\frac{3}{16}\,A_3\left[\left(\frac{1-e^{-\alpha_j\Delta}}{\alpha_j}\right)E + F\left(\frac{x_2 - x_1 e^{-\alpha_j\Delta}}{\alpha_j} - \frac{1-e^{-\alpha_j\Delta}}{\alpha_j^2}\right)\right]$$

$$+ \frac{\mu_s}{\mu}\,\frac{3}{16}\,A_3\mu\left[\left(\frac{1-e^{-\alpha_j\Delta}}{\alpha_j}\right)G + H\left(\frac{x_2 - x_1 e^{-\alpha_j\Delta}}{\alpha_j} - \frac{1-e^{-\alpha_j\Delta}}{\alpha_j^2}\right)\right] \quad (29)$$

where $\Delta = \Delta x = x_2 - x_1$

$$A = \frac{1}{\Delta x}\{x_2(FI0(J,x_1) + \mu^2 FI2(J,x_1)) - x_1(FI0(J,x_2) + \mu^2 FI2(J,x_2))\}$$

$$B = \frac{1}{\Delta x}\{FI0(J,x_2) - FI0(J,x_1) + \mu^2(FI2(J,x_2) - FI2(J,x_1))\}$$

$$C = \frac{1}{\Delta x} \{x_2 FI3(J, x_1) - x_1 FI3(J, x_2) + \mu^2 (x_2 FI1(J, x_1) - x_1 FI1(J, x_2))\}$$

$$D = \frac{1}{\Delta x} \{FI3(J, x_2) - FI3(J, x_1) + \mu^2 (FI1(J, x_2) - FI1(J, x_1))\}$$

$$E = \frac{1}{\Delta x} \{x_2 (FI0(J + 1, x_1) + \mu^2 FI2(J + 1, x_1)) - x_1 (FI0(J + 1, x_2)$$

$$+ \mu^2 FI2(J + 1, x_2))\}$$

$$F = \frac{1}{\Delta x} \{FI0(J + 1, x_2) - FI0(J + 1, x_1) + \mu^2 (FI2(J + 1, x_2) - FI2(J + 1, x_1))\}$$

$$G = \frac{1}{\Delta x} \{x_2 FI3(J + 1, x_1) - x_1 FI3(J + 1, x_2) + \mu^2 (x_2 FI1(J + 1, x_1)$$

$$- x_1 FI1(J + 1, x_2))\}$$

$$H = \frac{1}{\Delta x} \{FI3(J + 1, x_2) - FI3(J + 1, x_1) + \mu^2 (FI1(J + 1, x_2) - FI1(J + 1, x_1))\} \tag{30}$$

with $FI0(J, x_i) = 3I_{o_j}(x_i) - I_{2_j}(x_i)$

$$FI2(J, x_i) = 3I_{2_j}(x_i) - I_{o_j}(x_i)$$

$$FI3(J, x_i) = 3I_{3_j}(x_i) - 5I_{1_j}(x_i)$$

$$FI1(J, x_i) = 3I_{1_j}(x_i) - 5I_{3_j}(x_i)$$

$$A_1 = 3\overline{\gamma}_j + \frac{h}{m_o c^2} \frac{\nu_j^2}{\Delta \nu_j}$$

$$A_2 = 1 - A_1 \tag{31}$$

$$A_3 = \frac{h}{m_o c^2} \frac{\nu_{j+1}^2}{\Delta \nu_{j+1}}$$

Computationally, the solution to the integral will be inaccurate due to figure loss when $\alpha_j \Delta < 0.01$. Under this condition, one finds the following solution:

$$\frac{\mu_s}{\mu} \int_{x_1}^{x_2} \{\ \} e^{-\alpha_j (x_2 - x')} dx'$$

$$= \frac{\mu_s}{\mu} \frac{3}{16} A_2 \Delta \left[(FI0(J, x_1) + \mu^2 FI2(J, x_1)) \left(1 - \frac{1}{2} \alpha_j \Delta\right) + \frac{\Delta}{2} B \right]$$

$$- \frac{\mu_s}{\mu} \Delta \frac{3}{16} \mu A_1 \left[\left(1 - \frac{1}{2} \alpha_j \Delta\right) (FI3(J, x_1) + \mu^2 FI1(J, x_1)) + \frac{\Delta}{2} D \right]$$

$$+ \frac{\mu_s}{\mu} \Delta \frac{3}{16} A_3 \left[\left(1 - \frac{1}{2} \alpha_j \Delta\right) (FI0(J + 1, x_1) + \mu^2 FI2(J + 1, x_1)) + \frac{\Delta}{2} F \right]$$

$$+ \frac{\mu_s}{\mu} \Delta \frac{3}{16} \mu A_3 \left[\left(1 - \frac{1}{2} \alpha_j \Delta\right) (FI3(J + 1, x_1) + \mu^2 FI1(J + 1, x_1)) + \frac{\Delta}{2} H \right] \quad (32)$$

DISCUSSION OF THE NUMERICAL APPROXIMATIONS

In Eq. (7), the material heating rate for Compton scattering was derived. It will now be shown that numerically the heating rate calculated will be consistent with the analytical result. Integrating Eq. (24) over μ, one finds

$$\frac{1}{c} \nabla \cdot F_j = \mu_{a_j} (2B_j - E_j) - \mu_s E_j (1 - 2\overline{\gamma}_j) + \mu_s E_j \left(1 - 3\overline{\gamma}_j - \frac{h}{m_o c^2} \frac{\nu_j^2}{\Delta \nu_j}\right)$$

$$+ \mu_s \frac{h}{m_o c^2} \frac{\nu_{j+1}^2}{\Delta \nu_{j+1}} E_{j+1} \quad (33)$$

Summing on j, one obtains

$$\frac{1}{c}\nabla\cdot F = \sum_{j=1}^{N}\mu_{a_j}(2B_j - E_j) - \mu_s\sum_{j=1}^{N}\overline{\gamma}_j E_j - \mu_s\frac{h}{m_o c^2}\sum_{j=1}^{N}\left(E_j\frac{\nu_j^2}{\Delta\nu_j} - E_{j+1}\frac{\nu_{j+1}^2}{\Delta\nu_{j+1}}\right) \tag{34}$$

For the third term on the right-hand side, note that

$$\sum\left(E_j\frac{\nu_j^2}{\Delta\nu_j} - E_{j+1}\frac{\nu_{j+1}^2}{\Delta\nu_{j+1}}\right) = E_1\frac{\nu_1^2}{\Delta\nu_1} - E_{N+1}\frac{\nu_{jN+1}^2}{\Delta\nu_{N+1}} \tag{35}$$

Now, by definition, $\nu_1 = 0$ and $E_{N+1} = 0$. Thus, the calculated heating rate due to Compton scattering is

$$\mu_s c\sum_{j=1}^{N}\overline{\gamma}_j E_j \tag{36}$$

Comparing this with the analytical result, i.e.,

$$\mu_s\frac{hc}{m_o c^2}\int_o^\infty \nu E_\nu\, d\nu \tag{37}$$

one notes that the above sum is consistent with assuming a flat spectrum over the various groups. Moreover, in the limit as the number of groups increases, the sum approaches the analytical result.

A computational difficulty encountered with the present formulation is that the intensity $I_j(\mu)$ depends on the solid-angle moments of the intensity I_{o_j}, I_{1_j}, etc. However, if these quantities were known, the evaluation of the intensity would be superfluous, since one is usually concerned with finding heating rates. The solution to the transport equation gives the intensity $I_j^{n+1}(\mu)$ at time n + 1 in terms of the moment quantities at time n. The assumption made is that the moment quantities at time n are close to those at time n + 1. Computationally, there are two equivalent ways to achieve this result. The first way, and the least desirable, is to run the

calculation with very small time increments. Now, even if the moment quantities are rapidly changing, the errors involved are proportional to the time step. After a number of cycles in which the solution is constant, the moment quantities will also converge. A second way to guarantee that the moment quantities are consistent with the transport equation is to iterate on these quantities. A test can be made to see if the values at time n + 1 are different from those at time n. If differences are detected, the complete transport calculations can be rerun using the new, updated, moment quantities. This scheme is presently employed in the Thomson and Compton scattering subroutines. To calculate the number of iterations required for convergence, consider the following model for the case of Thomson scattering, i.e., $\gamma \to 0$. For this case, the transport equation becomes

$$\mu \frac{dI^{n+1}}{dx} = \mu_a' (B - I^{n+1}) - \mu_s I^{n+1} + \frac{3}{16} \mu_s [(3 - \mu^2) I_o^n + (3\mu^2 - 1) I_2^n] \quad (38)$$

If spatial homogeneity is assumed, then

$$I^{n+1}(\mu) = \frac{\mu_a}{\bar{\mu}} B + \frac{3}{16} \frac{\mu_s}{\bar{\mu}} [(3 - \mu^2) I_o^n + (3\mu^2 - 1) I_2^n] \quad (39)$$

where $\bar{\mu} = \mu_a + \mu_s$.

To find I_o^{n+1} and I_2^{n+1}, integrate over $d\mu$. Thus,

$$I_o^{n+1} = \frac{2\mu_a}{\bar{\mu}} B + \frac{\mu_s}{\bar{\mu}} I_o^n \quad (40)$$

and

$$I_2^{n+1} = \frac{2}{3} \frac{\mu_a}{\bar{\mu}} B + \frac{3}{10} \frac{\mu_s}{\bar{\mu}} I_o^n + \frac{1}{10} \frac{\mu_s}{\bar{\mu}} I_2^n \quad (41)$$

Solving these recursion equations, one finds that

$$I_o^n = 2B \left[1 - \left(\frac{\mu_s}{\bar{\mu}} \right)^n \right] \quad (42)$$

and

$$I_2^n = \frac{2B}{3}\left[1 - \left(\frac{\mu_s}{\bar{\mu}}\right)^n - \left(\frac{\mu_s}{10\,\bar{\mu}}\right)^2\right] \tag{43}$$

From the form of these equations, one can conclude that the convergence rate is controlled by the ratio $\mu_s/\mu_a + \mu_s$. Thus, in the interesting situation in which scattering is the dominant mechanism, the number of iterations required to achieve a given accuracy increases as the amount of absorption decreases. This fact should be kept in mind when employing the scattering code in regions with dominant scattering.

For the case of Compton scattering, consider the homogeneous transport equation, or

$$\begin{aligned} 0 = {} & \mu_a (B - I^{n+1}) - \mu_s I^{n+1}(1 - 2\gamma) + \frac{3}{16}\mu_s\left[(3 - \mu^2) I_o^n + (3\mu^2 - 1) I_2^n\right] \\ & - \frac{9}{16}\mu_s\gamma\left[(3 - \mu^2) I_o^n + \mu(3\mu^2 - 5) I_1^n + (3\mu^2 - 1) I_2^n + \mu(3 - 5\mu^2) I_3^n\right] \\ & + \frac{3}{16}\mu_s \frac{\partial}{\partial\gamma}\gamma^2\left[(3 - \mu^2) I_o^n + \mu(3\mu^2 - 5) I_1^n + (3\mu^2 - 1) I_2^n + \mu(3 - 5\mu^2) I_3^n\right] \end{aligned} \tag{44}$$

If one now integrates over $\int_{-1}^{1} d\mu$, one finds

$$\bar{\mu}\, I_o^{n+1} = 2\mu_a B + \mu_s (1 - 3\gamma) I_o^n + \mu_s \frac{\partial(\gamma^2 I_o^n)}{\partial\gamma} \tag{45}$$

where $\bar{\mu} = \mu_a + \mu_s(1 - 2\gamma)$.

Integrating over frequency, one finds

$$I_{o_j}^{n+1} = \frac{2\mu_{a_j}}{\bar{\mu}_j} B_j + \frac{\mu_s}{\bar{\mu}_j}(1 - 3\bar{\gamma}_j) I_{o_j}^n + \frac{\mu_s}{\bar{\mu}_j}\frac{h}{m_o c^2}\left[\frac{\nu_{j+1}^2}{\Delta\nu_{j+1}} I_{o_{j+1}}^n - \frac{\nu_j^2}{\Delta\nu_j} I_{o_j}^n\right] \tag{46}$$

where

$$\bar{\mu}_j = \mu_{a_j} + \mu_s(1 - 2\bar{\gamma}_j) \tag{47}$$

Since $I_{o_{k+1}} = 0$, the solution to the last equation is

$$I^n_{o_k} = B_k \frac{2\mu_{a_k}}{\left[\mu_{a_k} + \mu_s\left(\bar{\gamma}_k + \frac{h}{m_o c^2}\frac{\nu_k^2}{\Delta\nu_k}\right)\right]} \left\{1 - \left[\frac{\mu_s}{\bar{\mu}_k}\left(1 - 3\bar{\gamma}_k - \frac{h}{m_o c^2}\frac{\nu_k^2}{\Delta\nu_k}\right)\right]^n\right\} \tag{48}$$

The remaining equations can be solved in reverse order. What is significant is that the coefficient that determines the convergence is frequency-dependent, and, moreover, the higher the frequency, the faster the convergence, provided $\gamma < 0.2$.

Computationally, the iteration scheme has been developed for both the Thomson and Compton scattering subroutines. Presently, the options available for the iteration scheme are the number of iterations, an accuracy criterion to determine convergence, and an extrapolation switch allows one to use the rate of convergence to extrapolate to find the desired function.

SPHERICAL GEOMETRY

In spherical geometry, the transport equation (1) is replaced by

$$\frac{dI}{dx} = \mu_a' (B_\nu - I) + S \tag{49}$$

where x is now a coordinate measuring distance along a characteristic ray. In the treatment of the scattering terms, the only difference is that the μ's appearing in S(x) must be replaced by an average $\bar{\mu} = (\mu_1 + \mu_2)/2$, where μ_1 and μ_2 are the cosines of the angles of the characteristic ray with respect to the normal at x_1 and x_2, respectively.

EQUATIONS OF MOTION

The same independent coordinates are used in the OUTPUT code and SPUTTER code: mass m and time t. The Lagrangian mass

coordinate m is defined by

$$m = \int_0^r \alpha\, r'^{\alpha-1}\, \rho(r', t)\, dr' \tag{50}$$

where ρ is the density and

$$\alpha = \begin{cases} 1 & \text{plane} \\ 3 & \text{sphere} \end{cases}$$

This coordinate has the physical units of mass/cm^2 in plane geometry; whereas in spherical geometry, it is the mass interior to radius r divided by $4\pi/3$. If τ is the specific volume, the equation of continuity is given by

$$\frac{d\tau}{dt} = \tau\, r^{-(\alpha-1)} \frac{\partial}{\partial r}\left(r^{\alpha-1} \frac{dr}{dt}\right) \tag{51}$$

The momentum equation can be written as

$$\rho \frac{du}{dt} = \frac{\partial \sigma_{11}}{\partial r} + \frac{(\alpha - 1)}{2r}(2\sigma_{11} - \sigma_{22} - \sigma_{33}) \tag{52}$$

where $u = dr/dt$ and (σ_{ij}) is the symmetric stress tensor. The stress tensor is given by

$$\sigma_{ij} = -P_m\, \delta_{ij} - P_{ij} \tag{53}$$

where P_m is the material pressure including artificial viscosity, and P_{ij} is the radiation pressure tensor. In the case of plane geometry, $\alpha = 1$ and the equation becomes

$$\rho \frac{du}{dt} = -\frac{\partial(P_m + P_r)}{\partial r} \tag{54}$$

where P_r is the radiation pressure in the r direction.

This is the standard equation solved in the SPUTTER code. However, the SPUTTER program assumes that $P_r = (1/3)\, a\, \theta^4$, the equilibrium diffusion value. This assumption is not made in the OUTPUT program; instead, the

radiation pressure for a zone is computed as the second angular moment of the intensity. Since the intensity and its moments are computed on zone boundaries r_i, the radiation pressure in the zone $r_i \leq r < r_{i+1}$ is defined as the arithmetic mean

$$P_{r_{i+\frac{1}{2}}} = \frac{1}{2}(P_{r_i} + P_{r_{i+1}}) \tag{55}$$

In the case of spherical symmetry, one must evaluate σ_{22} and σ_{33}. The radiation pressure tensor is given by

$$(P) = \frac{1}{2\pi}\int_{4\pi} d\Omega\, \vec{\Omega}\vec{\Omega} I(\mu) \tag{56}$$

where μ is the cosine of the angle θ between the ray $\vec{\Omega}$ and the radius vector $\vec{r}$. If $\vec{r}$ is taken as a polar axis, an azimuthal angle ϕ can be introduced and $\vec{\Omega}$ can be expressed as a column vector

$$\vec{\Omega} = \begin{bmatrix} \Omega_1 \\ \Omega_2 \\ \Omega_3 \end{bmatrix} = \begin{bmatrix} \mu \\ \sqrt{1-\mu^2}\cos\phi \\ \sqrt{1-\mu^2}\sin\phi \end{bmatrix} \tag{57}$$

The dyadic $\vec{\Omega}\vec{\Omega}$ is then obtained by postmultiplying this column by its transpose, which gives

$$(P) = \frac{1}{2\pi}\int_{-1}^{1} d\mu \int_{0}^{2\pi} d\phi\, I(\mu) \begin{bmatrix} \mu^2 & \mu\sqrt{1-\mu^2}\cos\phi & \mu\sqrt{1-\mu^2}\sin\phi \\ \mu\sqrt{1-\mu^2}\cos\phi & (1-\mu^2)\cos^2\phi & (1-\mu^2)\cos\phi\sin\phi \\ \mu\sqrt{1-\mu^2}\sin\phi & (1-\mu^2)\sin\phi\cos\phi & (1-\mu^2)\sin^2\phi \end{bmatrix} \tag{58}$$

On evaluating the integrals, one obtains

$$P_{ij} = 0 \qquad i \neq j \tag{59}$$

$$P_{11} = \int_{-1}^{1} \mu^2 \, I(\mu) \, d\mu \tag{60}$$

$$P_{22} = P_{33} = \frac{1}{2} \int_{-1}^{1} (1 - \mu^2) \, I(\mu) \, d\mu \tag{61}$$

Since $P_{22} = P_{33} = 1/2 \, [E_r - P_{11}]$, where E_r is the radiation energy density,

$$E_r = \int_{-1}^{1} I \, d\mu \tag{62}$$

Eq. (52) for the spherical case is

$$\rho \frac{du}{dt} = - \frac{\partial (P_m + P_r)}{\partial r} - \frac{1}{r} (3P_r - E_r) \tag{63}$$

where $P_r = P_{11}$. The last term in Eq. (63) is in some cases a source of numerical noise, particularly at small radius r. Hence, a parameter S4 is employed in the code such that in the "diffusion" case, $P_r/E_r < S4$, a difference representation of Eq. (63) is used. However, in the "streaming" case, $P_r/E_r > S4$, one can rewrite Eq. (63) as

$$\rho \frac{\partial u}{\partial t} = - \frac{\partial P_m}{\partial r} - \frac{1}{r^2} \frac{\partial}{\partial r} (r^2 P_r) - \frac{1}{r} (P_r - E_r) \tag{64}$$

and a difference equation based on this form is used.

S4 should be assigned on the basis of the characteristics of the problem being solved; a typical value is 1/2.

ENERGY EQUATION

The equation for conservation of energy is given by

$$\frac{dE_m}{dt} + \tau \left[\frac{\partial E_r}{\partial t} + \nabla \cdot \vec{F} \right] = -(P_m + P_r) \, \dot{\tau} + \frac{(\alpha - 1)^{\tau}}{2r} (3P_r - E_r) \, u + \dot{e}_s \tag{65}$$

where E_m is the material specific internal energy, $\vec{F}$ is the flux of radiation,

and $\dot{e}_s$ is an external energy source rate per unit mass. The standard SPUTTER code takes the radiative heating rate per unit mass, $\dot{e}_r$, as

$$\dot{e}_r = -(\nabla \cdot \vec{F})\, \tau . \tag{66}$$

However, the OUTPUT code includes the radiative streaming contribution, and $\dot{e}_r$ is calculated in the spherical case as

$$\dot{e}_r = \left[-\nabla \cdot \vec{F} + \frac{1}{r} (3P_r - E_r)\, u \right] \tau . \tag{67}$$

The form $\tau(\partial E_r/\partial t)$ is combined with dE_m/dt, so that Eq. (65) is treated as an equation for the rate of change of total specific energy. The difference equations are then developed as in the standard SPUTTER code.

The energy source rates $\dot{e}_s$ are determined by the source routines QUE8, QUE9, QUE10. These source routines are described briefly in Appendix I.

After determining the change in total specific energy during a time interval due to $\dot{e}_r$, $\dot{e}_s$, and the radiative and material work terms as shown in Eq. (65), the material temperature is advanced by inverting the equation of state to find the temperature corresponding to the new values of E_m and τ.

In order to avoid excessive restriction of the time step during the early portion of a calculation, it has been found advisable to utilize the equilibrium diffusion approximation

$$E_r = a\, \theta^4$$

for the energy density of the radiation field in the energy conservation equation. This approximation is valid in the core, where most of the energy exchange between the field and the material occurs.

SECTION III

OUTPUT CODE PROGRAMMING

LOGIC OF THE CODE

The two basic independent variables in the OUTPUT code are mass and time. Each of these continuous variables is divided into discrete elements, the mass into an array of zones of variable size M_i and the time into a series of time steps Δt^n. The properties of the system are calculated for all zones at time t^{n+1}, from given values at time t^n. There are essentially two kinds of properties which define the system: kinematic properties, such as the positions R_i and velocities $\dot{R}_i$ of the zone boundaries; and thermodynamic properties, such as the specific volumes τ_i, the temperatures θ_i, the specific internal energies E_i, the material pressures P_i, and the specific heats at constant volume C_v. A specification of M_i, R_i, τ_i, and θ_i completely defines the system at any given time, assuming that local thermodynamic equilibrium prevails throughout the system. All kinematic quantities are functions of the first two variables, and all thermodynamic properties are functions of the last two. The heating rates in each zone--specifically, heating from an external source ($\dot{e}_{si}$) and heating by radiation transport within the system ($\dot{e}_{ri}$)--will generally depend on all four variables and the time.

The program is divided into two segments (MP1 and MP2) to reduce computer storage requirements. Segment MP1 sets up the initial conditions. The temperatures θ_i, masses G_i, velocities $\dot{R}_i$, and interface positions R_i for each zone are provided by card input. All other quantities necessary for complete problem specification are calculated within the MP1 segment. This segment is also utilized to redefine new zones during the course of a

calculation if, for reasons of economy or greater definition, a rezoning of the system is desired. MP1 performs the required peripheral operations, such as reading or changing dump tapes on restarts of a calculation.

Segment MP2 consists of two loops (see Fig. 1). The main loop represents one cycle, representing an advance in time, and the secondary loop represents a radiation subcycle. The division of the main loop into separate boxes corresponds to the way various phases of the calculation are parceled out to subroutines, called in turn by the main program (MP2). The labels next to the boxes are in some cases the names of the subroutines; in two cases, EOS and TEMPIT, they are names of "sub-subroutines" called by the subroutines. Unlabeled boxes signify computations (or logical decisions) made in the main program itself.

The cycle begins with a computation of the time increment $\Delta t^{n+1/2}$. The time increment is set equal to the minimum of (1) DTMAX1, DTMAX2, and DTMAX3, which are external time controls, (2) Courant stability conditions $\Delta t_c^{n+1/2}$, and (3) nine-tenths of the radiation time step $\Delta t_R^{n-1/2}$. The nine-tenths used for the radiation time calculation is introduced to prevent radiation subcycling due to small changes in Δt_R from one cycle to the next. DTR, the time increment used by those subroutines involved in the subcycling loop, is set to $\Delta t^{n+1/2}$. The hydrodynamics portion of the cycle is entered next, where the kinematic quantities are updated. The artificial viscosity term $P2_i$, which enters the calculation as a pressure to be added to the material pressure, acts as a shock-smoothing term, spreading the shock structure over three zones. The next two phases of the calculation compute the heat term ΔQ in the equation expressing the first law of thermodynamics, $\Delta Q = \Delta E + P\Delta V$. The heating rate due to an external source ($\dot{e}_{si}^{n+1/2}$) is calculated in one of several choices of sub-subroutines, depending on the nature of the source.

The heating rate due to radiation ($\dot{e}_{ri}^{n+1/2}$) is calculated in the RADTN section. The main subroutine of this section calls an auxiliary subroutine,

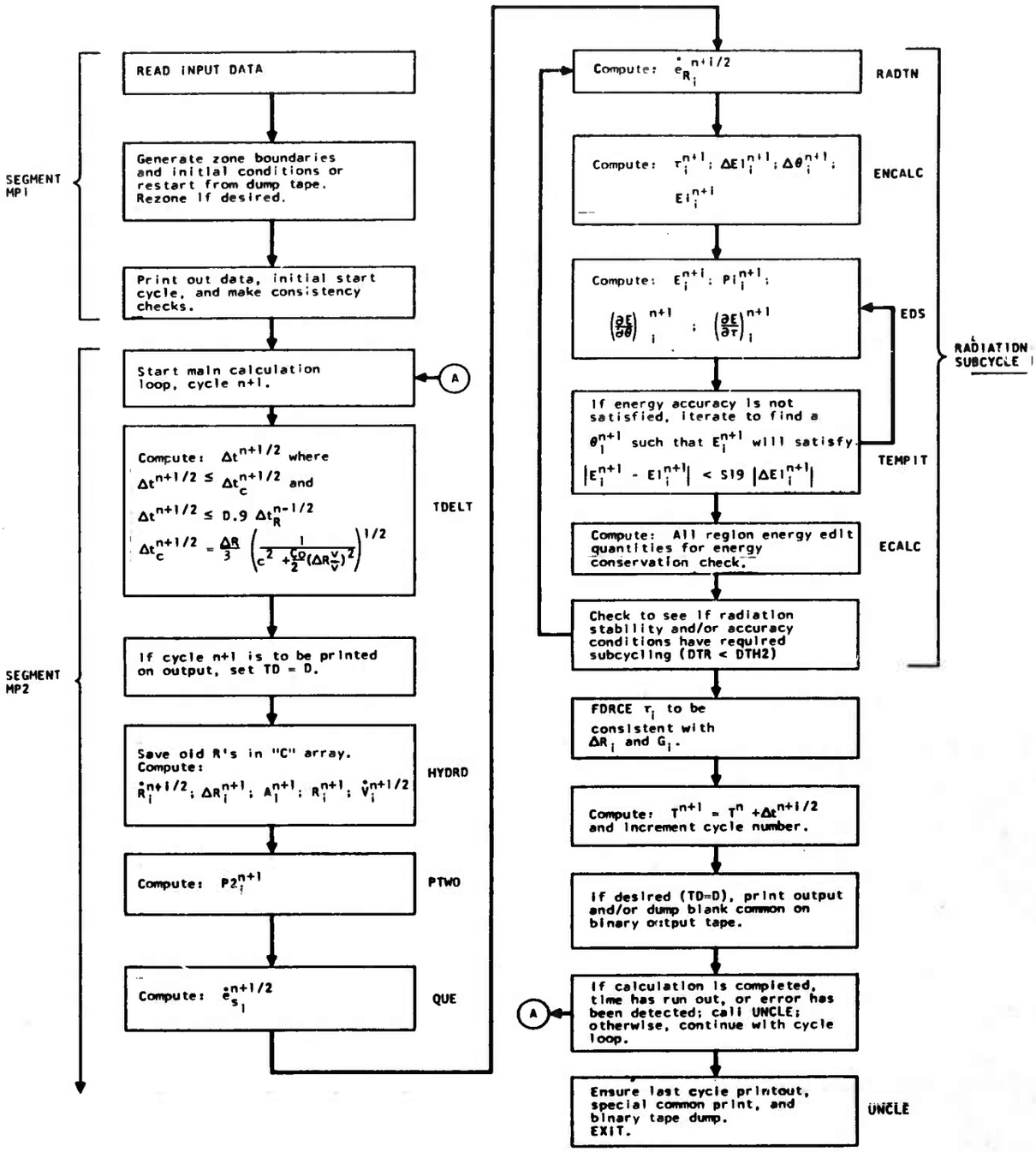


Figure 1. The OUTPUT code: Summary Flow Logic

KAPPA, for absorption coefficients. The calculation may be either frequency-independent (grey) or frequency-dependent. In the latter case, the absorption coefficients and radiation fluxes are computed in each of a desired set of frequency groups, and the fluxes are summed up to obtain the total flux at each boundary. Absorption coefficients in the grey case are Rosseland-averaged opacities and are computed from analytic fits to the numerical calculations of Stewart and Pyatt (Ref. 6). For multifrequency calculations, the program uses a table of group-averaged opacities, which are read from a data tape prepared by an auxiliary program.

ENCALC, where the next calculations are performed, gathers the heating rates, computes the work done by each zone from the pressure and the rate of volume change, and finds the increment of internal energy from the first-law equation. One then obtains the corresponding increment of temperature in each zone. After the temperature and specific volume are updated, the equation of state is used to find the internal energy E, the material pressure P1, and the two partial derivatives of E, $\partial E/\partial\theta$ and $\partial E/\partial\tau$. The difference between the first-law internal energy EI_i and the equation-of-state energy E_i is compared to the change in internal energy ΔEI_i as a check on the accuracy of the calculation. If the comparison shows they do not agree to within a certain specified value S19, the subroutine TEMPIT uses the regula-falsi and interval halving iteration methods to find a temperature for which the equation of state will return an acceptable E_i. At the conclusion of the energy checks in ENCALC, all quantities describing the system have been incremented from time t^n to t^{n+1}. The main program (MP2) checks the time step DTR to determine if the radiation subroutines have induced subcycling. If radiation stability requires subcycling, DTR will have been set such that $\Delta t^{n+1/2}$ is an even multiple of DTR. Subcycling continues until the sum of all subcycling time steps is equal to $\Delta t^{n+1/2}$.

The last act in the cycle is the updating of the time t^n to t^{n+1} and increasing of the cycle number by unity. After some decisions have been

made regarding whether to print the information for this cycle and/or to dump common on a binary dump tape for future restarts, control is passed to the beginning of the loop and a new cycle begins.

In table I, a brief definition of terms used in figure 1 is given and the variables used for storage in the code itself are specified.

FLOW CHART OF RADIATION

A flow chart of the radiation hierarchy is presented in figure 2 through 6. The figures that show the various subroutines are as follows:

RAD . . . . . Figure 2
STRANS . . . . . Figure 3
PTRANS . . . . . Figure 4
SCAT . . . . . Figure 5
STEP . . . . . Figure 6

OUTPUT CODE GLOSSARY

This section contains a complete list of the FORTRAN variables appearing in several subroutines of the OUTPUT code. For each variable, a brief definition or description is given. A number in parentheses superscript to a variable indicates that the variable has been defined in the list of another subroutine, as follows:

(1) SCAT
(2) STEP
(3) STRANS
(4) PTRANS
(5) RAD

Variables appear in alphabetical order within a subroutine list. The storage allocation--Blank Common, a name common, or private storage, which is used only within the subroutine--is also given.

TABLE I

DEFINITION OF TERMS USED IN FIGURE 1

OUTPUT		
Term	Code	Definition
$\Delta t^{n+1/2}$	= DTH2	= time increment for cycle loop
$\Delta t_c^{n+1/2}$	= RDIA	= maximum time step for Courant stability
$\Delta t_R^{n+1/2}$	= DTRMIN	= maximum time step for radiation stability for current cycle
$\Delta t_R^{n-1/2}$	= DTRMIN	= maximum time step for radiation stability for previous cycle
R_i^{n+1}	= R(i)	= zone boundary positions at time TH
$\dot{R}_i^{n+1/2}$	= RD(i)	= velocity of zone boundaries
ΔR_i^{n+1}	= DELTAR(i)	= R(i + 1) - R(i)
A_i^{n+1}	= A(i)	= area of zone ($\alpha r_i^{\alpha-1}$)
$\dot{V}_i^{n+1/2}$	= VD(i)	= rate of change of zone volumes
$P2_i^{n+1}$	= P2(i)	= artificial viscosity pressure
$\dot{e}_{si}^{n+1/2}$	= SMLQ(i)	= rate of energy deposition by source
$\dot{e}_{ri}^{n+1/2}$	= ER(i)	= rate of energy deposition by radiation
τ_i^{n+1}	= SV(i)	= specific volume of zone
ΔEI_i^{n+1}	= PB(i)	= first-law increment of energy change
$\Delta\theta_i^{n+1}$	= W(i)	= change in temperature during cycle
θ_i^{n+1}	= THETA(i)	= temperature of zone
EI_i^{n+1}	= EI(i)	= first-law internal energy
E_i^{n+1}	= E(i)	= equation-of-state internal energy
$P1_i^{n+1}$	= P1(i)	= equation-of-state material pressure
$(\partial E/\partial\theta)_i^{n+1}$	= CV(i)	= specific heat at constant volume
$(\partial E/\partial\tau)_i^{n+1}$	= PB1(i)	= self-explanatory
t	= TH	= time

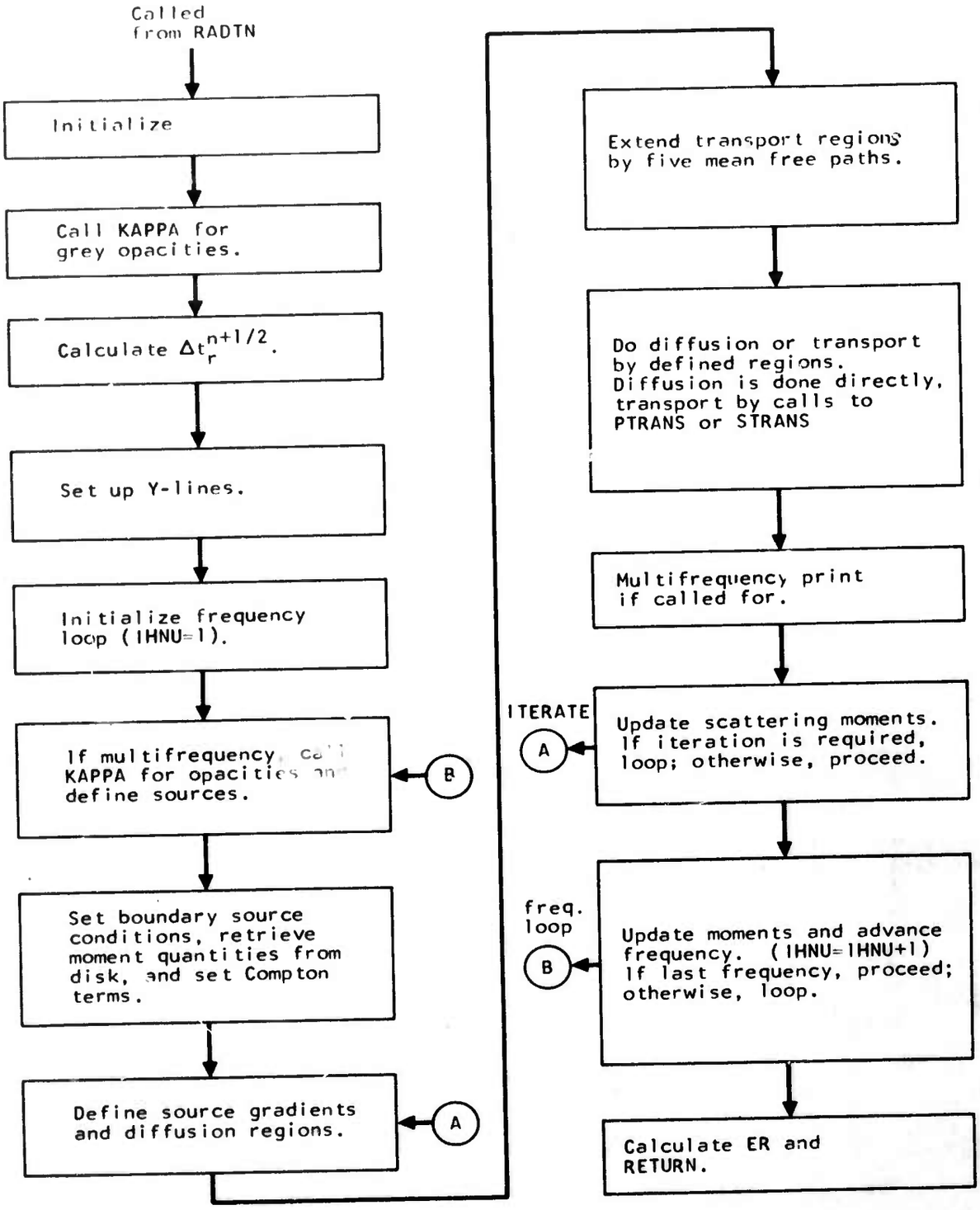

Called from RADTN
Initialize
Call KAPPA for grey opacities.
Calculate $\Delta t_r^{n+1/2}$.
Set up Y-lines.
Initialize frequency loop (IHNU=1).
If multifrequency, call KAPPA for opacities and define sources.
B
Set boundary source conditions, retrieve moment quantities from disk, and set Compton terms.
Define source gradients and diffusion regions.
A
Extend transport regions by five mean free paths.
Do diffusion or transport by defined regions. Diffusion is done directly, transport by calls to PTRANS or STRANS
Multifrequency print if called for.
ITERATE
A
Update scattering moments. If iteration is required, loop; otherwise, proceed.
freq. loop
B
Update moments and advance frequency. (IHNU=IHNU+1) If last frequency, proceed; otherwise, loop.
Calculate ER and RETURN.

Figure 2. RAD

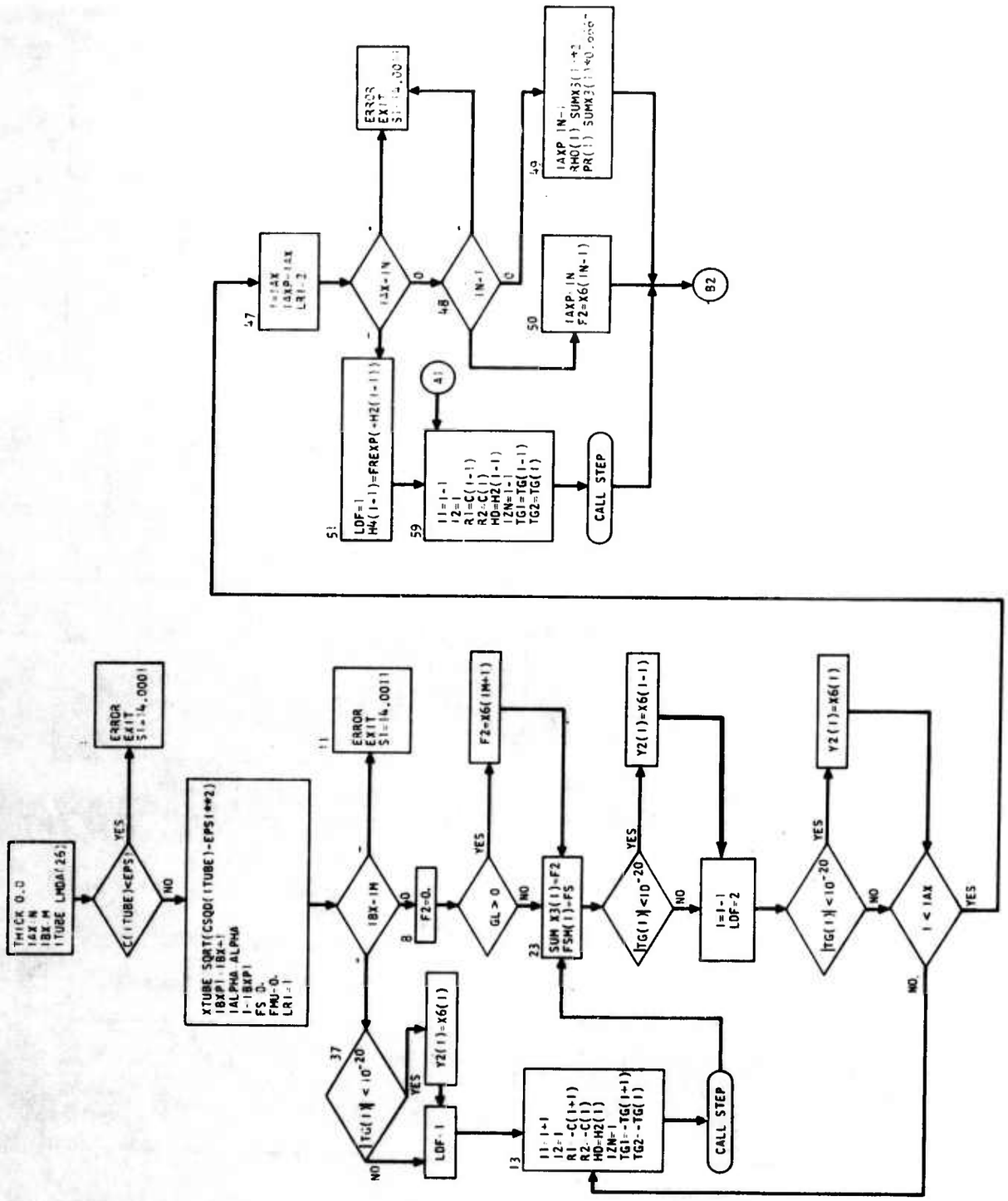


Figure 3. STRANS(N, M)

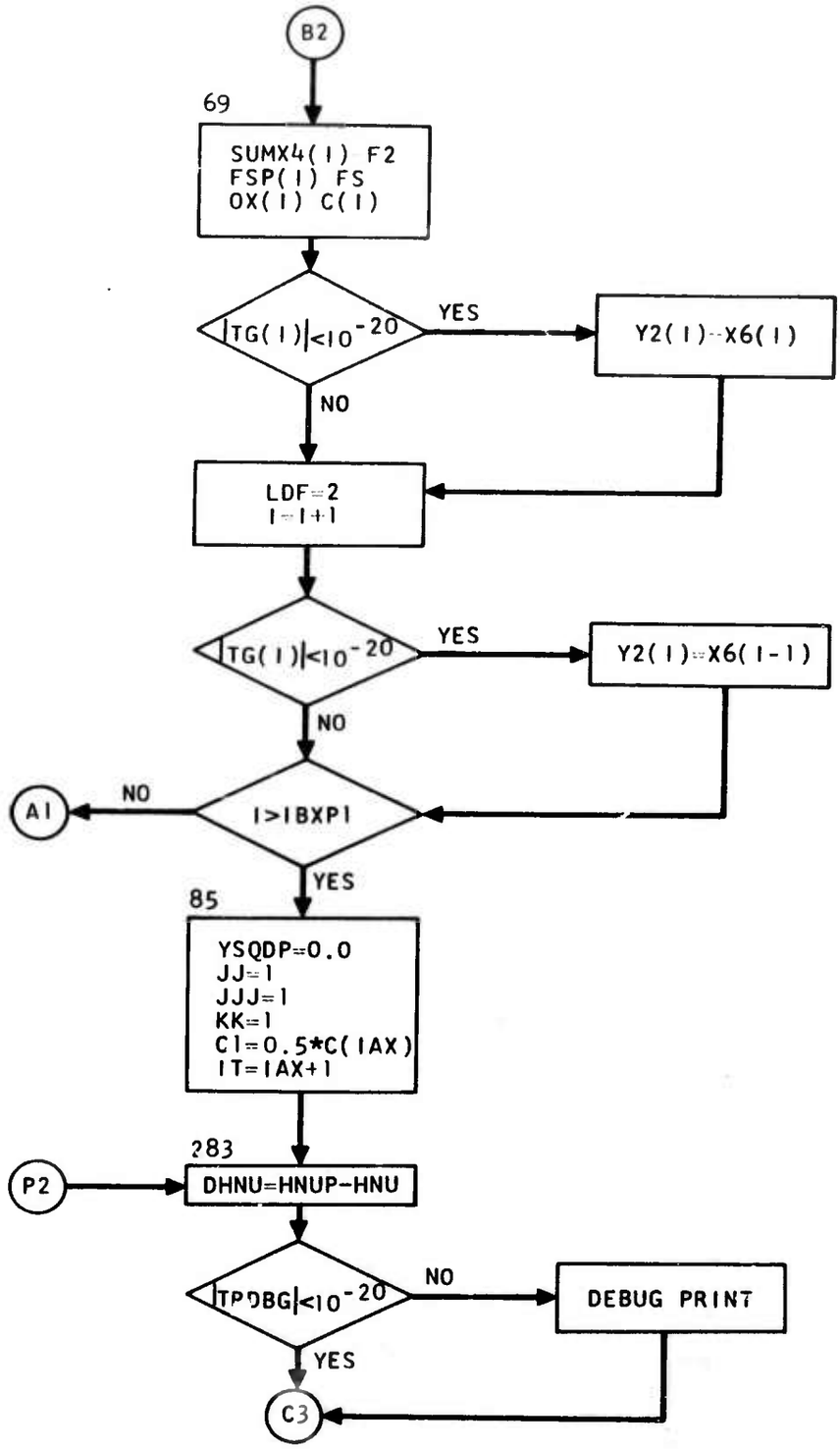


Figure 3 (continued). STRANS(N, M)

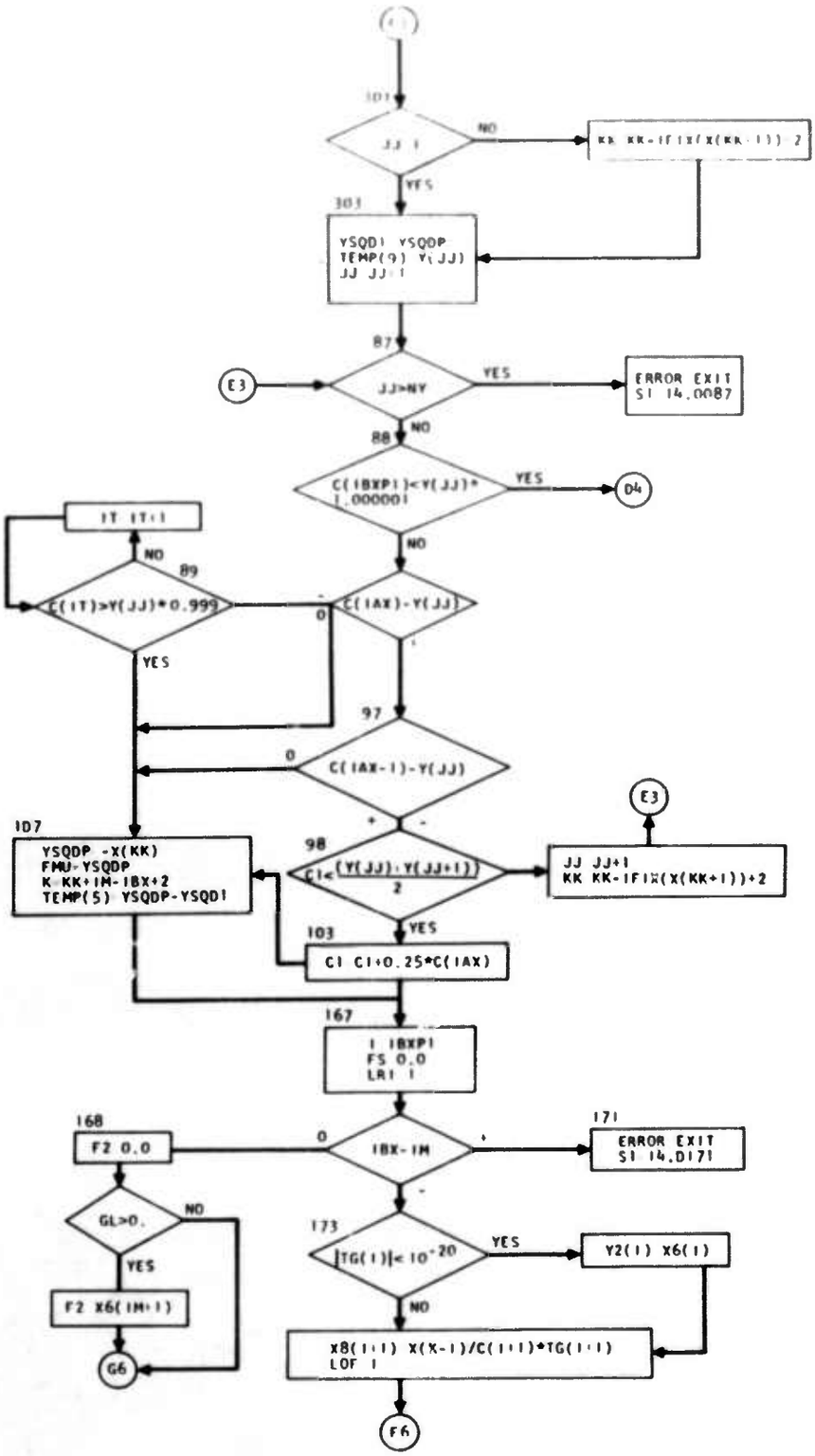


Figure 3 (continued). STRANS(N, M)

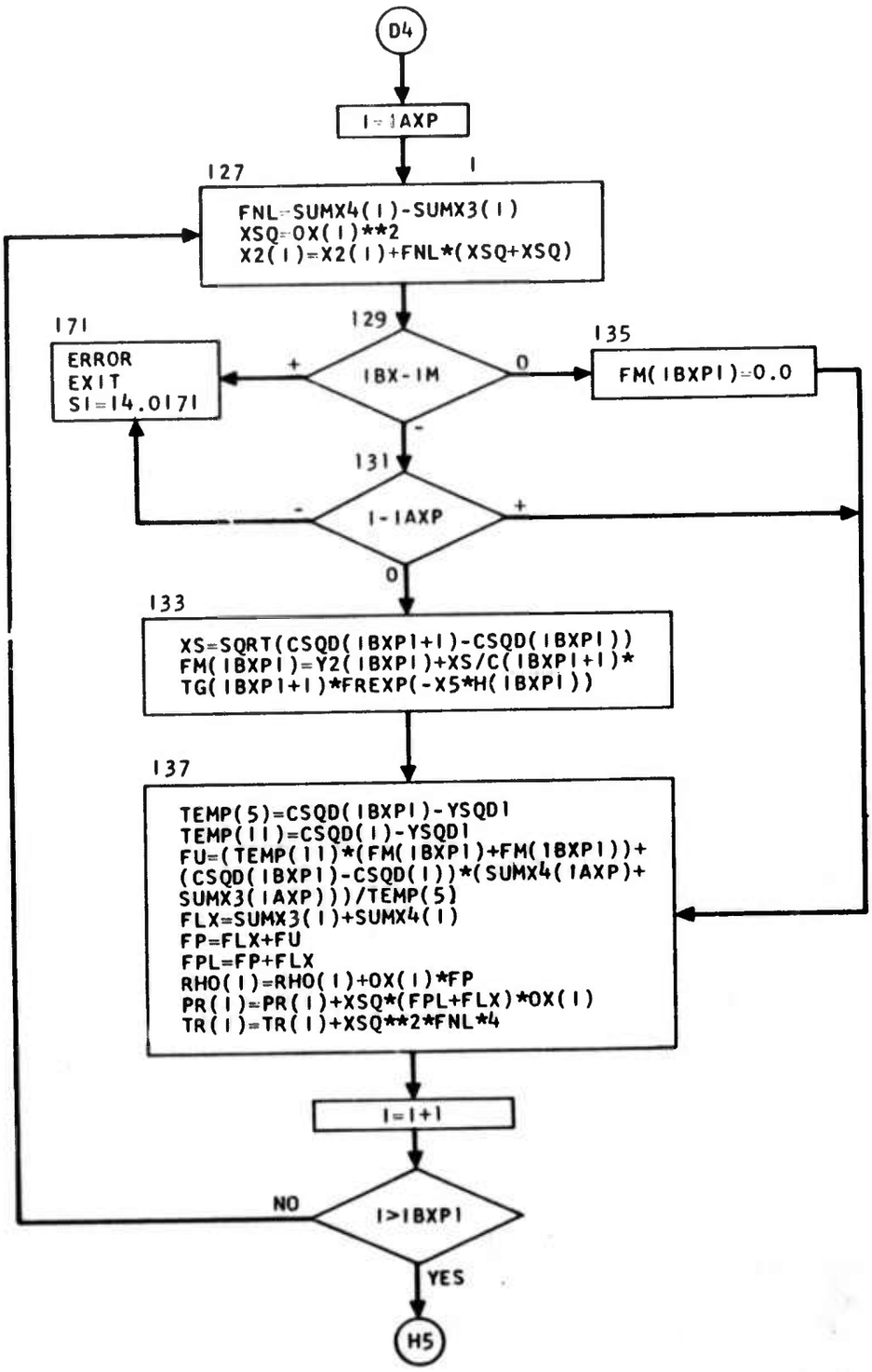


Figure 3 (continued). STRANS(N, M)

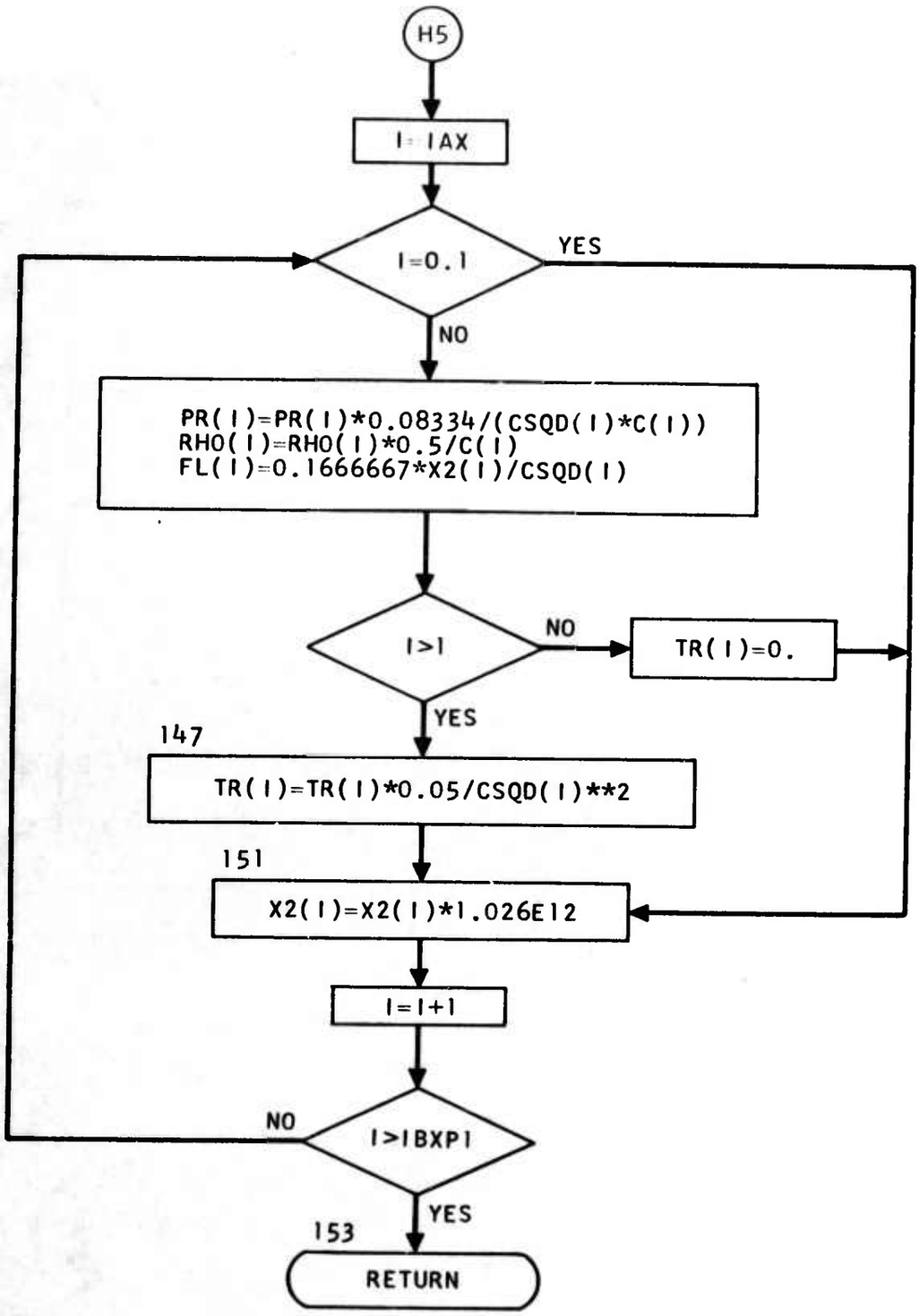


Figure 3 (continued). STRANS(N, M)

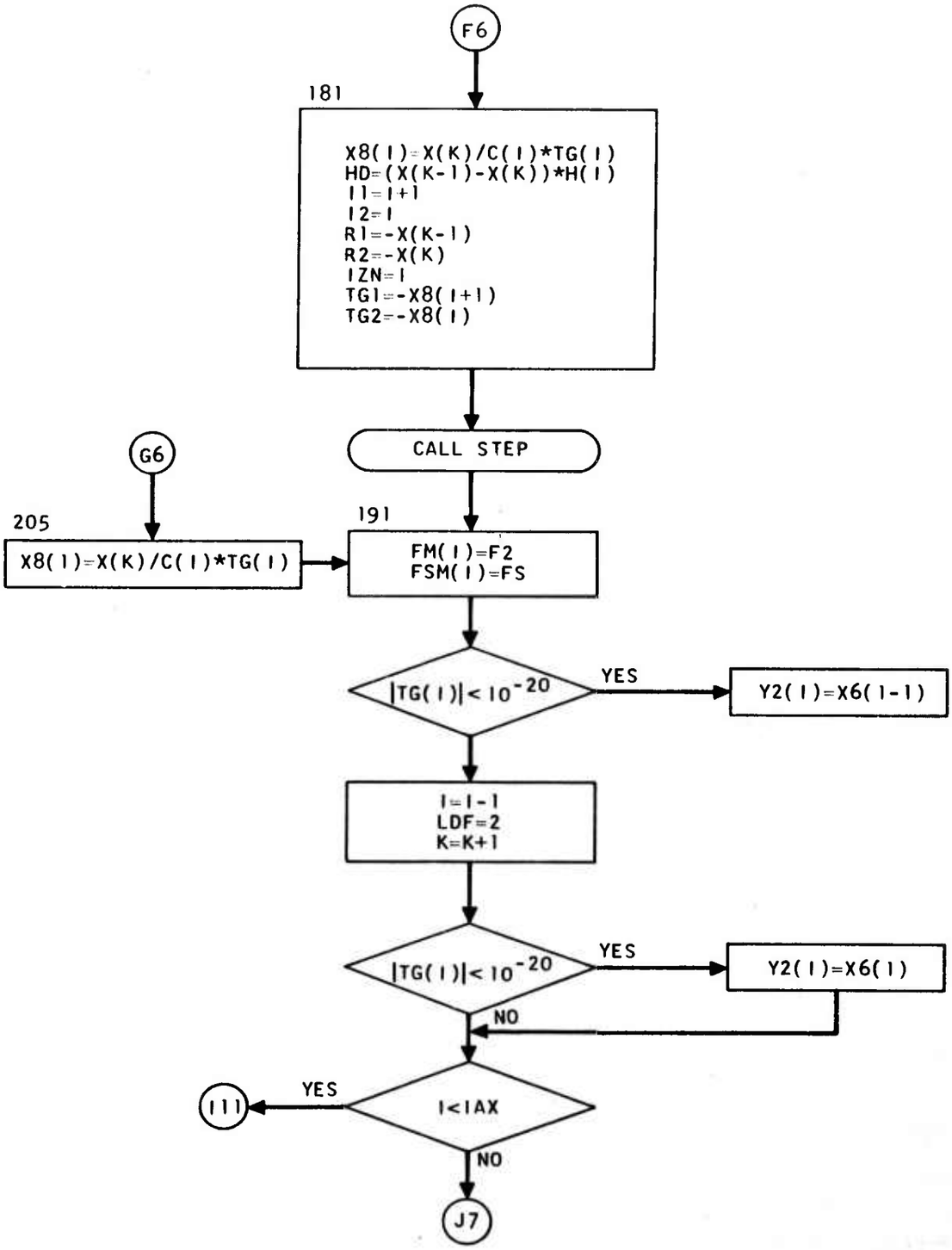


Figure 3 (continued). STRANS(N, M)

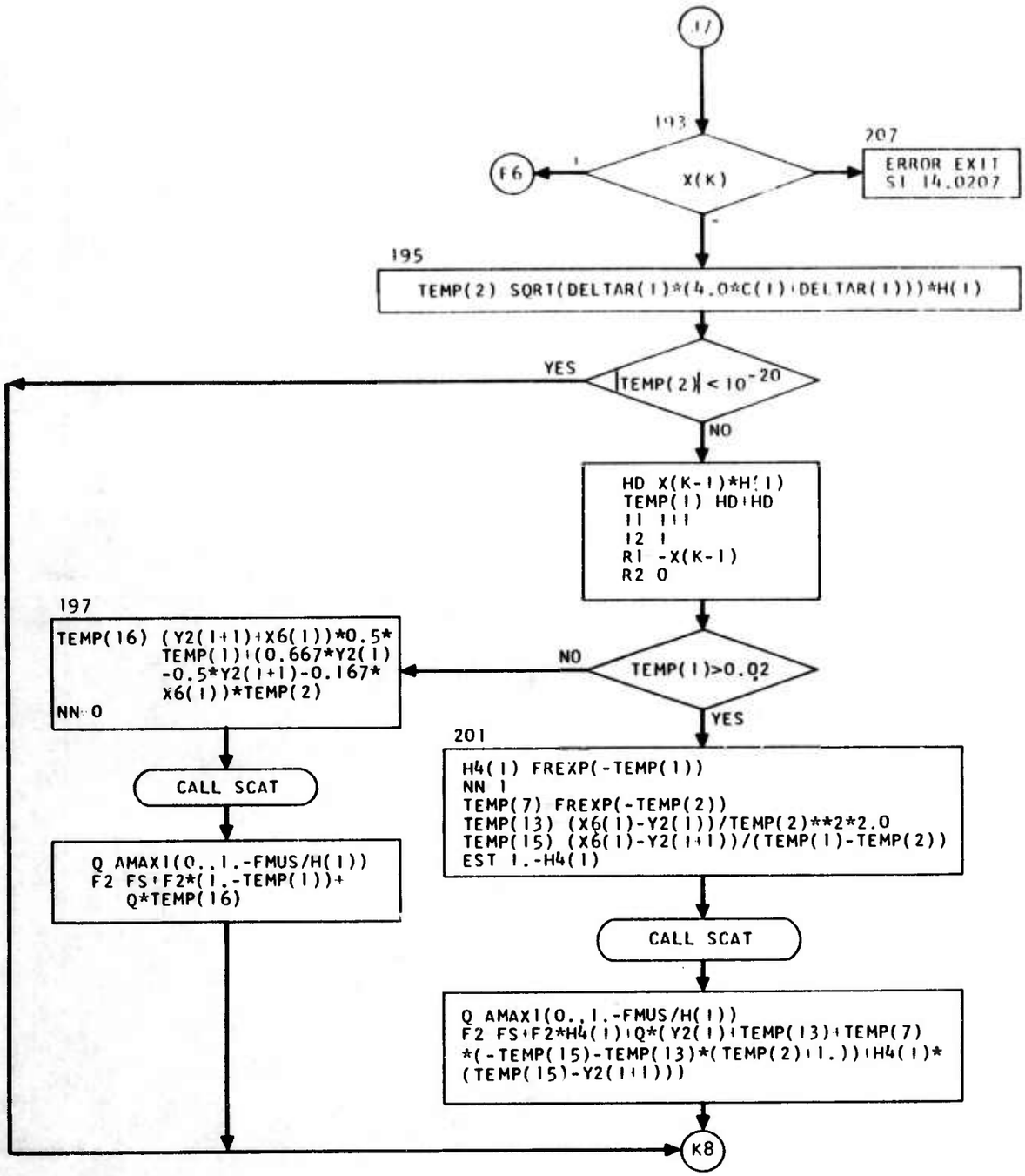


Figure 3 (continued). STRANS(N, M)

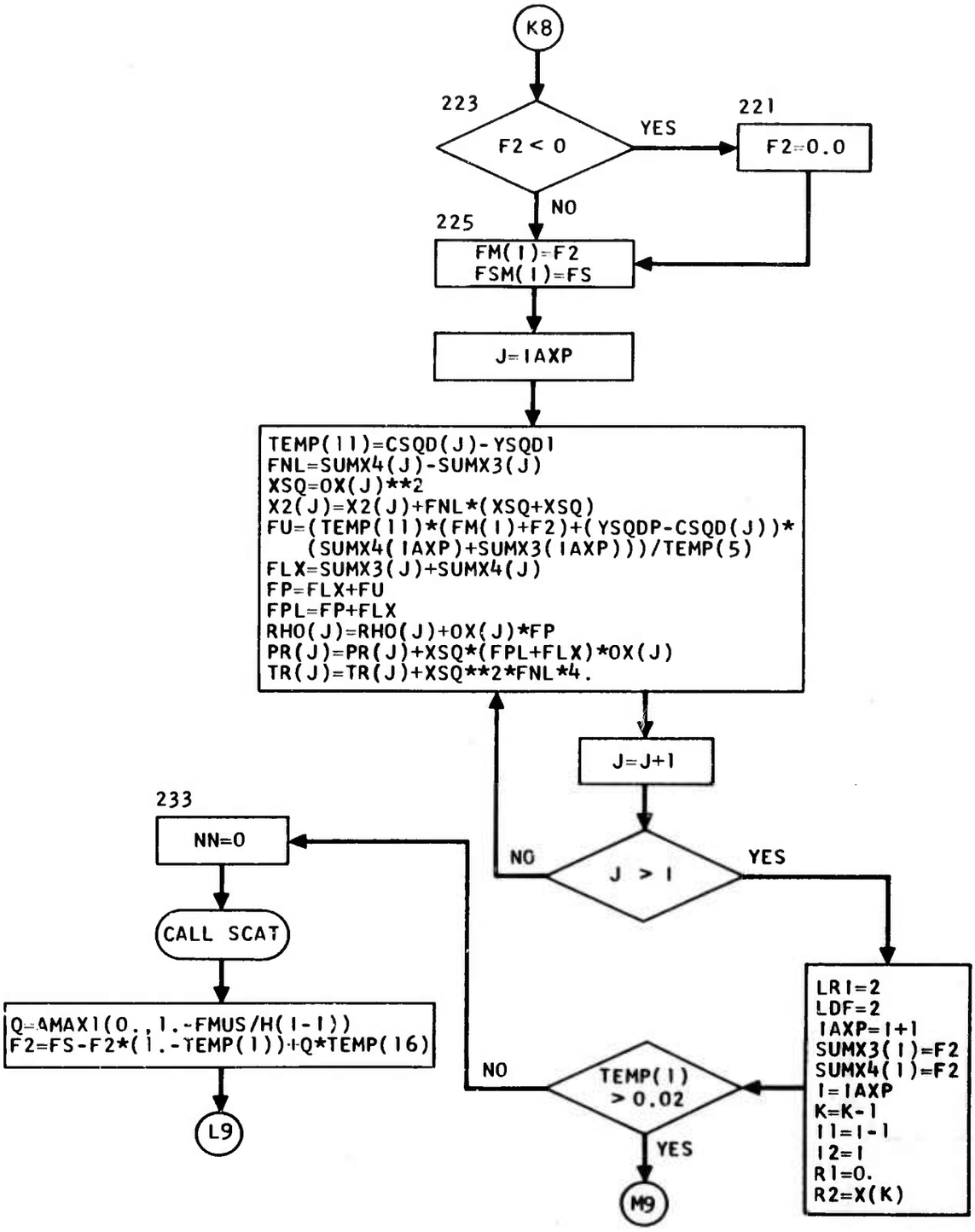


Figure 3 (continued). STRANS(N, M)

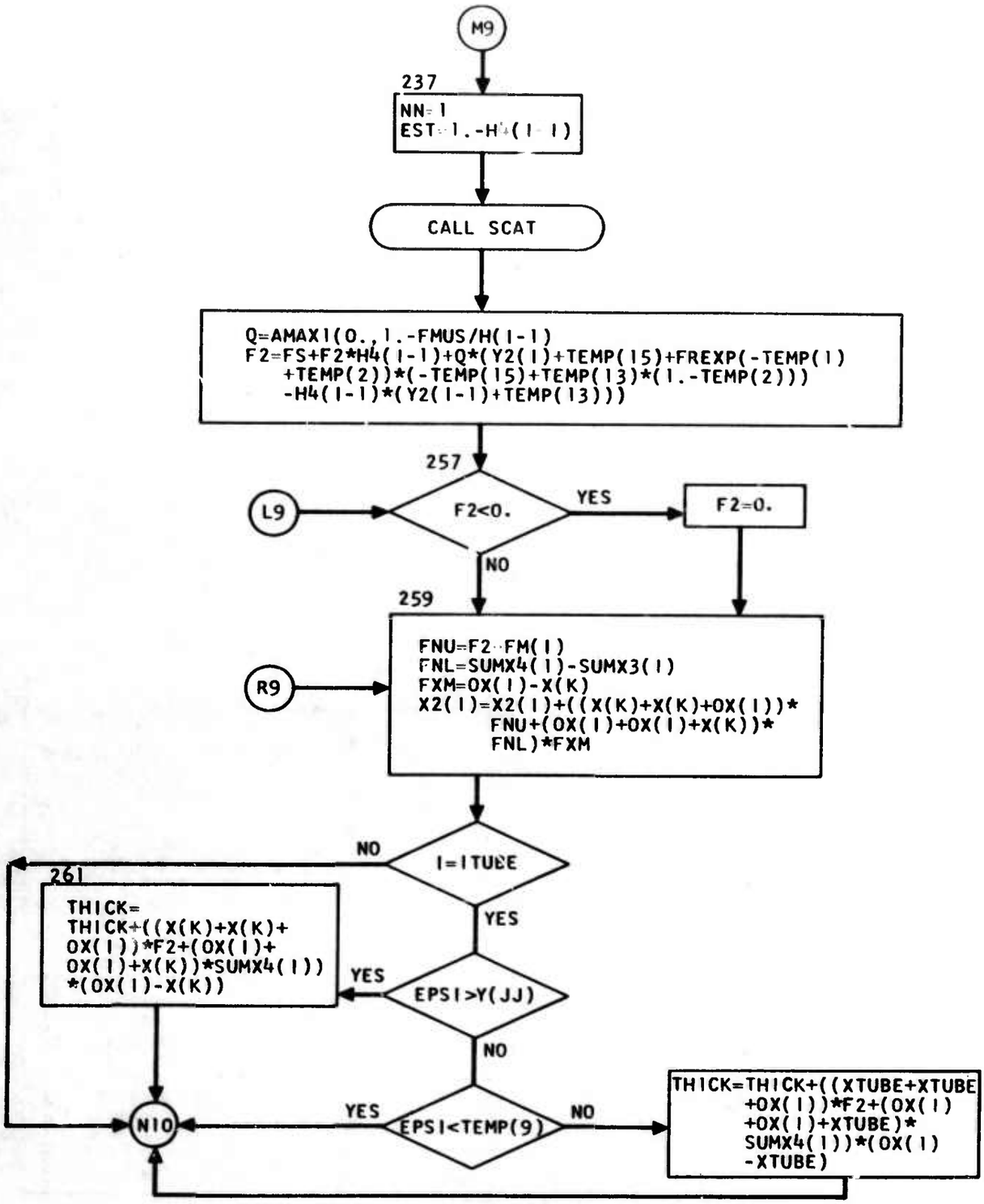


Figure 3 (continued). STRANS(N, M)

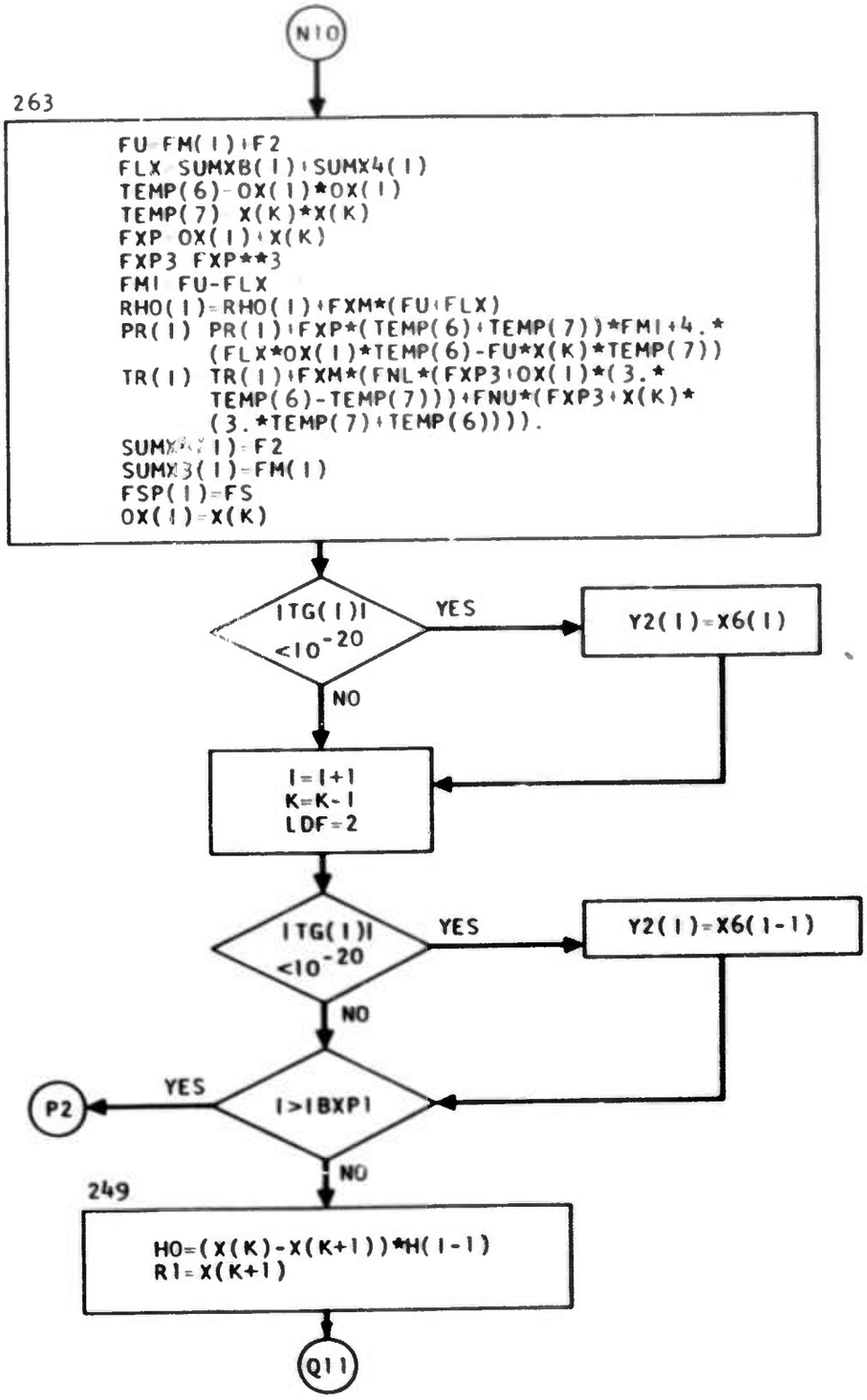


Figure 3 (continued). STRANS(N, M)

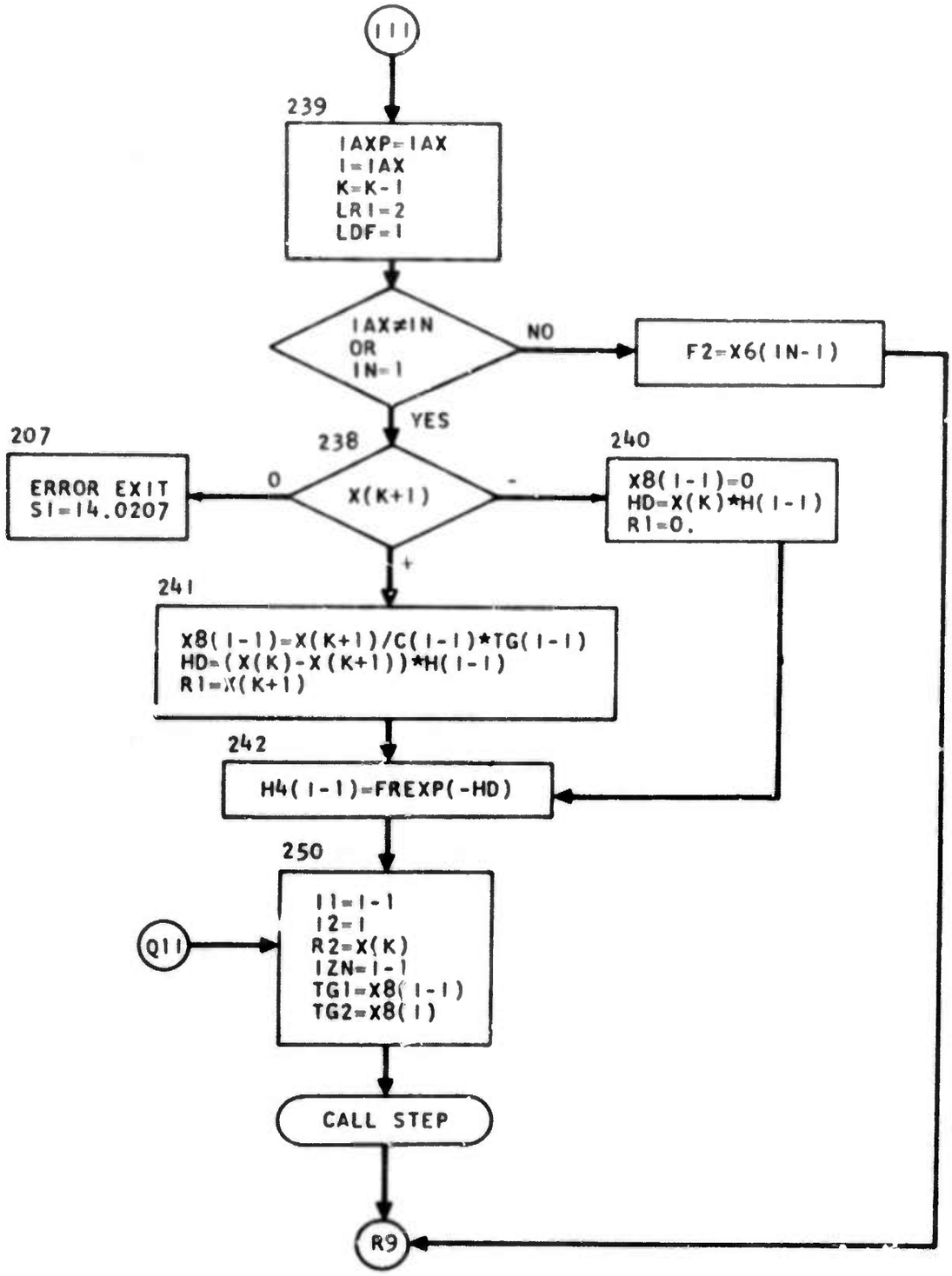


Figure 3 (concluded). STRANS(N, M)

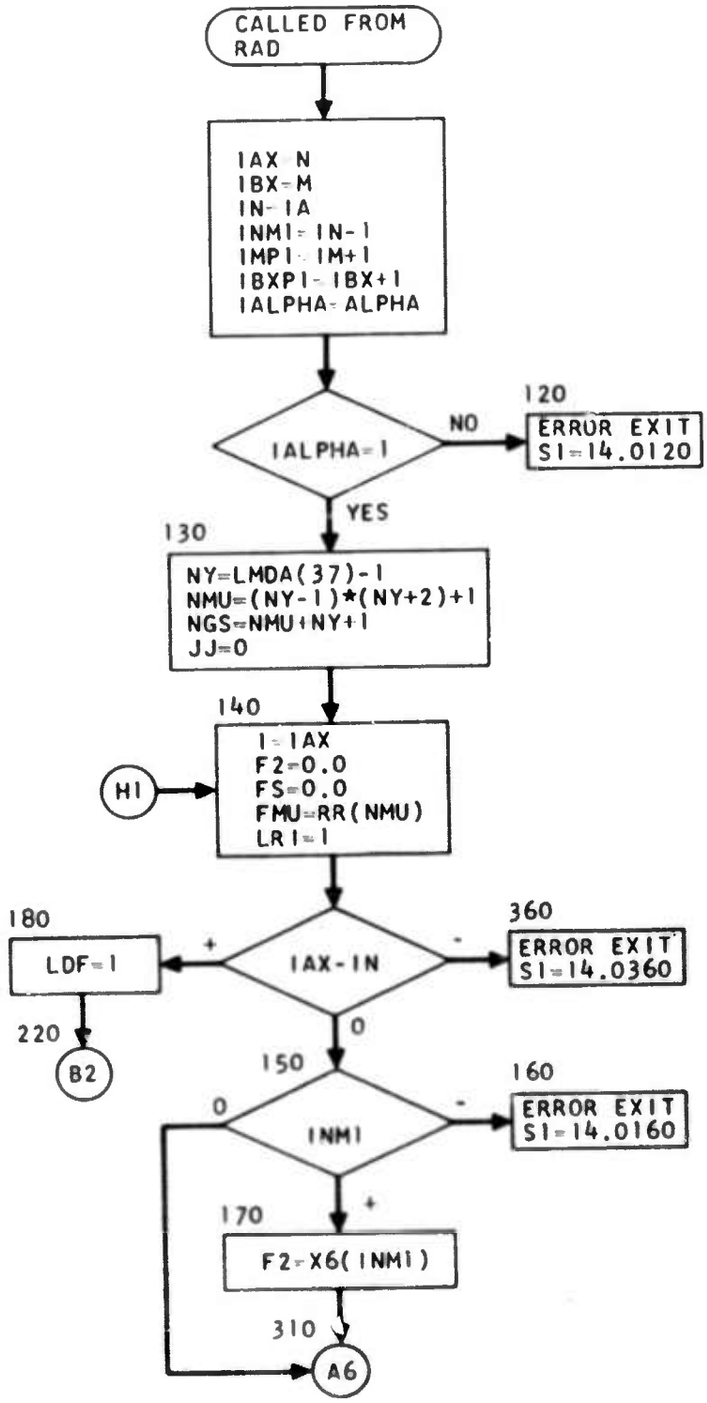


Figure 4. PTRANS

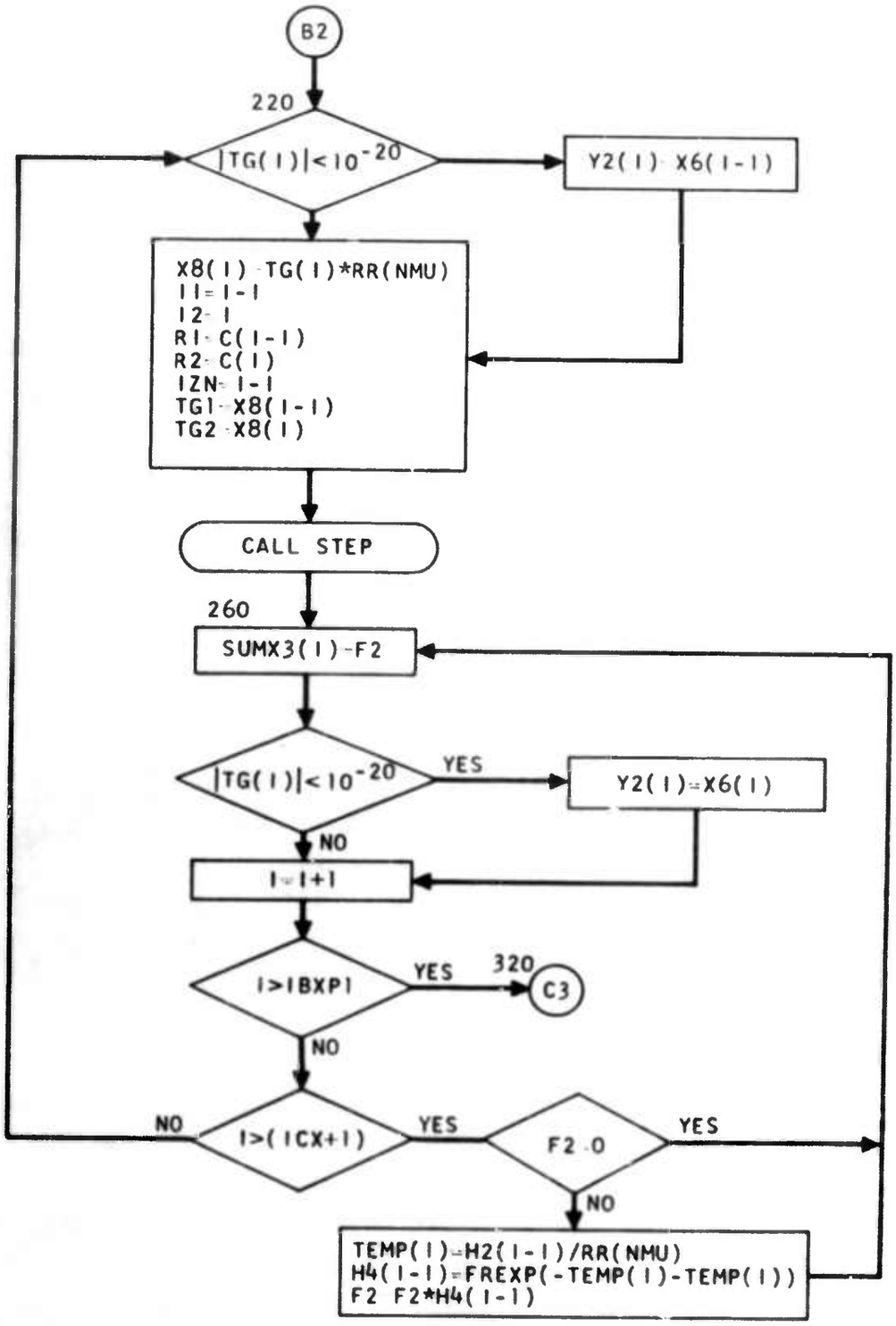


Figure 4 (continued). PTRANS

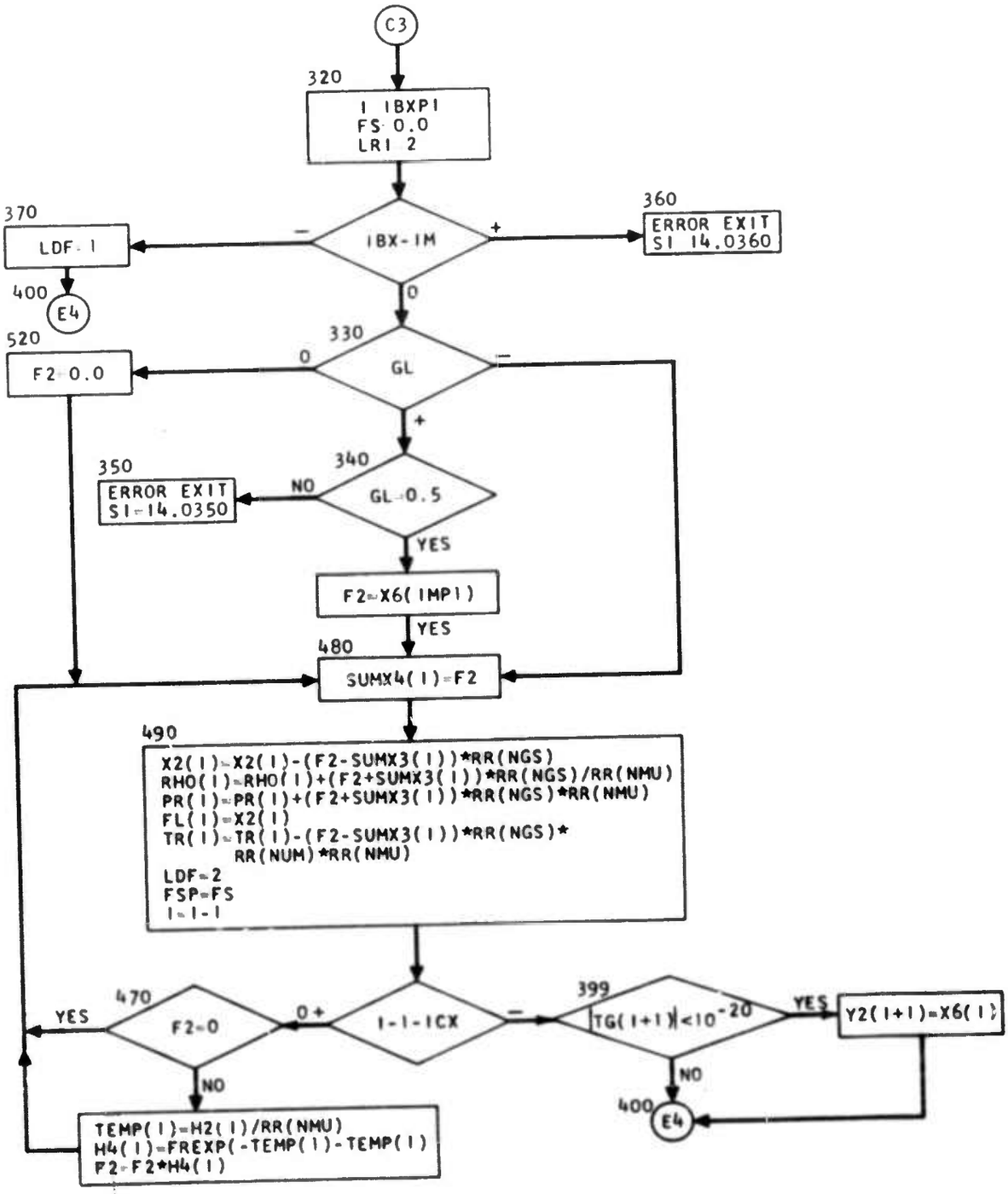


Figure 4 (continued). PTRANS

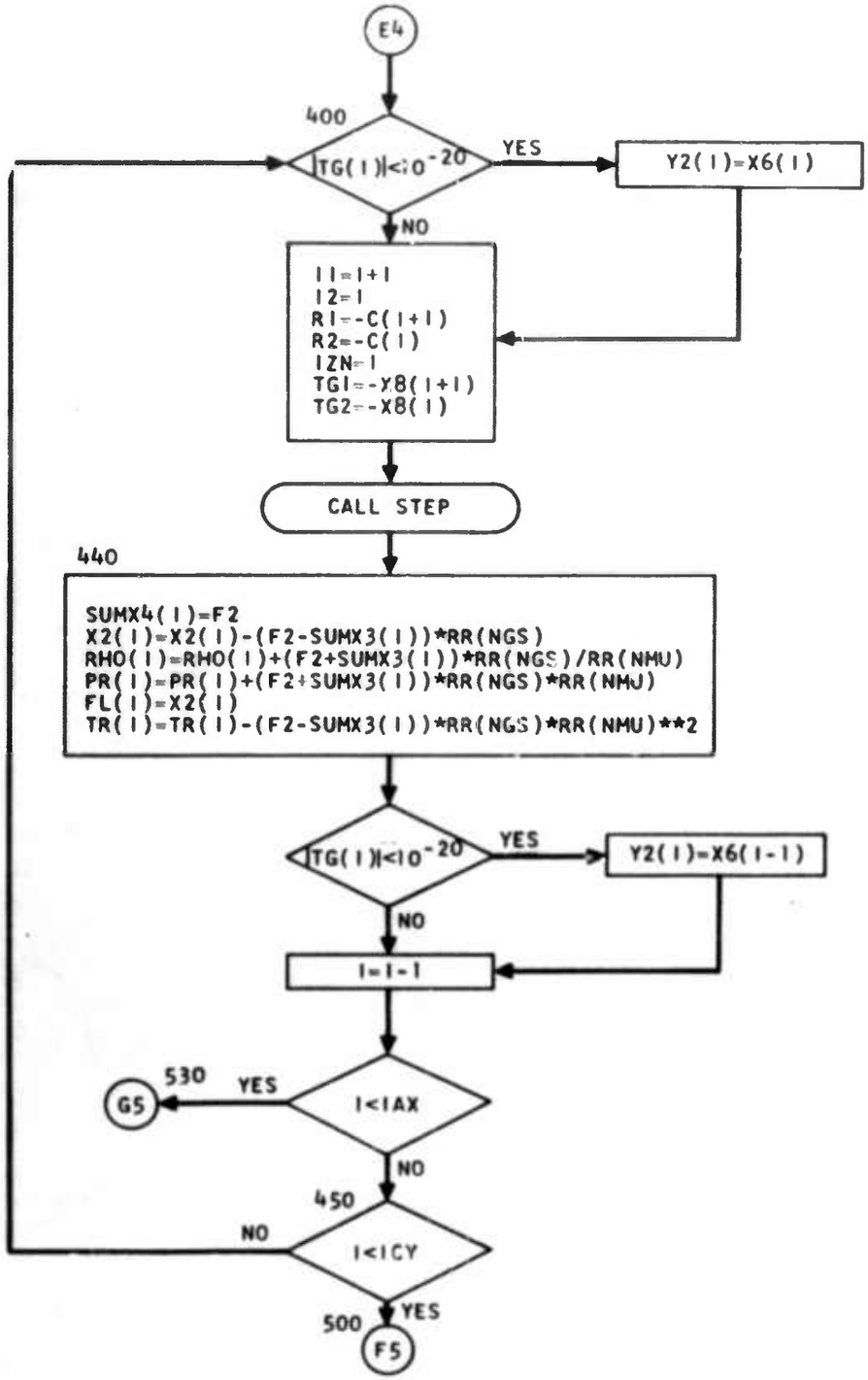


Figure 4 (continued). PTRANS

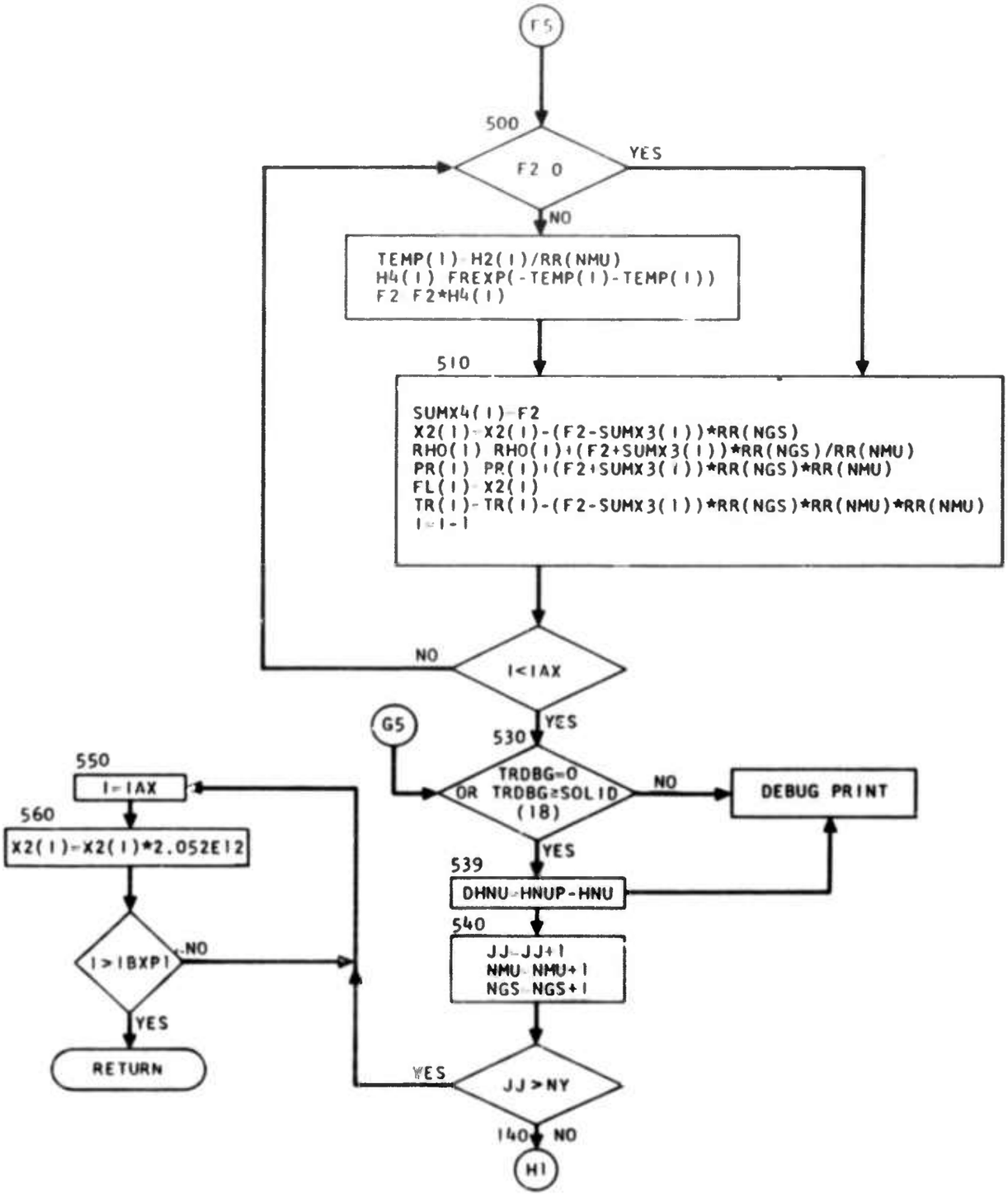


Figure 4 (continued). PTRANS

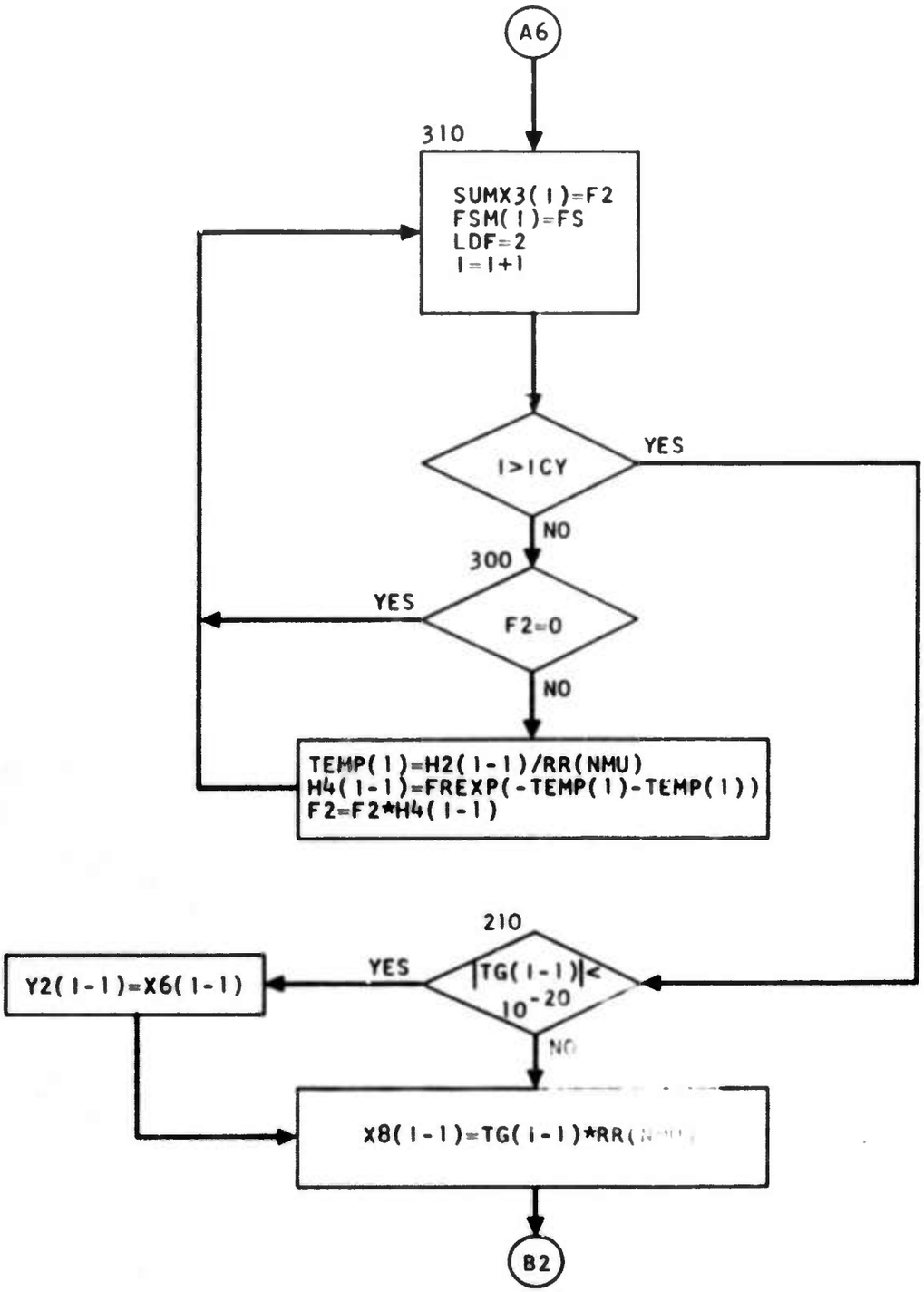


Figure 4 (concluded). PTRANS

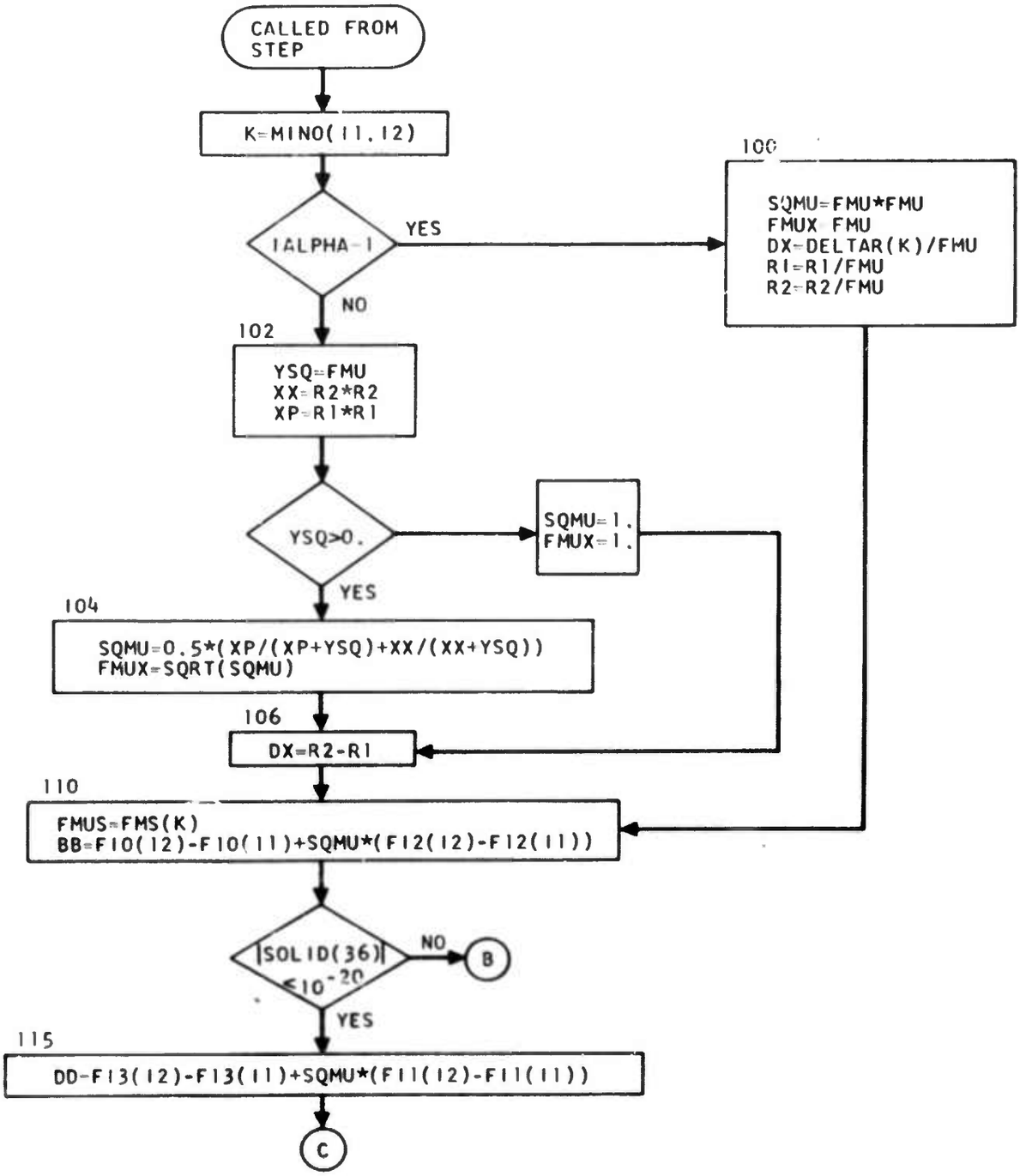


Figure 5. SCAT

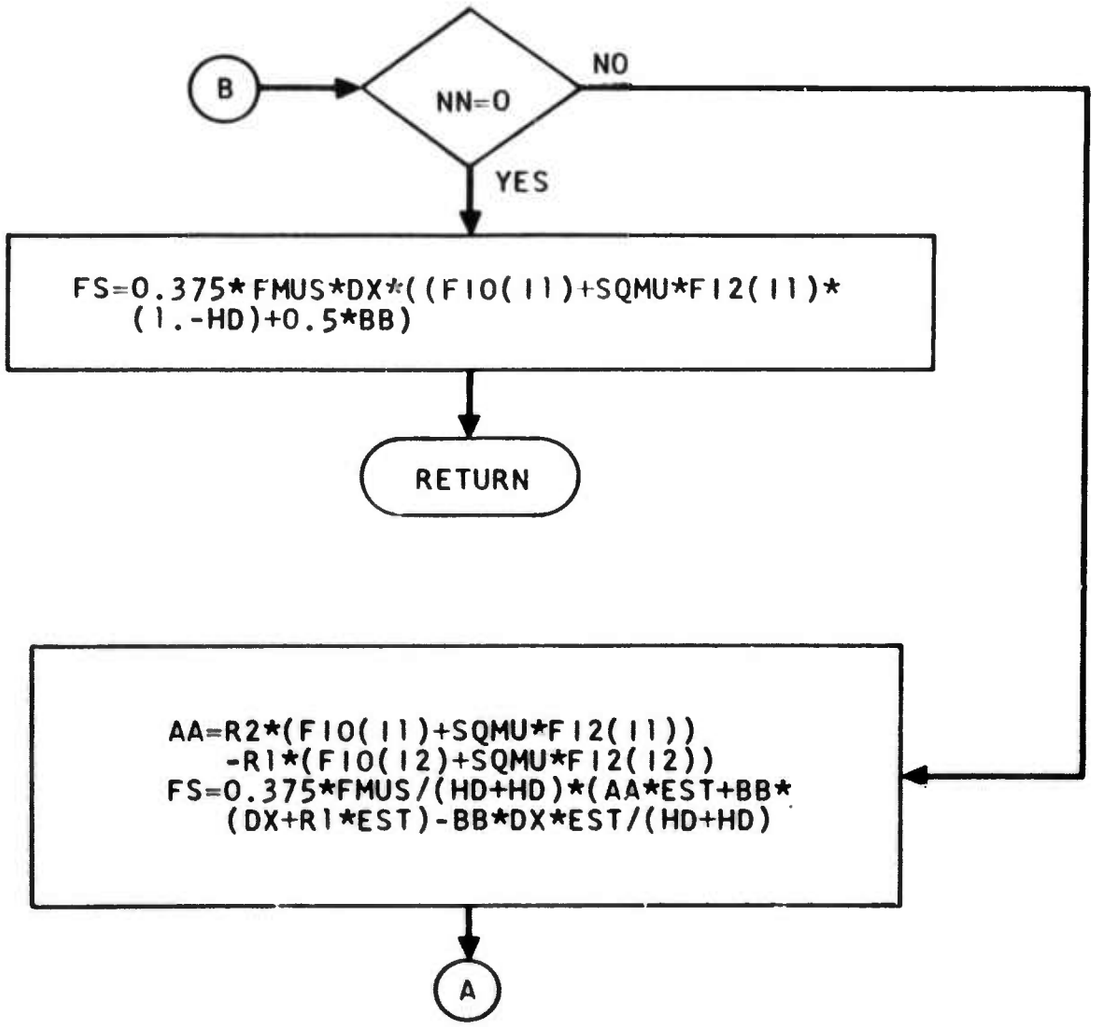


Figure 5 (continued). SCAT

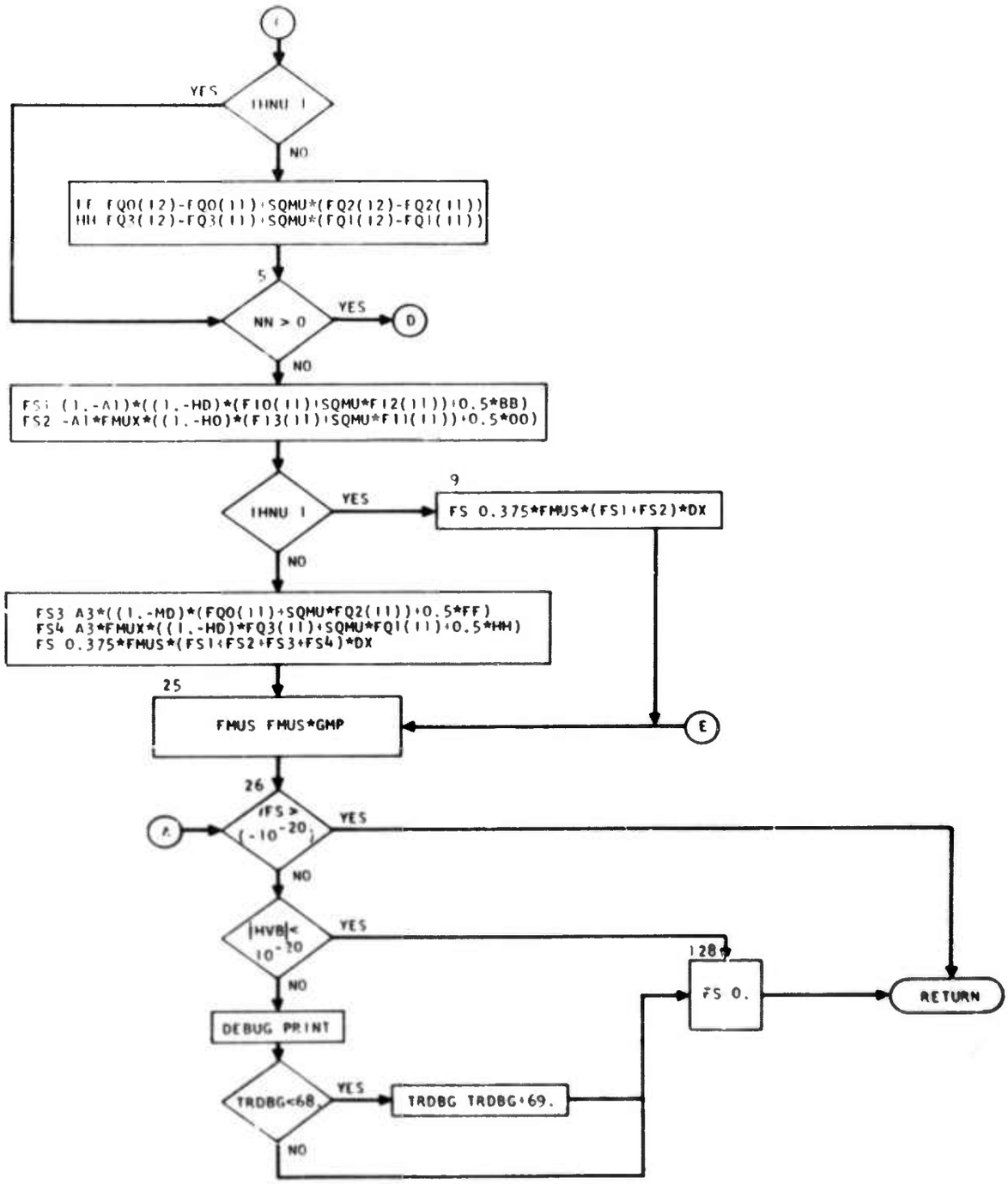


Figure 5 (continued). SCAT

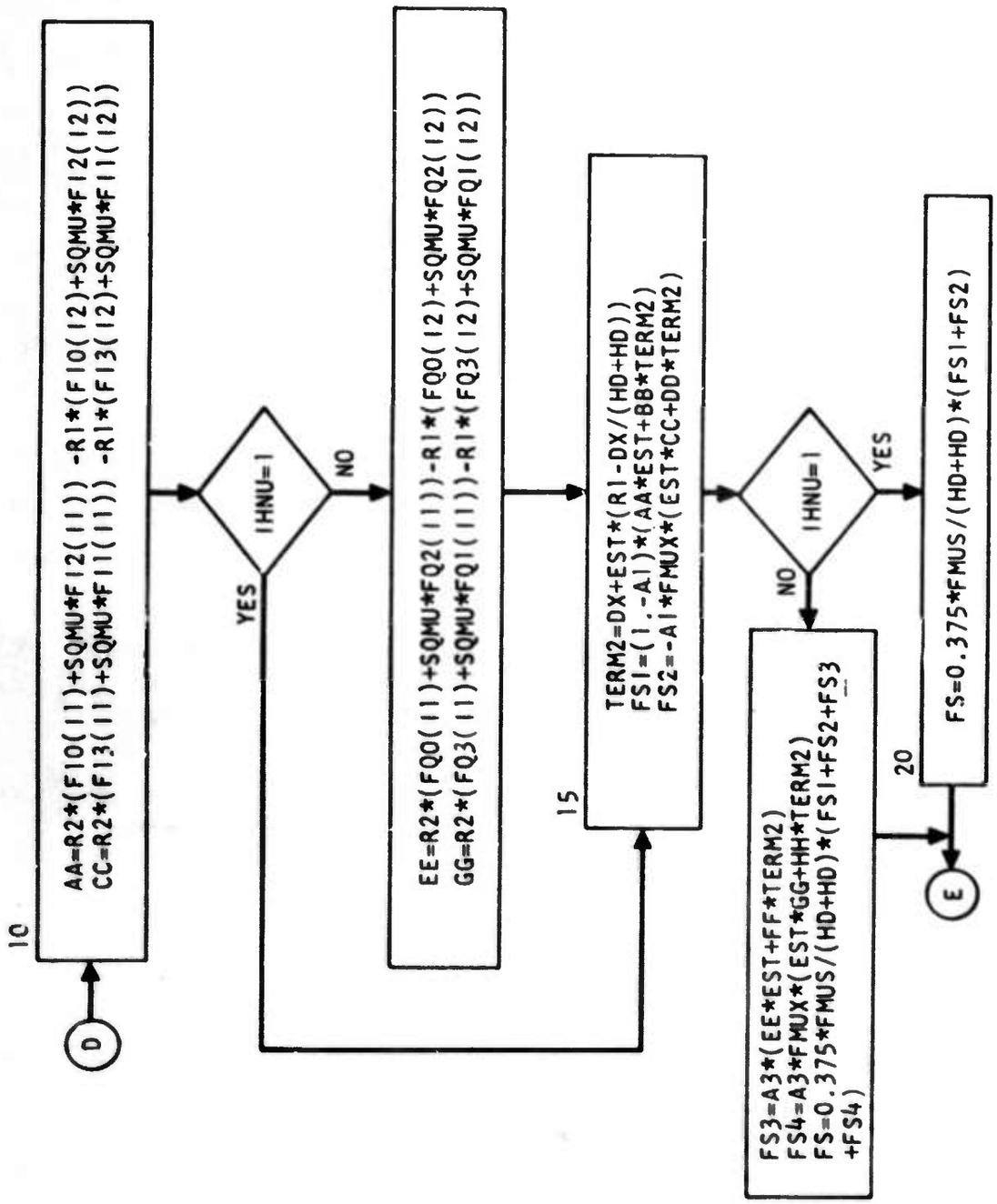


Figure 5 (concluded). SCAT

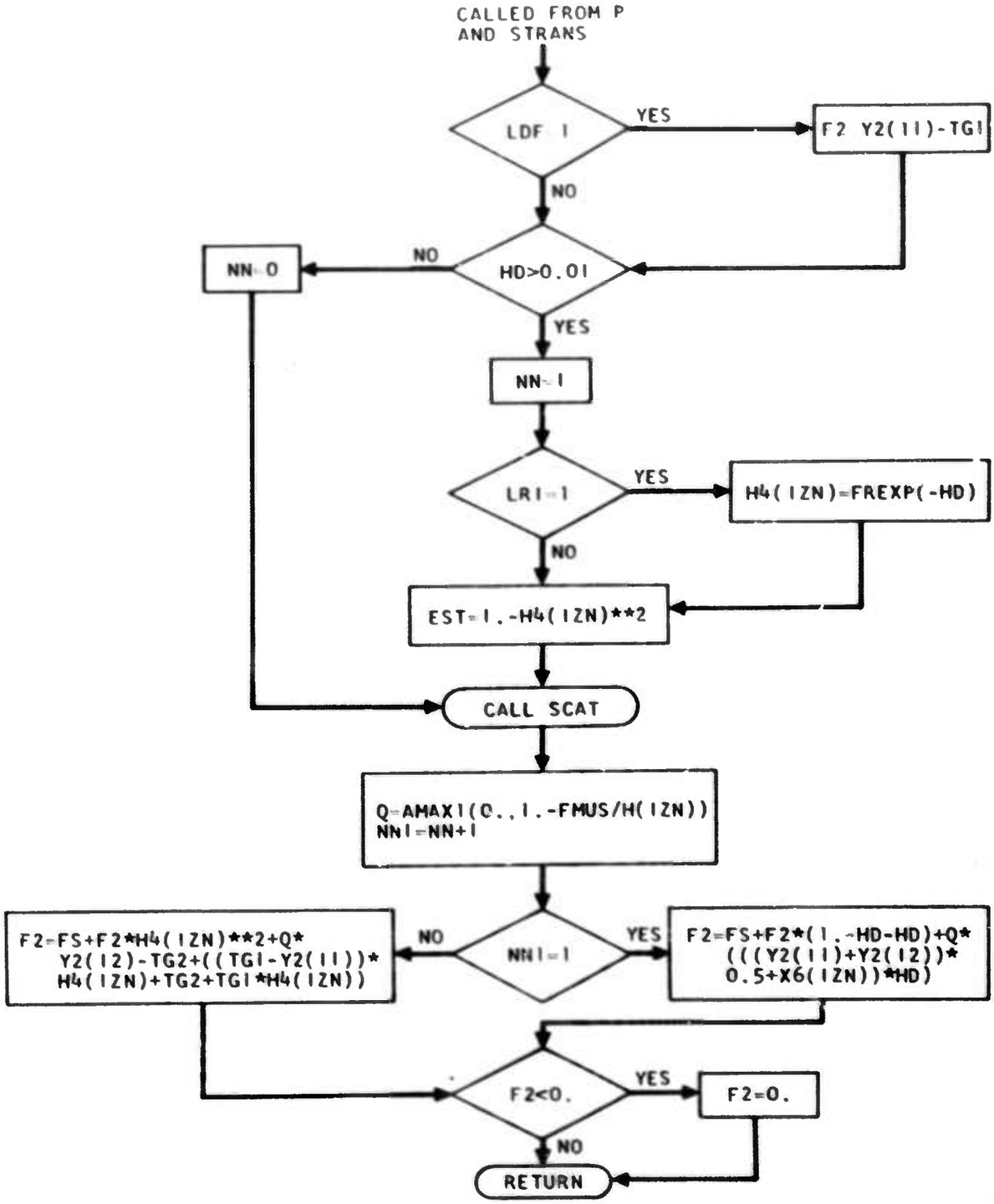


Figure 6. STEP

SCAT

AA	Following the notation of Eq. (30), AA is $A \cdot \Delta x$ as defined there. Private.
A1	This is defined in Eq. (31). It is evaluated in RAD. JIM Common.
A3	This is defined in Eq. (31). It is evaluated in RAD. JIM Common.
BB	This is $B \cdot \Delta x$ as defined in Eq. (30). Private.
CC	This is $C \cdot \Delta x$ as defined in Eq. (30). Private.
CVB	This input quantity, the negative intensity abort flag, is described on p. 87 of this report. Blank Common.
DD	This is $D \cdot \Delta x$ as defined in Eq. (30). Private.
DELTAR	Used in definition of DX in the plane case only. This variable in $r_{i+1}^{n+1} - r_i^{n+1}$, evaluated in HYDRO. Since r^n, the SPUTTER variable C, is used elsewhere in the radiation routines to define coordinates, it is recommended that the statement two lines below statement 100 be deleted and the GO TO 110 three lines below that be replaced by GO TO 106. This would give a more consistent, cheaper definition of DX. Blank Common.
DX	The distance from the initial to the final point of the current step along the characteristic ray, given in Eqs. (29) and (30), both as Δ and Δx. Private.
EE	This is $E \cdot \Delta x$ as defined in Eq. (30). Private.
EST	This is $1 - e^{-\Delta\tau}$, where $\Delta\tau$ is the optical depth of the current step. Evaluated in STEP and kept to avoid redundant calculation. JIM Common.
FF	This is $F \cdot \Delta x$ as defined in Eq. (30). Private
FI0	This is the mixture of moment quantities $3I_0 - I_2$, as defined in Eq. (31). The last character of the variable is a zero. Although doubly indexed (frequency, zone) in Eq. (31), it is singly indexed (zone) in the OUTPUT code. Since the code calculates downward in frequency, the variables for the next upper (previous)

FI0 (continued)	frequency are available in FQ0, etc. The full set of FI0, etc., over frequency is stored on drum or disc, since there is no longer room in core storage for the doubly indexed array. PALMER Common.
FI1	This is the mixture of moment quantities $3I_1 - 5I_3$, as defined in Eq. (31). Used only in Compton scattering. PALMER Common.
FI2	This is the mixture of moment quantities $3I_2 - I_0$, as defined in Eq. (31). PALMER Common.
FI3	This is the mixture of moment quantities $3I_3 - 5I_1$, as defined in Eq. (31). FI0, FI1, FI2, and FI3 are all evaluated in RAD. PALMER Common.
FMS	This zone array is $1/2\ \mu_s$, defined in Eq. (5), evaluated in RAD, using SOLID(37), an input quantity, for κ_s. Equivalenced to SMLA in Blank Common.
FMU	This is a linkage variable that provides information about the characteristic line. In plane geometry, it is simply $\lvert\mu\rvert$, the absolute value of the cosine of the angle with respect to the normal. In spherical geometry, however, it is y^2, the square of the impact parameter, evaluated once each y-line in STRANS. An approximate average value for μ is calculated in SCAT in this case. In both plane and spherical geometry, the derived parameter is the absolute value of the cosine. JIM Common.
FMUS	This variable, set to FMS(K) early in SCAT, is multiplied by GMP before being used in STEP to calculate an approximate $\mu_a/(\mu_a + \mu_s)$. The multiplication by GMP is done only in the case of Compton scattering. It is not clear that this variable is needed as linkage. A slight speed gain is achieved at the cost of clarity. JIM Common.
FMUX	This is the angular variable μ defined beneath Eq. (1). It is unfortunate that the angular variable μ can be so easily confused with the photon absorption and scattering coefficients μ_a and μ_s, but it appears to be the common notation and is reflected in this computer program. Private.

FQ0	This is the mixture of moment quantities $3I_0 - I_2$ and corresponds to the FI0 (J + 1, x) used in Eq. (30). That is, it is the FI0 zone array of the next higher (previously treated) frequency group. For the first group, these quantities are set zero in RAD and are not used in SCAT. It should be noted that the zero assumption is a particularly poor one as discussed on p. 82 of this report. The last character of FQ0 is a zero, and the array is in PALMER Common.
FQ1	The array corresponding to FI1. PALMER Common.
FQ2	The array corresponding to FI2. PALMER Common.
FQ3	The array corresponding to FI3. PALMER Common.
FS	This is the scattering intensity, the "result" of executing the SCAT routine. It is the right-hand side of Eq. (29). JIM Common.
FS1	The right-hand side of Eq. (29), which gives the detailed formulation of the scattering intensity, has four lines. Except for the factor $\mu_s/\mu \cdot 3/16$, FS1 is an intermediate term representing the first line. Private.
FS2	Represents the second line of the same equation. Private.
FS3	Represents the third line of the same equation. Private.
FS4	Represents the fourth line of the same equation. Private.
GG	This is $G \cdot \Delta x$ as defined in Eq. (30). Private
GMP	This is $1 - 2\gamma$, mentioned on p. 82 of this report. It appears in Eqs. (19) ff. JIM Common.
HD	This is $1/2\ \kappa\rho\Delta x$, where Δx is the geometrical length of the current step along the characteristic ray, ρ is the density, and κ is the photon coefficient $\kappa_a + \kappa_s$. Thus, HD, evaluated in PTRANS or STRANS and used in STEP and SCAT, is one-half the optical depth of the step. JIM Common.

HH	This is H · Δx as defined in Eq. (30). Private.
HVB	This input quantity, the negative scattering intensity debug print flag, is described on p. 87 of this report. Blank Common.
IALPHA	The geometry flag (1 = plane, 3 = sphere). Used in SCAT to obtain FMUX and SQMU, given FMU. Blank Common.
IHNU	The frequency group index, used in Compton scattering to branch to simpler coding for the first frequency group. LINDLY Common.
IMHAD	A divide check abort flag. Private.
I1	The index of the left-hand boundary of the current step. Evaluated in PTRANS or STRANS, used in STEP and SCAT. JIM Common.
I2	The corresponding index of the right-hand boundary. JIM Common.
K	The zone index of the current step, naturally the lesser of I1 and I2 provided that the characteristic ray at closest approach always is tangent to a zone boundary, as it is for the current standard SPUTTER and the OUTPUT code. Replacing K with IZN (see STEP) would remove this as a necessary condition, rendering SCAT safely generalizable. Private.
NN	This is a thick-thin flag set in STEP to allow SCAT to execute either Eq. (29) or Eq. (32), whichever is appropriate. JIM Common.
R1	The x-position of the left side of the step, not the radial position in spherical geometry. In STRANS, R1 and R2 are evaluated directly. In PTRANS, R1 and R2 are set to the slab coordinates and then adjusted for slant angle in SCAT. JIM Common.
R2	The x-position of the right side of the step. JIM Common.
SOLID(36)	The Compton switch described on p. 86 of this report. Blank Common.
SQMU	μ^2, where μ is given by the variable FMUX. Private.

S1 — The SPUTTER error flag. See pp. 88-91 of this report. Blank Common.

TERM2 — This is an intermediate quantity

$$\frac{x_2 - x_1 e^{-\alpha_i \Delta}}{\alpha_i} - \frac{1 - e^{-\alpha_i \Delta}}{\alpha_i^2}$$

appearing four times in Eq. (29). Private

TRDBG — This quantity, equivalenced to ACO3T4 in Blank Common, is the transport debug print flag. Zero for normal operation and no print, non-zero for transport debug print. It is changed in SCAT to trigger a print and then turned back in PTRANS or STRANS to forestall more prints, if HVB is set and a negative intensity is encountered.

XP — This is R1**2, used to find a μ in the spherical case. Private.

XX — This is R2**2, used to find a μ in the spherical case. Private.

YSQ — This is the square of the impact parameter, used to find μ in the spherical case. Private.

STEP

EST(1)

FMUS(1)

FS(1)

F2 — This is the intensity on the right side of the step, the "result" of executing the STEP routine. It appears as $I_j(x_2)$ on the left side of Eq. (27). JIM Common.

H — This is a zone array of $\kappa\rho = \mu_a' + \mu_s$, equivalenced to BIGB, evaluated in RAD, and used in the formation of Q. Blank Common.

HD(1)

H4	This is a zone array of $e^{-1/2\Delta\tau}$, where HD (see SCAT) is $1/2\Delta\tau$. It is formed in STEP if one is proceeding inward in spherical geometry or forward in slab geometry and is available in the reverse case. It is equivalenced to SMLH in Blank Common.
IZN	This is the index of the zone being traversed in the current step along the characteristic ray. Evaluated in PTRANS or STRANS, used in STEP. JIM Common.
$I1^{(1)}$	
$I2^{(1)}$	
LDF	In subsection 2.1.5 of reference 2, the three initial boundary conditions for I_{i-1} (initial value of F2) are described. For the first two of these, F2 is defined in PTRANS or STRANS, and for the general case, F2 is left over from the previous step. However, for the third case, diffusion, the initial intensity is given by Eq. (2.19) of reference 2, and this is executed in STEP. If LDF is 1, the diffusion boundary condition is applied. If LDF is 2, F2 is assumed to be properly initialized. LDF, in JIM Common, is evaluated in PTRANS or STRANS.
LRI	This is the left-right index, used to decide whether to evaluate H4. It is set in STRANS or PTRANS. JIM Common.
$NN^{(1)}$	
NN1	This is NN + 1, set to allow a computed GO TO on the thick-thin flag. A code reform would increase NN by 1 in the several places in PTRANS and STRANS where it is set, and would eliminate the need for a second variable. Private.
Q	This is, or should be, $\mu_a/(\mu_a + \mu_s)$. In the current, rather crude calculation of this quantity, Q is set zero in case the value should go negative. Private.
TG1	This is the slant source gradient along the characteristic ray, evaluated at the left side of the current step, R1. This quantity appears as $\mu_{i-1}(\partial B/\partial h)\|_{i-1}$ in Eq. (2.19) of reference 2. JIM Common.
TG2	This is the corresponding quantity evaluated at the right side, R2. JIM Common.

X6 — This is a zone array of the source B_i in Eq. (24), evaluated at the zone center. Calculated in RAD. Blank Common.

Y2 — This is a zone array of the source evaluated at the zone boundary according to criteria discussed in subsections 3. 2 and 5. 1. 3 of reference 2 (see also the model in subsection 2. 1. 1 of reference 2). Equivalenced to X5 in Blank Common, evaluated in RAD, and adjusted in STRANS if TG (see STRANS) is zero.

STRANS

Variables defined in the STEP or SCAT lists are given first.

DELTAR(1)	I2(1)
EST(1)	LDF(2)
FMU(1)	LRI(2)
FMUS(1)	NN(1)
FS(1)	R1(1)
F2(2)	R2(1)
H(2)	S1(1)
HD(1)	TG1(2)
H4(2)	TG2(2)
IALPHA(1)	TRDBG(1)
IHNU(1)	X6(2)
IZN(2)	Y2(2)
I1(1)	

ALPHA — The geometry indicator in real form (see IALPHA(1)). SPUTTER has both real and integer forms for this variable. Blank Common.

C — The "old" space variable, r_i^n, used throughout the radiation codes. Blank Common.

CNT1 — The updated cycle number, evaluated only if a transport debug print is called. Private.

CSQD	Evaluated in RAD and used there and in STRANS, this is a zone array of the square of the coordinate, C**2, and is provided to save multiplications within frequently executed loops. It probably saves relatively little time and can be considered one of the more expendable arrays. Equivalenced to CRTC in Blank Common.
C1	For IAX > 1, there is an interior solid or diffusion region. Even if this consists of many zones, one requires, nevertheless, only a few y-lines. As stated in subsection 2.2.2 of reference 2, "If a diffusion region having an outer boundary r_D exists inside the transport region, y-lines are placed as near as possible to 0.5 r_D, 0.75 r_D, and r_D penetrating the diffusion region." C1 is set first to 0.5 r_D and then to 0.75 r_D to provide this placement. Private.
DHNU	The width, in eV, of the current frequency group. Set in STRANS and it is probably not used. LINDLY Common.
EPSI	Radius of OUTPUT sample tube. Blank Common.
FL	A separate array of the first moment of the intensity, $\int_{-1}^{1} I\mu d\mu$, normalized differently from X2 and used in the evaluation of the scattering moment quantities. Equivalenced to SMLB in Blank Common.
FLX	An intermediate quantity, $I_- + I_+$ along the previous y-line, used in calculating the intensity moments. Private.
FM	The array of I_- along the current y-line. Four intensities are required to calculate the moment quantities for a particular zone boundary and y-band. One can be used immediately after being calculated; the others have to be available in zone array storage. Equivalenced to ER in Blank Common.
FM1	The intermediate quantity $(I_+ + I_-)$ along the current y-line minus $(I_+ + I_-)$ along the previous y-line. Private.
FNL	The intermediate quantity $(I_+ - I_-)$ along the previous y-line. Private.
FNU	The intermediate quantity $(I_+ \quad I_-)$ along the current y-line. Private.

FP	Evaluated and used in the "top slice" section, this intermediate quantity is $I_- + I_+ + I_T$, where I_T is an interpolated value at the top of the arc. See subsections 2.3.2 and 5.2.5 of reference 2. Private.
FPL	This is $2(I_- + I_+) + I_T$. See discussion of FP. Private.
FSM	The zone array of scattering intensity on the inward sweep. Stored for display in the debug print. Equivalenced to SMLD in Blank Common.
FSP	The corresponding array of scattering intensity for the outward sweep. Equivalenced to SMLE in Blank Common.
FU	I_T. See discussion of FP. Private.
FXM	On the zone boundary, the x of the previous y-line minus the x on the current y-line. Private.
FXP	On the zone boundary, the x of the previous y-line plus the x on the current y-line. Private.
FXP3	The cube of FXP, used twice in evaluating the third moment of the intensity. Private.
GL	If positive, there is a blackbody exterior to the radiation region. The initial intensity is set accordingly. Blank Common.
HNU	The frequency (eV) of the lower limit of the current frequency group. Set to 10^{-3} for a grey problem. LINDLY Common.
HNUP	The frequency (eV) at the upper limit of the current frequency group. LINDLY Common.
H2	Depending on SOLID(10), an input quantity, H2 is a zone array of one-half either the Planck or Rosseland optical depth. Planck if SOLID(10) is zero; otherwise, Rosseland. Used to define optical depth in the transport routines. Evaluated in RAD. Equivalenced to EC in Blank Common.
I	Generally used in STRANS to denote the zone or zone-boundary index. Private.
IAX	The left (interior) zone limit of the current transport subregion, inside of which may lie a diffusion region, an interior blackbody, or the center. Private, but linked to RAD by the first argument of the subroutine.

IAXP	An index denoting the lower limit of zone boundaries for which a top-slice calculation is to be made. Private.
IAXP1	The lower limit of zone boundaries to be treated in the transport debug print for a given y-line; this is the maximum of IAX, IAXP-1. Private.
IBX	The right (exterior) zone limit of the current transport subregion. Private, but linked to RAD by the second argument.
IBXP1	This is IBX+1 and is the upper zone-boundary limit of the current transport subregion. Private.
IM	The right (exterior) zone limit of the whole radiation region, set in RAD. LINDLY Common.
IN	The left (interior) zone limit of the whole radiation region, set in RAD. LINDLY Common.
IT	A running index used in setting up y-lines; its function is probably obsolete. Private.
ITUBE	Index of zone boundary at which OUTPUT sample tube is affixed. Set to LMDA(26), the input quantity, near the beginning of STRANS. Used only because subscripted subscripts are illegal in FORTRAN. Private.
J	Used as the running index of the top-slice DO loop, where I is a limit of the loop. Private.
JJ	The y-line index. Private.
JJJ	Set to JJ throughout, its function as distinct from JJ is to be found in the coding given in reference 2 (since deleted). It was involved in a y-line skipping procedure, now prohibited by scattering considerations. A code cleanup would remove JJJ. Private.
K	This is the index for the variable X. Private.
KK	A counter updated from the X array which gives a "master index" for a given y-line. Private.
KKK	An index for X used in the transport debug print. Private.

KOOOFX	A dummy argument used in CALL DVCHK, analogous to IMHAD[1]. When codes were processed from FORTRAN II to FORTRAN IV by SIFT, the dummy variable K000FX was invented, where the middle characters were zeros. By historical accident, the characters in this variable are letter O's. A code cleanup would change this to KX. Private.
KX	A dummy argument used in CALL DVCHK. Private.
LMDA(26)	The input quantity that defines ITUBE. Blank Common.
NY	The number of y-lines. LINDLY Common.
OX	A zone array storing X for the previous y-line. Since all the X are available, OX could be dispensed with if an index analogous to K but for the previous y-line were defined. Equivalenced to W in Blank Common.
PR	A zone array for the second moment of intensity, $\int_{-1}^{1} I\mu^2 \, d\mu$. Used in calculating the scattering moment quantities. Equivalenced to X7 in Blank Common.
Q	Same meaning as Q[2], but different storage. Private.
RHO	A zone array for the zeroth moment of intensity, $\int_{-1}^{1} I \, d\mu$. Used in calculating the scattering moment quantities and, in RAD and elsewhere, as radiation energy density. Blank Common.
SOLID(18)	The current cycle number. Blank Common.
SUMX3	A zone array for I_- along the previous y-line. See discussion of FM. Equivalenced to CHIC in Blank Common.
SUMX4	A zone array for I_+ along the previous y-line. See discussion of FM. Equivalenced to BC in Blank Common.
TEMP(1)	In SPUTTER, the TEMP array is used by many subroutines for scratch storage. Liberal use of it was made in STRANS, especially for "top-slice" coding. (See subsections 2.1.2, 2.3.2, and 5.2.5 of reference 2.) All the TEMP variables are in Blank Common. TEMP(1) is used to give half the optical depth of a top slice, or the full optical depth of one side of it.
TEMP(2)	This is $\Delta_{1/2}$ (defined in subsection 2.1.2 of reference 2).

TEMP(5)	This is $r^2_{IBXP1} - y^2_j$, where j is the index of the last y-line used. Intermediate quantity in calculating intensity moments in a top-slice calculation.
TEMP(6)	x^2 of a point on the previous y-line.
TEMP(7)	The corresponding x^2 for the current y-line. Also used for an entirely different purpose, e-TEMP(2) in a top-slice calculation.
TEMP(9)	Used as the y-value of the last y-line treated, which need not be Y(JJ-1), since lines may be skipped.
TEMP(11)	This is $r^2_i - y^2_j$, used in calculating FU in a top slice.
TEMP(13)	A special top-slice source gradient, F, defined in Eq. (2.13), subsection 2.1.2, reference 2.
TEMP(15)	G defined in Eq. (2.13), subsection 2.1.2, reference 2.
TEMP(16)	In the top-slice thin approximation, this is the last term of Eq. (2.15), subsection 2.1.2, reference 2.
TG	The source gradient, defined in RAD. It may be set zero depending on conditions discussed in subsection 5.1.3 of reference 2. See also table II in this report. This is a zone array equivalenced to V in Blank Common.
THICK	This is the "OUTPUT-output," in gross outward flux down a tube of specified radius at specified zone boundary. LINDLY Common.
TR	A zone array for the third moment of intensity, $\int_{-1}^{1} I\mu^3 \, d\mu$. Used in calculating the scattering moment quantities. Equivalenced to SMLC in Blank Common.
X	This is an array of all the values of $\sqrt{r^2_i - y^2_j}$ for all y-lines set up early in RAD. The X array is evaluated in RAD, outside the frequency loop, in order to save taking thousands of square roots within the frequency loop, say, in STRANS. For each y-line, in addition to the set of x values, there are stored in the X array the number of x values and the negative of y^2. DAVIS Common.
XS	In the final top-slice calculation, this variable is $r^2_{IBXP1+1} - r^2_{IBXP1}$. Used to calculate an initial diffusion intensity. Private.
XSQ	For a given cell boundary, this is x^2 for the previous y-line. Used as an intermediate quantity in evaluating moments. Private.

XTUBE	This is $\sqrt{r^2_{ITUBE} - EPSI^2}$, the x-value of the intersection of the OUTPUT sample tube with the zone boundary at which the tube is affixed. Private.
X2	This is the first moment of the intensity $\int_{-1}^{1} I\mu \, d\mu$, normalized before exiting STRANS to serve as the radiation flux for the calculation of heating rates. Blank Common.
X8	This is a zone array of the slant source gradient, TG · x/r. Equivalenced to X4 in Blank Common.
Y	This is the array of values of y, the impact parameter, for y-lines. Equivalenced to BIGA in Blank Common.
YSQDP	This is convenient storage for y^2 of the current y-line. Private.
YSQD1	This is convenient storage for y^2 of the previous y-line. Private.

PTRANS

Variables defined in the STEP, SCAT, or STRANS lists are given first.

ALPHA(3)	H2(3)	KOOOFX(3)	TG1(2)
C(3)	H4(2)	LDF(2)	TG2(2)
DHNU(3)	I(3)	LRI(2)	TR(3)
FL(3)	IALPHA(1)	PR(3)	TRDBG(1)
FMU(1)	IAX(3)	RHO(3)	X2(3)
FS(1)	IBX(3)	R1(1)	X6(2)
FSM(3)	IBXP1(3)	R2(1)	X8(3)
FSP(3)	IM(3)	SOLID(18)(3)	Y2(2)
F2(2)	IN(3)	SUMX3(3)	
GL(3)	IZN(2)	SUMX4(3)	
HNU(3)	I1(1)	S1(1)	
HNUP(3)	I2(1)	TG(3)	

IA	The left-hand (interior) zone index of the SPUTTER vapor region. Since this may not correspond to the left limit of the radiation region, IN (defined in RAD) should be used and not redefined (perhaps erroneously) in PTRANS. Code revision is needed here. Blank Common.
ICX	The right-hand zone limit of region with source. Set to IM in RAD, it is retained solely to procrastinate on cleanup in PTRANS. DAVIS Common.
ICY	The left-hand zone limit of region with source. See ICX. DAVIS Common.
IMP1	IM+1. See IM(3). Private.
INM1	IN-1. See IN(3). Private.
JJ	The index of a characteristic line, analogous to the y-line index JJ(3). Maximum legitimate value is 5. Private.
JJJ	JJ+1, used in the transport debug print. Private.
LMDA(37)	The input quantity specifying the number of characteristic lines to be used (a maximum of 6). Blank Common.
NGS	The index of Gauss weights. See RR. Private.
NMU	The index of angles. See RR. Private.
NY	The upper limit to JJ, set to LMDA(37)-1. LINDLY Common.
RR	The plane transport calculation is a scheme of evaluating intensities along characteristic lines and integrating these (forming the moments) by the "double Gaussian" method, where special weighting quantities corresponding to the angular intervals are stored. A table of average angles and corresponding Gauss weights for 2, 3, 4, 5, and 6 angular intervals is stored by DATA statement in RR and used in the finite sum formulation in the code. There are 40 entries. Private.
TEMP(1)	This is $1/2\ \rho\kappa\ \Delta x$, one-half the slant optical depth, calculated in the case of no source, an option now eliminated. See ICX, ICY, and p. 79 of this report. A code cleanup would delete reference to TEMP(1). Blank Common.

RAD

Variables defined in SCAT, STEP, STRANS, or PTRANS are given first.

A1(1)	FQ0(1)	IBX(3)	SOLID(36)(1)
A3(1)	FQ1(1)	ICX(4)	S1(1)
C(3)	FQ2(1)	ICY(4)	TG(3)
CNT1(3)	FQ3(1)	IHNU(1)	THICK(3)
CSQD(3)	GMP(1)	IM(3)	TR(3)
DHNU(3)	H(2)	IMP1(4)	X(3)
FI0(1)	HNU(3)	IN(3)	X2(3)
FI1(1)	HNUP(3)	INM1(4)	X6(2)
FI2(1)	H2(3)	KX(3)	Y(3)
FI3(1)	I(3)	PR(3)	Y2(2)
FL(3)	IALPHA(1)	RHO(3)	
FMS(1)	IAX(3)	SOLID(18)(3)	

A — The SPUTTER area term, $\alpha r^{\alpha-1}$, a zone array, used in calculating the radiation flux at the external boundary for either diffusion or no vapor. Blank Common.

A1P — This is the intermediate quantity $h\nu_j^2/m_e C^2 \Delta\nu_j$ in Eq. (31). Used in forming A1. Private.

BETA — The quantity $h\nu/\theta$, often represented by the variable u. In this case, $h\nu$ is the minimum photon energy for the current frequency group. Private.

BETAP — The quantity $h\nu/\theta$, where $h\nu$ is the maximum photon energy for the current frequency group. Private.

BLANK3 — Used in radiation supercycling. If the time step calculation in RAD calls for supercycling, BLANK3 is set to the current time plus whatever is allowed for the supercycle. Blank Common.

CAPAC	κ_{Planck}, evaluated in KAPPA or one of its subroutines and used in RAD. CAPAC(150-152) is reserved for special input quantities. See p. 86 of this report. Blank Common.
CAPAR	$\kappa_{Rosseland}$, evaluated in KAPPA or one of its subroutines and used in RAD. CAPAR(121-150) used for up to 15 frequencies of "OUTPUT-output" flux rates and fluxes accumulated over time. This rather clumsy storage mechanism sets an upper limit of 120 zones and 15 frequencies for problems run on the OUTPUT code.
CNTMAX	This is the SPUTTER cycle limit and is tested so that, assuming one wants a multifrequency print with the regular SPUTTER print, a print is obtained for the last cycle. Blank Common.
CPA	This is the Rosseland κ with scattering, adjusted for Compton scattering if appropriate. Used in forming the optical depth arrays. Private.
CPB	This is the Planck κ with scattering, used in forming the $H^{(2)}$ and $H2^{(3)}$ arrays if SOLID(10) is zero. Private.
CPC	This is the Rosseland κ with scattering, not adjusted for Compton scattering. Private.
CV	This is the array of C_v, specific heat, calculated elsewhere in SPUTTER and used in RAD to formulate the stability time step. Blank Common.
DFB	The portion of the area of the Planck function, normalized to 1, occupied by the current frequency group at a given temperature. Private.
DHNUP	The width of the previous (next higher) frequency group, used in calculating $A3^{(1)}$. Private.
DTH2	The current SPUTTER time step, set in the TDELT routine. Blank Common.
DTR	The time step that governs RAD. This is usually set to DTH2 in TDELT, but is set smaller in RAD if subcycling is called for, such that the SPUTTER master time step is an integral multiple of DTR. Blank Common.

DTRMIN	The actual minimum radiation time step calculated in RAD. This is then used to determine whether subcycling or supercycling is necessary. Blank Common.
DTR1	A "running minimum" time step, set so that at the end of the loop, the smallest and the next-to-smallest time step can be saved. Private.
DTR2	A "running second-smallest" time step, corresponding to DTR1 above. Private.
E	The SPUTTER zone array for internal energy per unit mass, used in the time step energy accuracy calculation. Blank Common.
EC	This is the heating rate due to conduction, zeroed out at the end of RAD to avoid later trouble. Blank Common.
EDITMF	The multifrequency edit flag, equivalenced to S12 in Blank Common. It should be noted that one sometimes wishes to get "multifrequency" prints when running grey problems. Some of the intermediate quantities printed out are of general interest and value in troubleshooting.
EK	This array is used to accumulate radiation energy density over frequency, serving the same purpose as the old variable SUMRHO (see Ref. 2), now deleted. $RHO^{(3)}$ is set to EK after exit from the frequency loop. Blank Common.
ELM	This is a special array of internal energy in a "lambda region" (see Ref. 3). It is used in RAD to form quickly the total internal energy in the radiation region for use in the time-step calculation. See WSB, WSBB. Blank Common.
EO	A special storage for the index of the zone which has the smallest radiation time step. Used in PRINT. Blank Common.
ER	The heating rate due to radiation transfer. While the radiation energy density and radiation pressure are used elsewhere in the code, and the flux is edited and viewed with interest, it is safe to say that calculating ER is the basic purpose of RAD and its subroutines. Blank Common.

FIOSV	Temporary storage for FIO while testing whether to iterate. Unfortunately, the third character is a letter "O," not a zero. Private.
FI1SV	Temporary storage for FI1 while testing whether to iterate. Private.
FI3SV	Temporary storage for FI3 while testing whether to iterate. Private.
G	This SPUTTER array of mass per volume factor is used in converting energy per unit mass to energy preparatory to calculating the energy accuracy time step. Blank Common.
GAMMA	This is the intermediate quantity $\overline{\gamma}$ defined beneath Eq. (15). Private.
GL	This is the right (exterior) boundary flag, specifying blackbody exterior if GL = 1/2, vacuum otherwise. STRANS and PTRANS initialize a blackbody intensity for any positive value of GL (see $GL^{(3)}$). There are historical reasons for the inconsistency, but it is not justified. Blank Common.
GR	Maximum allowed number of radiation supercycles. Blank Common.
HCB	See p. 87 of this report. Blank Common.
HHTAX	This is $2\ \kappa_s\ \overline{\gamma}$, used to adjust the absorption coefficient for Compton scattering. See Eq. (33). Private.
HNUP4	The fourth power of the upper limit of photon energy for the current frequency group. Perhaps it is not used in the current version of RAD. Private.
HNUX	Set to the minimum of $HNUP^{(3)}$ and 10^5 to avoid execution of Compton scattering at invalid frequencies. Used in forming $A3^{(1)}$. Private.
HNU4	The fourth power of the lower limit of photon energy for the current frequency group. This, like HNUP4, may be expendable. Private.
H3	This is $1/2\ \rho\ \kappa_R\ \Delta r$, where κ_R is the local Rosseland mean absorption coefficient adjusted for scattering. Used only in RAD. The array $H2^{(3)}$ is set to H3 if SOLID(10) is nonzero. Equivalenced to BR in Blank Common.

IA	The left-hand (interior) zone limit to the vapor region. IN(3) is set to it unconditionally in this version of RAD. IN can take on other values, if the programmer wishes to confine the radiation region to only part of the vapor (e.g., the part in local thermodynamic equilibrium), but this would require a small programming change. Blank Common.
IB	The right-hand (exterior) zone boundary limit to the vapor region. For generality, this should be replaced by IMP1(4). Blank Common.
IBM1	This is IB-1, the right-hand (exterior) zone limit to the vapor region. IM(3) set unconditionally to IBM1 in this version of RAD. Blank Common.
ICXM1	This is ICX(4)-1, evaluated as a separate variable solely for use as the upper limit of a DO statement. Private.
IDMX	The dimension limit for the X array, currently 4000. When testing an index against a dimension limit in the body of a computer program, it is good practice to have this a variable set at the beginning of the code to facilitate later changes in the size of the array. Private.
IJZILC	Purpose unknown. Private.
IMN1	This is the index of the zone with the smallest radiation time step. EO is set to IMN1. Private.
IMN2	This is the index of the zone with the second-smallest radiation time step. Private.
INP1	This is IN+1 defined solely to serve as the lower limit of a DO loop. Private.
IQEM	The index of the zone boundary suffering the worst change in FIO. Used in monitoring the scattering iteration. Private.
IR	The index of the rightmost (exterior) zone for which one wishes to calculate radiation. In reference 2, IR is set and used, but not discussed. In the fireball configuration, it was desired not to do radiation for zones colder than, say, 0.05 eV. IR was set to the index of the outermost zone warmer than that. The code is now in the rather hazardous situation that IR is set to IM if one does scattering or has a blackbody exterior. Otherwise, it is not evaluated at all. This should be repaired. Private.

J	A y-line index while the $X^{(3)}$ array is being formed. Also used as a zone-boundary index while enlarging the transport subregions by five mean free paths on each side. Private.
JDRUM	The logical unit, either 25 or 26, of the drum being read for moment quantities. PALMER Common.
JDRUMI	The logical unit, either 26 or 25, of the drum on which moment quantities are being written. Private.
JK	The y-line index advanced while y-lines are being formed. Private.
K	A counter, used as other than zero only if more than 4000 entries in the X array are required to place a y-line every zone. The code will successively try to place a y-line every $(K+1)^{st}$ zone until K reaches 10, at which point the code aborts. Private.
KK	A zone-boundary counter advanced as the X array is formed for a given y-line. Private.
KKK	A special index to insert the number of X entries for the current y-line into the X array. Private.
KMAX	The multifrequency flag. Zero, grey; nonzero, multifrequency. This is a standard SPUTTER input quantity. Blank Common.
K000FX	This divide check flag has zeros, contrasting with $KOOOFX^{(3)}$. A genuine holdover from the days of SIFT. Private.
K1	A counter to skip zones so that a y-line is drawn every $(K+1)^{st}$ zone. See K above. Private.
LMDA(37)	Same as $LMDA(37)^{(4)}$, but used in RAD for definition of external input intensities, a feature deleted from the OUTPUT code. (See page 81 of this report.) Reference to LMDA(37) should be removed from RAD. Blank Common.
MAXLM	The number of lambda regions. Used in calculating WSB from ELM. Blank Common.
NHNU	The number of frequency groups, specified in the OUTPUT code by LMDA(36). See p. 86 of this report. LINDLY Common.
NMU	The number of characteristic rays in plane geometry. Set to LMDA(37). The FORTRAN statement that does this should be removed. Private.

NRAD	The number of radiation subcycles, set at the end of the time-step calculation if appropriate. Abort if NRAD > 50. Blank Common.
NSMLR	Set to 1 at the beginning of RAD, it appears never to be used or reset. The statement should be removed. Blank Common.
NY	The number of y-lines if spherical geometry. LINDLY Common.
Q	A dummy variable, it is $\Delta\tau$ (optical depth) in defining source gradients for forced diffusion and serves as the normalized "OUTPUT-output" flux. Private.
QD	The denominator in the relative difference expression for FIO, the iteration test. Private.
QE	The relative difference of FIO, tested against CAPAC(150). See p. 86 of this report. Private.
QEM	The largest of the QE's. Used along with IQEM to monitor the iteration. Private.
QN	The numerator in the relative difference expression for FIO, the iteration test. Private.
QQ1	This is $\rho\Delta r$, the formulation of which is geometry-dependent. Used in forming optical depths. Private.
Q1	A zone array of θ^4, used to avoid calculating θ^4 within the frequency loop. Very dispensable if one is tight for storage. Equivalenced to PB in Blank Common.
Q3	Integrated optical depth, a zone array used only in the section expanding transport subregions by five mean free paths on each side. See subsection 3.2 of reference 2 and p. 80 of this report. Equivalenced to GOFR in Blank Common.
Q31	A running integrated optical depth. Quite dispensable. Private.
Q37	Zone array for log θ, used in linear-in-log interpolation for multifrequency absorption coefficients in DIANA. Equivalenced to CAR in Blank Common.
Q38	Zone array for -log ρ, used similarly. Equivalenced to CHIR in Blank Common.
RD	The SPUTTER array of velocity, used in computing the radiation work term portion of the heating rate. Blank Common.

RDD	Used to store radiation energy density calculated on the previous cycle. Blank Common.
SLUG	The fraction of the internal energy of a zone allowed to leak out (or be added; the latter is causing difficulties) of a zone in the time step calculated in the energy accuracy criterion. An input quantity, usually set to 0.1. Blank Common.
SMLR	Radiation pressure, summed over frequency, formed in RAD, used in HYDRO. Blank Common.
SOLID(10)	The Planck-Rosseland switch. Zero, Rosseland; nonzero, Planck. A standard SPUTTER input quantity. Blank Common.
SOLID(37)	See p. 86 of this report. Blank Common.
SUMX2	The sum over frequency groups of $X2^{(3)}$. X2 is set to SUMX2 at the end of RAD. Equivalenced to CRTR in Blank Common.
SUMX3	Same as $SUMX3^{(3)}$. Zeroed in RAD for no good reason.
SUMX4	Same as $SUMX4^{(3)}$. Zeroed in RAD for no good reason.
SV	The specific volume, $1/\rho$, a regular SPUTTER zone array. Used in forming optical depths. Blank Common.
TAUX	See the discussion of SOLID(37) on p. 86 of this report. TAUX is added to the absorption coefficient, so it is zero if SOLID(37) is negative; otherwise it assumes the value of SOLID(37). Private.
TAX	This is $2\kappa_s/m_e c^2$. See HHTAX. Private.
TD	A variable set in MP2 as a print flag. Used in RAD to make the multifrequency print coincide with the regular SPUTTER print. Blank Common.
TELM(25)	An input quantity to adjust the time step by a constant factor. Blank Common.
TELM(26)	Set to DTR1. Blank Common.
TELM(27)	Set to IMN1. Blank Common.
TELM(28)	Set to DTR2. Blank Common.
TELM(29)	Set to IMN2. Blank Common.

TELM(30)	The advanced cycle number, making CNT1(3) redundant. Blank Common.
TEMP(1, 2, 3)	Used as intermediate quantities in the time-step calculation. Blank Common.
TH	The SPUTTER variable indicating time. Used in evaluating BLANK3. Blank Common.
THETA	The zone array of temperature in eV. Blank Common.
THETAK(103)T4	See p. 86 of this report. Blank Common.
THTAMX	The highest temperature in the problem, formerly used in evaluating IR. Its sole purpose now is to bypass the radiation calculation for problems colder than 0.05 eV throughout. Private.
TSI	Used in calculating X values to indicate the point of closest approach if negative, or x if positive. Private.
T4	The scattering moment iteration counter. Compared with CAPAC(152). See p. 86 of this report. Private.
WSB	The total internal energy in the problem, used in the energy accuracy time-step criterion to ignore zones whose internal energy is less than 0.001 WSB. Private.
WSBB	The internal energy of a zone in the energy accuracy time-step calculation. Private.
X3	An array of flags to define the transport and diffusion subregions. If for a zone X3 is -1, the zone is in a diffusion region. If X3 = 0., the zone is in a transport region. Other values of X3 are nonsense. Blank Common.
X4	Used to denote y^2 for each y-line formed. Later zeroed and used by equivalence in PTRANS and STRANS. Blank Common.
ZP1(18)	Another place for the SPUTTER time step, used in calculating NRAD and DTR if there is to be radiation subcycling. Blank Common.
ZZ	A flag in the scattering moment iteration test. If any zone requires iteration, the flag is turned on. Off: ZZ = 0. On: ZZ = 1. Private.

APPENDIX I

THE OUTPUT CODE AS A MODIFICATION OF SPUTTER

INTRODUCTION AND SUMMARY

The OUTPUT code is a version of SPUTTER (Ref. 3) that is adapted to a special class of problems. Radiation transfer is especially important in determining the behavior of such problems, and the OUTPUT code differs from SPUTTER primarily in its more sophisticated treatment of radiation transfer and in the deletion of space-consuming portions of SPUTTER that deal with matter in the solid state. It should be borne in mind that the OUTPUT code is under development and is continually being changed. Any description of it will therefore rapidly lose accuracy of detail, and major changes made in the near future may go unreported for some time. However, the present configuration is a convenient one to describe thoroughly. Since a large fraction of the content of the OUTPUT code has been described in earlier reports (Refs. 2, 3), much of the material presented in this appendix pertains to changes made in the older programs. Three areas of the OUTPUT code are discussed: (1) changes in SPUTTER subroutines, other than radiation subroutines, (2) changes in the radiation routines, and (3) progress in treating Compton scattering. Changes now in progress include input quantities whose use differs from their use in standard SPUTTER and the abort indicators.

CHANGES IN SPUTTER SUBROUTINES OTHER THAN RADIATION SUBROUTINES

Altered Routines

MP2

This routine has been changed to eliminate references to CNDCTN and the boil codes, which have been deleted. Another change eliminates division by BLANK1 when it is zero. This change has also been incorporated in the standard SPUTTER code.

HYDRO

A small section that does "dummy hydro" (sets C and DELTAR to their appropriate values, but makes no changes in radii or velocities) has been added. This section is executed if S4 is negative. The option is very useful when one wishes to observe the effects of radiation transfer in a static configuration. Changes to delete references to solid material regions and permit the use of more accurate radiation pressures available from the OUTPUT radiation routines are now under development.

EOS

This routine has been changed to incorporate the actual radiation pressure, rather than an equilibrium diffusion approximation. Reference to ZPART, an array of 760 words not used by the OUTPUT code, has been deleted.

ECALC

Changes to eliminate treatment of solids and improve the precision of the source treatment are under development.

RTAPE

This routine, which picks up the desired configuration from the SPUTTER dump tape, has been modified to pick up additional data (moment quantities and, in the future, intensities) and set up the drum storage for them.

WTAPE

This routine does the write operations corresponding to RTAPE. Also, on initial starts, where there are no data to pick up, the drum storage is set up and appropriate starting values are written.

KAPPA

A change has been made to catch division by zero before exit. This may become standard.

KAP6

This routine, which is valuable in test problems, uses the THETAK array to define the frequency table and a corresponding set of absorption coefficients (independent of temperature and density) without using a DIANE tape. It is not available in the standard SPUTTER code.

KAP12

This routine gives an analytic approximation for the grey absorption coefficient of uranium as a function of temperature and density. It is not available in the standard SPUTTER code.

QUE8

This source routine deposits energy (evaluates SMLQ) into a predetermined set of contiguous zones, the energy being distributed uniformly over "mass space." The rate varies stepwise with time. The RDK array is used as input for the zone limits, the time cuts, and the energy deposition rates.

QUE9

This source routine is similar to QUE8, except that it allows for several (up to seven) regions or sets of contiguous zones, each of which has its own set of time cuts and energy deposition rates. RDK storage limits require that no region have more than six distinct time sections.

QUE10

This source routine is like QUE8 in that it allows only one region. But instead of the energy source being distributed uniformly, it is distributed as some power of the space variable, the exponent being determined by values of the energy deposition rate specified at the limits of the region.

DIVCHK

This is a machine-language routine which makes a report each time a division by zero is made. It is handy to have if one still wishes to abort the run when such a division occurs; in addition, there is a report precisely indicating where the division occurred. This routine, which was written by the Gulf General Atomic systems group, is not generally available or widely advertised, because it carries with it the hazard of uncontrolled computer behavior should the routine be overlaid by other coding subsequent to a call to it. The OUTPUT code precludes this possibility.

The MAP

All large programs on the UNIVAC-1108 make use of the MAP (Memory Allocation Processer) to fit their coding into the available storage with appropriate overlays. The SPUTTER and OUTPUT codes are no exception. The OUTPUT MAP differs from the SPUTTER MAP as follows:

1. DIVCHK is explicitly represented at the independent level with no overlay possible. (SPUTTER does not have DIVCHK at all.)
2. RADTN is segmented along with MP2, allowing an overlay with MP1, rather than being independent.
3. NAMEC (a name common block used only in MP1 and its subroutines) is segmented with MP1, so as to allow overlay with MP2, etc.
4. The overlay of the KAP routines has been deleted because, for reasons that are not now clear, it does not function properly. The storage penalty this causes has been minimized.

5. Several USE cards are provided for those routines bearing the same name as standard, undeleted SPUTTER routines.

Deleted Routines

The standard SPUTTER subroutines CNDCTN, BOIL, and CBOIL have been deleted, as have references to them in MP2. NONEQ and some other subroutines may soon also be deleted.

Dummy Routines

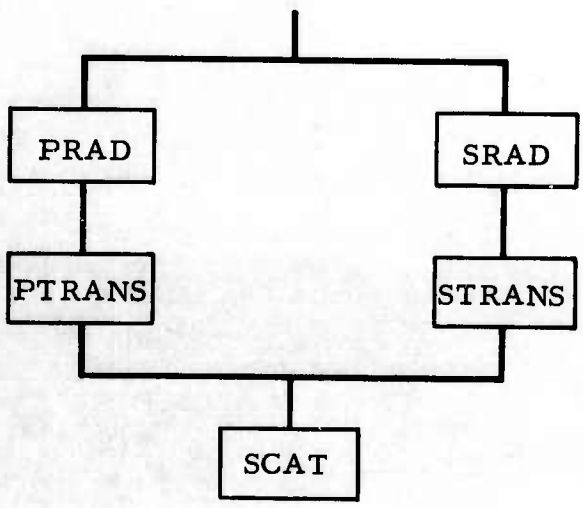
It has been convenient in several instances to write dummy subroutines with the same name as standard SPUTTER subroutines, since outright deletion of the latter would require extensive changes elsewhere in the code. The standard subroutines and the reasons why they are undesirable are as follows:

1. DRAD, ERAD, QUE4. These refer to a 642-word array not needed by the OUTPUT code.
2. QUE16, NONEQ. These refer to a 760-word array not used by the OUTPUT code. NONEQ, furthermore, has nearly 300 words of private data storage.
3. CMOL, KAP5. Both have considerable private data storage.

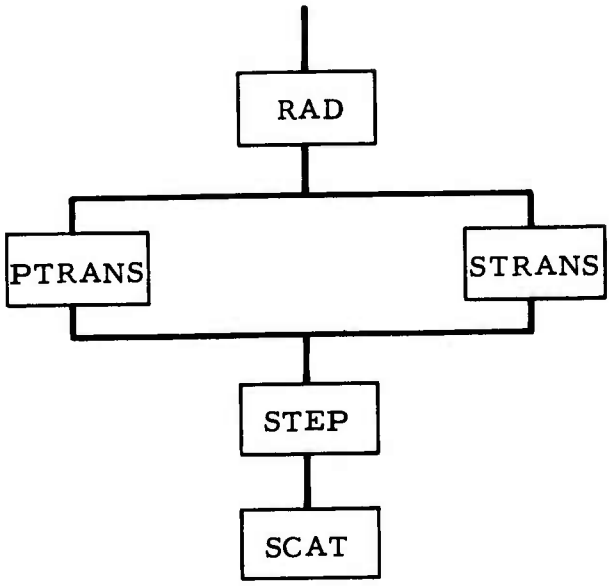
CHANGES IN RADIATION ROUTINES

Two substantial changes in program organization have been made in the past few months. (1) The codes PRAD and SRAD, executed for plane and spherical geometry, respectively, have been replaced by one code, RAD. The two codes were over 90 percent the same, line for line, and considerable duplication had taken place in maintaining them. The necessary allowances for geometry were incorporated, and the codes were unified. This change has been made both in the standard SPUTTER and the OUTPUT codes. (2) In PTRANS and STRANS, the coding to solve the transport equation was repeated many times and in several forms to allow for different

configurations. (See the STRANS program listing in reference 2.) Considerable duplication of effort has resulted because scattering led to considerable changes in these codes, other minor changes are made from time to time, and more sophisticated solutions of the transport equation are being coded. The advantages of solving the transport equation in only one place in the code became more apparent. The new subroutine, STEP, solves the transport equation in general form for one increment along a characteristic line. Calls to STEP have been incorporated in STRANS and PTRANS. The data block COMMON/JIM/, originally provided for linkage between the transport routines and SCAT, has been expanded by six words to accommodate STEP. The call hierarchy of the radiation routines was formerly as follows:



The new hierarchy, which results in considerable reduction of program storage and much more understandable codes, is as follows:



STEP has been added only in the OUTPUT code.

Another change made in both the standard SPUTTER and the OUTPUT versions of RAD is the elimination of several input parameters. The deleted parameters are described briefly in table II and in detail in reference 2. Some of the parameters listed in reference 2 were assigned different SPUTTER variable names after the reference was issued. The more recent names are also given in table II. In some cases, the option involving the parameter has been removed altogether, and for these no "built-in" value is given. Instances where built-in values differ from the suggestions in reference 2 reflect experience in running problems.

Two rather substantial deletions have been made in the OUTPUT version of RAD. (1) ICX and ICY have been eliminated as special indices indicating sourceless subregions of the radiation region. This eliminates quite a bit of complicated branching, and the time saved by doing simpler calculations in sourceless regions, although substantial in some configurations run on standard SPUTTER, would be insignificant in most applications of the OUTPUT code. (2) The multifrequency merge procedure

TABLE II

DELETED VARIABLES

Name Used in reference 2	Recent name(s)	Value suggested in reference 2	Built-in value	Purpose
CB*	DELPRT	0	---	Brightness print (option deleted)
GA	GA	0.33	0.333	Source, optical depth gradient criterion (TG)
GL	GA, GR, (0.333)	0.3	---	Source, MFP gradient criterion (y-lines, option deleted)
CMIN	AC	0.3	--(∞)	Minimum depth for TG criterion (option deleted)
ACO3T4	TA	0.1	0.01	Half-optical depth for thick-thin transition
S15	S15	1	---	Restart on grey calculation, not needed with current DIANA
TELM(37)	TELM(37)	0.005	0.001	Fraction of total energy in zone for time-step criteria
CVB	CVB	0	0.5	Select y-lines
HVB	HVB	5	5	Buffer of transport region in number of mean free paths
HCB	HCB	0.1	0.1	Diffusion criterion
Not mentioned	BOILB = NTIMES	--	50	Subcycle limit

*CB is currently used in standard SPUTTER as a multifrequency merge criterion, replacing the constant 10.0 in reference 2. The OUTPUT code has no frequency merging.

has been taken out. Although it may save time in some applications, no provision for merging has been made in the scattering coding. The variable CB, of course, is now not used in the OUTPUT code. Another, less significant feature deleted in the OUTPUT code is the provision for external nonthermal radiation intensities as an energy source in plane geometry.

A major addition to RAD is the calculation of the moment quantities, used as scattering source terms in the SCAT routine, first reported in reference 7. An iteration procedure to obtain better values of the moment quantities at cycle (n + 1) (the scattering equation is implicit in this respect), described in section 1 has been incorporated. The FQ0, FQ1, FQ2, and FQ3 arrays should not be updated inside the iteration loop, since they are the moment quantities for the previous frequency. This error would cause trouble only in Compton scattering. The updating has been moved outside the iteration loop, and the scheme now works well for both Thomson and Compton scattering. The choice of three words at the end of the CAPAC array as input parameters to control the iteration has been retained. These are described in "Input Quantities" of this appendix. However, the size of the array is the standard SPUTTER value of 152.

The X array, the set of all values $x_{ij} = \sqrt{r_i^2 - y_j^2}$, is calculated early in RAD to avoid taking many square roots within the frequency loop. In reference 2, this array was given 2400 words of essentially private data storage. (This would allow 66 zones if a y-line were drawn at each boundary.) In the standard SPUTTER version of RAD, the X array is stored in 1064 words of SPUTTER Blank Common, allowing for 41 zones with y-line every zone. Since OUTPUT calculations will have many zones as a result of complex configurations, and since accuracy in the scattering calculation requires a y-line at every boundary, the private storage has been reinstated in the OUTPUT code; this storage is 4000 words, allowing for 86 zones. The

scratch area in SPUTTER Blank Common made available by this change has been taken up by intermediate moment quantities and scattering parameters.

Three variables used in the Compton scattering calculation are dependent only on frequency and not on position:

1. $$GMP = 1 - 2\gamma \text{ , where } \gamma = \frac{1/2(h\nu_- + h\nu_+)}{m_e c^2}$$

2. $$A1 = \frac{h\nu_-^2}{m_e c^2 (h\nu_+ - h\nu_-)} + 3\gamma$$

3. $$A3 = \frac{h\nu_+^2}{m_e c^2 (h\nu_{++} - h\nu_+)}$$

Although evaluated in SCAT, they should be calculated only once per frequency in order to save time. This is done in RAD.

PROGRESS IN TREATING COMPTON SCATTERING

Satisfactory results have been obtained for a test problem with spherical geometry analogous to the test problem with plane geometry described in appendix IV. However, some interesting difficulties arose, which have not yet been resolved. At high frequency, for sufficiently large negative $dI/d\nu$, where I may be intensity or some moment quantity (these usually vary similarly with ν), the code will calculate a negative scattering intensity. At present, the code sets the negative intensity to zero and goes on. (There are input parameters to trigger a debug print or abort, or both.) The large negative $dI/d\nu$, with the concomitant negative intensities, has appeared in two different situations.

First, in the calculation of the highest-frequency group, the starting value for $I_x(\nu_j)$ is zero. This results in the appearance of negative intensities, but at least some sort of radiation field description is achieved. Two schemes

have been proposed for improving the formulation of $I_x(\nu_j)$. The better one will soon be chosen and incorporated in the code. However, this case of the first frequency is a rather artificial way of arriving at large negative $dI/d\nu$.

The other situation arose when an attempt was made to refine the frequency interval. The result was, for one frequency group, a bistable oscillation in the iteration procedure for obtaining updated moment quantities. It is believed that it arose in the following manner. First, given zero starting values for the moment quantities, the code had a positive $dI/d\nu$ and calculated scattering intensities, generating moment quantities appropriate for that frequency. Then the code noted that an iteration was necessary and set the "old" moment quantities to the "new" ones. (See "Input Quantities" in this appendix. CAPAC(151) was 0.) It proceeded to do Compton scattering, found large negative $dI/d\nu$, calculated negative intensities, set them to zero, generated zero moment quantities as a result, iterated again, and at the third pass was right where it started. While this may not be an exact description of what happened, it is probably close enough to indicate the trouble unambiguously. The "extrapolation switch" described in section II of this volume (CAPAC(151) in the code) could easily be used as an interpolation switch by assigning to it a value between 0 and -1. Interpolation is suggested by the fact that the first "crack" at a solution, resulting in large negative $dI/d\nu$, may have been an overshoot. This idea was tried out with CAPAC(151) = -0.5 and proved successful. There was no convergence difficulty in areas of negative $dI/d\nu$. However, at lower frequencies the convergence, while monotonic, was discouragingly slow. This suggests a possible frequency-dependent extrapolation switch.

In summary, Compton scattering in the OUTPUT code is at present a laboratory curiosity. It appears to work well, if not reliably, in an interesting test problem. (It takes about three times as long to calculate as Thomson scattering.) However, this tentative state should change shortly as experience is acquired in using Compton scattering in production

problems. It should be emphasized that Thomson scattering has been used for over six months to calculate complex problems, and a number of shortcomings, which appear only in unforeseeable configurations, have been found and overcome.

CHANGES IN PROGRESS

Several areas of current code development relevant to the OUTPUT code are not discussed in detail in this report. These include improvements in the nonequilibrium radiation diffusion code DRAD, incorporation of Compton scattering in DRAD, changes in the energy bookkeeping (routines ECHK and PRINT), and modifications to provide free drum input-output. Three other changes in the program are as follows:

1. Improved source interpolation in spherical geometry. The current code follows the original STRANS (Ref. 2) logic of step-or-linear interpolation of the source, with a linear-quadratic fit across the "top slice." This is being replaced with a linear-in-r^2 interpolation scheme developed by J. R. Triplett (Ref. 3). The option of a piecewise constant source, as described in reference 2, is retained. Each "step" along a y-line is divided into two intervals equal in r^2 to conform with the new interpolation scheme. Although this change has been essentially completely checked out, it is not included in this report.
2. The Sampson approximation of the average absorption coefficient, where $\bar{\kappa} = (b + \kappa_R)/(b + \kappa_p) \cdot \kappa_p$ and b varies as the integrated optical depth, appears to be a desirable first step toward a more sophisticated transmission function treatment than the one now being used.
3. Saving intensities. Future code development in several areas, e.g., retardation, more accurate calculation of moment quantities, and improved Compton scattering recipes, will require the storage

of the entire set of intensities calculated at cell-ray intersections. This change also was completed too late for inclusion in the present report.

For each frequency, given that the "x" storage ($x_{ij} = \sqrt{r_i^2 - y_j^2}$) for all values on one side of the plane of symmetry is 4000 words, the intensity store will require 8000 words of random access storage, plus 8000 times an upper limit to the number of frequencies for drum storage. This requirement can be met, but not economically on the UNIVAC-1108. (The UNIVAC-1108 has the odd feature of a 3/8-μsec fetch from opposite bank versus a 3/4-μsec fetch from same bank, so that it pays to put coding and data in opposite halves of the "almost-random access" fast storage.) The speed penalty can probably be minimized so as to be negligible on long, expensive problems by an adroit choice of what data are to be kept in the wrong half of the store. Other problems are definition of the appropriate set of intensities for a cell boundary treated by diffusion and definition of intensities for y-lines where a specific calculation is not made. At present, the OUTPUT code sets up a y-line at every zone boundary and calculates intensities along all of these. However, one might wish to run a problem with more than 86 zones, the maximum possible for less than 8000 intensities, or one might wish to skip y-lines to save time.

FORTRAN LISTINGS

Appendix III contains FORTRAN listings for the principal subroutines of the OUTPUT code: RAD, PTRANS, STRANS, STEP, SCAT, QUE8, QUE9, QUE10, HYDRO, RTAPE, WTAPE, and the MAP. For brevity, SPUTTER blank common, which is used in all the subroutines, is listed only in RAD. The equivalence table used in RAD, PTRANS, STRANS, and STEP is also listed only in RAD.

INPUT QUANTITIES

The input quantities listed below are (1) parameters used in the Compton and Thomson scattering treatment, (2) special parameters for the "OUTPUT-output," a special edit, and (3) various quantities used by the nonstandard source and opacity routines.

THETAK(103)	Required input. Sets value of HNUP. Compton scattering does not allow large values of HNUP. There is no safety coding, such as "if zero, set to 10^6." It must be entered.
SOLID(36)	Compton switch. If zero, Compton scattering is calculated; if nonzero, Thomson scattering.
SOLID(37)	Scattering coefficient. If negative, it is not added to the absorption coefficient from the DIANE tape, but the absolute value is used as the scattering coefficient. If positive, κ(DIANE) is assumed to be κ_a only, and κ_s = SOLID(37) is added. SOLID(37) = 0 would provide a very inefficient "no scattering" calculation.
LMDA(36)	Required input for NHNU. The subroutines WTAPE and RTAPE, which set up the drum storage for the scattering source terms and process these on a nonstandard SPUTTER dump tape, must know the value of NHNU before the DIANE tape is read. Using the dimension limit of 20 would avoid this, but would lead to inefficiencies. (MUST BE LOADED IN FIRST SET OF CARDS.)
CAPAC(150)	Scattering iteration convergence coefficient, usually 0.05.
CAPAC(151)	Scattering iteration extrapolation parameter, usually 0.5.
CAPAC(152)	Scattering iteration recycle limit. Zero, no iteration. Maximum allowed value is 8. Usual value is 4.
EPSI	Radius of OUTPUT sample tube.
LMDA(26)	Index of zone boundary at which OUTPUT sample tube is affixed.

CVB — If CVB is zero, negative scattering intensities are set to zero and the problem continues. If CVB is nonzero and a negative scattering intensity arises, the code calls UNCLE.

HVB — If HVB is zero, negative scattering intensities go unreported. If HVB is nonzero and a negative scattering intensity arises, a brief data report is given, and a y-line print is triggered.

HCB — The normal SPUTTER RAD meaning applies here. Negative forces diffusion; positive forces transport; zero lets the code decide.

RDK — This array is used in standard SPUTTER to provide input for the various source routines, and the OUTPUT code does the same.

QUE8: Energy is supplied uniformly in mass space within a defined region (i.e., all zones within the region receive a constant ergs/sec/gm) at a rate that varies stepwise with time. RDK(1) is the index of the first zone in the region; RDK(2) is the index of the last zone in the region. Up to 50 time cuts can be specified in RDK(3) - RDK(52). The 49 rates for the corresponding periods (in ergs/sec for the whole region) are given in RDK(54) - RDK(102). Energy source rate for t > RDK(52) is zero.

QUE9: This routine is similar to QUE8, except that the fine time definition is sacrificed for some spatial definition. Up to six different contiguous regions can be defined (seven bounding zone indices provided). Each has a separate set of up to six source rates and time cuts. Detailed input specification appears in the FORTRAN listing.

QUE10: Energy is supplied as g^{-x} in mass space, where g is a mass space coordinate and x is an exponent determined by the average energy rate and by the rate specified at the right boundary. The two rates are specified for each given period. Ten periods are allowed. Time cuts are given by RDK(3) - RDK(13), the average rates by RDK(54) - RDK(63), and the boundary rates by RDK(44) - RDK(53).

THETAK — This array is used as input to KAP6/JP. If one wishes to run a multifrequency problem without using a DIANE tape, one must specify the number of frequency groups and the boundaries, in eV, of the desired

frequency groups. KAP6 specifies these and also a constant absorption coefficient, independent of density and temperature, for each frequency group. Up to 20 frequency groups are allowed. THETAK(61) - THETAK(80) gives the lower boundary frequencies. THETAK(81) - THETAK(100) gives the absorption coefficients. THETAK(101) gives the number of frequency groups; THETAK(102) gives the grey absorption coefficient; and THETAK(103) gives the upper boundary frequency of the top group, as indicated on p. 86 of this report.

S1 FLAGS IN THE RADIATION ROUTINES

The SPUTTER code follows the practice of setting the variable S1 to some value and calling UNCLE in case of serious trouble. The integer portion of the S1 flag indicates the subroutine, and the four digits after the decimal point indicate the FORTRAN statement number. The S1 flags for the radiation routines in the OUTPUT code are listed and commented on below.

RAD

S1 Flag	Immediate Cause	Probable Remote Causes and Comments
13.0102	Zero or negative CAPAC or CAPAR (grey)	An opacity of interest has not been evaluated. This usually happens with untested KAP routines.
13.0112	Small Δt causes more than 50 radiation subcycles	Can be caused on first cycle by improperly set TELM(25) or SLUG, or any time by actual pathologies in CV, THETA, SV, or opacity, or simply by failure to start the problem with a small enough time step.
13.0150	Divide check	Division by zero. See the preceding DIVCHK diagnostic print for locations of divide instruction and divisor.
13.0119	K > 10	At least 10 attempts have been made to space y-lines so that x-storage is not overtaxed, and these have failed. A code change is necessary, or the problem must be rerun with fewer zones.

S1 Flag	Immediate Cause	Probable Remote Causes and Comments
13.0452	Divide check	Same as 13.0150.
13.0460	Negative INM1	Absurd. Indicates a radiation zone with zero or negative index.
13.0530	Zero or negative CAPAC or CAPAR (multifrequency)	See 13.0102
13.0652	Zero or negative optical depth	Something has gone wrong with the definition of H3 in the preceding lines of code.
13.0654	GL > 0.9, HCB < 0	An attempt is being made to force diffusion and provide external source intensities, two incompatible problem specifications.
13.0692	Divide check	Same as 13.0150.
13.0720	Positive X3	Absurd. Code sets X3 either zero or negative as a diffusion flag.
13.0962	IALPHA = 2	A transport calculation in cylindrical geometry is being attempted.
13.0982	IR < IM	Absurd in present code. IR set to IM earlier.
13.1070	Divide check	Same as 13.0150.

PTRANS

14.0100	Divide check	Same as 13.0150
14.0120	IALPHA > 1	Somehow PTRANS called for nonplane geometry. Absurd.
14.0160	INM1 negative	See 13.0460.
14.0350	GL > 0, GL ≠ 0.5	The external source intensity option has been deleted. GL therefore has a meaningless value.
14.0360	IBX > IM	Absurd. A portion of the transport region seems to be outside the radiation region.

STRANS

S1 Flag	Immediate Cause	Probable Remote Causes and Comments
14.0001	Divide check	Same as 13.0150.
14.0005	IALPHA ≠ 3	Somehow STRANS called for nonspherical geometry. Absurd.
14.0011	IBX > IM	See PTRANS 14.0360.
14.0087	y-line index out of range	The most likely cause for this stop is scrambled radii.
14.0152	Divide check	Same as 13.0150.
14.0171	IBX > IM	See PTRANS 14.0360.
14.0207	X(K) = 0.0	This is an absurd stop. Any occurrence of it in the OUTPUT code would have to be carefully examined for the cause.

STEP

No S1 interrupts appear in the program.

SCAT

75.001	Divide check	Same as 13.0150.
75.008	FS < 0, CVB ≠ 0	Negative scattering intensity with abort flag set. If HVB also ≠ 0, a diagnostic print is given.
75.0009	Divide check in SCAT	Same as 13.0150.

KAPPA

15.0500	Bad QLM (J + 17)	Improper optical property specification resulting in an attempt to call a non-existent KAP routine.
15.0810	Divide check	Same as 13.0150.

KAP6

S1 Flag	Immediate Cause	Probable Remote Causes and Comments

No S1 interrupts appear in this program.

KAP12

No S1 interrupts appear in this program.

APPENDIX II

DESCRIPTION OF INPUT FOR A SAMPLE PROBLEM

The debug test problem described in this appendix was run on the UNIVAC-1108 about September 15, 1967, and on the CDC 6600 at the Air Force Weapons Laboratory, Kirtland AFB, New Mexico, on September 22. The two runs matched within expected roundoff differences. The calculation was a multifrequency transport calculation with Compton scattering, using dummy hydrodynamics and the KAP6 opacity routine.

The problem consisted of a sphere with a radius of 10 cm, which contained 10 zones, with a temperature of 8 keV, and was surrounded by a shell with a thickness of 10 cm, which contained 20 zones, at a temperature of 600 eV. The density was taken as one in all zones, and the Rosseland opacity as 0.2 cm^2/g in all groups.

The input deck consists of SPUTTER Common input cards only, except for an initial header card which contains arbitrary identifying information in Columns 1-72. These Common input cards have the following format:

Col. 1: 1 denotes the last card of the deck and must appear on that card. 2 specifies that the data on the card will be converted to fixed point and appear as INTEGER variables in Common.

Blank (or 1) specifies that the data on the card will appear as REAL variables (floating-decimal form) in Common.

Cols. 2-6: Location relative to start of Blank Common in which the first data word on the card is to be stored.

Col. 7: Number of data fields on the card (maximum 7).

Cols. 8-70: Up to seven data fields, of nine columns each, contain numerical data to be read under the format OP7E9. 4. Blank fields generate zeros (unless they are excluded by the field number in Col. 7).

Cols. 71-80: Card identification information.

The test problem input deck is shown in table III. Each card, identified by its initial location number, is discussed below. Data fields containing 0. can, of course, be omitted, but are included in several cases for expository reasons.

68: FREQ gives the number of cycles between prints. CNTMAX, in 69, gives the cycle number at which the problem is to be terminated.

1: Zone-boundary indices for the "lambda" regions (which are usually regions of different materials). For one lambda region of 30 zones, the two limits, 1 and 31, are given.

19: LMDA(19) is a flag which, if >0, will trigger a complete print of Blank Common as if there were an error exit, even if the problem terminates normally. Since the extra information is often useful, setting LMDA(19) to 1 has become standard practice.

36: LMDA(36) is a special quantity specifying the number of frequencies. This is discussed further on p. 86 of this report. In the present case, there were 20 frequencies.

40: Several numbers are given on this card: the SPUTTER variables IA, IB, ICA, ICB, and KMAX, respectively. The nonzero value of KMAX dictates multifrequency. The other numbers, index limits, are required by the special XCARDS as a substitute for normal SPUTTER problem generation.

53: IG is another quantity needed by XCARDS. This is the extreme upper-limit index to the problem. When one remembers that SPUTTER has indices for upper limit to vapor, upper limit to solid, upper limit to radiation regions, upper limit to non-LTE region, etc., the significance of the term "extreme upper limit" becomes clear; and IG does serve a purpose.

65: TMAX is the problem time at which the problem is terminated. An absurdly large value is set here, since one wishes to limit the run by cycle count instead.

TABLE III

TEST PROBLEM INPUT DECK

COMPT	ON TEST --	20 FREQ	WITH CAPA	C(151) =	-0.2	SEPTEMBER	18, 1967	

Column

1	2-6	7	8-16	17-25	26-34	35-43	44-52	53-61	62-70	71-80
	68	3	5.0	20.						FREQCNTMAX
2	1	2	1.	31.						
2	19	1	1.0							LMDA(19)
2	36	1	20.							LMDA(36)
2	40	5	1.	31.	1.	31.	1.			
2	53	1	31.							IG
	65	1	1.0 +05							TMAX
	77	1	0.							CVB
	78	1	.1							SLUG
	79	1	3.0							ALPHA
	81	1	0.							HVB
	83	1	0.							HCB
	90	1	0.0							GL
	93	1	1. +10							RHOR
	100	1								
	107	1	1.0 -11							JC
	109	1	9.0 -09							TE
	115	3	1.0 -13	5.0 -10	1.0 -09					DTMAX1-2-3
	127	1	0.							TRDBG
	137	1	3.							S2
	138	1	1.0							S3 NO COND
	139	1	-1.0							S4 NO BOIL
	140	1	10.0							S5
	147	1	1.0							EDITMF
	151	1	0.0							
	160	7	0.	1.	2.	3.	4.	5.	6.	

(Table continued on next page)

TABLE III (continued)

COMPT	ON TEST --	20 FREQ	WITH CAPA	C(151) =	-0.2	SEPTEMBER	18, 1967	

Column

	2-6	7	8-16	17-25	26-34	35-43	44-52	53-61	62-70	71-80
1	167	7	7.	3.	9.	10.	10. 5	11.	11. 5	
	174	7	12.	12. 5	13.	13. 5	14.	14. 5	15.	
	181	7	15. 5	16.	16. 5	17.	17. 5	18.	18. 5	
	188	3	19.	19. 5	20.					
	2021	7	1.	1.	1.	1.	1.	1.	1.	
	2028	7	1.	1.	1.	1.	1.	1.	1.	
	2035	7	1.	1.	1.	1.	1.	1.	1.	
	2042	7	1.	1.	1.	1.	1.	1.	1.	
	2049	3	1.	1.						
	2325	7	8000.	8000.	8000.	8000.	8000.	8000.	8000.	
	2332	7	8000.	8000.	8000.	600.	600.	600.	600.	
	2339	7	600.	600.	600.	600.	600.	600.	600.	
	2346	7	600.	600.	600.	600.	600.	600.	600.	
	2353	3	600.	600.						
	7338	3	. 01	-0. 2	8.					CAPAC150-2
	8405	1	1.							
	8681	1	206.							
2	9405	1	1.							
	9332	7	76000.	72000.	68000.	64000.	60000.	56000.	52000.	
	9339	7	48000.	44000.	40000.	36000.	32000.	28000.	24000.	
	9346	6	20000.	16000.	12000.	8000.	4000.	.001		
	9352	7	. 2	. 2	. 2	. 2	. 2	. 2	. 2	
	9359	7	. 2	. 2	. 2	. 2	. 2	. 2	. 2	
	9366	6	. 2	. 2	. 2	. 2	. 2	. 2		
	9372	3	20.	. 2	80000.					
	8466	1	0. 5							TELM(25)
	8853	1	10. 0							SOLID(10)
	8884	1	0.							SOLID(36)
	8885	1	-. 1999							SOLID(37)
1	8882	1	0.							SOLID(34)

77: CVB, described on p. 87 of this volume, is set zero in this case because one knows that negative scattering intensities will arise in the first frequency group, and one wishes to ignore them.

78: This quantity, SLUG, is described on p. 71 of this report. Its normal value, 0.1, appears here.

79: ALPHA (see p. 17 of this report). Set 3. for spherical geometry.

81: HVB (see p. 87 of this report). Set zero to bypass debug print.

83: HCB (see p. 87 of this report). Set zero to let code decide.

90: GL (see pp. 58 and 67 of this report). Set zero to provide exterior vacuum.

93: RHOR. Special flag for air equation of state. Set big by habit. Not needed for this problem.

100: RPIA. If zero, radiation terms are added in the equation-of-state calculation. Normally set zero.

107: TC is the time before which DTMAX1 applies, and after which DTMAX2 applies.

109: TE is the time before which DTMAX2 applies, and after which DTMAX 3 applies.

115: The time step is usually controlled by physical considerations (e.g., hydro or radiation time-step controls). However, if the user feels that these might be too generous in some cases, he may specify an upper limit to the time step, one for each of three specified time intervals, namely, DTMAX1, DTMAX2, DTMAX3. Some number must be specified for these. In this problem, it was desired that a quasi-steady-state radiation field be established in a time short compared with cooling times. Since retardation is not included here, an arbitrarily small time step is indicated, and one was chosen.

127: TRDBG, otherwise known as AC03T4, described on p. 54 of this report. Set zero to avoid debug print.

137: S2 is the radiation flag, tested in MP2 and in the switching routine RADTN. A value of 2 means that RAD is to be called. Zero bypasses radiation altogether.

138: S3. Set nonzero to bypass conduction. Since the appropriate subroutine has been deleted from the OUTPUT code, this input quantity is unnecessary.

139: S4. Its original meaning, "don't call BOIL," has, with the deletion of BOIL, been changed to allow for "dummy hydro" or no motion if set negative. This was desired for this test problem.

140: S5. Used to indicate the logical unit of the SPUTTER dump tape. The value 10 is a typical one.

147: EDITMF, otherwise known as S12. Described on p. 66 of this report. Set to 1 to deliver the multifrequency edit.

151: S16. This is a flag that tells MP1 (the generator-setup-rezone section of SPUTTER) whether the problem is an "initial" or cold start or a "restart." Zero, the former; one, the latter. This problem is an "initial" start, where all parameters must be supplied by the user and a zero-cycle dump prepared. Hence the value zero.

160-188: R (radii) for the 31 zone boundaries.

2021-2049: SV (inverse densities) for the 30 zones.

2325-2353: THETA (temperatures in eV) for the 30 zones.

7338: These are the three parameters controlling iteration on the moment quantities. They are described on p. 86 of this volume and are also discussed on p. 83. It is stated on p. 83 that CAPAC(151) = 0. did not work, whereas CAPAC(151) = -0.5 worked well. CAPAC(151) = -0.2, which was used in this problem, proved even better.

8405: OKLM(1). This equation-of-state flag results in a call to EIONM5 for hydrogen. A suitable dummy material.

8681: The value 206. results in a call to KAP6, a special OUTPUT opacity subroutine described in Appendix A.

9405: MAXLM is the number of "lambda" regions in this configuration.

9332-9346: THETAK(61-80) is used by KAP6 to define the frequency groups.

9352-9366: THETAK(81-100) is used by KAP6 to define the opacities.

9372: THETAK(101-103) is used for KAP6 to define NHNU, the grey opacity, and the top frequency limit.

8466: TELM(25) (defined on p. 71 of this report). Set to 0.5 as a holdover from another problem. Not needed as long as the time step is held down by DTMAX1, 2, 3.

8858: SOLID(10) (defined on p. 71 of this report). Set nonzero for Rosseland opacities. Superfluous when KAP6 is used, as in this case.

8884: SOLID(36) (defined on p. 86 of this report). Set zero for Compton scattering.

8885: SOLID(37) (defined on p. 86 of this report). The peculiar value of -0.1999 is given so that $\overline{\kappa} > \kappa_s$ in all cases.

8882: SOLID(34), the starting cycle number. The 1 in Col. 1 indicates that input is complete. Contrary to normal SPUTTER generation, this style of problem specification has only one set of input cards.

A second test calculation has been carried out to test the sensitivity of the results to the parameter S4. The problem was as follows:

Region 1 $0 < r < 15$ cm

$\rho = 1.$

$\theta = 8-.433\ r$ keV

$\Delta r = 1.$ cm

Region 2 $15 < r < 150$ cm

$\rho = 31/r^3$

$\theta = 600$ eV

$g = 10$ (i.e., total mass of each zone is $4/3\ \pi \times 10$ g)

The Rosseland optical depth of Region 2 was 0.7. Three values of S4 were tried: 0.33, 0.5, and 1. The first of these effectively forces use of motion equation differencing based on Eq. (64) even in the diffusion limit. The singularity at $r = 0$, represented by the last term in Eq. (64), causes the velocity to diverge near the center, as shown in figure 7 for time 2.36×10^{-9} sec. The use of an S4 value higher than 1/3 allows the use of Eq. (63) in the central region, and more reasonable results are obtained. No significant difference between the results for S4 = 0.5 and 1.0 at low radii or between any of the results for $r > 4$ cm was noted. A calculation with a very small core radius would presumably indicate that the value 0.5 is superior, but additional work is required before this point can be established.

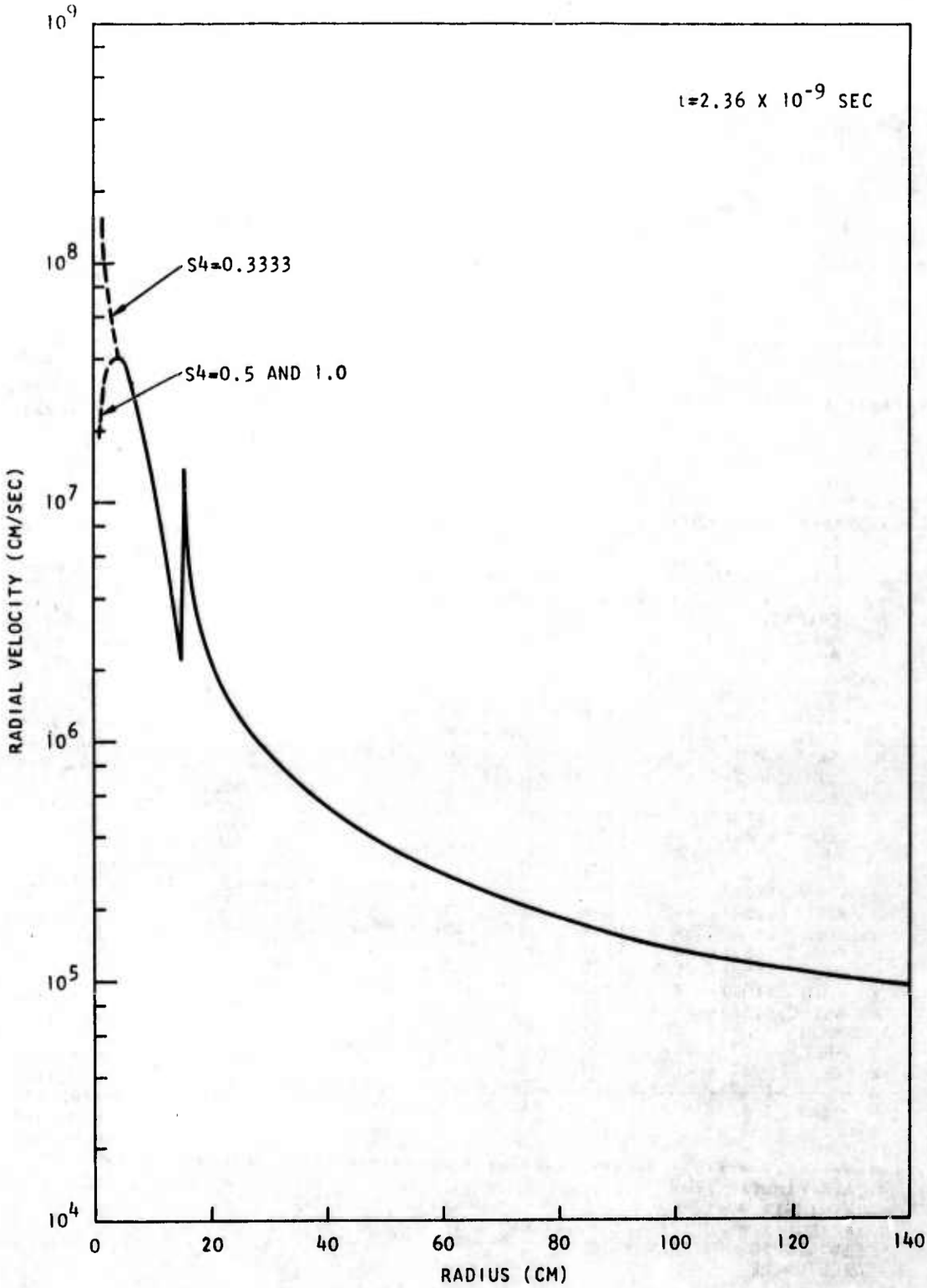


Figure 7. Dependence of Radial Velocity on Parameter S4

APPENDIX III

LISTING OF OUTPUT CODE ROUTINES

```
WIT FOR QUE8/OUT, QUE8/OUT, QUE8/OUT1
      SUBROUTINE QUE8
C     SPECIAL SOURCE FOR J. PALMER
C     RDK(1)= LEFT ZONE BOUNDARY
C     RDK(2)= RIGHT ZONE BOUNDARY
C     RDK(3-52)= TIMES FOR GIVEN EDOT
C     RDK(53-104)= EDOTS FOR GIVEN TIMES
C*************************************************************************KAP20070
C                                                                         *KAP20080
C*                    S P U T T E R   C O M M O N                        **KAP20090
C*                                                                       **KAP20100
C*                                                                       **KAP20110
      COMMON   LMDA(37), NR    , NSMLR , IA    , IB    , ICA   , ICB   ,KAP20120
     1   KMAX  , BLANK1, BLANK2, BLANK3, IAP1  , IBP1  , ICAP1 , ICBP1 ,KAP20130
     2   II    , IG    , NRAD  , BLANK4, IAM1  , IBM1  , ICAM1 , ICBM1 ,KAP20140
     3   IIP1  , IGM1  , IALPHA, BLANK5, TH    , TMAX  , BLANK6, DELPRT,KAP20150
     4   FREQ  , CNTMAX, AR    , ASMLR , PUSHA , PUSHB , BOILA , BOILB ,KAP20160
     5   CVA   , CVB   , SLUG  , ALPHA , HVA   , HVB   , HCA   , HCB   ,KAP20170
     6   EMINA , EMINB , CA    , CB    , GA    , GB    , GL    , GR    ,KAP20180
     7   RHOL  , RHOR  , EPIO  , EPSI  , RIA   , RIB   , RDIA  , RDIB  ,KAP20190
     8   RPIA  , RPIB  , RPDIA , RPDIB , TPRINT, TA    , TB    , TC     KAP20200
      COMMON     TD    , TE    , DTH2  , DTH2P , DTH1  , DTRMIN, DTMAX ,KAP20210
     1   DTMAX1, DTMAX2, DTMAX3, DTR   , SWITCH, CO    , CMIN  , DELTA ,KAP20220
     2   GAMA  , WCRIT , SIGMAQ, AC    , ACO3T4, CNVRT , SUMRA , SUMRB ,KAP20230
     3   ROIA  , ROIAM1, ROIB  , ROIBP1, GMS   , S1    , S2    , S3    ,KAP20240
     4   S4    , S5    , S6    , S7    , S8    , S9    , S10   , S11   ,KAP20250
     5   S12   , S13   , S14   , S15   , S16   , S17   , S18   , S19   ,KAP20260
     6   S20   , EO    , FO    , TAU   , ZERO  , R    (152), DELTAR(152),KAP20270
     7  ASQ   (152), RD    (152), VD    (152), RDD   (152), SMLR  (152),KAP20280
     8  DELR  ( 37), P     (152), P1    (152), PB    (152), PB1   (152) KAP20290
      COMMON         P2    (152), SV    (152), RHO   (152), THETA (152),KAP20300
     1  W     (152), E     (152), EI    (152), EK    (152), A     (152),KAP20310
     2  V     (152), G     (152), D     (152), C     (152), X2    (152),KAP20320
     3  X3    (152), X4    (152), X5    (152), X6    (152), X7    (152),KAP20330
     4  SMLA  (152), SMLB  (152), SMLC  (152), SMLD  (152), SMLE  (152),KAP20340
     5  EC    (152), ER    (152), SMLQ  (152), SMLH  (152), BIGA  (152),KAP20350
     6  BIGB  (152), CV    (152), BC    (152), BR    (152), CHIC  (152),KAP20360
     7  CHIR  (152), CAPAC (152), CAPAR (152), CRTC  (152), CRTR  (152),KAP20370
     8  CRTPC (152), GOFR  (152), FEW   (152), CAR   (152), OKLM  ( 37) KAP20380
      COMMON         TELM  ( 37), EKLM  ( 37), ELM   ( 37), FCLM  ( 37),KAP20390
     1  FRLM  ( 37), WLM   ( 37), QLM   ( 37), AMASNO( 37), CHRNO ( 37),KAP20400
     2  ZP1   ( 37), ZP2   ( 37), SOLID ( 37), ECHCK ( 37), RK    (104),KAP20410
     3  RL    ( 37), RHOK  (104), RDK   (104), THETAK(104), TEMP  ( 16),KAP20420
     4  HEAD  ( 12), MAXL        , MAXLM                                 KAP20430
C                                                                        KAP20440
C*                                                                      **KAP20450
C*************************************************************************KAP20460
      DATA FIRST/0./
      IF(FIRST) 40,10,40
   10 IF (RDK(1)* RDK(2) .GT. 0.1) GO TO 20
      S1=74.0010
      CALL UNCLE
   20 IL=RDK(1)
      IR=RDK(2)
      SUMG=0.
      DO 30 I=IL,IR
```

```
 30 SUMG=SUMG+G(I)
 40 DO 50 I=1,152
 50 SMLG(I)=0.
    T2= TH + DTH2
    IF(T2 .LT. RDK(3)) GO TO 1000
    DO 60 J=4,52
    IF(RDK(J) .GT. T2) GO TO 70
    IF(RDK(J) .EQ. 0.) GO TO 1000
 60 CONTINUE
 70 J= J-1
    SOLID(8)=RDK(J+50)
    IF(RDK(J) .LE. TH) GO TO 80
    TEMP(1)=(RDK(J)-TH)*RDK(J+49)+RDK(J+50)*(T2-RDK(J))
    SOLID(8)= TEMP(1)/DTH2
 80 CNVRT= CNVRT + SOLID(8)*DTH2
    TEMP(1) = SOLID(8) * .25873241 / SUMG
    DO 90 I=IL,IR
 90 SMLG(I) = TEMP(1) * G(I)
1000 FIRST= 1.
    RETURN
    END
```

```
@I FOR QUE9/JPB, QUE9/JPB, QUE9/JP1
      SUBROUTINE  QUE9
C*********************************************************************
C                                                                    *
C*                    S P U T T E R   C O M M O N                  **
C*                                                                  **
C*                                                                  **
      COMMON   LMDA(37), NR     , NSMLR , IA     , IB     , ICA    , ICB    ,
     1   KMAX  , BLANK1, BLANK2, BLANK3, IAP1   , IBP1   , ICAP1  , ICBP1  ,
     2   II    , IG    , NRAD  , BLANK4, IAM1   , IBM1   , ICAM1  , ICBM1  ,
     3   IIP1  , IGM1  , IALPHA, BLANK5, TH     , TMAX   , BLANK6, DELPRT,
     4   FREQ  , CNTMAX, AR    , ASMLR , PUSHA  , PUSHB  , BOILA  , BOILB  ,
     5   CVA   , CVB   , SLUG  , ALPHA , HVA    , HVB    , HCA    , HCB    ,
     6   EMINA , EMINB , CA    , CB    , GA     , GB     , GL     , GR     ,
     7   RHOL  , RHOR  , EPIO  , EPSI  , RIA    , RIB    , RDIA   , RDIB   ,
     8   RPIA  , RPIB  , RPDIA , RPDIB , TPRINT, TA     , TB     , TC
      COMMON     TD    , TE    , DTH2  , DTH2P , DTH1   , DTRMIN, DTMAX  ,
     1   DTMAX1, DTMAX2, DTMAX3, DTR   , SWITCH, CO     , CMIN   , DELTA  ,
     2   GAMA  , WCRIT , SIGMAQ, AC    , ACO3T4, CNVRT  , SUMRA  , SUMRB  ,
     3   ROIA  , ROIAM1, ROIB  , ROIBP1, GMS    , S1     , S2     , S3     ,
     4   S4    , S5    , S6    , S7    , S8     , S9     , S10    , S11    ,
     5   S12   , S13   , S14   , S15   , S16    , S17    , S18    , S19    ,
     6   S20   , EO    , FO    , TAU   , ZERO   , R    (152), DELTAR(152),
     7  ASQ   (152), RD     (152), VD     (152), RDD    (152), SMLR   (152),
     8  DELR  ( 37), P      (152), P1     (152), PB     (152), PB1    (152)
      COMMON         P2     (152), SV     (152), RHO    (152), THETA  (152),
     1  W     (152), E      (152), EI     (152), EK     (152), A      (152),
     2  V     (152), G      (152), D      (152), C      (152), X2     (152),
     3  X3    (152), X4     (152), X5     (152), X6     (152), X7     (152),
     4  SMLA  (152), SMLB   (152), SMLC   (152), SMLD   (152), SMLE   (152),
     5  EC    (152), ER     (152), SMLQ   (152), SMLH   (152), BIGA   (152),
     6  BIGB  (152), CV     (152), BC     (152), BR     (152), CHIC   (152),
     7  CHIR  (152), CAPAC  (152), CAPAR  (152), CRTC   (152), CRTR   (152),
     8  CRTPC (152), GOFR   (152), FEW    (152), CAR    (152), OKLM   ( 37)
      COMMON         TELM   ( 37), EKLM   ( 37), ELM    ( 37), FCLM   ( 37),
     1  FRLM  ( 37), WLM    ( 37), QLM    ( 37), AMASNO( 37), CHRNO  ( 37),
     2  ZP1   ( 37), ZP2    ( 37), SOLID  ( 37), ECHCK ( 37), RK     (104),
     3  RL    ( 37), RHOK   (104), RDK    (104), THETAK(104), TEMP   ( 16),
     4  HEAD  ( 12), MAXL         , MAXLM
C
C                                                                    **
C*********************************************************************
      DATA FIRST/0./
      N=RDK(101)
      IF(FIRST.GT..5) GO TO 25
      DO 20 K=1,N
      IL=RDK(K)
      IR=RDK(K+1)-1.
      RDK(94+K)=0.
      DO 10 I=IL,IR
   10 RDK(94+K)=RDK(94+K)+G(I)
   20 CONTINUE
   25 DO 30 I=1,152
   30 SMLQ(I)=0.
```

```
      DO 99 K=1,N
      T2=TH+DTH2
      IF(T2.LT. 1.E-20) GO TO 100
      M=10+(K-1)*12
      IF(T2.LT.RDK(M)) GO TO 99
      M1 = M + 1
      M5 = M + 5
      DO  40  J = M1, M5
      L = J
      IF(RDK(J).GT. T2) GO TO 50
   40 CONTINUE
      GO TO 99
   50 SOLID(8)=RDK(L+5)
      IF (RDK(L-1) .LT. TH)  GO TO 60
      Q = (RDK(L-1) - TH) * RDK(L+4)
      IF (L .EQ. M1)  Q = 0.
      TEMP(2) = (T2 - RDK(L-1)) * RDK(L+5) + Q
      SOLID(8)=TEMP(2)/DTH2
   60 CNVRT=CNVRT+SOLID(8)*DTH2
      TEMP(1)=.23873241*SOLID(8)/RDK(94+K)
      IL=RDK(K)
      IR=RDK(K+1)-1.
      DO 70 I=IL,IR
   70 SMLQ(I)=TEMP(1)*G(I)
   99 CONTINUE
  100 FIRST=1.
      RPIB=CNVRT
      RETURN
C
C
C
C     RDK(1)-RDK(7) CONTAIN BDRY OF SOURCE REGIONS
C     RDK(10)-RDK(15) CONTAIN TIME CUTS FOR FIRST GROUP
C     RDK(16)-RDK(21) CONTAIN RATES FOR FIRST GROUP
C
C     RDK(22)-RDK(27)- TIME   2ND GROUP
C     RDK(28)-RDK(33)  RATES
C     RDK(34)-RDK(39)  TIME   3RD GROUP
C     RDK(40-45)  RATES
C
C     RDK(46-51) TIMES  4TH GROUP
C     RDK(52-57) RATES
C
C     RDK(58-63)  TIMES 5TH GROUP
C     RDK(64-69)  RATES
C
C     RDK(70-75)  TIMES 6TH GROUP
C     RDK(76-81)  RATES
C
C     RDK(95-100) CONTAIN MASS OF EACH GROUP
C     RDK(101)  NO. OF  MATERIAL GROUPS
C
C     K IS SOURCE REGION INDEX
C     J, L ARE TIME CUT INDICES
C     M(K) IS THE RDK TABLE INDICATOR


C VEAT.  IF TIME EXCEEDS LAST CUT, SOURCE SET ZERO.
      END
```

```
@,T FOR QUE10/OUT, QUE10/OUT, QUE10/OUT1
      SUBROUTINE  QUE10
C MPILED JULY 18, 1967   JEZ
C     SPECIAL SOURCE FOR J. PALMER
C     SOURCE VARIES AS R**-N
C     RDK(1)= LEFT ZONE BOUNDARY
C     RDK(2)= RIGHT ZONE BOUNDARY
C     RDK(3-52)= TIMES FOR GIVEN EDOT
C     RDK(53-104)= EDOTS FOR GIVEN TIMES
C*****************************************************************KAP20070
C                                                                  *KAP20080
C*                    S P U T T E R   C O M M O N                 **KAP20090
C*                                                                **KAP20100
C*                                                                **KAP20110
      COMMON   LMDA(37), NR     , NSMLR , IA     , IB     , ICA    , ICB    ,KAP20120
     1   KMAX  , BLANK1, BLANK2, BLANK3, IAP1  , IBP1  , ICAP1 , ICBP1 ,KAP20130
     2   II    , IG    , NRAD  , BLANK4, IAM1  , IBM1  , ICAM1 , ICBM1 ,KAP20140
     3   IIP1  , IGM1  , IALPHA, BLANK5, TH    , TMAX  , BLANK6, DELPRT,KAP20150
     4   FREQ  , CNTMAX, AR    , ASMLR , PUSHA , PUSHB , BOILA , BOILB ,KAP20160
     5   CVA   , CVB   , SLUG  , ALPHA , HVA   , HVB   , HCA   , HCB   ,KAP20170
     6   EMINA , EMINB , CA    , CB    , GA    , GB    , GL    , GR    ,KAP20180
     7   RHOL  , RHOR  , EP10  , EPSI  , RIA   , RIB   , RDIA  , RDIB  ,KAP20190
     8   RPIA  , RPIB  , RPDIA , RPDIB , TPRINT, TA    , TB    , TC     KAP20200
      COMMON     TU    , TE    , DTH2  , DTH2P , DTH1  , DTRMIN, DTMAX ,KAP20210
     1   DTMAX1, DTMAX2, DTMAX3, DTR   , SWITCH, CO    , CMIN  , DELTA ,KAP20220
     2   GAMA  , WCRIT , SIGMAG, AC    , ACO3T4, CNVRT , SUMRA , SUMRB ,KAP20230
     3   RO1A  , RO1AM1, ROIB  , ROIBP1, GMS   , S1    , S2    , S3    ,KAP20240
     4   S4    , S5    , S6    , S7    , S8    , S9    , S10   , S11   ,KAP20250
     5   S12   , S13   , S14   , S15   , S16   , S17   , S18   , S19   ,KAP20260
     6   S20   , EO    , FO    , TAU   , ZERO  , R    (152), DELTAR(152),KAP20270
     7  ASQ   (152), RD     (152), VD     (152), RDD    (152), SMLR   (152),KAP20280
     8  DELR  ( 37), P      (152), P1     (152), PB     (152), PB1    (152) KAP20290
      COMMON         P2     (152), SV     (152), RHO    (152), THETA  (152),KAP20300
     1  W     (152), E      (152), EI     (152), EK     (152), A      (152),KAP20310
     2  V     (152), G      (152), D      (152), C      (152), X2     (152),KAP20320
     3  X3    (152), X4     (152), X5     (152), X6     (152), X7     (152),KAP20330
     4  SMLA  (152), SMLB   (152), SMLC   (152), SMLD   (152), SMLE   (152),KAP20340
     5  EC    (152), ER     (152), SMLQ   (152), SMLH   (152), BIGA   (152),KAP20350
     6  BIGB  (152), CV     (152), BC     (152), BR     (152), CHIC   (152),KAP20360
     7  CHIR  (152), CAPAC  (152), CAPAR  (152), CRTC   (152), CRTR   (152),KAP20370
     8  CRTPC (152), GOFR   (152), FEW    (152), CAR    (152), OKLM   ( 37) KAP20380
      COMMON         TELM   ( 37), EKLM   ( 37), ELM    ( 37), FCLM   ( 37),KAP20390
     1  FRLM  ( 37), WLM    ( 37), QLM    ( 37), AMASNO( 37), CHRNO  ( 37),KAP20400
     2  ZP1   ( 37), ZP2    ( 37), SOL1D  ( 37), ECHCK ( 37), RK     (104),KAP20410
     3  RL    ( 37), RHOK   (104), RDK    (104), THETAK(104), TEMP   ( 16),KAP20420
     4  HEAD  ( 12), MAXL         , MAXLM                                  KAP20430
C                                                                          KAP20440
C                                                                         **KAP20450
C*****************************************************************KAP20460
      DATA FIRST/0./
      IF(FIRST) 40,10,40
   10 IF (RDK(1)* RDK(2) .GT. 0.1) GO TO 20
      S1=74.0010
      CALL UNCLE
```

```
   20 IL=RDK(1)
      IR=RDK(2)
      SUMG=0.
      DO 30 I=IL,IR
   30 SUMG=SUMG+G(I)
      SUMG = SUMG-.5*G(IR)
   40 DO 50 I=I,152
   50 SMLQ(I)=0.
      T2= TH + DTH2
      IF(T2 .LT. RDK(3)) GO TO 1000
      DO 60 J=4,52
      IF(RDK(J) .GT. T2) GO TO 70
      IF(RDK(J) .EQ. 0.) GO TO 1000
   60 CONTINUE
   70 J= J-1
      TEMP(2) = RDK(J+40)
      SOLID(8)=RDK(J+50)
      IF(RDK(J) .LE. TH) GO TO 80
      TEMP(1)=(RDK(J)-TH)*RDK(J+49)+RDK(J+50)*(T2-RDK(J))
      TEMP(2) = (RDK(J)-TH)*RDK(J+39)+RDK(J+40)*(T2-RDK(J))
      TEMP(2) = TEMP(2)/DTH2
      SOLID(8)= TEMP(1)/DTH2
   80 BETA = 4.18879*SUMG*TEMP(2)/SOLID(8)-1.
      SUMQ = 0.
      SUMS = -.5*G(IL-1)
      DO 90 I=IL,IR
      SUMS = SUMS+.5*(G(I-1)+G(I))
      TEMP(I) = TEMP(2)*(SUMS/SUMG)**BETA
      SMLQ(I) = TEMP(1)*G(I)
   90 SUMQ = SUMQ+SMLQ(I)*4.18879
      RPIB = SUMQ-SOLID(8)
      DO 95 I=IL,IR
   95 SMLQ(I) = SMLQ(I)*(SOLID(8)/SUMQ)
 1000 FIRST= 1.
      RETURN
      END
```

```
@IT FOR KAPPA/ST, KAPPA/ST, KAPPA/STD
      SUBROUTINE KAPPA(N,IM)
C     OUTPUT VERSION THAT INCLUDES DIVIDE CHECK TEST
COMPILED  MAY 22, 1967  WBL
C
C     COMPILED ON DECEMBER 8,1966, BY LAURA NORRIS
C                                                                       KAPP0020
C                                                                       KAPP0040
C                                                                       KAPP0050
C*********************************************************************KAPP0060
C                                                                      *KAPP0070
C*                    S P U T T E R   C O M M O N                     **KAPP0080
C*                                                                    **KAPP0090
C*                                                                    **KAPP0100
      COMMON   LMDA(37), NR     , NSMLR , IA    , IB    , ICA   , ICB   ,KAPP0110
     1   KMAX  , BLANK1, BLANK2, BLANK3, IAP1  , IBP1  , ICAP1 , ICBP1 ,KAPP0120
     2   II    , IG    , NRAD  , BLANK4, IAM1  , IBM1  , ICAM1 , ICBM1 ,KAPP0130
     3   IIP1  , IGM1  , IALPHA, BLANK5, TH    , TMAX  , BLANK6, DELPRT,KAPP0140
     4   FREQ  , CNTMAX, AR    , ASMLR , PUSHA , PUSHB , BOILA , BOILB ,KAPP0150
     5   CVA   , CVB   , SLUG  , ALPHA , HVA   , HVB   , HCA   , HCB   ,KAPP0160
     6   EMINA , EMINB , CA    , CB    , GA    , GB    , GL    , GR    ,KAPP0170
     7   RHOL  , RHOR  , EPIO  , EPSI  , RIA   , RIB   , RDIA  , RDIB  ,KAPP0180
     8   RPIA  , RPIB  , RPDIA , RPDIB , TPRINT, TA    , TB    , TC    KAPP0190
      COMMON     TD    , TE    , DTH2  , DTH2P , DTH1  , DTRMIN, DTMAX ,KAPP0200
     1   DTMAX1, DTMAX2, DTMAX3, DTR   , SWITCH, CO    , CMIN  , DELTA ,KAPP0210
     2   GAMA  , WCRIT , SIGMAQ, AC    , ACO3T4, CNVRT , SUMRA , SUMRB ,KAPP0220
     3   ROIA  , ROIAM1, ROIB  , ROIBP1, GMS   , S1    , S2    , S3    ,KAPP0230
     4   S4    , S5    , S6    , S7    , S8    , S9    , S10   , S11   ,KAPP0240
     5   S12   , S13   , S14   , S15   , S16   , S17   , S18   , S19   ,KAPP0250
     6   S20   , EO    , FO    , TAU   , ZERO  , R   (152), DELTAR(152),KAPP0260
     7  ASQ   (152), RD    (152), VD    (152), ROD   (152), SMLR  (152),KAPP0270
     8  DELR  ( 37), P     (152), P1    (152), PB    (152), PB1   (152) KAPP0280
      COMMON         P2    (152), SV    (152), RHO   (152), THETA (152),KAPP0290
     1  W     (152), E     (152), EI    (152), EK    (152), A     (152),KAPP0300
     2  V     (152), G     (152), D     (152), C     (152), X2    (152),KAPP0310
     3  X3    (152), X4    (152), X5    (152), X6    (152), X7    (152),KAPP0320
     4  SMLA  (152), SMLB  (152), SMLC  (152), SMLD  (152), SMLE  (152),KAPP0330
     5  EC    (152), ER    (152), SMLQ  (152), SMLH  (152), BIGA  (152),KAPP0340
     6  BIGB  (152), CV    (152), BC    (152), BR    (152), CHIC  (152),KAPP0350
     7  CHIR  (152), CAPAC (152), CAPAR (152), CRTC  (152), CRTR  (152),KAPP0360
     8  CRTPC (152), GOFR  (152), FEW   (152), CAR   (152), OKLM  ( 37) KAPP0370
      COMMON         TELM  ( 37), EKLM  ( 37), ELM   ( 37), FCLM  ( 37),KAPP0380
     1  FRLM  ( 37), WLM   ( 37), QLM   ( 37), AMASNO( 37), CHRNO ( 37),KAPP0390
     2  ZP1   ( 37), ZP2   ( 37), SOLID ( 37), ECHCK ( 37), RK    (104),KAPP0400
     3  RL    ( 37), RHOK  (104), ROK   (104), THETAK(104), TEMP  ( 16),KAPP0410
     4  HEAD  ( 12), MAXL        , MAXLM                                KAPP0420
C                                                                       KAPP0430
C*                                                                    **KAPP0440
C*********************************************************************KAPP0450
      COMMON /LINDLY/ HNU,SGNL,IHNU,NHNU,HNUP,NT,IM,IN,DHNU,THICK,NY    KAPP0460
C                                                                       KAPP0470
C                                                                       KAPP0480
C     AMASNO(18-34) RESERVED FOR DESIGNATION OF DIANE TAPE UNIT.
C
```

```
C
      NT=0
      SGNL=0.
C
C
      M = IM
      IL = N
  100 DO 200 J=1, MAXL.
      IF(IL.LT.LMDA(J)) GO TO 300
  200 CONTINUE
      S1 = 15.0200
      CALL UNCLE
  300 IR=MIN0(LMDA(J)-1,M)
      J= J - 1
      IF(QLM(J+17))400,350,400
  350 QLM(J+17)=ABS(OKLM(J))
  400 CONTINUE
      SOLID(20)= IL
      SOLID(21)=IR
      SOLID(22)=J
      IF(AMASNO(J+17) .GT. 0.) GO TO 600
      L = 2
      MATERL=QLM(J+17) + .5
      IF(MATERL .GT.200) L=MATERL - 200
      IF(MATERL .EQ. 1) L=3
      IF(MATERL .EQ. 6) L=1
      IF(MATERL .EQ. 13) L=5
         IF (MATERL .EQ. 101 .OR. MATERL .EQ. 103) L=I
      IF(MATERL .EQ. 102)L=8
      IF(L .LT. 13) GO TO 500
      S1= 15.0500
      CALL UNCLE
  500 GO TO (1,2,3,4,5,6,7,8,9,10,11,12),L
    1 CALL KAP1                                                    KAPP1170
      GO TO 700
    2 CALL KAP2                                                    KAPP1190
      GO TO 700
    3 CALL KAP3                                                    KAPP1210
      GO TO 700
    4 CALL KAP4                                                    KAPP1230
      GO TO 700
    5 CALL KAP5                                                    KAPP1250
      GO TO 700
    6 CALL KAP6                                                    KAPP1270
      GO TO 700
    7 CALL KAP7                                                    KAPP1290
      GO TO 700
    8 CALL KAP8                                                    KAPP1310
      GO TO 700
    9 CALL KAP9                                                    KAPP1330
      GO TO 700
   10 CALL KAP10                                                   KAPP1350
      GO TO 700
   11 CALL KAP11                                                   KAPP1370
      GO TO 700
   12 CALL KAP12                                                   KAPP1390
      GO TO 700
  600 CALL DIANA(J)
  700 DO 800 I=IL,IR
      CAPAR(I) = AMIN1(CAPAR(I), 2.820E6/THETA(I))
  800 CONTINUE
      CALL DVCHK(KX)
      GO TO (810, 820), KX
  810 S1 = 15.0810
      CALL UNCLE
  820 IL=IR + 1
      IF (IL .GT. M) RETURN
      GO TO 100
      END
```

```
@, FOR KAP6/JP, KAP6/JP, KAP6/JP1
      SUBROUTINE  KAP6
COMPILED  NOVEMBER 11, 1966 ABL
C     SPECIAL KAP ROUTINE FOR CONSTANT INPUT MULTIFREQUENCY OPACITIES
C     THETAK(61-80) SPECIFIES FREQUENCY
C     THETAK(81-100) SPECIFIES OPACITY
C*****************************************************************
C                                                                 *
C*                    S P U T T E R   C O M M O N                **
C*                                                                **
C*                                                                **
      COMMON   LMDA(37), NK     , NSMLR , IA     , IB     , ICA    , ICB    ,
     1   KMAX  , BLANK1, BLANK2, BLANK3, IAP1   , IBP1   , ICAP1  , ICBP1  ,
     2   II    , IG    , NRAD  , BLANK4, IAM1   , IBM1   , ICAM1  , ICBM1  ,
     3   IIP1  , IGM1  , IALPHA, BLANK5, TN     , TMAX   , BLANK6, DELPRT,
     4   FREQ  , CNTMAX, AR    , ASMLR , PUSHA  , PUSHB  , BOILA  , BOILB  ,
     5   CVA   , CVB   , SLUG  , ALPHA , HVA    , HVB    , HCA    , HCB    ,
     6   EMINA , EMINB , CA    , CB    , GA     , GB     , GL     , GR     ,
     7   RHOL  , RHOR  , EPIO  , EPSI  , RIA    , RIB    , RDIA   , RDIB   ,
     8   RPIA  , RPIB  , RPDIA , RPDIB , TPRINT, TA     , TB     , TC
      COMMON     TD    , TE    , DTH2  , DTH2P , DTH1  , DTRMIN, DTMAX  ,
     1   DTMAX1, DTMAX2, DTMAX3, DTR   , SWITCH, CO     , CMIN   , DELTA  ,
     2   GAMA  , WCRIT , SIGMAQ, AC    , ACO3T4, CNVRT  , SUMRA  , SUMRB  ,
     3   ROIA  , ROIAM1, ROIB  , ROIBP1, GMS    , S1     , S2     , S3     ,
     4   S4    , S5    , S6    , S7    , S8     , S9     , S10    , S11    ,
     5   S12   , S13   , S14   , S15   , S16    , S17    , S18    , S19    ,
     6   S20   , EO    , FO    , TAU   , ZERO   , R    (152), DELTAR(152),
     7  ASQ   (152), RD     (152), VD     (152), RDO    (152), SMLR   (152),
     8  DELR  ( 37), P      (152), P1     (152), PB     (152), PB1    (152)
      COMMON         P2     (152), SV     (152), RHO    (152), THETA  (152),
     1  W     (152), E      (152), EI     (152), EK     (152), A      (152),
     2  V     (152), G      (152), D      (152), C      (152), X2     (152),
     3  X3    (152), X4     (152), X5     (152), X6     (152), X7     (152),
     4  SMLA  (152), SMLB   (152), SMLC   (152), SMLD   (152), SMLE   (152),
     5  EC    (152), ER     (152), SMLQ   (152), SMLH   (152), BIGA   (152),
     6  BIGB  (152), CV     (152), BC     (152), BR     (152), CHIC   (152),
     7  CHIR  (152), CAPAC  (152), CAPAR  (152), CRTC   (152), CRTR   (152),
     8  CRTPC (152), GOFR   (152), FEW    (152), CAR    (152), OKLM   ( 37)
      COMMON         TELM   ( 37), EKLM   ( 37), ELM    ( 37), FCLM   ( 37),
     1  FRLM  ( 37), WLM    ( 37), QLM    ( 37), AMASNO( 37), CHRNO  ( 37),
     2  ZP1   ( 37), ZP2    ( 37), SOLID  ( 37), ECHCK  ( 37), RK     (104),
     3  RL    ( 37), RHOK   (104), RDK    (104), THETAK(104), TEMP   ( 16),
     4  HEAD  ( 12), MAXL         , MAXLM
C
C                                                                 **
C*****************************************************************
      COMMON /LINDLY/ HNU,SGNL,IHNU,NHNU,HNUP,NT,IM,IN,DHNU,THICK,NY
      IF  (IHNU .EQ. 1)  NHNU = THETAK(101)
      HNU = THETAK(IHNU+60)
      IK = SOLID(20)
      IL = SOLID(21)
      DO  10  I = IK, IL
      IF (IHNU .GT. 0)  GO TO 6
C     GREY KAPPA


      CAPAR (I) = THETAK(102)
      GO TO 10
C     MULTIFREQUENCY KAPPA
    6 CAPAR(I) = THETAK(IHNU+80)
   10 CAPAC(I) = CAPAR(I)
      RETURN
      END
```

```
W,T FOR KAP12/JP, KAP12/JP, KAP12/JP1
      SUBROUTINE KAP12                                                  KAP10010
C                                                                       KAP10020
C                                                                       ES3 0040
C*********************************************************************
C                                                                      *
C*                    S P U T T E R   C O M M O N                    **
C*                                                                   **
C*                                                                   **
      COMMON   LMDA(37), NR    , NSMLR , IA    , IB    , ICA   , ICB   ,
     1  KMAX  , BLANK1, BLANK2, BLANK3, IAP1  , IBP1  , ICAP1 , ICBP1 ,
     2  II    , IG    , NRAD  , BLANK4, IAM1  , IBM1  , ICAM1 , ICBM1 ,
     3  IIP1  , IGM1  , IALPHA, BLANK5, TH    , TMAX  , BLANK6, DELPRT,
     4  FREQ  , CNTMAX, AR    , ASMLR , PUSHA , PUSHB , BOILA , BOILB ,
     5  CVA   , CVB   , SLUG  , ALPHA , HVA   , HVB   , HCA   , HCB   ,
     6  EMINA , EMINB , CA    , CB    , GA    , GB    , GL    , GR    ,
     7  RHOL  , RHOR  , EPIO  , EPSI  , RIA   , RIB   , RDIA  , RDIB  ,
     8  RPIA  , RPIB  , RPDIA , RPDIB , TPRINT, TA    , TB    , TC
      COMMON   TD    , TE    , DTH2  , DTH2P , DTH1  , DTRMIN, DTMAX ,
     1  DTMAX1, DTMAX2, DTMAX3, DTR   , SWITCH, CO    , CMIN  , DELTA ,
     2  GAMA  , aCRIT , SIGMAQ, AC    , ACO3T4, CNVRT , SUMRA , SUMRB ,
     3  ROIA  , ROIAM1, ROIB  , ROIBP1, GMS   , S1    , S2    , S3    ,
     4  S4    , S5    , S6    , S7    , S8    , S9    , S10   , S11   ,
     5  S12   , S13   , S14   , S15   , S16   , S17   , S18   , S19   ,
     6  S20   , EO    , FO    , TAU   , ZERO  , R    (152), DELTAR(152),
     7  ASQ  (152), RD    (152), VD    (152), RDD   (152), SMLR  (152),
     8  DELR ( 37), P     (152), P1    (152), PB    (152), PB1   (152)
      COMMON        P2    (152), SV    (152), RHO   (152), THETA (152),
     1  W    (152), E     (152), EI    (152), EK    (152), A     (152),
     2  V    (152), G     (152), D     (152), C     (152), X2    (152),
     3  X3   (152), X4    (152), X5    (152), X6    (152), X7    (152),
     4  SMLA (152), SMLB  (152), SMLC  (152), SMLD  (152), SMLE  (152),
     5  EC   (152), ER    (152), SMLQ  (152), SMLH  (152), BIGA  (152),
     6  BIGB (152), CV    (152), BC    (152), BR    (152), CHIC  (152),
     7  CHIR (152), CAPAC (152), CAPAR (152), CRTC  (152), CRTR  (152),
     8  CRTPC (152), GOFR (152), FEW   (152), CAR   (152), OKLM  ( 37)
      COMMON        TELM  ( 37), EKLM  ( 37), ELM   ( 37), FCLM  ( 37),
     1  FRLM ( 37), WLM   ( 37), QLM   ( 37), AMASNO( 37), CHRNO ( 37),
     2  ZP1  ( 37), ZP2   ( 37), SOLID ( 37), ECHCK ( 37), RK    (104),
     3  RL   ( 37), RHOK  (104), RDK   (104), THETAK(104), TEMP  ( 16),
     4  HEAD ( 12), MAXL       , MAXLM
      IL=SOLID(21)                                                      KAP10050
C
C                                                                      **
C*********************************************************************
C                                                                       KAP10030
      IK=SOLID(20)                                                      KAP10040
      J=SOLID(22)                                                       KAP10060
      CHRN=92.0                                                         KAP10070
      AMASN=4.017E+9                                                    KAP10080
      ZPA=2.408E-03                                                     KAP10090
      ZPB=3.821E+04                                                     KAP10100
      DO 1000 I=IK,IL                                                   KAP10110
      IF(THETA(I).NE.0.) GO TO 1
```

```
      CAPAR(I)=.2
      CAPAC(I)=.2
      GO TO 1000
    1 IXT=1
      TEMP(3)=THETA(I)**2                                               KAP10200
      TEMP(4)=TEMP(3)**2                                                KAP10210
      TEMP(5)=THETA(I)**1.5                                             KAP10220
C     *   *   *   *   *   *   *   *   *   *   *   *   *   *   *   *   *   *   *
      IF(SV(I).GE.10.  )GO TO 200
      IF(SV(I).LE.1.   )GO TO 10
      IXT=2
      SVI=SV(I)
      SV(I)=10.
      DYDY=ALOG( 10./SVI)/(   2.3025851)
      GO TO 200
    5 SV(I)=1.
      TEMP(6)=CAPAR(I)
C     *   *   *   *   *   *   *   *   *   *   *   *   *   *   *   *   *   *   *
   10 IF(THETA(I)-1000.0)12,12,14                                       KAP10260
   12 CAPAR(I)=5.49E+6/(TEMP(5)*(1.0+1.E-6*SV(I)*TEMP(3)))+13.1*        KAP10270
    1 SQRT(SV(I))                                                       KAP10280
      CAPAR(I) = AMAX1(OKLM(J+17) * CAPAR(I), .2)
      GO TO 20                                                          KAP10300
   14 CAPAR(I)=(1.0+1.75E12/TEMP(4))*(.0789+2.784E21/(TEMP(3)*(7.6E13*  KAP10310
    1 SQRT(SQRT(SV(I)))  + TEMP(4)*SV(I))))                             KAP10320
      CAPAR(I) = AMAX1(OKLM(J+17) * CAPAR(I), .2)
   20 GO TO (350,340),IXT
C     *   *   *   *   *   *   *   *   *   *   *   *   *   *   *   *   *   *   *
  200 CONTINUE
      IF (THETA(I)-2.0) 201,201,202
  201 EFF=1.E2                                                          KAP10410
      GO TO 300                                                         KAP10420
  202 IF (THETA(I)-20.0) 203,203,204                                    KAP10430
  203 EFF=9.E2/(THETA(I)+1.0)**2+2.5E-5*THETA(I)**5                     KAP10440
      GO TO 300                                                         KAP10450
  204 IF (THETA(I)-100.0) 205,205,206                                   KAP10460
  205 EFF=6.56E5/THETA(I)**3+5.E-5*THETA(I)**3                          KAP10470
      GO TO 300                                                         KAP10480
  206 EFF=6.0+4.4E5/THETA(I)**2                                         KAP10490
  300 CONTINUE                                                          KAP10500
      WS=SQRT(THETA(I))                                                 KAP10510
      WSA = FEW(I)**2/SV(I)
      IF(FEW(I).LT.1.) GO TO 330
      WSA=WSA*FEW(I)
      GO TO 335
  330 WSA = AMIN1(WSA, 1.E10/AMASN*THETA(I)*WS*EXP(-8.0/THETA(I)))
  335 CAPAR(I) = AMASN**2*9.06E-14/THETA(I)**3*WSA/WS
      CAPAR(I)=AMAX1(OKLM(J+17)*EFF*CAPAR(I),.2)
      GO TO (350,5),IXT
C     *   *   *   *   *   *   *   *   *   *   *   *   *   *   *   *   *   *   *
  340 CAPAR(I)=EXP(ALOG(TEMP(6))+(ALOG(CAPAR(I))-ALOG(TEMP(6)))*DYDY)
      SV(I)=SVI
C                                                                       KAP10600
C     *   *   *   *   *   *   *   *   *   *   *   *   *   *   *   *   *   *   *
  350 WSB=13.6/THETA(I)*(CHRN**2)                                       KAP10610


      IF(FEW(I).EQ.0.) GO TO 370
  360 WSC=1.E+10/AMASN*TEMP(5)/FEW(I)*SV(I)
      GO TO 380
  370 WSC=      1.
  380 CONTINUE
      CAPAC(I)=.8/*CAPAR(I)*AMIN1(1.0+WSB,1.0+ALOG(WSC))                KAP10630
      CAPAC(I)=AMAX1(CAPAC(I),CAPAR(I))                                 KAP10640
 1000 CONTINUE                                                          KAP10650
      RETURN                                                            KAP10660
      END                                                               KAP10670
```

```
@I FOR RTAPE/ORIG, RTAPE/ORIG, RTAPE/A1
      SUBROUTINE RTAPE(NTAPE,CYCLE)                                     RTAP0010
C
C COMPILED  APRIL 4, 1967  WBL
C     SPECIAL VERSION FOR COMPTON SCATTERING CODES
C*****************************************************************RTAP0020
C                                                                    *RTAP0030
C                    S P U T T E R   C O M M O N                    **RTAP0040
C*                                                                   **RTAP0050
C*                                                                   **RTAP0060
      COMMON   LMDA(37), NR    , NSMLR , IA    , IB    , ICA   , ICB   ,RTAP0070
     1   KMAX  , BLANK1, BLANK2, BLANK3, IAP1  , IBP1  , ICAP1 , ICBP1 ,RTAP0080
     2   II    , IG    , NRAD  , BLANK4, IAM1  , IBM1  , ICAM1 , ICBM1 ,RTAP0090
     3   IIP1  , IGM1  , IALPHA, BLANK5, TH    , TMAX  , BLANK6, DELPRT,RTAP0100
     4   FREQ  , CNTMAX, AR    , ASMLR , PUSHA , PUSHB , BOILA , BOILB ,RTAP0110
     5   CVA   , CVB   , SLUG  , ALPHA , HVA   , HVB   , HCA   , HCB   ,RTAP0120
     6   EMINA , EMINB , CA    , CB    , GA    , GB    , GL    , GR    ,RTAP0130
     7   RHOL  , RHOR  , EPIO  , EPSI  , RIA   , RIB   , RDIA  , RDIB  ,RTAP0140
     8   RPIA  , RPIB  , RPDIA , RPDIB , TPRINT, TA    , TB    , TC     RTAP0150
      COMMON     TD    , TE    , DTH2  , DTH2P , DTH1  , DTRMIN, DTMAX ,RTAP0160
     1   DTMAX1, DTMAX2, DTMAX3, DTR   , SWITCH, CO    , CMIN  , DELTA ,RTAP0170
     2   GAMA  , WCRIT , SIGMAG, AC    , ACO3T4, CNVPT , SUMRA , SUMRB ,RTAP0180
     3   ROIA  , ROIAM1, ROIBP1, GMS   , S1    , S2    , S3    ,RTAP0190
     4   S4    , S5    , S6    , S7    , S8    , S9    , S10   , S11   ,RTAP0200
     5   S12   , S13   , S14   , S15   , S16   , S17   , S18   , S19   ,RTAP0210
     6   S20   , EO    , FO    , TAU   , ZERO  , R     (152), DELTAR(152),RTAP0220
     7  ASQ    (152), RD     (152), VD     (152), RDD    (152), SMLR   (152),RTAP0230
     8  DELR   ( 37), P      (152), P1     (152), PB     (152), PB1    (152) RTAP0240
      COMMON           P2     (152), SV     (152), RHO    (152), THETA  (152),RTAP0250
     1  W      (152), E      (152), EI     (152), EK     (152), A      (152),RTAP0260
     2  V      (152), G      (152), D      (152), C      (152), X2     (152),RTAP0270
     3  X3     (152), X4     (152), X5     (152), X6     (152), X7     (152),RTAP0280
     4  SMLA   (152), SMLB   (152), SMLC   (152), SMLD   (152), SMLE   (152),RTAP0290
     5  EC     (152), ER     (152), SMLQ   (152), SMLH   (152), BIGA   (152),RTAP0300
     6  BIGB   (152), CV     (152), BC     (152), BR     (152), CHIC   (152),RTAP0310
     7  CHIR   (152), CAPAC  (152), CAPAR  (152), CRTC   (152), CRTR   (152),RTAP0320
     8  CRTPC  (152), GOFR   (152), FEW    (152), CAR    (152), OKLM   ( 37) RTAP0330
      COMMON           TELM   ( 37), EKLM   ( 37), ELM    ( 37), FCLM   ( 37),RTAP0340
     1  FRLM   ( 37), WLM    ( 37), QLM    ( 37), AMASNO( 37), CHRNO   ( 37),RTAP0350
     2  ZP1    ( 37), ZP2    ( 37), SOLID  ( 37), ECHCK ( 37), RK     (104),RTAP0360
     3  RL     ( 37), RHOK   (104), RDK    (104), THETAK(104), TEMP   ( 16),RTAP0370
     4  HEAD   ( 12), MAXL         , MAXLM                                 RTAP0380
C                                                                         RTAP0390
C                                                                        **RTAP0400
C*****************************************************************RTAP0410
      COMMON /LINDLY/ HNU,SGNL,IHNU,NHNU,HNUP,NT,IM,IN,DHNU,THICK,NY
      COMMON /PALMER/  FI0(152), FI1(152), FI2(152), FI3(152), FQ0(152),
     2 FQ1(152), FQ2(152), FQ3(152), JDRUM
C     RTAPE DEFINES JDRUM ON RESTARTS.  WTAPE DEFINES IT ON INITIAL STARTS.
      NHNU = LMDA(36)
      REWIND NTAPE                                                      RTAP0420
   10 READ (NTAPE) COUNT                                                RTAP0430
      IF (COUNT.LT.0..OR.COUNT.GT.CYCLE) GO TO 30                       RTAP0440
      IF (ABS(FO) .GT. 1.E-20)  READ (NTAPE)
```

```
      IF (ABS(COUNT - CYCLE) .LT. 1.E-20)  GO TO 20
      WRITE (6,50) COUNT
   50 FORMAT (1H0 5X, 6HCYCLE F6.0, 8H SKIPPED)
      READ (NTAPE)                                                      RTAP0460
      DO  15  I = 1, NHNU
   15 READ (NTAPE)                                                      RTAP0470
      GO TO 10                                                          RTAP0480
   20 READ (NTAPE)(LMDA(I),I=1,9405)
      JDRUN = 25
      LMDA(36) = NHNU
      DO  25  I = 1, NHNU
      READ (NTAPE)  FI0, FI1, FI2, FI3
   25 WRITE (JDRUM)  FI0, FI1, FI2, FI3                                 RTAP0490
      RETURN                                                            RTAP0500
   30 S1 = 40.
      WRITE (6, 40) SOLID(34)
   40 FORMAT (1H0 5X  6HCYCLE  F6.0, 17H NOT ON DUMP TAPE )
      CALL EXIT                                                         RTAP0520
      END
```

```
@I FOR  WTAPE/SP, WTAPE/SP, WTAPE/SP1                                   WTAP0010
      SUBROUTINE   WTAPE
COMPILED  APRIL 27, 1967  WDL
C     SPECIAL VERSION FOR COMPTON SCATTERING CODES                      WTAP0030
C                                                                       WTAP0040
C*********************************************************************WTAP0050
C                                                                     **WTAP0060
C*                    S P U T T E R   C O M M O N                     **WTAP0070
C*                                                                    **WTAP0080
C*
      COMMON   LMDA(37), NR     , NSMLR , IA    , IB    , ICA   , ICB   ,WTAP0090
     1   KMAX  , BLANK1, BLANK2, BLANK3, IAP1  , IBP1  , ICAP1 , ICBP1 ,WTAP0100
     2   II    , IG    , NRAD  , BLANK4, IAM1  , IBM1  , ICAM1 , ICBM1 ,WTAP0110
     3   IIP1  , IGM1  , IALPHA, BLANK5, TH    , TMAX  , BLANK6, DELPRT,WTAP0120
     4   FREQ  , CNTMAX, AR    , ASMLR , PUSHA , PUSHB , BOILA , BOILB ,WTAP0130
     5   CVA   , CVB   , SLUG  , ALPHA , HVA   , HVB   , HCA   , HCB   ,WTAP0140
     6   EMINA , EMINB , CA    , CB    , GA    , GB    , GL    , GR    ,WTAP0150
     7   RHOL  , RHOR  , EPIO  , EPSI  , RIA   , RIB   , RDIA  , RDIB  ,WTAP0160
     8   RPIA  , RPIB  , RPDIA , RPDIB , TPRINT, TA    , TB    , TC    ,WTAP0170
      COMMON     TD    , TE    , DTH2  , DTH2P , DTH1  , DTRMIN, DTMAX ,WTAP0180
     1   DTMAX1, DTMAX2, DTMAX3, DTR   , SWITCH, CO    , CMIN  , DELTA ,WTAP0190
     2   GAMA  , WCRIT , SIGMAU, AC    , ACO3T4, CNVRT , SUMRA , SUMRB ,WTAP0200
     3   ROIA  , ROIAM1, ROIB  , ROIBP1, GMS   , S1    , S2    , S3    ,WTAP0210
     4   S4    , S5    , S6    , S7    , S8    , S9    , S10   , S11   ,WTAP0220
     5   S12   , S13   , S14   , S15   , S16   , S17   , S18   , S19   ,WTAP0230
     6   S20   , EO    , FO    , TAU   , ZERO  , R   (152), DELTAR(152),WTAP0240
     7  ASG   (152), RO    (152), VO    (152), RUD   (152), SMLR  (152),WTAP0250
     8  DELR  ( 37), P     (152), P1    (152), PB    (152), PB1   (152) WTAP0260
      COMMON         P2    (152), SV    (152), RHO   (152), THETA (152),WTAP0270
     1  W     (152), E     (152), EI    (152), EK    (152), A     (152),WTAP0280
     2  V     (152), G     (152), D     (152), C     (152), X2    (152),WTAP0290
     3  X3    (152), X4    (152), X5    (152), X6    (152), X7    (152),WTAP0300
     4  SMLA  (152), SMLB  (152), SMLC  (152), SMLD  (152), SMLE  (152),WTAP0310
     5  EC    (152), ER    (152), SMLQ  (152), SMLH  (152), BIGA  (152),WTAP0320
     6  BIGB  (152), CV    (152), BC    (152), BR    (152), CHIC  (152),WTAP0330
     7  CHIR  (152), CAPAC (152), CAPAR (152), CRTC  (152), CRTR  (152),WTAP0340
     8  CRTPC (152), GOFR  (152), FEW   (152), CAR   (152), OKLM  ( 37) WTAP0350
      COMMON         TELM  ( 37), EKLM  ( 37), ELM   ( 37), FCLM  ( 37),WTAP0360
     1  FRLM  ( 37), WLM   ( 37), QLM   ( 37), AMASHO( 37), CHRNO ( 37),WTAP0370
     2  ZP1   ( 37), ZP2   ( 37), SOLID ( 37), ECHCK ( 37), RK    (104),WTAP0380
     3  RL    ( 37), RHOK  (104), RDK   (104), THETAK(104), TEMP  ( 16),WTAP0390
     4  HEAD  ( 12), MAXL        , MAXLM                               WTAP0400
                                                                       WTAP0410
C                                                                     **WTAP0420
C                                                                       WTAP0430
C*********************************************************************
      COMMON /LINDLY/ HNU,SGMIL,IHNU,NHNU,HNUP,NT,IM,IN,DHNU,THICK,NY
      COMMON /PALMER/  FI0(152), FI1(152), FI2(152), FI3(152), FQ0(152),
     2 FQ1(152), FQ2(152), FQ3(152), JDRUM
      COMMON /CNTWL/ SCYCLE, JMULT                                      WTAP0440
C                                                                       WTAP0450
      N=55                                                              WTAP0460
      WS=-3.0                                                           WTAP0470
      WRITE (N)  SOLID(18)
      IF (ABS(FO) .GT. 1.E-20)  WRITE (N)  TH
                                                                        WTAP0490
      WRITE (N)(LMDA(I),I=1,9405)
      NHNU = LMDA(36)
      IF (SOLID(18) .GT. SCYCLE)  REWIND JDRUM
      DO  10  I = 1, NHNU
      IF (SOLID(18) .GT. SCYCLE)  READ (JDRUM)  FI0, FI1, FI2, FI3
   10 WRITE (N)  FI0, FI1, FI2, FI3
C     WTAPE DEFINES JDRUM ON INITIAL STARTS.  RTAPE DOES IT ON RESTARTS.
      IF (SOLID(34) .GT. 0. .OR. SOLID(18) .GT. 0.)  GO TO 20
      JDRUM = 25
      REWIND JDRUM
      DO  15  I = 1, NHNU
   15 WRITE (JDRUM)  FI0, FI1, FI2, FI3                                 WTAP0500
   20 WRITE (N) WS                                                      WTAP0510
      BACKSPACE N                                                       WTAP0560
      RETURN                                                            WTAP0570
      END
```

```
$I    FOR    MP2/XX,MP2/XX,MP2/XXX
      SUBROUTINE MP2
C     OUTPUT VERSION -- BOIL, CNDCTN DELETED
C
C                                                                       3MAI0010
C                                                                       3MAI0030
C*********************************************************************3MAI0040
C                                                                       *3MAI0050
C*                    S P U T T E R   C O M M O N                     **3MAI0060
C*                                                                    **3MAI0070
C*                                                                    **3MAI0080
      COMMON   LMDA(37), NR     , NSMLR , IA     , IB     , ICA    , ICB    ,3MAI0090
     1   KMAX  , BLANK1, BLANK2, BLANK3, IAP1   , IBP1   , ICAP1  , ICBP1  ,3MAI0100
     2   II    , IG    , NRAD  , BLANK4, IAM1   , IBM1   , ICAM1  , ICBM1  ,3MAI0110
     3   IIP1  , IGM1  , IALPHA, BLANK5, TH     , TMAX   , BLANK6, DELPRT,3MAI0120
     4   FRLQ  , CNTMAX, AR    , ASMLR , PUSHA  , PUSHB  , BOILA  , BOILB  ,3MAI0130
     5   CVA   , CVB   , SLUG  , ALPHA , HVA    , HVB    , HCA    , HCB    ,3MAI0140
     6   EMINA , EMINB , CA    , CB    , GA     , GB     , GL     , GR     ,3MAI0150
     7   RHOL  , RHOR  , EPIO  , EPSI  , RIA    , RIB    , RDIA   , RDIB   ,3MAI0160
     8   RPIA  , RPIB  , RPDIA , RPDIB , TPRINT, TA     , TB     , TC      3MAI0170
      COMMON   TD    , TE    , DTH2  , DTH2P , DTH1  , DTRMIN, DTMAX  ,3MAI0180
     1   DTMAX1, DTMAX2, DTMAX3, DTR   , SWITCH, CO    , CMIN   , DELTA  ,3MAI0190
     2   GAMA  , WCRIT , SIGMAQ, AC    , ACO3T4, CNVRT , SUMRA  , SUMRB  ,3MAI0200
     3   ROIA  , ROIAM1, ROIB  , ROIBP , GMS   , S1    , S2     , S3     ,3MAI0210
     4   S4    , S5    , S6    , S7    , S8    , S9    , S10    , S11    ,3MAI0220
     5   S12   , S13   , S14   , S15   , S16   , S17   , S18    , S19    ,3MAI0230
     6   S20   , EO    , FO    , TAU   , ZERO  , R     (152), DELTAR(152),3MAI0240
     7  ASQ    (152), RD     (152), VD     (152), RDD    (152), SMLR   (152),3MAI0250
     8  DELR   ( 37), P      (152), PI     (152), PB     (152), PB1    (152) 3MAI0260
      COMMON          P2     (152), SV     (152), RHO    (152), THETA  (152),3MAI0270
     1  W      (152), E      (152), EI     (152), EK     (152), A      (152),3MAI0280
     2  V      (152), G      (152), D      (152), C      (152), X2     (152),3MAI0290
     3  X3     (152), X4     (152), X5     (152), X6     (152), X7     (152),3MAI0300
     4  SMLA   (152), SMLB   (152), SMLC   (152), SMLD   (152), SMLE   (152),3MAI0310
     5  EC     (152), ER     (152), SMLG   (152), SMLH   (152), BIGA   (152),3MAI0320
     6  BIGB   (152), CV     (152), BC     (152), BR     (152), CHIC   (152),3MAI0330
     7  CHIR   (152), CAPAC  (152), CAPAR  (152), CRTC   (152), CRTR   (152),3MAI0340
     8  CRTPC  (152), GOFR   (152), FEW    (152), CAR    (152), OKLM   ( 37) 3MAI0350
      COMMON          TELM   ( 37), EKLM   ( 37), ELM    ( 37), FCLM   ( 37),3MAI0360
     1  FRLM   ( 37), WLM    ( 37), QLM    ( 37), AMASNO( 37), CHRNO  ( 37),3MAI0370
     2  ZP1    ( 37), ZP2    ( 37), SOLID  ( 37), ECHCK ( 37), RK     (104),3MAI0380
     3  RL     ( 37), RHOK   (104), RDK    (104), THETAK(104), TEMP   ( 16),3MAI0390
     4  HEAD   ( 12), MAXL         , MAXLM                                 3MAI0400
C                                                                       3MAI0410
C*                                                                    **3MAI0420
C*********************************************************************3MAI0430
      COMMON /CNTRL/     SCYCLE, JMULT                                  3MAI0440
C *********************************************************************3MAI0450
      EQUIVALENCE  (S12,EDITMF)                                         3MAI0460
C              HYDRO SUB-CYCLE VERSION 9/25/63                         *3MAI0470
C*********************************************************************3MAI0480
      TO=0.
      IF(BLANK2 .GT.1.E-15)TPRINT=TH + BLANK2
C
    5 IF (WARN(IHR)) 10, 600, 600                                       3MAI0490
                                                                        3MAI0570
```

```
   10 IF (EKLM(19)) 501, 520, 501                                       3MAI0580
  501 CONTINUE                                                          3MAI0590
      CALL AUTORZ                                                       3MAI0600
  520 IF(GMS)530,201,530                                                3MAI0610
  530 CALL DEZONE                                                       3MAI[illegible]0
  201 CONTINUE                                                          3MAI0630
   40 CALL TDELT                                                        3MAI0640
      TD=TD+1.
      IF(BLANK2 .LT. 1.E-15) GO TO 170
      IF(TD .GT. FREQ) GO TO 171
      IF(TPRINT .GT. TH+ DTH2) GO TO 100
      TPRINT= TPRINT + BLANK2
      IF(TH .GT. TPRINT) BLANK2 = 0.
      GO TO 171
  170 IF(AMOD(SOLID(18)+1.,FREQ).GT. 0.5)GO TO 100
  171 TD=0.
  100 CONTINUE
C*********************************************************************3MAI0650
C                 INTEGRAL   SUR                                       *3MAI0660
C*********************************************************************3MAI0670
      IF(PUSHA) 2000,2010,2001
 2000 IBD=IBM1
      GO TO 2010
 2001 IBD = IA
 2010 CONTINUE                                                          3MAI0720
  204 CALL HYDRO                                                        3MAI0730
  202 CALL PTWO                                                         3MAI0740
C                                                                       3MAI0750
C            SELECT SOURCE                                              3MAI0760
      IF (ABS(S6) .LT. 1.E-20)  GO TO 80
      CALL GUE
C                                                                       3MAI0950
   80 CONTINUE                                                          3MAI0960
      DTR=DTH2                                                          3MAI0990
      ZP1(18)=DTH2                                                      3MAI1000
      ZP1(19)=0.0                                                       3MAI1010
   84 CONTINUE                                                          3MAI1020
      IF (ABS(S2) .LT. 1.E-20)  GO TO 88
C     CHECK TO SEE IF RADIATION NEEDS TO BE DONE ON CURRENT SUBCYCLE
   85 IF(TD.LT.0.5 .OR. SOLID(18)+1.1.GT.CNTMAX)GO TO 86
      IF (BLANK3-TH-DTH2-DTR+ZP1(18)) 86,88,88
   86 CALL RADTN                                                        3MAI1050
   88 CONTINUE                                                          3MAI1060
      CALL ENCALC                                                       3MAI1110
      CALL ECALC                                                        3MAI1120
      NRAD=NRAD-1                                                       3MAI1130
      IF(NRAD.LE.0.OR.(ZP1(18)/DTR).LT.1.5) GO TO 110
  105 CALL SSWTCH (6, KOOOFX)                                           3MAI1150
      GO TO (106, 107), KOOOFX                                          3MAI1160
  106 S1 = 1.0106                                                       3MAI1170
      GO TO 610                                                         3MAI1180
  107 CONTINUE                                                          3MAI1190
      IF (WARN(IHR)) 108, 605, 605                                      3MAI1200
  108 ZP1(18)=ZP1(18)-DTR                                               3MAI1210
      ZP1(19)=ZP1(19)+1.0                                               3MAI1220
```

```
      GO TO 84                                                          3MAI1230
  110 CONTINUE                                                          3MAI1240
C     FORCE SV TO BE CONSISTENT WITH R AND G
      DO 111 I=IA,IBM1
      SV(I)=DELTAR(I)/G(I)
      IF(IALPHA.EQ.1) GO TO 111
      TEMP(1)=R(I+I)+R(1)
      IF(IALPHA.EQ.3) TEMP(1)=TEMP(1)*R(I+1)+R(I)**2
      SV(I)=SV(I)*TEMP(1)
  111 CONTINUE
      SOLID(28) = P(IBD)
      BLANK4 = BLANK4 + SOLID(28)*DTH2
  109 SOLID(18)=SOLID(18)+1.0                                           3MAI1300
      COUNT=SOLID(18)                                                   3MAI1310
      TH=TH+DTH2                                                        3MAI1320
  180 IF (COUNT - CNTMAX) 190, 301, 301
  190 IF(TH .GT. THMAX) GO TO 301
      IF (ABS(BLANK1) .LT. 0.1)  GO TO 195
      IF (AMOD(SOLID(18), BLANK1) .LT. 0.5)  CALL WTAPE
  195 IF (TD .GT. 0.5)  GO TO 210
      CALL PRINT
      IF(BLANK1 .LT. 0.5) CALL WTAPE
  210 CALL SSWTCH(6,K000FX)                                             3MAI1390
       GO TO(250,5),K000FX                                              3MAI1400
  250 S1 = 1.0250                                                       3MAI1410
      GO TO 610                                                         3MAI1420
  301 S1 = 1.0301                                                       3MAI1430
      GO TO 610                                                         3MAI1440
  600 S1 = 1.0600                                                       3MAI1450
      GO TO 610                                                         3MAI1460
  605 S1 = 1.0605                                                       3MAI1470
  610 CALL UNCLE                                                        3MAI1510
      END
```

```
@IT FOR HYDRO/OUT, HYDRO/OUT, HYDRO/OUTI                                HYDR0010
      SUBROUTINE HYDRO
C     OUTPUT VERSION OF HYDRO
C     DEVELOPED BY JIM PALMER
COMPILED  SEPTEMBER 1, 1967  WBL
C
C USES RADIATION PRESSURE TENSOR
C                                                                       HYDR0050
C                                                                       HYDR0060
C*********************************************************************HYDR0070
C                                                                       **HYDR0080
C*                    S P U T T E R   C O M M O N                       **HYDR0090
C*                                                                      **HYDR0100
C*
      COMMON   LMDA(37), NR     , NSMLR , IA     , IB     , ICA    , ICB    ,HYDR0110
     1   KMAX  , BLANK1, BLANK2, BLANK3, IAP1   , IBP1   , ICAP1  , ICBP1  ,HYDR0120
     2   II    , IG    , NRAD  , BLANK4, IAM1   , IBM1   , ICAM1  , ICBM1  ,HYDR0130
     3   IIP1  , IGM1  , IALPHA, BLANK5, TH     , TMAX   , BLANK6, DELPRT,HYDR0140
     4   FREQ  , CNTMAX, AR    , ASMLR , PUSHA  , PUSHB  , BOILA  , BOILB  ,HYDR0150
     5   CVA   , CVB   , SLUG  , ALPHA , HVA    , HVB    , HCA    , HCB    ,HYDR0160
     6   EMINA , EMINB , CA    , CB    , GA     , GB     , GL     , GR     ,HYDR0170
     7   RHOL  , RHOR  , EPIO  , EPSI  , RIA    , RIB    , RDIA   , RDIB   ,HYDR0180
     8   RPIA  , RPIB  , RPDIA , RPDIB , TPRINT, TA     , TB     , TC      HYDR0190
      COMMON     TD    , TE    , DTH2  , DTH2P  , DTH1   , DTRMIN, DTMAX  ,HYDR0200
     1   DTMAX1, DTMAX2, DTMAX3, DTR   , SWITCH, CO     , CMIN   , DELTA  ,HYDR0210
     2   GAMA  , WCRIT , SIGMAJ, AC    , ACO3T4, CNVRT  , SUMRA  , SUMRB  ,HYDR0220
     3   ROIA  , ROIAM1, ROIB  , ROIBP1, GMS    , S1     , S2     , S3     ,HYDR0230
     4   S4    , S5    , S6    , S7    , S8     , S9     , S10    , S11    ,HYDR0240
     5   S12   , S13   , S14   , S15   , S16    , S17    , S18    , S19    ,HYDR0250
     6   S20   , EO    , FO    , TAU   , ZERO   , R    (152), DELTAR(152),HYDR0260
     7  ASQ   (152), RD     (152), VD     (152), RDD    (152), SMLR   (152),HYDR0270
     8  DELR  ( 37), P      (152), P1     (152), PB     (152), PB1    (152) HYDR0280
      COMMON         P2     (152), SV     (152), RHO    (152), THETA  (152),HYDR0290
     1  W     (152), E      (152), EI     (152), EK     (152), A      (152),HYDR0300
     2  V     (152), G      (152), D      (152), C      (152), X2     (152),HYDR0310
     3  X3    (152), X4     (152), X5     (152), X6     (152), X7     (152),HYDR0320
     4  SMLA  (152), SMLB   (152), SMLC   (152), SMLD   (152), SMLE   (152),HYDR0330
     5  EC    (152), ER     (152), SMLQ   (152), SMLH   (152), BIGA   (152),HYDR0340
     6  BIGB  (152), CV     (152), BC     (152), BR     (152), CHIC   (152),HYDR0350
     7  CHIR  (152), CAPAC  (152), CAPAR  (152), CRTC   (152), CRTR   (152),HYDR0360
     8  CRTPC (152), GOFR   (152), FEW    (152), CAR    (152), OKLM   ( 37) HYDR0370
      COMMON         TELM   ( 37), EKLM   ( 37), ELM    ( 37), FCLM   ( 37),HYDR0380
     1  FRLM  ( 37), WLM    ( 37), QLM    ( 37), AMASNO( 37), CHRNO  ( 37),HYDR0390
     2  ZP1   ( 37), ZP2    ( 37), SOLID  ( 37), ECHCK ( 37), RK     (104),HYDR0400
     3  RL    ( 37), RHOK   (104), RDK    (104), THETAK(104), TEMP   ( 16),HYDR0410
     4  HEAD  ( 12), MAXL         , MAXLM                                 HYDR0420
                                                                          HYDR0430
C                                                                       **HYDR0440
C*********************************************************************HYDR0450
C                                                                       HYDR0460
C                                                                       HYDR0470
C                                                                       HYDR0480
C                                                                       HYDR0490
C
      IL = IA
```

```
      IR = IB
      CALL DVCHK(KDMY)
      IAM1 = IA-1
C S4 NEGATIVE GIVES DUMMY HYDRO
      IF(S4)10,20,20
   10 IBM1 = IB-1
      DO 15 I=IA,IBM1
      C(I) = R(I)
   15 DELTAR(I) = R(I+1)-R(I)
      C(IB) = R(IB)
      GO TO 70
   20 P(IB) = 0.
      G(IB) = 0.
      RHO(IB) = 0.
      SV(IB) = 0.
      IALPHA = ALPHA
      DO 30 I=IL,IR
      C(I) = R(I)
      IF(IALPHA.EQ.3)GO TO 25
      IF(I.EQ.IB)P(IB) = 0.
      IF (I .NE. 1)  GO TO 23
      RD(1) = RD(1) - P(1) / G(1) * A(1) * DTH1
      GO TO 30
   23 RD(I) = RD(I) + (2. * (P(I-1) - P(I)) / (G(I) + G(I-1)) * A(I)) *
     2 DTH1
      GO TO 30
   25 IF (I .NE. 1)  GO TO 27
      RD(1) = 0.
      GO TO 30
   27 CONTINUE
      AA1=2.*A(I)*(P(I-1)-P(I)+(SMLR(I+1)-SMLR(I-1))/2.)/(G(I)+G(I-1))
      IF(AMIN1(RHO(I),RHO(I+1)).LT. 1.E-10) GO TO 28
      IF (AMIN1(SMLR(I) / RHO(1), SMLR(I+1) / RHO(I+1)) .LT. S4)
     2 GO TO 28
      AA2=(A(I-1)*SMLR(I-1)-A(I+1)*SMLR(I+1))/(G(I-1)+G(I))
      AA3 = (RHO(I) - SMLR(I)) * (SV(I) + SV(I-1)) / (C(I) + C(I))
      RD(I) = RD(I) + DTH1 * (AA1 + AA2 + AA3)
      GO TO 30
   28 CONTINUE
      IF(I.EQ.IB)P(IB) = 0.
      BB2=A(I)*(SMLR(I-1)-SMLR(I+1))/(G(I)+G(I-1))
      BB3=(RHO(I)-3.*SMLR(I))*(SV(I)+SV(I-1))/(C(I)+C(I))
      RD(I)=RD(I)+DTH1*(AA1+BB2+BB3)
      CALL DVCHK(KP)
      IF(KP.LT. 2) X=SQRT(-KP)
   30 CONTINUE
      R(IA) = R(IA)+RD(IA)*DTH2
      DO 50 I=IA,IBM1
      TEMP(1) = DELTAR(I)+(RD(I+1)-RD(I))*DTH2
      R(I+1) = R(I)+TEMP(1)
      IF(S10)41,42,43
   41 A(I) = 1.
      VD(I) = RD(I+1)-RD(I)
      GO TO 50
   42 S1 = 7.1
```

```
      CALL UNCLE
   43 A(I) = 3.*R(I)*R(I)
      CALL DVCHK(KP)
      IF(KP.LT. 2) X=SQRT(-KP)
      IF((ABS(R(I+1)-C(I+1))+ABS(R(I)-C(I)))/(R(I+1)+R(I)).LT.I.E-6)GO T
     10 45
      VD(I) = (TEMP(1)*(R(I+I)*(R(I+I)+R(I))+R(I)*R(I))-DELTAR(I)*(C(I+I
     1)*(C(I+1)+C(I))+C(I)*C(I)))/DTH2
      GO TO 50
   45 VD(I) = (R(I+1)*R(I+1)+R(I)*(R(I+I)+R(I)))*(RD(I+I)-RD(I))
   50 DELTAR(I) = TEMP(1)
      A(IH) = ALPHA*R(IG)**(ALPHA-I.)
      CALL DVCHK(KP)
      IF(KP .GT. 1) GO TO 70
      SI=7.129
      X=-I.
      X=SQRT(X)
      CALL UNCLE
   70 CONTINUE
      RETURN
      END
```

```
Q.T FOR ECALC/OUT, ECALC/OUT, ECALC/OUT1
C     OUTPUT VERSION OF ECALC
      SUBROUTINE ECALC                                                  ECAL0010
C COMPILED  OCTOBER 9, 1967  WJL
C     RECODED BY J PRAGER, 18 APRIL 1967
C     COMPILED JUNE 3, 1966
C         COMPILED 1 NOV 1965                                           ECAL0020
C         INCLUDES INTEGRATED FLUX THRU NR SURFACE                      ECAL0030
C                          ( FRLM(19) ).                                ECAL0040
C                                                                       ECAL0050
C                                                                       ECAL0060
C                                                                       ECAL0070
C.*********************************************************************ECAL0080
C                                                                      *ECAL0090
C*                    S P U T T E R   C O M M O N                     **ECAL0100
C*                                                                    **ECAL0110
C*                                                                    **ECAL0120
      COMMON   LMDA(37), NR     , NSMLR , IA     , IB     , ICA    , ICB    ,ECAL0130
     1   KMAX  , BLANK1, BLANK2, BLANK3, IAP1  , IBP1  , ICAP1 , ICBP1 ,ECAL0140
     2   II    , IG    , NRAD  , BLANK4, IAM1  , IBM1  , ICAM1 , ICBM1 ,ECAL0150
     3   IIP1  , IGM1  , IALPHA, BLANK5, TH    , TMAX  , BLANK6, DELPHT,ECAL0160
     4   FREQ  , CNTMAX, AR    , ASMLR , PUSHA , PUSHB , BOILA , BOILB ,ECAL0170
     5   CVA   , CVB   , SLUG  , ALPHA , HVA   , HVB   , HCA   , HCB   ,ECAL0180
     6   EMINA , EMINB , CA    , CB    , GA    , GB    , GL    , GR    ,ECAL0190
     7   RHOL  , RHOR  , EPIO  , EPSI  , RIA   , RIB   , RDIA  , RDIB  ,ECAL0200
     8   RPIA  , RPIB  , RPDIA , RPDIB , TPRINT, TA    , TB    , TC     ECAL0210
      COMMON     TD    , TE    , DTH2  , DTH2P , DTH1  , DTRMIN, DTMAX ,ECAL0220
     1   DTMAX1, DTMAX2, DTMAX3, DTR   , SWITCH, CO    , CMIN  , DELTA ,ECAL0230
     2   GAMA  , WCRIT , SIGMAQ, AC    , ACOST4, CNVRT , SUMRA , SUMRB ,ECAL0240
     3   ROIA  , ROIAM1, ROIB  , ROIBP1, GMS   , S1    , S2    , S3    ,ECAL0250
     4   S4    , S5    , S6    , S7    , S8    , S9    , S10   , S11   ,ECAL0260
     5   S12   , S13   , S14   , S15   , S16   , S17   , S18   , S19   ,ECAL0270
     6   S20   , EO    , FO    , TAU   , ZERO  , R    (152), DELTAR(152),ECAL0280
     7  ASG   (152), RU    (152), VU    (152), RUD   (152), SMLR  (152),ECAL0290
     8  DELR  ( 37), P     (152), P1    (152), PB    (152), PB1   (152) ECAL0300
      COMMON         P2    (152), SV    (152), RHO   (152), THETA (152),ECAL0310
     1  W     (152), E     (152), EI    (152), EK    (152), A     (152),ECAL0320
     2  V     (152), G     (152), D     (152), C     (152), X2    (152),ECAL0330
     3  X3    (152), X4    (152), X5    (152), X6    (152), X7    (152),ECAL0340
     4  SMLA  (152), SMLB  (152), SMLC  (152), SMLD  (152), SMLE  (152),ECAL0350
     5  EC    (152), ER    (152), SMLQ  (152), SMLH  (152), BIGA  (152),ECAL0360
     6  BIGB  (152), CV    (152), BC    (152), BR    (152), CHIC  (152),ECAL0370
     7  CHIK  (152), CAPAC (152), CAPAR (152), CRTC  (152), CRTR  (152),ECAL0380
     8  CRTPC (152), GOFR  (152), FEW   (152), CAR   (152), OKLM  ( 37) ECAL0390
      COMMON         TELM  ( 37), EKLM  ( 37), ELM   ( 37), FCLM  ( 37),ECAL0400
     1  FRLM  ( 37), WLM   ( 37), QLM   ( 37), AMASNO( 37), CHRNO ( 37),ECAL0410
     2  ZP1   ( 37), ZP2   ( 37), SOLID ( 37), ECHCK ( 37), RK    (104),ECAL0420
     3  RL    ( 37), RHOK  (104), RDK   (104), THETAK(104), TEMP  ( 16),ECAL0430
     4  HEAD  ( 12), MAXL        , MAXLM                               ECAL0440
C                                                                      ECAL0450
C                                                                     **ECAL0460
C.*********************************************************************ECAL0470
C                                                                      ECAL0480
      EQUIVALENCE (LMDA(24), IBB)
```

```
      DIMENSION  ERL4(1)
      EQUIVALENCE  (FCLM, ERLM)                                         ECAL0490
C                                                                       ECAL0500
C
      IF (PUSHA) 1, 5, 5
    1 IC = IB
      FRLM(18) = FRL4(18) + DTR*X2(IA)
      IF (EMINA - EI(ICBM1)) 2, 2, 10
    2 IF (ICB - IG) 3, 3, 10
    3 ICBM1 = ICB
      ICB = ICBP1
      ICBP1 = ICB + 1
      CALL EOS (ICBM1)
      GO TO 10
    5 IC = IA
      FRLM(18) = FRLM(18) + DTR*X2(IB)
      IF (IFIX( PUSHA) .EQ. 0)  GO TO 10
      IF (S3) 10,6, 10
    6 IF (EMINA .GT. EI(ICA)) GO TO 10
      IF (ICA .EQ. 1) GO TO 10
      ICAP1 = ICA
      ICA = ICAM1
      ICAM1 = ICA - 1
      CALL EOS (ICA)
   10 CONTINUE
      DO 160 J = 1, MAXL
      ELM(J) = 0.
      IL = LMDA(J)
      NVAP = 0
      IF (IL .GE. IA .AND. IL .LE. IB)  NVAP = 1
      IF (J .EQ. MAXL)  GO TO 115
      IR = LMDA(J+1) - 1
      DO 110 I = IL, IR
      ELM(J) = ELM(J) + G(I)*E(I)
      IF (IFIX(S2) .EQ. 0)  GO TO 105
      TEMP(1) = DELTAH(I)
      IF (S10) 104, 103, 102
  102 TEMP(1) = TEMP(1) * (3. * R(I) * (H(I) + TEMP(1)) + TEMP(1)**2)
      GO TO 104
  103 TEMP(1) = TEMP(1)*(2.*R(I) + TEMP(1))
  104 ERLM(J) = ERLM(J) + RHO(I) * TEMP(1)
      IF (IFIX(S2) .NE. 3)  GO TO 105
      ELM(J) = ELM(J) + RHO(I) * TEMP(1)
  105 IF (IFIX(S6) .EQ. 0) GO TO 110
      QLM(J) = QLM(J) + SMLQ(I)*DTR
  110 CONTINUE
  115 IM = IL
      IMM1 = IM - 1
      IF (NVAP .NE. 1) GO TO 170
      FRLM(J) = FRLM(J) + DTR*X2(IM)
      IF (IM .EQ. 1) GO TO 180
      GX = G(IM)
      IF (IFIX(BOILA) .EQ. 0 .OR. IM .NE. IC)  GO TO 160
      GX = SOLID(24)*G(IBB)
  152 IF (PUSHA) 160, 160, 155
```

```
155 WLM(J) = WLM(J) + (P(IA-1)*G(IA) + P(IA)*GX)*RD(IA)*DTR/(GX +
   1 G(IA)) * A(IA)
    GO TO 180
160 WLM(J) = WLM(J) + (P(IMM1)*GX + P(IM)*G(IMM1))*RD(IM)*DTR/(GX +
   1 G(IMM1))*A(IM)
    GO TO 180
170 IF (SJ) 180, 175, 180
175 IF (IM .NE. IA .AND. IM .NE. IB) FCLM(J) = FCLM(J) + DTR*(X7(IM) -
   1 DELTA*(W(IM)*X5(IM) - W(IMM1)*X6(IM)))
180 CONTINUE
    IF (IFIX(SUMRA) .EQ.0) GO TO 200
    DO 190 I = IA, IBM1
190 RDD(I) = RDD(I) + EK(I)*(SV(I)*P(I) + E(I) + (RD(I)*RD(I) +
   1 RD(I+1)*RD(I+1))/4.)*DTR
200 FRLM(19) = FRLM(19) + DTR*X2(NR)
    P(152) = AMAX1(P(152), SOLID(28))
    RETURN                                                          ECAL1110
    END                                                             ECAL1120
```

```
U,T FOR EOS/OUT, EOS/OUT, EOS/OUT1
      SUBROUTINE EOS(JJ)
C     OUTPUT VERSION OF EOS -- CHANGES TO USE THE RADIATION PRESSURE
CALCULATED IN THE SCATTERING TRANSPORT CODE
COMPILED  SEPTEMBER 1, 1967  RJL
C     COMPILED FEB. 15,1967 R. SCHLAUG
C     INCLUDES SPECIAL SECTION FOR X-RAY SOURCE ROUTINE
C       THAT HANDLES DEPOSITION IN MULTI ELEMENT MATERIALS
C     COMPILED ON MAY 31,1966 ADDING TEST ON NONEQ OPTION BEFORE
C          TAKING PATH =-3
C     COMPILED MAY 18, 1966  BY G. A. LANE
C     COMPILED MAY 13, 1965.  RSE  TAKES ADVANTAGE OF NEW PATH (-3.) IN
C     EIONX.
C                                                                        EOS 0030
C     COMPILED ON MARCH 31,1966  ADDING COMMON FOR NRAR    (GE)
C                                                                        EOS 0040
C ***********************************************************************
C *                                                                     *
C *                    S P U T T E R   C O M M O N                      **
C *                                                                     **
C *                                                                     **
C *                                                                     **
      COMMON   LMDA(37), NR     , NSMLR , IA     , IB     , ICA    , ICB    ,
     1   KMAX  , BLANK1, BLANK2, BLANK3, IAP1   , IBP1   , ICAP1  , ICBP1  ,
     2   II    , IG    , NRAD  , BLANK4, IAM1   , IBM1   , ICAM1  , ICBM1  ,
     3   IIP1  , IGM1  , IALPHA, BLANK5, TH     , TMAX   , BLANK6, DELPRT,
     4   FREQ  , CNTMAX, AR    , ASMLR , PUSHA  , PUSHB  , ROILA  , ROILB  ,
     5   CVA   , CVB   , SLUG  , ALPHA , HVA    , HVB    , HCA    , HCB    ,
     6   EMINA , EMINB , CA    , CB    , GA     , GB     , GL     , GR     ,
     7   RMOL  , RMOR  , EPIO  , EPSI  , RIA    , RIB    , RDIA   , RDIB   ,
     8   RPIA  , RPIB  , RPDIA , RPDIB , TPRINT, TA     , TB     , TC
      COMMON   TD    , TE    , DTH2  , DTH2P , DTH1  , DTRMIN, DTMAX ,
     1   DTMAX1, DTMAX2, DTMAX3, DTR   , SWITCH, CO     , CMIN   , DELTA ,
     2   GAMA  , WCRIT , SIGMAU, AC    , ACO3T4, CNVRT  , SUMRA  , SUMRB  ,
     3   ROIA  , ROIAM1, ROIB  , ROIBP1, GMS    , S1     , S2     , S3     ,
     4   S4    , S5    , S6    , S7    , S8     , S9     , S10    , S11    ,
     5   S12   , S13   , S14   , S15   , S16    , S17    , S18    , S19    ,
     6   S20   , EO    , FO    , TAU   , ZERO   , R    (152), DELTAR(152),
     7  ASO   (152), RD    (152), VD    (152), RDD   (152), SMLR  (152),
     8  DELR  ( 37), P     (152), P1    (152), PB    (152), PBI   (152)
      COMMON          P2    (152), SV    (152), RHO   (152), THETA (152),
     1  W     (152), E     (152), EI    (152), EK    (152), A     (152),
     2  V     (152), G     (152), D     (152), C     (152), X2    (152),
     3  X3    (152), X4    (152), X5    (152), X6    (152), X7    (152),
     4  SMLA  (152), SMLB  (152), SMLC  (152), SMLD  (152), SMLE  (152),
     5  EC    (152), ER    (152), SMLG  (152), SMLH  (152), BIGA  (152),
     6  BIGB  (152), CV    (152), BC    (152), BR    (152), CHIC  (152),
     7  CHIR  (152), CAPAC (152), CAPAR (152), CRTC  (152), CRTR  (152),
     8  CRTPC (152), GOFR  (152), FEW   (152), CAR   (152), OKLM  ( 37)
      COMMON          TELM  ( 37), EKLM  ( 37), ELM   ( 37), FCLM  ( 37),
     1  FRLM  ( 37), WLM   ( 37), QLM   ( 37), AMASNO( 37), CHRNO ( 37),
     2  ZP1   ( 37), ZP2   ( 37), SOLID ( 37), ECHCK ( 37), RK    (104),
     3  RL    ( 37), RHOK  (104), ROK   (104), THETAK(104), TEMP  ( 16),
     4  HEAD  ( 12), MAXL        , MAXLM
C
```

```
C
C*****************************************************************
C
C
      COMMON/LMS/ EION(20)
      EQUIVALENCE(EION(1),ZBAR)
      EQUIVALENCE(EION(10),ZEAN)
      COMMON/LMSE/MATERL,ILEMNT,SNAFU,I1,I2,I3,I4,I5,I6,I7,I8,I9,I10,J1,
     2  J2,J3,J4,J5,J6,J7
      DATA MATERL,ILEMNT,SNAFU,(1,(2,I3,I4,I5,I6,I7,I8,I9,I10,J1,J2,J3,
     2  J4,J5,J6,J7/20*0.,0.,17*0/
      EQUIVALENCE (L,MATERL)
      EQUIVALENCE (SNAFU,PATH)
      COMMON/LMSC/ M(51)
      DIMENSION Z(51),PART(51)
      EQUIVALENCE(M(1),NOLMNT), (M(2),Z(2)),(M(3),PART(3))
      COMMON/LMSD/          TLMS(30)
      EQUIVALENCE(TLMS(15),DZDTAU )
      EQUIVALENCE(TLMS(16),DZDTHT)
C                                                                       EOS 1070
      COMMON/CNTRL/SCYCLE,JMULT
      COMMON/GE/NBAR
      REAL NBAR
      NBAR=       1.
      IF(SOLID(18).EQ.SCYCLE) I10=0
      I = JJ
      IX = NR - 1
      NX = 1
      IF (PUSHA) 303,2,302
  302 IF (I - IAM1) 1,1,2
  303 IX = NR
      NX = -1
      IF (I - IB) 2,1,1
    1 E(I)=CVA*(THETA(I)-.025)                                          EOS 1120
      CV(I)=CVA                                                         EOS 1130
      PB1(I)=0.0                                                        EOS 1140
      P1(I)=0.0                                                         EOS 1150
      GO TO 500
    2 CONTINUE                                                          EOS 1170
      DO 100 J=1, MAXLM                                                 EOS 1180
      IF (I-LMDA(J+1)) 5,6,6                                            EOS 1190
    5 SOLID(20)=I                                                       EOS 1200
      SOLID(21)=I                                                       EOS 1210
      SOLID(22)=J                                                       EOS 1220
C
         IF (OKLM(J) .EQ. 0. ) GO TO 4
C     MATERIAL NUMBER OF ZERO LEADS TO AN ERROR EXIT
         IF (INT(OKLM(J)) .EQ.0) GO TO 1
C     MATERIAL NUMBER LESS THAN ZERO AND GREATER THAN -1 OR GREATER
C        THAN ZERO AND LESS THAN ONE WILL BYPASS ALL EQUATIONS OF STATE.
      IF (OKLM(J)) 3,4,57
    3 L=        .5-OKLM(J)
      EROR=     -2.
      GO TO 58
    4 CONTINUE
```

```
C     MATERIAL NUMBER OF ZERO LEADS TO AN ERROR EXIT
      S1 = 4.0004
      CALL UNCLE
C     OKLM(J) NOT PROPERLY ENTERED IN INPUT
C
   57 L=          .5+OKLM(J)
      EROR=       0.
      IF ((I-IX)*NA.GT.0 .AND. ZP1(26).NE.0.) EROR = -3.0
   58 CONTINUE
         IF (L.LE.200 OR.L.GE.301.AND.L.LE.400) GO TO 7
      IF (L .EQ. 208 .AND. SMLA(I) .GT. RHOR) GO TO 10
C     TO AVOID 'EIONX', SET RHOR .EQ. 1.E38.
C
      GO TO 8
C
   10 CONTINUE
C     THIS PATH IF OKLM(J) .EQ. 208, FORCES 'EIONX' IF AND ONLY IF
C     TEMPERATURE OF ZONE AT START OF CYCLE .GT. RHOR.
      L = 102
      GO TO 7
C
   23 CONTINUE
C     THIS PATH IF OKLM(J) .EQ. 102, FORCES 'ES8' IF AND ONLY IF
C     TEMPERATURE OF ZONE AT START OF CYCLE .LE. RHOR.
      L = 208
      GO TO 8
C
    7 CONTINUE
      IF (L .EQ. 102 .AND. SMLA(I) .LE. RHOR) GO TO 23
C     TO AVOID 'ES8' SET RHOR .EQ. -1.E38.
         IF(L.EQ.101.OR.L.EQ.102.OR.L.EQ.6.OR.L.EQ.306) EION(14)=RIA
      IF(EROR.EQ.(-3.0)) ZBAR = FLW(I)
      IF (OKLM(J) .GT. 100.) GO TO 60
      CALL EIONM5(THETA(I),SV(I),L,EROR)
      GO TO 61
   60 CALL EIONX (THETA(I),SV(I),L,EROR)
   61 CONTINUE
         IF (L.GE.201 .AND. L .LE. 300 ) GO TO 9
      NBAR=       EION(17)
      IF (S11)  54,52,51
   52 IF (EROR)  53,54,55
   55 S11=       EROR + 100. * FLOAT(I)
      GO TO 54
   51 IF (EROR)   53,54,54
   53 S11=       EROR-FLOAT(I)*100.
C
   54 CONTINUE
C
         IF (EION(14) .EQ. 0. ) GO TO 901
      S1=         EION(14)
      CALL UNCLE
C     EION(14) IS SET EQUAL TO ZERO BY ANY VALID EXIT
C
  901 CONTINUE
C
```

```
      P1(I) = EION(7)
      E(I) = EION(8)
      IF ((I-IX)*NX.GT.0 .AND. ZP1(26).NE.0.) GO TO 200
      CV(I) = EION(9)
      ASQ(I) = EION(11)
      FEW(I) = EION(3)
      PB1(I) = EION(10)
      IF (R1B.EQ.0.) GO TO 199
      IF (SV(I).GE.SOLID(17)) GO TO 199
      P1(I) = P1(1) + 1.E12*(SOLID(17)/SV(1)-1.)**2
      ASQ(I) = SQRT(ASQ(1)**2+2.E12*SOLID(17)*(SOLID(17)/SV(I)-1.))
      GO TO 199
    8 CONTINUE
C
    9 CONTINUE
      L=        L-200
      GO TO (11,12,13,14,15,16,17,18,19,20,21,22),L                    EOS 1240
   11 CALL ES1                                                         EOS 1250
      GO TO 200                                                        EOS 1260
   12 CALL ES2                                                         EOS 1270
      GO TO 200                                                        EOS 1280
   13 CALL ES3                                                         EOS 1290
      GO TO 200                                                        EOS 1300
   14 CALL ES4                                                         EOS 1310
      GO TO 200                                                        EOS 1320
   15 CALL ES5                                                         EOS 1330
      GO TO 200                                                        EOS 1340
   16 CALL ES6                                                         EOS 1350
      GO TO 200                                                        EOS 1360
   17 CALL ES7                                                         EOS 1370
      GO TO 200                                                        EOS 1380
   18 CALL ES8                                                         EOS 1390
      GO TO 200                                                        EOS 1400
   19 CALL ES9                                                         EOS 1410
      GO TO 200                                                        EOS 1420
   20 CALL ES10                                                        EOS 1430
      GO TO 200                                                        EOS 1440
   21 CALL ES11                                                        EOS 1450
      GO TO 200                                                        EOS 1460
   22 CALL ES12                                                        EOS 1470
      GO TO 200                                                        EOS 1480
    6 CONTINUE                                                         EOS 1490
  100 CONTINUE                                                         EOS 1500
C     ASQ IS SPEED OF SOUND
  200 ASQ(I) = SQRT(.25*GAMA*P1(I)*SV(1))
  199 IF (IFIX(S2) .EQ. 3)  GO TO 404
      GO TO 150
  404 P1(I) = RHO(I) * 0.3333333 + P1(1)
      GO TO 400
  150 IF(RPIA)400,201,400
  201 TEMP(1)=THETA(I)**4                                              EOS 1520
      P1(I)=P1(I)+.5*(SMLR(I)+SMLR(I+1))
      PB1(I)=137.0*TEMP(1)+PB1(I)                                      EOS 1540
      E(I)=E(I)+137.0*TEMP(1)*SV(I)                                    EOS 1550
      CV(I)=CV(I)+548.0*TEMP(1)/THETA(I)*SV(1)                         EOS 1560


  400 IF (S4.NE.0.) GO TO 401
      IF (ECHCK(J+17).EQ.0.) ECHCK(J+17) = HVA + HCA - 1.5 * AMASNO(J)
     1                *(HCA/CVA+.025)*(1./NBAR + FEW(I))
  401 E(I) = E(I) + ECHCK(J+17)
  500 RETURN
      END                                                              EOS 1580
```

```
@, FOR RAD/BL, RAD/BL, RAD/BL1
      SUBROUTINE  RAD
C COMPILED  OCTOBER 9, 1967  ADL
COMPTON SCATTERING WITH OPTION FOR THOMSON SCATTERING
C     UNIFIED RADIATION CODE -- PLANE OR SPHERICAL TRANSPORT
C     DIFFUSION IN PLANE, CYLINDRICAL, OR SPHERICAL GEOMETRY
CAVEAT.  MIXTURE OF TRANSPORT AND DIFFUSION IN CYL. GEOMETRY PROHIBITED.
C*****************************************************************PRAD  60
C*                    S P U T T E R   C O M M O N                 **PRAD  70
C                                                                  *PRAD  80
      COMMON   LMDA(37), NR     , NSMLR , IA     , IB     , ICA    , ICB    ,PRAD  90
     1   KMAX  , BLANK1, BLANK2, BLANK3, IAP1   , IBP1   , ICAP1  , ICBP1  ,PRAD 100
     2   II    , IG    , NRAD  , BLANK4, IAM1   , IBM1   , ICAM1  , ICBM1  ,PRAD 110
     3   IIP1  , IGM1  , IALPHA, BLANK5, TH     , TMAX   , BLANK6, DELPRT,PRAD 120
     4   FREQ  , CNTMAX, AR    , ASMLR , PUSHA  , PUSHB  , BOILA  , BOILB  ,PRAD 130
     5   CVA   , CVB   , SLUG  , ALPHA , HVA    , HVB    , HCA    , HCB    ,PRAD 140
     6   EMINA , EMINB , CA    , CB    , GA     , GB     , GL     , GR     ,PRAD 150
     7   RHOL  , RHOR  , EPIO  , EPSI  , RIA    , RIB    , RDIA   , RDIB   ,PRAD 160
     8   RPIA  , RPIB  , RPDIA , RPDIB , TPRINT, TA     , TB     , TC      PRAD 170
      COMMON     TD    , TE    , DTH2  , DTH2P , DTH1   , DTRMIN, DTMAX  ,PRAD 180
     1   DTMAX1, DTMAX2, DTMAX3, DTR   , SWITCH, CO     , CMIN   , DELTA  ,PRAD 190
     2   GAMA  , WCRIT , SIGMAJ, AC    , ACO3T4, CNVRT  , SUMRA  , SUMRB  ,PRAD 200
     3   ROIA  , ROIAM1, ROIB  , ROIBP1, GMS    , S1     , S2     , S3     ,PRAD 210
     4   S4    , S5    , S6    , S7    , S8     , S9     , S10    , S11    ,PRAD 220
     5   S12   , S13   , S14   , S15   , S16    , S17    , S18    , S19    ,PRAD 230
     6   S20   , EO    , FO    , TAU   , ZERO   , R    (152), DELTAR(152),PRAD 240
     7  ASQ   (152), RD    (152), VD    (152), RDD   (152), SMLR  (152),PRAD 250
     8  DELR  ( 37), P     (152), P1    (152), PB    (152), PB1   (152) PRAD 260
      COMMON          P2    (152), SV    (152), RHO   (152), THETA (152),PRAD 270
     1  W     (152), E     (152), EI    (152), EK    (152), A     (152),PRAD 280
     2  V     (152), G     (152), D     (152), C     (152), X2    (152),PRAD 290
     3  X3    (152), X4    (152), X5    (152), X6    (152), X7    (152),PRAD 300
     4  SMLA  (152), SMLB  (152), SMLC  (152), SMLD  (152), SMLE  (152),PRAD 310
     5  EC    (152), ER    (152), SMLQ  (152), SMLH  (152), BIGA  (152),PRAD 320
     6  BIGU  (152), CV    (152), BC    (152), BR    (152), CHIC  (152),PRAD 330
     7  CHIR  (152), CAPAC (152), CAPAR (152), CRTC  (152), CRTR  (152),PRAD 340
     8  CRTPC (152), GOFR  (152), FEW   (152), CAR   (152), OKLM  ( 37) PRAD 350
      COMMON          TELM  ( 37), EKLM  ( 37), ELM   ( 37), FCLM  ( 37),PRAD 360
     1  FRLM  ( 37), WLM   ( 37), QLM   ( 37), AMASNO( 37), CHRNO ( 37),PRAD 370
     2  ZP1   ( 37), ZP2   ( 37), SOLID ( 37), ECHCK ( 37), RK    (104),PRAD 380
     3  RL    ( 37), RHOK  (104), RDK   (104), THETAK(104), TEMP  ( 16),PRAD 390
     4  HEAD  ( 12), MAXL        , MAXLM                                 PRAD 400
C                                                                     **PRAD 410
C*****************************************************************PRAD 420
      COMMON /LINDLY/ HNU,SGNL,IHNU,NHNU,HNUP,NT,IM,IN,DHNU,THICK,NY     PRAD 460
      COMMON /CNTRL/ SCYCLE, JHULT                                       PRAD 470
      COMMON /DAVIS/  X(4000), ICX, ICY
      COMMON /PALMER/  FI0(152), FI1(152), FI2(152), FI3(152), FQ0(152),
     2 FQ1(152), FQ2(152), FQ3(152), JDRUM
      COMMON /JIM/ NN, FMU, R1, R2, HD, EST, I1, I2, GMP, A1, A3, FMUS,
     2 FS, LDF, LRI, IZN, TG1, TG2, F2
C                                                                     PRAD 500
      DIMENSION   CSQD  (1), PR    (1), FM    (1), H     (1), H2    (1),
     1 H3    (1), H4    (1), FMS   (1), Q1    (1), TG    (1), Q3    (1),
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     2 Q37    (1), Q38    (1), SUMX2 (1), SUMX3 (1), SUMX4 (1), X8     (1),P     550
     3 Y      (1), Y2     (1), OX    (1), FL    (1), TR    (1), FSM    (1),P
     4 FSP    (1)                                                          P
C                                                                          P     570
      EQUIVALENCE          (AC03T4,TRDBG), (BC    ,SUMX4), (BIGA ,Y     ),P     580
     1        (BIGB ,H    ), (BR    ,H3   ), (CAR  ,Q37  ), (CHIC ,SUMX3),P     590
     2        (CHIR ,Q38  ), (CRTR ,SUMX2), (X7   ,PR   ), (GOFR ,Q3   ),P     600
     3        ( PB  ,Q1   ), (S12  ,EDITMF), (EC   ,H2   ), (  W  ,OX   ),P
     4        (SMLA ,FMS  ), (SMLB ,FL   ), (SMLC ,TR   ), (SMLH ,H4   ),P
     5        (ER   ,FM   ), (V    ,TG   ), (SMLD ,FSM  ), (CRTC ,CSOD ),P
     6        (X5   ,Y2   ), (X4   ,X8   ), (SMLE ,FSP  )                  P
C.*********************************************************************P     660
C                                                                        *P     670
C                 OX CONTAINS X FROM THE PREVIOUS Y LINE                 *P     680
C                                                                        *P     690
C                          CSOD    SAME AS   CRTC                        *P     700
C                          EDITMF  SAME AS    S12                        *P     710
C                          Q1      SAME AS     PB                        *P
C                          FM      SAME AS     ER                        *P
C                          H       SAME AS   BIGB                        *P     740
C                          H2      SAME AS     EC                        *P
C                          H3      SAME AS     BR                        *P     760
C                          H4      SAME AS   SMLH                        *P     770
C                          PR      SAME AS     X7                        *P
C                          FMS     SAME AS   SMLA                        *P
C                          FL      SAME AS   SMLB                        *P
C                          TR      SAME AS   SMLC                        *P
C                          FSM     SAME AS   SMLD                        *P
C                          FSP     SAME AS   SMLE                        *P
C                          Y2      SAME AS     X5                        *P
C                          OX      SAME AS      W                        *P
C                          TG      SAME AS      V                        *P
C                          Q3      SAME AS   GOFR                        *P     830
C                          Q37     SAME AS    CAR                        *P     840
C                          Q38     SAME AS   CHIR                        *P     850
C                          SUMX2   SAME AS   CRTR                        *P     860
C                          SUMX3   SAME AS   CHIC                        *P     870
C                          SUMX4   SAME AS     BC                        *P     880
C                          TRDBG   SAME AS AC03T4                        *P     890
C                          Y       SAME AS   BIGA                        *P     910
C                          X8      SAME AS     X4                        *P
C                                                                        *P     940
C*********************************************************************PRAD 800
C                                                                        PRAD 890
C     SOLID(37) IS THE SCATTERING COEFFICIENT                            P
C     SOLID(36) IS THE COMPTON SWITCH.  ZERO, COMPTON; NONZERO, THOMSON.P
C     FI0, FI1, FI2, FI3, FREQUENCY-DEPENDENT SCATTERING SOURCES,        P
C     READ IN FROM DRUM, ALTERNATELY FROM LOGICAL UNITS 25 AND 26.       P
C     RECIPROCAL ELECTRON REST ENERGY IN EV**-1 IS 1.95692E-6            P
      IDMX = 4000                                                        P
      T4 = 1.                                                            P
      TAX = ABS(SOLID(37)) * 1.95692E-6                                  P
      IF (ABS(SOLID(36)) .GT. 1.E-20)  TAX = 0.                          P
      JDRUMI = 51 - JDRUM                                                P
      REWIND JDRUM                                                       P
```

```
      RE.IND JDRUMI                                                     P
      IM=IBM1                                                           PRAD 930
      IN=IA                                                             PRAD 940
      IMPI=IM+1                                                         PRAD1040
      INMI=IN-1                                                         PRAD1050
      CALL UVCHK (KDUPX)                                                PRAD1060
      CALL       UVCKON                                                 P
      IF (IMPI-IN) 30,30,40                                             PRAD1070
C                                                                       PRAD1080
C                          NO VAPOR ZONES                               PRAD1090
C                                                                       PRAD1100
   30 X2(IMP1) = 1.0285E12 * A(IMPI) * (THETA(IM)**4 - THETA(IMP1)**4)  P
      ER(IM)=-X2(IMP1)                                                  PRAD1120
      GO TO 1320                                                        PRAD1130
   40 THTAMX = .025                                                     P
      DO 100 I=IN,IM                                                    P
C                                                                       PRAD1250
C                 SET UP FOR KAPPA INTERPOLATION                        PRAD1260
C                                                                       PRAD1270
      Q1(I)=THETA(I)**4                                                 PRAD1280
      Q37(I)=ALOG(THETA(I))                                             PRAD1290
      Q38(I)=ALOG(SV(I))                                                PRAD1300
      FMS(I) = ABS(SOLID(37)) * 0.5 / SV(I)                             P
      CSQD(I) = C(I)**2                                                 P
      IF (THETA(I) .GT. THTAMX)  THTAMX = THETA(I)                      P
  100 CONTINUE                                                          PRAD1380
      IF (THTAMX .LT. THETA(IMP1))  THTAMX = THETA(IMPI)
      IF (INMI .GT. 0 .AND. THTAMX .LT. THETA(INMI))  THTAMX=THETA(INMI)P
      IF (THTAMX .LT. 0.05  .AND. GL .LT. 1.-30 .AND. INMI .LE. 0)      P
    2 GO TO 1320                                                        P
      CSQD(IMP1) = C(IMP1)**2                                           P
      IF (ABS(SOLID(37)) .GT. 1.E-20)  IH = IM                          P
      IHNU=0                                                            P
      CALL KAPPA(IN,IM)                                                 P
C                 MINIMUM RADIATION TIME STEP                           P
      #SB=0.                                                            P
      DO 101 I=1,MAXLM                                                  P
  101 #SB=#SB+ELM(I)                                                    P
      DTR1=1.E10                                                        P
      DTR2=1.E10                                                        P
      DO 107 I=IN,IM                                                    P
      IF (AMIN1(CAPAC(I),CAPAR(I)).GT.0.) GO TO 102                     P
      S1=13.0102                                                        P
      CALL UNCLE                                                        P
  102 IF (ABS(SOLID(10)) .LT. 1.E-20)  GO TO 103                        P
      TEMP(1)=CAPAR(I)                                                  P
      TEMP(3)=CAPAR(I)                                                  P
      GO TO 104                                                         P
  103 TEMP(1)=CAPAC(I)                                                  P
      TEMP(3)=CAPAC(I)                                                  P
  104 IF (THETA(I).LT..001) GO TO 107                                   P
      H(I) = .5*TEMP(1)/SV(I)*DELTAR(I)                                 P
      TEMP(1)=1.E10                                                     P
      TEMP(2)=1.E10                                                     P
      #SBB=E(I)*G(I)                                                    P
```

```
      IF (ABS(ER(I)) .LT. 1.E-20 .OR. WSBD .LT. .001 * WSB) GO TO 105   P
C      ACCURACY CRITERION                                               P
      TEMP(1)=SLUG*WSBD/ABS(ER(I))                                      P
C      STABILITY CRITERION                                              P
  105 TEMP(2) = TELM(25) * (AMIN1(TEMP(1), (.5 + 1.5 * H(I)**2) * CV(I)/P
     1 (4.1132E12*TEMP(3)*THETA(I)**3)))                                P
      IF (TEMP(2) .LT. 1.E-20)  GO TO 107                               P
      IF (TEMP(2).GT.DTR1) GO TO 106                                    P
      DTR2=DTR1                                                         P
      IMN2=IMN1                                                         P
      DTR1=TEMP(2)                                                      P
      IMN1=I                                                            P
      GO TO 107                                                         P
  106 IF (TEMP(2).GT.DTR2) GO TO 107                                    P
      DTR2=TEMP(2)                                                      P
      IMN2=I                                                            P
  107 CONTINUE                                                          P
      DTRMIN=DTR1                                                       P
      EO=IMN1                                                           P
      IF (DTR1.GT.TELM(26)) GO TO 108                                   P
      TELM(26)=DTR1                                                     P
      TELM(27)=IMN1                                                     P
      TELM(28)=DTR2                                                     P
      TELM(29)=IMN2                                                     P
      TELM(30)=SOLID(16)+1.                                             P
  108 IF (DTRMIN-DTR) 111,112,109                                       P
  109 BLANKJ=TH+AMIN1(DTRMIN,GR*DTH2)                                   P
      GO TO 112                                                         P
  111 NRAD=ZP1(18)/DTRMIN + 1.                                          P
      DTR=ZP1(18)/FLOAT(NRAD)                                           P
      IF (NRAD .LE. 50)   GO TO 112                                     P
      S1=13.0112                                                        P
      CALL UNCLE                                                        P
  112 CALL UVCHK(KX)                                                    P
      GO TO (150,160), KX                                               P
  150 S1 = 13.0150                                                      P
      CALL UNCLE                                                        P
  160 IF (GL .GT. 0.)  IR = IM                                          P
      GO TO (128, 113, 113), IALPHA                                     P
C                                                                       P
C ANACTERISTICS IN NONPLANE GEOMETRY -- SET UP X AND Y OUTSIDE FREQ LOOPP
C                                                                       P
  113 K = 0                                                             P
C                 DETERMINE WHETHER TO SKIP ZONES WITH Y-LINES          P   1470
  114 K1=K                                                              P
      Y(1)=0.0                                                          P   1500
      X4(1) = 0.0                                                       P
      JK=1                                                              P   1530
C*********************************************************************P   1540
C                                                                     *P   1550
C                          S E T   U P   Y   L I N E S                *P   1560
C                                                                     *P   1570
C*********************************************************************P   1580
C                 DRAW Y LINES---ONE FOR EACH LARGE TEMPERATURE CHANGE  P   1600
C                 FORCE Y LINE ON SURFACE OF SOLID IF ANY               P   1610
```

```
C                NO Y GREATER THAN C(IR+1)                                P
C                                                                         P    1630
      IF (IN .LE. 1)  GO TO 115                                           P
      JK = 2                                                              P
      Y(2) = C(IN)                                                        P
      X4(2) = CSQD(IN)                                                    P
  115 DO 118 I = IN, IR                                                   P
      IF (ABS(Q37(I+1) - Q37(I)) - 0.5)  117, 117, 116                    P
  116 JK=JK+1                                                             P    1670
      Y(JK)=C(I+1)                                                        P
      X4(JK) = CSQD(I+1)                                                  P    1690
      K1=K                                                                P
      GO TO 118                                                           P
  117 IF (K1 .LE. 0 .OR. I .EQ. IR) GO TO 116                             P
      K1=K1-1                                                             P
  118 CONTINUE                                                            P    1740
      NY=JK                                                               P
      GO TO 120                                                           P
  119 K=K+1                                                               P
      IF (K .LE. 10)  GO TO 114                                           P
      S1 = 13.0119                                                        P
      CALL UNCLE                                                          P
C*********************************************************************P    1780
C                                                                     *P    1790
C        F I N D   C O M P L E T E   S E T   O F   X   V A L U E S    *P    1800
C                  (INTERSECTIONS OF RADII WITH Y LINES)              *P    1810
C                                                                     *P    1820
C*********************************************************************P    1830
C                                                                         P    1840
C                FORMAT= -X4, -NUMBER OF INTERSECTIONS,X'S.               P
C                                                                         P    1860
  120 K2=1                                                                P
      DO 125 J=2,JK                                                       P    1890
      I=IMP1                                                              P
      X(K2) = -X4(J)                                                      P    1910
      K2=K2+2                                                             P    1920
      KK=1                                                                P
  121 TS1 = CSQD(I) - X4(J)                                               P
      IF (TS1)  124, 124, 122                                             P
  122 X(K2)=SQRT(TS1)                                                     P    1960
      K2=K2+1                                                             P
      IF (K2-IDMX)  123, 123, 119                                         P
  123 I=I-1                                                               P    1990
      KK=KK+1                                                             P
      GO TO 121                                                           P
  124  KKK=K2-KK                                                          P    2020
      X(KKK)=-(KK-1)                                                      P
  125 CONTINUE                                                            P
C                FINISH X-BLOCK WITH A NEGATIVE NUMBER                    P    2070
      X(K2)=-1.0
C*********************************************************************PRAD1420
C                                                                     *PRAD1430
C                B E G I N   F R E Q U _ N C Y   L O O P              *PRAD1440
C*********************************************************************PRAD1460
C                                                                      PRAD1480
```

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C                 SET UP MAX FREQ BOUNDARY                              PRAD1490
C                                                                       PRAD1500
COMPTON SCATTERING FORBIDS VERY HIGH FREQUENCIES.                       P
C     THETAK(103) CHOSEN TO BE COMPATIBLE WITH KAP6/JP                  P
  128 HNUP = THETAK(103)
      IHNU=1                                                            PRAD1520
      DO 129 I=IN,IMP1
      X4(I) = 0.
      FQ0(I) = 0.
      FQ1(I) = 0.
      FQ2(I) = 0.
      FQ3(I) = 0.
      RDD(I) = EK(I)
      EK(I) = 0.
      SMLR(I) = 0.
  129 SUMX2(I)=0.0
      IF (KMAX .NE. 0)  GO TO 310
C                                                                       PRAD2070
C                 MONOFREQUENCY CALCULATION                             PRAD2080
C                                                                       PRAD2090
  210 NHNU=1                                                            PRAD2100
      DO 220 I=IN,IM                                                    PRAD2120
  220 Xo(I)=Q1(I)                                                       PRAD2140
  240 DFB = 1.0                                                         PRAD2180
      HNU = .001                                                        PRAD2190
      DHNU = THETAK(103)
      ICX = IM
      ICY=IN                                                            PRAD2220
      GO TO 460                                                         PRAD2230
C                                                                       PRAD2450
C                 TYPICAL GROUP CALCULATION OF SOURCES                  PRAD2460
C                                                                       PRAD2470
  310 CALL KAPPA(IN,IM)                                                 PRAD2480
      ZZ = 0.
      DHNUP = DHNU
      DHNU=HNUP-HNU                                                     PRAD2490
  350 ICX = IM
      ICY = IN                                                          PRAD2610
      IF (GL .LT. 1.E-20)  GO TO 370
      DO 360 I=IN,IM                                                    PRAD2640
      DFB = PLNKUT(HNU / THETA(I), HNUP / THETA(I))                     PRAD2650
  360 X6(I)=DFB*Q1(I)                                                   PRAD2660
      GO TO 460                                                         PRAD2670
  370 DO 450 I=IN,IM                                                    PRAD2680
      BETA=HNU/THETA(I)                                                 PRAD2690
C                                                                       PRAD2700
C                 AVOID CALCULATION OF DFB LESS THAN 1E-5               PRAD2710
C                                                                       PRAD2720
      IF (BETA .GT. 19.)  GO TO 430
      BETAP = HNUP / THETA(I)
      IF (BETAP .GT. 0.01)  GO TO 440
  430 X6(I)=0.0                                                         PRAD2860
      GO TO 450                                                         PRAD2880
C                                                                       PRAD2890
C                 FORM SOURCE X6
```

```
C                                                                       PRAD2910
  440 DFB=PLNKUT(BETA,BETAP)                                            PRAD2920
      X6(I)=DFB*Q1(I)                                                   PRAD2930
  450 CONTINUE                                                          PRAD2980
      CALL DVCHK(KX)
      GO TO (452, 460), KX
  452 S1 = 13.0452
      CALL UNCLE
  460 IF (INM1)  470, 490, 480
C                                                                       PRAD3000
C                 SET BLACKBODY CONDITION FOR IA GREATER THAN 1         PRAD3010
C                                                                       PRAD3020
  470 S1 = 13.0470
      CALL UNCLE                                                        PRAD3040
  480 DFB = PLNKUT (HNU/THETA(INM1),HNUP/THETA(INM1))                   PRAD3050
      X6(INM1) = DFB * THETA(INM1)**4                                   PRAD3060
C     SET BLACKBODY CONDITION IF DESIRED FOR IMP1                       PRAD3070
  490 IF (ABS(GL - 0.5) .GT. 1.E-5)  GO TO 510
      IF (ABS(THETA(IMP1)) .LT. 1.E-20)  GO TO 500
      FMS(INM1) = 0.
      DFB = PLNKUT(HNU / THETA(IMP1), HNUP / THETA(IMP1))               PRAD3100
      X6(IMP1) = DFB * THETA(IMP1)**4                                   PRAD3110
      FMS(IMP1) = 0.
      GO TO 510                                                         PRAD3120
  500 X6(IMP1)=0.                                                       PRAD3130
  510 IF (ABS(SOLID(37)) .LT. 1.E-20)  GO TO 515
C     SCATTERING.  SET RADIATION REGION ACTIVE THROUGHOUT, BRING IN DATA
C     FROM DRUM, AND SET UP COMPTON SCATTERING FREQUENCY PARAMETERS
      ICY = IN
      ICX = IM
      READ (JDRUM)  FI0, FI1, FI2, FI3
      HNUX = AMIN1(HNUP, 1.E5)
      GAMMA = AMIN1(0.2, 0.97846E-6 * (HNU + HNUX))
      A1P = HNU**2 / DHNU * 1.95692E-6
      IF (IHNU .EQ. 1)  GO TO 512
      A3 = HNUX**2 / DHNUP * 1.95692E-6
  512 A1 = A1P + 3. * GAMMA
      GMP = 1. - 2. * GAMMA
  515 Q31=0.0
C                                                                       PRAD3150
C                 FORM ROSSELAND AND PLANCK OPTICAL DEPTHS              PRAD3160
C                                                                       PRAD3170
      DO 570 I=IN,IM                                                    PRAD3180
      IF (CAPAR(I)) 530,530,520                                         PRAD3190
  520 IF (CAPAC(I)) 530,530,540                                         PRAD3200
  530 S1=13.0530
      CALL UNCLE                                                        PRAD3220
  540 TAUX = AMAX1(SOLID(37), 0.)
C     SPECIAL CODING TO FORCE KAPPAS TO BE AT LEAST 0.2
      CPC = AMAX1(CAPAR(I) + TAUX, 0.2)
C     HHTAX MUST BE LIMITED TO 2 * GAMMA * KAPPA(S) = .08
      HHTAX = AMIN1(TAX * (HNU + HNUX), 0.08)
      GO TO (542, 544, 544), IALPHA
  542 QQ1 = G(I)
      GO TO 546
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  544 QQ1 = (C(I+1) - C(I)) / SV(I)
  546 CPA = CPC - HHTAX
      H3(I) = CPA * QQ1
C CHOOSE ALL ROSSELAND IF SOLID(10) IS NONZERO
      IF (ABS(SOLID(10)) .LT. 1.E-20)  GO TO 550
      H2(I) = H3(I)                                                     PRAD3280
      H(I) = CPA / SV(I)
      GO TO 560                                                         PRAD3290
  550 CPB = AMAX1(CAPAC(I) + TAUX, 0.2)
      H2(I) = CPB * QQ1
      H(I) = CPB / SV(I)
  560 Q31=Q31+H3(1)                                                     PRAD3310
      Q3(I+1)=Q31                                                       PRAD3320
      H(I) = 0.5 * H(I)
      H2(I)=0.5*H2(I)                                                   PRAD3330
      H3(I)=0.5*H3(I)                                                   PRAD3340
      X2(I)=0.0                                                         PRAD3380
      X3(I)=0.0                                                         PRAD3390
      X4(I)=0.0                                                         PRAD3400
      Y2(I) = 0.
      TG(I) = 0.
      RHO(I) = 0.
      PR(I) = 0.
      FL(I) = 0.
  570 TR(I) = 0.
      X2(IMP1)=0.0                                                      PRAD3420
      X3(IMP1)=0.0                                                      PRAD3430
      X4(IMP1)=0.0                                                      PRAD3440
      TG(IMP1) = 0.
      RHO(IMP1) = 0.
      PR(IMP1) = 0.
      FL(IMP1) = 0.
      TR(IMP1) = 0.
      Y2(IN)=X6(IN)
      TG(IN)=0.0                                                        PRAD3520
C                                                                       PRAD3570
C     FORM Y2 AND TG  SET X3=-1 IF A DIFFUSION CRITERION MET USING HCB  PRAD3580
C                                                                       PRAD3590
  600 ICXM1=ICX-1                                                       PRAD3600
      IF (ICY.GT.ICXM1) GO TO 650                                       PRAD3610
      DO 640 I=ICY,ICXM1                                                PRAD3620
      TEMP(1)=H3(I+1)+H3(I)                                             PRAD3630
      IF (AMAX1(X6(I),X6(I+1)).LT.1.E-30) GO TO 610
      IF (ABS((H3(I) - H3(I+1)) / TEMP(1)) .GT. 0.333)  GO TO 610
      IF (ABS((X6(I)-X6(I+1)) / (X6(I)+X6(I+1))) .LT. 0.333)  GO TO 620
  610 TG(I+1)=0.0                                                       PRAD3680
      GO TO 640                                                         PRAD3690
  620 TG(I+1)=(X6(I+1)-X6(I))/TEMP(1)                                   PRAD3700
      Y2(I+1)=(X6(I+1)*H3(I)+X6(I)*H3(I+1))/TEMP(1)                     PRAD3740
C     FORCE TRANSPORT FOR RAPIDLY VARYING SOURCE OR POSITIVE HCB
      IF (ABS(TG(I+1)) .GT. 0.1 * Y2(I+1) .OR. HCB .GT. 0.)  GO TO 640
  630 X3(I+1)=-1.0                                                      PRAD3760
  640 CONTINUE                                                          PRAD3770
C     FORCE DIFFUSION FOR NEGATIVE HCB
  650 IF (HCB)  651, 655, 655
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  65  IF (GL .GT. 0.9)  GO TO 654
      INP1 = IN + 1
      X3(1) = -1.
      DO  653  I = INP1, IM
      Q = H3(I-1) + H3(I)
      IF (Q .GT. 0.)  GO TO 652
      S1 = 13.0652
      CALL UNCLE
  652 TG(I) = (X6(I) - X6(I-1)) / Q
  653 X3(I) = -1.
      GO TO 655
  654 S1 = 13.0654
      CALL UNCLE
C                                                                       PRAD3780
C     LAST ZONE MUST BE TRANSPORT IF EXTERNAL INPUT INTENSITIES PROVIDED
  655 IF (GL .GT. 0.9)  X3(IM) = 0.0
      IF (ABS(GL - 0.5) .LT. 1.E-5)  GO TO 690
      Y2(IMP1)=X6(ICX)                                                  PRAD3910
      TG(IMP1)=0.0                                                      PRAD3920
C                                                                       PRAD3930
C EXTEND TRANSPORT REGION BOUNDARIES TO PROVIDE 5 MEAN FREE PATHS
C                                                                       PRAD3960
  690 I=IN+1                                                            PRAD3970
      CALL DVCHK(KX)
      GO TO (692, 700), KX
  692 S1 = 13.0692
      CALL UNCLE
  700 IF (X3(I)) 710,730,720                                            PRAD3980
  710 I=I+1                                                             PRAD3990
      IF (I-ICX-1) 700,730,820                                          PRAD4000
  720 S1=13.0720
      CALL UNCLE                                                        PRAD4020
  730 IF (I .EQ. IMP1)  GO TO 820
      J = I - 1
  740 IF (Q3(I)-Q3(J)- 5.) 750,750,760
  750 X3(J) = 0.0                                                       PRAD4050
      J=J-1                                                             PRAD4060
      IF (J-IN) 760,740,740                                             PRAD4070
  760 I=I+1                                                             PRAD4080
      IF (I-ICX-1) 770,770,820                                          PRAD4090
  770 IF (X3(I)) 780,760,720                                            PRAD4100
  780 J=I                                                               PRAD4110
  790 IF (Q3(J)-Q3(I-1)- 5.) 800,800,710
  800 X3(J) = 0.0                                                       PRAD4130
      J=J+1                                                             PRAD4140
      IF (J-ICX-1) 790,810,810                                          PRAD4150
  810 I = J                                                             PRAD4160
      GO TO 710                                                         PRAD4170
  820 I=IN+1                                                            PRAD4180
C                                                                       PRAD4190
C                 TEST TO FORM TRANSPORT REGIONS                        PRAD4200
C                                                                       PRAD4210
      IF (X3(IN)) 890,830,720
  830 IAX=IN                                                            PRAD4230
  840 IF (X3(I)) 860,850,720                                            PRAD4240
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C                                                                       PRAD4250
C                 REMOVE ONE ZONE DIFFUSION REGION                      PRAD4260
C                                                                       PRAD4270
  850 I=I+1                                                             PRAD4280
      IF (I-ICX-1) 840,950,950                                          PRAD4290
  860 I=I+1                                                             PRAD4300
      IF (I-ICX-1) 870,950,950                                          PRAD4310
  870 IF (X3(I))  880, 875, 720
  875 X3(I-1) = 0.
      GO TO 840
  880 IBX=I-3                                                           PRAD4330
      IF (IBX.LT.IAX) GO TO 970                                         PRAD4340
      GO TO 960                                                         PRAD4350
  890 IF (IN.GT.1) GO TO 910                                            PRAD4360
C     ASSUME C(1) = 0.
  900 X2(1) = 0.0
      FL(1) = 0.
      GO TO 920                                                         PRAD4380
  910 X2(IN) = 1.0283E12 * A(IN) * (X6(IN-1) - X6(IN))                  PRAD4390
      FL(IN) = 0.5 * (X6(IN-1) - X6(IN))
  920 PR(IN) = Y2(IN) * 0.6666667
      RHO(IN) = Y2(IN) + Y2(IN)
      FL(IN) = -.6666667 * TG(IN)
      TR(IN) = 0.6 * FL(IN)
  925 IF (X3(I))  930, 940, 720
C     FORM X2 FOR DIFFUSION ZONES IN ORDER                              PRAD4410
  930 X2(I) = -1.37E12 * TG(I) * A(I)                                   PRAD4420
      PR(I) = Y2(I) * .6666667
      RHO(I) = Y2(I) + Y2(I)
      FL(I) = -.6666667 * TG(I)
      TR(I) = .6 * FL(I)
      I=I+1                                                             PRAD4430
      IF (I - ICX - 1)  925, 980, 980
C                                                                       PRAD4450
C                 DO TRANSPORT TO IM IN REGION OF NO SOURCE             PRAD4460
C                                                                       PRAD4470
  940 IAX=I                                                             PRAD4480
      GO TO 850                                                         PRAD4490
  950 IBX=IR
  960 IF (IAX .GT. ICX)  GO TO 965
      GO TO (961, 962, 963), IALPHA
  961 CALL PTRANS(IAX, IBX)
      GO TO 965
  962 S1 = 13.0962
      CALL UNCLE
  963 CALL STRANS(IAX, IBX)
  965 IF (IBX-IM) 970,1030,1030                                         PRAD4520
  970 I=IBX+2                                                           PRAD4530
      GO TO 930                                                         PRAD4540
  980 IF (I.GT.IR) GO TO 981
      IAX=I                                                             PRAD4560
      GO TO 950                                                         PRAD4570
  981 IF (IR .EQ. IM)  GO TO 990
      S1 = 13.0982
      CALL UNCLE
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C     RIGHT-HAND BOUNDARY CONDITION FOR DIFFUSION ZONES                PRAD4580
C VEAT.  MAY NEED RHO, FL, TR HERE.
  990 IF (GL) 1000,1010,1020                                           PRAD4590
 1000 X2(IMP1) = 0.                                                    PRAD4600
      GO TO 1030                                                       PRAD4610
 1010 X2(IMP1) = 1.0283E12 * X6(IM) * A(IMP1)
      GO TO 1025
 1020 X2(IMP1) = 1.0283E12 * (X6(IM) - X6(IMP1)) * A(IMP1)
 1025 RHO(IMP1) = Y2(IMP1) + Y2(IMP1)
      PR(IMP1) = 0.3333333 * RHO(IMP1)
      FL(IMP1) = X2(IMP1) / A(IMP1) * 4.8624E-13
      TR(IMP1) = FL(IMP1) * 0.6
C                                                                      PRAD4650
C                 OPTIONAL EDIT OF X2 ETC.                             PRAD4660
C                                                                      PRAD4670
 1030 IF (ABS(EDITMF) .LT. 1.E-20 .OR. ZZ .GT. 1.E-20)  GO TO 1040
      CNT1=SOLID(18)+1.0                                               PRAD4690
      IF(TD.GT.0.5.AND.CNT1.LT.CNTMAX)GO TO 1040
      WRITE (6,3) CNT1, TH, HNU, HNUP, IR, ICX, ICY
      WRITE (6,4)
      DO 1035 I = IN,IMP1
      WRITE (6,6) I, C(I), X6(I), H2(I), H3(I), TG(I), Y2(I), X3(I),
     1X2(I), RHO(I), PR(I), TR(I)
 1035 CONTINUE
    3 FORMAT  (9H1CYCLE = F7.0, 9H  TIME = E13.6, 12H   HNU FROM F8.2,
     2 4H TO F8.2, 10X2HIRI4, 10X3HICXI4, 10X3HICYI4/)
    4 FORMAT  (3X1HI, 10X1HR, 10X2HX6, 10X2HH2, 10X2HH3, 10X2HTG,
     2 10X2HY2, 3X2HX3, 10X2HX2, 9X3HRHO, 10X2HPR, 10X2HTR)
    6 FORMAT  (I4, 1PE11.4, 5E12.5, 0PF5.1, 1P4E12.5)
 1040 IF (T4 .GT. CAPAC(152))  GO TO 1055
      ZZ=0.
      QEM = 0.
      DO  1053  I = IN, IMP1
      FIOSV=3.*RHO(I)-PR(I)
      FI2SV=3.*PR(I)-RHO(I)
      FI1SV = 3. * FL(I) - 5. * TR(I)
      FI3SV = 3. * TR(I) - 5. * FL(I)
      QN = FIOSV - FIO(I)
      QD = FIOSV + FIO(I)
      IF (ABS(QD) .GT. 0.)  GO TO 1051
      GO TO 1053
 1051 QE = ABS(QN / QD)
      IF (QE .LT. CAPAC(150))  GO TO 1052
      ZZ = 1.
      IF (QE .LT. QEM)  GO TO 1052
      IQEM = I
      QEM = QE
 1052 FIO(I) = FIOSV + CAPAC(151) * QN
      FI2(I) = FI2SV + CAPAC(151) * (FI2SV - FI2(I))
      FI1(I) = FI1SV + CAPAC(151) * (FI1SV - FI1(I))
      FI3(I) = FI3SV + CAPAC(151) * (FI3SV - FI3(I))
 1053 CONTINUE
      T4 = T4 + 1.
      IF (T4 .GT. 9. .OR. ZZ .LT. 0.1)  GO TO 1055
      CNT1 = SOLID(18) + 1.0
```

```
      WRITE (6,8)  CNT1, IHNU, T4, QEM, IQEM
    8 FORMAT  (29H SCATTERING ITERATION, CYCLE F5.0, 9H  IHNU = I2, 7H,
     2T4 = F3.0, 32H LARGEST RELATIVE DIFFERENCE IS F5.3, 9H IN ZONE I3)
      GO TO 515
 1055 DO  1057  I = IN, IMP1
      FQ0(I) = FI0(I)
      FQ1(I) = FI1(I)
      FQ2(I) = FI2(I)
      FQ3(I) = FI3(I)
      SUMX2(I)=SUMX2(I)+X2(I)                                          PRAD4810
      EK(I) = RHO(I) * 68.5 + EK(I)
      SMLR(I) = SMLR(I)+PR(I)*68.5
      FI0(I) = 3. * RHO(I) - PR(I)
      FI2(I) = 3. * PR(I) - RHO(I)
      FI1(I) = 3. * FL(I) - 5. * TR(I)
 1057 FI3(I) = 3. * TR(I) - 5. * FL(I)
      Q = THICK * 1.026E12
      CAPAR(IHNU+135) = CAPAR(IHNU+135) + 0.5 * DTR * (CAPAR(IHNU+120) +
     2 Q)
      CAPAR(IHNU+120) = Q
      IF (ABS(SOLID(37)) .GT. 1.E-20)  WRITE(JDRUMI)  FI0, FI1, FI2, FI3
C                                                                      PRAD4830
C     ADVANCE FREQ, STORE EMERGENT FLUX, TEST FOR COMPLETION OF GROUPS  PRAD4840
C                                                                      PRAD4850
      HNUP=HNU                                                         PRAD4860
      DHNUP = DHNU
      IHNU = IHNU + 1                                                  PRAD4880
      T4 = 1.
      IF (IHNU-NHNU) 1060,1060,1080                                    PRAD4890
 1060 CALL JVCHK (K000FX)                                              PRAD4900
      GO TO (1070,310), K000FX                                         PRAD4910
C*********************************************************************PRAD4920
C                                                                     *PRAD4930
C                    E N D   F R E Q U E N C Y   L O O P              *PRAD4940
C                                                                     *PRAD4950
C*********************************************************************PRAD4960
 1070 S1 = 13.1070                                                     PRAD4970
      CALL UNCLE                                                       PRAD4980
 1080 SUMX2(INM1) = 0.0                                                PRAD4990
      JURUM = JDRUMI
      REWIND JDRUM
      DO  1090  I = IN, IM
      EC(I) = 0.
      X2(I) = SUMX2(I)                                                 PRAD5020
      RHO(I) = EK(I)
      ER(I) = SUMX2(I) - SUMX2(I+1) + 0.5 * (A(I+1) * (3. * SMLR(I+1) -
     2 EK(I+1)) - A(I) * (3. * SMLR(I) - EK(I)))
 1090 CONTINUE
      X2(IMP1) = SUMX2(IMP1)
      RHO(IMP1) = EK(IMP1)
C     EDIT OF OUTPUT OUTPUT
      IF (TD .GT. 0.5 .AND. CNT1 .LT. CNTMAX)  GO TO 1320
      WRITE (6,5)  CNT1, TH
      WRITE (6,7)  (CAPAR(I+120), I=1,NHNU)
      WRITE (6,7)  (CAPAR(I+135), I=1,NHNU)


    5 FORMAT  (25H OUTPUT OUTPUT FOR CYCLE F7.0, 10X7HTIME = 1PE13.6)
    7 FORMAT  (1P10E12.5)
 1320 RETURN
      END                                                              PRAD6030
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@IT FOR PTRANS/P, PTRANS/P, PTRANS/P1
      SUBROUTINE PTRANS(N,M)
C COMPILED  OCTOBER 9, 1967  WBL
C     PLANE CHARACTERISTIC TRACE WITH DOUBLE GAUSSIAN INTEGRATION        PTRA0030
C     USES THE RADIATION TRANSPORT 'STEP' SUBROUTINE
C*********************************************************************PTRA0050
C*                    S P U T T E R   C O M M O N                    **PTRA0060
C                                                                      *PTRA0070
      COMMON  LMDA(37), NR     , NSMLR , IA     , IB     , ICA    , ICB    ,PTRA0080
     1  KMAX  , BLANK1, BLANK2, BLANK3, IAP1   , IBP1   , ICAP1  , ICBP1  ,PTRA0090
     2  II    , IG    , NRAD  , BLANK4, IAM1   , IBM1   , ICAM1  , ICBM1  ,PTRA0100
     3  IIP1  , IGM1  , IALPHA, BLANK5, TH     , TMAX   , BLANK6, DELPRT,PTRA0110
     4  FREQ  , CNTMAX, AR    , ASMLR , PUSHA  , PUSHB  , BOILA  , BOILB  ,PTRA0120
     5  CVA   , CVB   , SLUG  , ALPHA , HVA    , HVB    , HCA    , HCB    ,PTRA0130
     6  EMINA , EMINB , CA    , CB    , GA     , GB     , GL     , GR     ,PTRA0140
     7  RHOL  , RHOR  , EPIO  , EPSI  , RIA    , RIB    , RDIA   , RDIB   ,PTRA0150
     8  RPIA  , RPIB  , RPDIA , RPDIB , TPRINT, TA     , TB     , TC      PTRA0160
      COMMON   TD     , TE    , DTH2  , DTH2P , DTH1   , DTRMIN, DTMAX  ,PTRA0170
     1  DTMAX1, DTMAX2, DTMAX3, DTR   , SWITCH, CO     , CMIN   , DELTA  ,PTRA0180
     2  GAMA  , WCRIT , SIGMAQ, AC    , ACO3T4, CNVRT  , SUMRA  , SUMRB  ,PTRA0190
     3  ROIA  , ROIAM1, ROIB  , ROIBP1, GMS    , S1     , S2     , S3     ,PTRA0200
     4  S4    , S5    , S6    , S7    , S8     , S9     , S10    , S11    ,PTRA0210
     5  S12   , S13   , S14   , S15   , S16    , S17    , S18    , S19    ,PTRA0220
     6  S20   , EO    , FO    , TAU   , ZERO   , R    (152), DELTAR(152),PTRA0230
     7  ASQ  (152), RD     (152), VD     (152), RDD    (152), SMLR   (152),PTRA0240
     8  DELR ( 37), P      (152), P1     (152), PB     (152), PB1    (152) PTRA0250
      COMMON         P2     (152), SV     (152), RHO    (152), THETA (152),PTRA0260
     1  W    (152), E      (152), EI     (152), EK     (152), A      (152),PTRA0270
     2  V    (152), G      (152), D      (152), C      (152), X2     (152),PTRA0280
     3  X3   (152), X4     (152), X5     (152), X6     (152), X7     (152),PTRA0290
     4  SMLA (152), SMLB   (152), SMLC   (152), SMLD   (152), SMLE   (152),PTRA0300
     5  EC   (152), ER     (152), SMLQ   (152), SMLH   (152), BIGA   (152),PTRA0310
     6  BIGB (152), CV     (152), BC     (152), BR     (152), CHIC   (152),PTRA0320
     7  CHIR (152), CAPAC  (152), CAPAR  (152), CRTC   (152), CRTR   (152),PTRA0330
     8  CRTPC (152), GOFR  (152), FEW    (152), CAR    (152), OKLM   ( 37) PTRA0340
      COMMON         TELM   ( 37), EKLM   ( 37), ELM    ( 37), FCLM   ( 37),PTRA0350
     1  FRLM ( 37), WLM    ( 37), QLM    ( 37), AMASNO( 37), CHRNO ( 37),PTRA0360
     2  ZP1  ( 37), ZP2    ( 37), SOLID  ( 37), ECHCK ( 37), RK     (104),PTRA0370
     3  RL   ( 37), RHOK   (104), RDK    (104), THETAK(104), TEMP   ( 16),PTRA0380
     4  HEAD ( 12), MAXL         , MAXLM                                  PTRA0390
C                                                                      **PTRA0400
C*********************************************************************PTRA0410
      COMMON /LINDLY/ HNU,SGNL,IHNU,NHNU,HNUP,NT,IM,IN,DHNU,THICK,NY     PTRA0450
      COMMON /CNTRL/ SCYCLE, JMULT                                       PTRA0460
      COMMON /DAVIS/  X(4000), ICX, ICY
      COMMON /JIM/ NN, FMU, R1, R2, HD, EST, I1, I2, GMP, A1, A3, FMUS,
     2 FS, LDF, LRI, IZN, TG1, TG2, F2
C*********************************************************************PTRA0540
      DIMENSION  RR(40)                                                  PTRA0550
      DATA  RR/2.113248E-01,7.886752E-01,1.056624E-01,3.943376E-01,      PTRA0560
     1         1.127017E-01,5.000000E-01,8.872983E-01,3.130600E-02,      PTRA0570
     2         2.222222E-01,2.464718E-01,6.943180E-02,3.300095E-01,      PTRA0580
     3         6.699905E-01,9.305682E-01,1.207610E-02,1.076071E-01,      PTRA0590
     4         2.184655E-01,1.618513E-01,4.691010E-02,2.307653E-01,      PTRA0600
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     5          5.000000E-01,7.092347E-01,9.530899E-01,5.557100E-03,     PTRA0610
     6          5.522540E-02,1.422222E-01,1.840889E-01,1.129063E-01,     PTRA0620
     7          3.376520E-02,1.093953E-01,3.806903E-01,6.193096E-01,     PTRA0630
     8          8.306047E-01,9.662348E-01,2.892400E-03,3.055570E-02,     PTRA0640
     9          8.906520E-02,1.448918E-01,1.498251E-01,8.276980E-02/     PTRA0650
C                                                                        *PTRA0660
C*****************************************************************PTRA0900
      DIMENSION   CSQD  (1), PR    (1), FM    (1), H     (1), H2    (1),
     1 H3    (1), H4    (1), FMS   (1), Q1    (1), TG    (1), Q3    (1),
     2 Q37   (1), Q38   (1), SUMX2 (1), SUMX3 (1), SUMX4 (1), X8    (1),P    550
     3 Y     (1), Y2    (1), OX    (1), FL    (1), TR    (1), FSM   (1),P
     4 FSP   (1)                                                        P
C                                                                       P    570
      EQUIVALENCE          (AC03T4,TRDBG), (BC    ,SUMX4), (BIGA ,Y    ),P    580
     1        (BIGB , H    ), (BR    ,H3    ), (CAR   ,Q37   ), (CHIC ,SUMX3),P    590
     2        (CHIR ,Q38   ), (CRTR ,SUMX2), (X7    ,PR    ), (GOFR ,Q3    ),P    600
     3        ( PB  ,Q1    ), (S12  ,EDITMF), (EC    ,H2    ), (  W  ,OX    ),P
     4        (SMLA ,FMS   ), (SMLB ,FL    ), (SMLC  ,TR    ), (SMLH ,H4    ),P
     5        (ER   ,FM    ), (V    ,TG    ), (SMLD  ,FSM   ), (CRTC ,CSQD  ),P
     6        (X5   ,Y2    ), (X4   ,X8    ), (SMLE  ,FSP   )                P
C*****************************************************************P    660
C                                                                       *P    670
C                OX CONTAINS X FROM THE PREVIOUS Y LINE                 *P    680
C                                                                       *P    690
C                        CSQD   SAME AS   CRTC                          *P    700
C                        EDITMF SAME AS    S12                          *P    710
C                        Q1     SAME AS     PB                          *P
C                        FM     SAME AS     ER                          *P
C                        H      SAME AS   BIGB                          *P    740
C                        H2     SAME AS     EC                          *P
C                        H3     SAME AS     BR                          *P    760
C                        H4     SAME AS   SMLH                          *P    770
C                        PR     SAME AS     X7                          *P
C                        FMS    SAME AS   SMLA                          *P
C                        FL     SAME AS   SMLB                          *P
C                        TR     SAME AS   SMLC                          *P
C                        FSM    SAME AS   SMLD                          *P
C                        FSP    SAME AS   SMLE                          *P
C                        Y2     SAME AS     X5                          *P
C                        OX     SAME AS      W                          *P
C                        TG     SAME AS      V                          *P
C                        Q3     SAME AS   GOFR                          *P
C                        Q37    SAME AS    CAR                          *P    840
C                        Q38    SAME AS   CHIR                          *P    850
C                        SUMX2  SAME AS   CRTR                          *P    860
C                        SUMX3  SAME AS   CHIC                          *P    870
C                        SUMX4  SAME AS     BC                          *P    880
C                        TRDBG  SAME AS AC03T4                          *P    890
C                        Y      SAME AS   BIGA                          *P    910
C                        X8     SAME AS     X4                          *P
C                                                                       *P    940
C*****************************************************************TRAN 930
C                                                                      *PTRA0910
C                        P L A N E S   O N L Y                         *PTRA0920
C                                                                      *PTRA0930
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C.*****************************************************************PTRA0940
      IAX=N                                                          PTRA0950
      IBX=M                                                          PTRA0960
      INM1=IN-1                                                      PTRA0980
      IMP1 = IM + 1                                                  PTRA0990
      CALL DVCHK(KOOOFX)                                             PTRA1000
      GO TO (100,110), KOOOFX                                        PTRA1010
  100 S1=14.0100                                                     PTRA1020
      CALL UNCLE                                                     PTRA1030
  110 IBXP1=IBX+1                                                    PTRA1040
      IALPHA=ALPHA                                                   PTRA1050
C                                                                    PTRA1060
C                 ERROR IF NOT PLANE                                 PTRA1070
C                                                                    PTRA1080
      GO TO (130,120,120), IALPHA                                    PTRA1090
  120 S1=14.0120                                                     PTRA1100
      CALL UNCLE                                                     PTRA1110
  130 NY = LMDA(37) - 1                                              PTRA1120
      NMU = (NY - 1) * (NY + 2) + 1                                  PTRA1130
      NGS = NMU + NY + 1                                             PTRA1140
      JJ = 0                                                         PTRA1150
C                                                                    PTRA1160
C                 DO POSITIVE ANGLES FIRST                           PTRA1170
C                                                                    PTRA1180
  140 I=IAX                                                          PTRA1190
      F2=0.0                                                         PTRA1200
      FS = 0.0
      FMU = RR(NMU)
      LRI = 1
C                                                                    PTRA1210
C     IF IAX=IN TRANSFER TO 150 TO SET SPECIAL BOUNDARY CONDITIONS   PTRA1220
C                                                                    PTRA1230
      IF (IAX-IN) 360,150,180                                        PTRA1240
C                                                                    PTRA1250
C                 CALCULATE BOUNDARY SOURCE INTENSITY                PTRA1260
C                                                                    PTRA1270
  150 IF (INM1) 160,310,170                                          PTRA1280
C                                                                    PTRA1290
C                 SET BLACKBODY CONDITION FOR PUSHER                 PTRA1300
C                                                                    PTRA1310
  160 S1=14.0160                                                     PTRA1320
      CALL UNCLE                                                     PTRA1330
  170 F2=X6(INM1)                                                    PTRA1340
      GO TO 310                                                      PTRA1350
C                                                                    PTRA1360
C                 DIFFUSION BOUNDARY CONDITION AT IAX                PTRA1370
C                                                                    PTRA1380
  180 LDF = 1
      GO TO 220
  210 IF (ABS(TG(I-1)) .LT. 1.E-20)  Y2(I-1) = X6(I-1)
      X8(I-1)=TG(I-1)*RK(NMU)                                        PTRA1500
C                                                                    PTRA1510
C                 REGULAR INTEGRATION STEP FOR F2, POSITIVE MU       PTRA1520
C                                                                    PTRA1530
  220 IF (ABS(TG(I)) .LT. 1.E-20)  Y2(I) = X6(I-1)
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```
      X8(I)=TG(1)*RR(NMU)                                               PTRA1550
      I1 = 1 - 1
      I2 = 1
      R1 = C(I-1)
      R2 = C(1)
      IZN = 1 - I
      TG1 = X8(I-1)
      TG2 = X8(I)
      HU = H2(I-1)/RR(NMU)
      CALL STEP
  260 SUMX3(I)=F2
      IF (ABS(TG(I)) .LT. 1.E-20)  Y2(I) = X6(I)                        PTRA1640
      I=I+1
      IF (I .GT. IBXP1)  GO TO 320                                      PTRA1660
      IF (I .LE. ICX + 1)  GO TO 220
C
C                 NO SOURCE IN ZONE GREATER THAN ICX                    PTRA1740
C VEAT.  SCATTERING IN SOURCELESS REGION NOT HANDLED PROPERLY HERE      PTRA1750
      IF (F2.EQ.0.0) GO TO 260
      TEMP(1)=H2(I-1)/RR(NMU)
      H4(I-1)=FREXP(-TEMP(1)-TEMP(1))                                   PTRA1780
      F2=F2*H4(I-1)                                                     PTRA1790
      GO TO 260                                                         PTRA1800
  300 IF (F2.EQ.0.0) GO TO 310                                          PTRA1810
      TEMP(1)=H2(1-1)/RR(NMU)                                           PTRA1820
      H4(I-1)=FREXP(-TEMP(1)-TEMP(1))                                   PTRA1830
      F2=F2*H4(I-1)                                                     PTRA1840
  310 SUMX3(I) = F2 .                                                   PTRA1850
      FSM(1) = FS                                                       PTRA1860
      LDF = 2
      I=I+1
      IF (I-ICY) 300,300,210                                            PTRA1870
C                                                                       PTRA1880
C                 DO NEGATIVE ANGLES SECOND                             PTRA1890
C                                                                       PTRA1900
  320 I=IBXP1                                                           PTRA1910
      FS = 0.0                                                          PTRA1920
      LRI = 2
      IF (IBX-IM) 370,330,360
  330 IF (GL) 480,520,340                                               PTRA1930
C     GL = 1/2 MEANS BLACKBODY CONDITION SET AT IMP1                    PTRA1940
C     GL = POSITIVE INTEGER INPUT OPTION DELETED                        PTRA1950
C     GL = 0 MEANS VACUUM AT IMP1
C     GL NEGATIVE MEANS REFLECTIVE CONDITION AT IMP1                    PTRA1970
  340 IF (GL.NE.0.5) GO TO 350                                          PTRA1980
      F2 = X6(IMP1)                                                     PTRA1990
      GO TO 480                                                         PTRA2000
  350 S1 = 14.0350                                                      PTRA2010
      CALL UNCLE
C
C                 ERROR IF INDEX EXCEEDS NORMAL RANGE                   PTRA2050
C                                                                       PTRA2060
  360 S1=14.0360                                                        PTRA2070
      CALL UNCLE                                                        PTRA2080
C                                                                       PTRA2090
                                                                        PTRA2100
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C                 DIFFUSION BOUNDARY CONDITION AT IBXP1                          PTRA2110
C                                                                                PTRA2120
  370 LDF = 1
      GO TO 400
  399 IF (ABS(TG(I+1)) .LT. 1.E-20)  Y2(I+1) = X6(I)
C                                                                                PTRA2230
C                 REGULAR INTEGRATION STEP FOR F2, NEGATIVE MU                   PTRA2240
C                                                                                PTRA2250
  400 IF (ABS(TG(I)) .LT. 1.E-20)  Y2(I) = X6(I)
      I1 = I + 1
      I2 = I
      R1 = -C(I+1)
      R2 = -C(I)
      IZN = I
      TG1 = -X8(I+1)
      TG2 = -X8(I)
      HO = H2(I)/RR(NMU)
      CALL STEP
  440 SUMX4(I)=F2
C                                                                                PTRA2330
C                 FORM CONTRIBUTION TO X2                                        PTRA2340
C                                                                                PTRA2350
      X2(I)=X2(I)-(F2-SUMX3(I))*RR(NGS)                                          PTRA2360
      RHO(I) = RHO(I) + (F2 + SUMX3(I)) * RR(NGS) / RR(NMU)                      PTRA2370
      PR(I) = PR(I) + (F2 + SUMX3(I)) * RR(NGS) * RR(NMU)
      FL(I) = X2(I)
      TR(I) = TR(I) - (F2 - SUMX3(I)) * RR(NGS) * RR(NMU) * RR(NMU)
      IF (ABS(TG(I)) .LT. 1.E-20)  Y2(I) = X6(I-1)
      I=I-1
      IF (I-IAX) 530,450,450                                                     PTRA2420
  450 IF (I-ICY) 500,400,400                                                     PTRA2430
C                                                                                PTRA2440
C                 NO SOURCE IN ZONE LESS THAN ICY                                PTRA2470
C                                                                                PTRA2480
  470 IF (F2.EQ.0.0) GO TO 480                                                   PTRA2490
      TEMP(1)=H2(I)/RR(NMU)                                                      PTRA2500
      H4(I)=FREXP(-TEMP(1)-TEMP(1))                                              PTRA2510
      F2=F2*H4(I)                                                                PTRA2520
  480 SUMX4(I)=F2                                                                PTRA2530
  490 X2(I)=X2(I)-(F2-SUMX3(I))*RR(NGS)                                          PTRA2540
      RHO(I) = RHO(I) + (F2 + SUMX3(I)) * RR(NGS) / RR(NMU)                      PTRA2550
      PR(I) = PR(I) + (F2 + SUMX3(I)) * RR(NGS) * RR(NMU)
      FL(I) = X2(I)
      TR(I) = TR(I) - (F2 - SUMX3(I)) * RR(NGS) * RR(NMU) * RR(NMU)
      LDF = 2
      FSP(I) = FS
      I=I-1
      IF (I-1-ICX) 399,470,470                                                   PTRA2560
C                                                                                PTRA2570
C                 NO SOURCE IN ZONE LESS THAN ICY                                PTRA2580
C                                                                                PTRA2590
  500 IF (F2.EQ.0.0) GO TO 510                                                   PTRA2600
      TEMP(1)=H2(I)/RR(NMU)                                                      PTRA2610
      H4(I)=FREXP(-TEMP(1)-TEMP(1))                                              PTRA2620
      F2=F2*H4(I)                                                                PTRA2630
                                                                                 PTRA2640
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```
  510 SUMX4(I)=F2
      X2(I)=X2(I)-(F2-SUMX3(I))*RR(NGS)                                 PTRA2650
      RHO(I) = RHO(I) + (F2 + SUMX3(I)) * RR(NGS) / RR(NMU)             PTRA2660
      PR(I) = PR(I) + (F2 + SUMX3(I)) * RR(NGS) * RR(NMU)
      FL(I) = X2(I)
      TR(I) = TR(I) - (F2 - SUMX3(I)) * RR(NGS) * RR(NMU) * RR(NMU)
      I=I-1
      IF (I-IAX) 530,500,500                                            PTRA2670
  520 F2=0.0                                                            PTRA2680
      GO TO 480                                                         PTRA2690
  530 CONTINUE                                                          PTRA2700
      IF (ABS(TRDBG) .LT. 1.E-20)  GO TO 539                            PTRA2710
C       DEBUG PRINT OF INTENSITIES
      JJJ = JJ + 1
      IF (JJJ .EQ. 1) WRITE (6,8)
      WRITE (6,10) JJJ, RR(NMU)
      WRITE (6,9)
      DO 65  I = IAX, IBXP1                                             REDI0920
   65 WRITE (6,5) I, SUMX3(I), SUMX4(I)
    5 FORMAT (I4, 1PE11.4, E14.7 )
    8 FORMAT  (28H1PLANE TRANSPORT DEBUG PRINT/)
    9 FORMAT  (7X1HI, 7X7HI RIGHT, 8X6HI LEFT)                          REDI0640
   10 FORMAT  (27H GAUSSIAN QUADRATURE ANGLE I2, 17H WHOSE COSINE IS F11REDI0650
     2.8/)                                                              REDI0660
      IF (TRDBG .GT. 68.)  TRDBG = TRDBG - 69.                          REDI0670
  539 DHNU=HNUP-HNU
  540 JJ = JJ + 1                                                       PTRA2810
      NMU = NMU + 1                                                     PTRA2820
      NGS = NGS + 1                                                     PTRA2830
      IF (JJ-NY) 140,140,550                                            PTRA2840
  550 DO 560 I=IAX,IBXP1                                                PTRA2850
  560 X2(I) = X2(I)* 2.052E12                                           PTRA2860
      RETURN                                                            PTRA2870
      END                                                               PTRA2880
                                                                        PTRA2890
```

```
QT FOR STRANS/S, STRANS/S, STRANS/S1
      SUBROUTINE  STRANS(N,M)
COMPILED  OCTOBER 9, 1967  WBL
C     MODIFIED FOR COMPTON SCATTERING AND IMPROVED LOGIC
C     ANGULAR INTEGRATIONS ON LINEAR FORM                                    TRAN  20
C     CONNECTED LINEAR-QUADRATIC INTERPOLATION AT X=0.                       TRAN  30
C     EPSI IS Y LIMIT OF EDIT TUBE
C     LMDA(26) IS INTERFACE INDEX OF EDIT TUBE APERTURE
C
C*****************************************************************
C                                                                 *
C*                    S P U T T E R   C O M M O N                **
C*                                                                **
C*                                                                **
      COMMON   LMDA(37), NR     , NSMLR , IA     , IB     , ICA    , ICB    ,
     1   KMAX  , BLANK1, BLANK2, BLANK3, IAP1   , IBP1   , ICAP1  , ICBP1  ,
     2   II    , IG    , NRAD  , BLANK4, IAM1   , IBM1   , ICAM1  , ICBM1  ,
     3   IIP1  , IGM1  , IALPHA, BLANK5, TH     , TMAX   , BLANK6, DELPRT,
     4   FREQ  , CNTMAX, AR    , ASMLR , PUSHA  , PUSHB  , BOILA  , BOILB  ,
     5   CVA   , CVB   , SLUG  , ALPHA , HVA    , HVB    , HCA    , HCB    ,
     6   EMINA , EMINB , CA    , CB    , GA     , GB     , GL     , GR     ,
     7   RHOL  , RHOR  , EPIO  , EPSI  , RIA    , RIB    , RDIA   , RDIB   ,
     8   RPIA  , RPIB  , RPDIA , RPDIB , TPRINT, TA     , TB     , TC
      COMMON     TD    , TE    , DTH2  , DTH2P , DTH1   , DTRMIN, DTMAX ,
     1   DTMAX1, DTMAX2, DTMAX3, DTR   , SWITCH, CO     , CMIN   , DELTA ,
     2   GAMA  , WCRIT , SIGMAU, AC    , ACO3T4, CNVRT  , SUMRA  , SUMRB  ,
     3   ROIA  , ROIAM1, ROIB  , ROIBP1, GMS    , S1     , S2     , S3     ,
     4   S4    , S5    , S6    , S7    , S8     , S9     , S10    , S11    ,
     5   S12   , S13   , S14   , S15   , S16    , S17    , S18    , S19    ,
     6   S20   , EO    , FO    , TAU   , ZERO   , R    (152), DELTAR(152),
     7  ASG   (152), RD     (152), VD     (152), RDD    (152), SMLR   (152),
     8  DELR  ( 37), P      (152), P1     (152), PB     (152), PB1    (152)
      COMMON         P2     (152), SV     (152), RHO    (152), THETA  (152),
     1  W     (152), E      (152), EI     (152), EK     (152), A      (152),
     2  V     (152), G      (152), D      (152), C      (152), X2     (152),
     3  X3    (152), X4     (152), X5     (152), X6     (152), X7     (152),
     4  SMLA  (152), SMLB   (152), SMLC   (152), SMLD   (152), SMLE   (152),
     5  EC    (152), EK     (152), SMLQ   (152), SMLH   (152), BIGA   (152),
     6  BIGB  (152), CV     (152), BC     (152), BR     (152), CHIC   (152),
     7  CHIR  (152), CAPAC  (152), CAPAR  (152), CRTC   (152), CRTR   (152),
     8  CRTPC (152), GOFR   (152), FEW    (152), CAR    (152), OKLM   ( 37)
      COMMON         TELM   ( 37), EKLM   ( 37), ELM    ( 37), FCLM   ( 37),
     1  FRLM  ( 37), WLM    ( 37), QLM    ( 37), AMASNO( 37), CHRNO  ( 37),
     2  ZP1   ( 37), ZP2    ( 37), SOLID  ( 37), ECHCK ( 37), RK     (104),
     3  RL    ( 37), RHOK   (104), RDK    (104), THETAK(104), TEMP   ( 16),
     4  HEAD  ( 12), MAXL         , MAXLM
C                                                                 **
C
C*****************************************************************
C*****************************************************************TRAN 430
C                                                                 *TRAN 440
      COMMON /LINDLY/ HNU,SGNL,IHNU,NHNU,HNUP,NT,IM,IN,DHNU,THICK,NY    TRAN 450
C                                                                      TRAN 480
      COMMON /DAVIS/  X(4000), ICX, ICY
```

```
      COMMON /JIM/ NN, FMU, R1, R2, HD, EST, I1, I2, GMP, A1, A3, FMUS,
     2 FS, LDF, LRI, LRN, TG1, TG2, F2
      DIMENSION   CSQD  (1), PR    (1), FM    (1), H     (1), H2    (1),
     1 H3    (1), H4    (1), FMS   (1), Q1    (1), TG    (1), Q3    (1),
     2 Q37   (1), Q38   (1), SUMX2 (1), SUMX3 (1), SUMX4 (1), X8    (1),P     550
     3 Y     (1), Y2    (1), OX    (1), FL    (1), TR    (1), FSM   (1),P
     4 FSP   (1)                                                        P
C                                                                       P     570
      EQUIVALENCE          (AC03T4,TRDBG), (BC    ,SUMX4), (BIGA ,Y    ),P     580
     1        (BIGB , H    ), (BR    ,H3    ), (CAR   ,Q37   ), (CHIC ,SUMX3),P     590
     2        (CHIR ,Q38   ), (CRTR ,SUMX2), (X7    ,PR    ), (GOFR ,Q3    ),P     600
     3        ( PB  ,Q1    ), (S12 ,EDITMF), (EC    ,H2    ), (  W  ,OX    ),P
     4        (SMLA ,FMS   ), (SMLB ,FL    ), (SMLC ,TR    ), (SMLH ,H4    ),P
     5        (ER   ,FM    ), (V    ,TG    ), (SMLD ,FSM   ), (CRTC ,CSQD  ),P
     6        (X5   ,Y2    ), (X4   ,X8    ), (SMLE ,FSP   )                 P
C ***********************************************************************P     660
C                 OX CONTAINS X FROM THE PREVIOUS Y LINE                 *P     680
C                                                                        *P     690
C                        CSQD   SAME AS   CRTC                           *P     700
C                        EDITMF SAME AS    S12                           *P     710
C                        Q1     SAME AS     PB                           *P
C                        FM     SAME AS     ER                           *P
C                        H      SAME AS   BIGB                           *P     740
C                        H2     SAME AS     EC                           *P
C                        H3     SAME AS     BR                           *P     760
C                        H4     SAME AS   SMLH                           *P     770
C                        PR     SAME AS     X7                           *P
C                        FMS    SAME AS   SMLA                           *P
C                        FL     SAME AS   SMLB                           *P
C                        TR     SAME AS   SMLC                           *P
C                        FSM    SAME AS   SMLD                           *P
C                        FSP    SAME AS   SMLE                           *P
C                        Y2     SAME AS     X5                           *P
C                        OX     SAME AS      W                           *P
C                        TG     SAME AS      V                           *P
C                        Q3     SAME AS   GOFR                           *P     830
C                        Q37    SAME AS    CAR                           *P     840
C                        Q38    SAME AS   CHIR                           *P     850
C                        SUMX2  SAME AS   CRTR                           *P     860
C                        SUMX3  SAME AS   CHIC                           *P     870
C                        SUMX4  SAME AS     BC                           *P     880
C                        TRDBG  SAME AS AC03T4                           *P     890
C                        Y      SAME AS   BIGA                           *P     910
C                        X8     SAME AS     X4                           *P
C                                                                        *P     940
C ***********************************************************************TRAN 930
C                                                                        TRAN 940
C                                                                        TRAN1040
      IAX=N                                                              TRAN1050
      IBX=M                                                              TRAN1060
      THICK = 0.0
      ITUBE = LMDA(26)
      IF (C(ITUBE) .LT. EPSI)  GO TO 1
      XTUBE = SQRT(CSQD(ITUBE) - EPSI**2)
      CALL DVCHK(KX)
```

```
      GO TO (1,3), KX
    1 S1=14.0001                                                      TRAN1090
      CALL UNCLE                                                      TRAN1100
    3 IBXP1=IBX+1                                                     TRAN1110
      IALPHA=ALPHA                                                    TRAN1120
C                                                                     TRAN1130
C               ERROR IF NOT SPHERE                                   TRAN1140
C                                                                     TRAN1150
      GO TO (5,5,7), IALPHA                                           TRAN1160
    5 S1=14.0005                                                      TRAN1170
      CALL UNCLE                                                      TRAN1180
C                                                                     TRAN1190
C               SPHERE ONLY                                           TRAN1200
C                                                                     TRAN1210
    7 I=IBXP1                                                         TRAN1220
      FS = 0.0
      FMU = 0.0
      LRI = 1
      IF (IBX - IM)  37, 8, 11
    8 F2 = 0.0
      IF (GL .GT. 0.)  F2 = X6(IM+1)
      GO TO 23
C                                                                     TRAN1250
C               ERROR IF INDEX EXCEEDS NORMAL RANGE                   TRAN1260
C                                                                     TRAN1270
   11 S1=14.0011                                                      TRAN1280
      CALL UNCLE                                                      TRAN1290
C*********************************************************************TRAN1300
C                                                                    *TRAN1310
C                    C A L C U L A T E   Y = 0   R A Y               *TRAN1320
C                                                                    *TRAN1330
C*********************************************************************TRAN1340
C                                                                     TRAN1350
C               LHS OF RAY FIRST, STORE F2 IN SUMX3.                  TRAN1360
C                                                                     TRAN1370
   13 I1 = I + 1
      I2 = I
      R1 = -C(I+1)
      R2 = -C(I)
      HD = H2(I)
      IZN = I
      TG1 = -TG(I+1)
      TG2 = -TG(I)
      CALL STEP
C                                                                     TRAN1700
C               SAVE LHS INTENSITIES IN SUMX3                         TRAN1710
C                                                                     TRAN1720
   23 SUMX3(I)=F2                                                     TRAN1730
      FSM(I) = FS
      IF (ABS(TG(I)) .LT. 1.E-20)  Y2(I) = X6(I-1)
      I=I-1                                                           TRAN1750
      LDF = 2
      IF (ABS(TG(I)) .LT. 1.E-20)  Y2(I) = X6(I)
      IF (I-IAX) 47,13,13                                             TRAN1770
C                                                                     TRAN1990
```

```
C                 DIFFUSION BOUNDARY CONDITION AT IBXP1                 TRAN2000
C                                                                       TRAN2010
   37 IF (ABS(TG(I)) .LT. 1.E-20)  Y2(I) = X6(I)
      LDF = 1
      GO TO 13
C                                                                       TRAN2380
C                 RHS OF RAY                                            TRAN2390
C                                                                       TRAN2400
   47 I=IAX                                                             TRAN2410
      IAXP=IAX                                                          TRAN2420
      LRI = 2
      IF (IAX - IN)  11, 48, 51
   48 IF (IN - 1)  11, 49, 50
   49 IAXP=IN+1                                                         TRAN2440
      RHO(1)=SUMX3(1)*2.                                                TRAN2450
      PR(1)=SUMX3(1)*.6667                                              TRAN2460
      GO TO 69                                                          TRAN2490
   50 IAXP = IN
      F2 = X6(IN-1)
      GO TO 69
C                                                                       TRAN2500
C                 DIFFUSION BOUNDARY CONDITION AT IAX                   TRAN2510
C                                                                       TRAN2520
   51 LDF = 1
      H4(I-1) = FREXP(-H2(I-1))
      GO TO 59
C                                                                       TRAN2830
C                 REGULAR INTEGRATION STEP (Y=0,RHS)                    TRAN2840
C                                                                       TRAN2850
   59 I1 = I - 1
      I2 = I
      R1 = C(I-1)
      R2 = C(I)
      HD = H2(I-1)
      IZN = I - 1
      TG1 = TG(I-1)
      TG2 = TG(I)
      CALL STEP
C                                                                       TRAN3120
C                 SAVE RHS INTENSITIES IN SUMX4                         TRAN3130
C                                                                       TRAN3140
   69 SUMX4(I) = F2                                                     TRAN3140
      FSP(I) = FS
      OX(I)=C(I)                                                        TRAN3160
      IF (ABS(TG(I)) .LT. 1.E-20)  Y2(I) = X6(I)
      LDF = 2
      I=I+1                                                             TRAN3180
      IF (ABS(TG(I)) .LT. 1.E-20)  Y2(I) = X6(I-1)
      IF (I-IBXP1) 59, 59, 85
C*****************************************************************TRAN3470
C                                                                 *TRAN3480
C                    C O M P L E T E   Y = 0   R A Y              *TRAN3490
C                                                                 *TRAN3500
C*****************************************************************TRAN3510
   85 YSQDP=0.0
```

```
      JJ=1                                                              TRAN3530
      JJJ=1                                                             TRAN3540
      KK=1                                                              TRAN3550
C                                                                       TRAN3560
C               SEARCH FOR Y-LINE NEAR HALF OF C(IAX)                   TRAN3570
C                                                                       TRAN3580
      C1=0.50*C(IAX)                                                    TRAN3590
      IT = IAX + 1
      GO TO 283
C*****************************************************************TRAN3620
C                                                                      *TRAN3630
C                        S E T   U P   Y - L I N E S                   *TRAN3640
C                                                                      *TRAN3650
C*****************************************************************TRAN3660
C                                                                       TRAN3670
C               FIRST, TEST IF Y LIES OUTSIDE OF ACTIVE MESH.           TRAN3680
C                                                                       TRAN3690
   87 IF (JJ .LE. NY)  GO TO 88
      S1 = 14.0087
      CALL UNCLE
   88 IF (C(IBXP1) .LT. Y(JJ) * 1.000001)  GO TO 127
C     Y-LINE IS INSIDE ACTIVE MESH.
      IF (C(IAX)-Y(JJ)) 89,107,97
   89 IF (C(IT) .GT. Y(JJ) * .999999)  GO TO 107
      IT = IT + 1
      GO TO 89
   97 IF (C(IAX-1) - Y(JJ))  98, 107, 98                                TRAN3730
   98 IF (C1 .LT. 0.5 * (Y(JJ) + Y(JJ+1)))  GO TO 103
      JJ=JJ+1
      KK=KK-IFIX(X(KK+1))+2                                             TRAN3790
      GO TO 87                                                          TRAN3800
C                                                                       TRAN3810
C               SEARCH FOR Y-LINE NEAR THREE QUARTERS OF C(IAX)         TRAN3820
C                                                                       TRAN3830
  103 C1=C1+0.25*C(IAX)                                                 TRAN3840
C CALCULABLE Y-LINE FOUND -- PROCEED
  107 YSQDP=-X(KK)                                                      TRAN3870
      FMU = YSQDP
      K=KK+IM-I3X+2                                                     TRAN3880
      TEMP(5)=YSQDP-YSQD1                                               TRAN3890
      GO TO 167                                                         TRAN3900
C                                                                      *TRAN4170
C               COMPLETE X2 INTEGRATION WHEN LAST Y-LINE USED          *TRAN4180
C                                                                      *TRAN4190
C*****************************************************************TRAN4200
  127 DO 139 I=IAXP,IBXP1                                               TRAN4210
C                                                                       TRAN4220
C       ANGULAR INTEGRATION OF X2 USING LINEAR INTERPOLATIOM            TRAN4230
C                                                                       TRAN4240
      FNL = SUMX4(I) - SUMX3(I)
      XSQ = OX(I)**2
      X2(I) = X2(I) + FNL * (XSQ + XSQ)
  129 IF (IBX-IM) 131,135,171
  131 IF (I-IAXP) 171,133,137                                           TRAN4290
  133 XS=SQRT(CSQD(IBXP1+1)-CSQD(IBXP1))                                TRAN4300
                                                                        TRAN4310
```

```
      FM(IBXP1) = Y2(IBXP1) + XS / C(IBXP1+1) * TG(IBXP1+1) *
     2 FREXP(-XS * H(IBXP1))
      GO TO 137
  135 FM(IBXP1)=0.0                                                    TRAN4340
  137 TEMP(5)=CSQD(IBXP1)-YSQD1                                        TRAN4350
      TEMP(11)= CSQD(I)-YSQD1
      FU=(TEMP(11)*(FM(IBXP1)+FM(IBXP1))+(CSQD(IBXP1)-
     1      CSQD(I))*(SUMX4(IAXP)+SUMX3(IAXP)))/TEMP(5)
      FLX = SUMX3(I) + SUMX4(I)
      FP = FLX + FU
      FPL = FP + FLX
      RHO(I)=RHO(I)+OX(I)*FP
      PR(I) = PR(I) + XSQ * (FPL + FLX) * OX(I)                        TRAN4440
      TR(I) = TR(I) + XSQ**2 * FNL * 4.
  139 CONTINUE
C*********************************************************************TRAN4500
C                                                                     *TRAN4510
C       C O M P L E T I O N   O F   X 2   I N T E G R A T I O N   A T *TRAN4520
C                   E N D   O F   T R A N S   R E G I O N             *TRAN4530
C                                                                     *TRAN4540
C*********************************************************************TRAN4550
      DO 151 I=IAX,IBXP1
      IF (I.EQ.1) GO TO 151
      PR(I)=PR(I)*.08334/(CSQD(I)*C(I))                                TRAN4690
      RHO(I)=RHO(I)*0.50/C(I)                                          TRAN4700
      FL(I) = .1666667 * X2(I) / CSQD(I)
      IF (I .GT. 1)  GO TO 147
      TR(I) = 0.
      GO TO 151
  147 TR(I) = TR(I) + .05 / CSQD(I)**2
  151 X2(I)=X2(I)*1.026E12                                             TRAN4730
      CALL DVCHK(KX)
      GO TO (152, 153), KX
  152 S1 = 14.0152
      CALL UNCLE
  153 RETURN                                                           TRAN4740
C*********************************************************************TRAN5230
C                                                                     *TRAN5240
C          T Y P I C A L   Y-L I N E   I N T E G R A T I O N          *TRAN5250
C                                                                     *TRAN5260
C*********************************************************************TRAN5270
C                                                                      TRAN5280
C               LHS CALCULATION FIRST,STORE F2 IN FM                   TRAN5290
C                                                                      TRAN5300
  167 I=IBXP1                                                          TRAN5310
      FS = 0.0
      LRI = 1
      IF (IBX - IM)  173, 168, 171
  168 F2 = 0.0
      IF (GL .GT. 0.)  F2 = X6(IM+1)
      GO TO 205
C
C               ERROR IF INDEX EXCEEDS NORMAL RANGE                    TRAN5340
C                                                                      TRAN5350
  171 S1=14.0171                                                       TRAN5360
                                                                       TRAN5370
```

```
      CALL UNCLE                                                        TRAN5380
C                                                                       TRAN5390
C               DIFFUSION BOUNDARY CONDITION AT IBXP1                   TRAN5400
C                                                                       TRAN5410
  173 IF (ABS(TG(I)) .LT. 1.E-20)  Y2(I) = X6(I)
      X8(I+1) = X(K-1) / C(I+1) * TG(I+1)
      LDF = 1
C                                                                       TRAN5730
C               SAVE X8 FOR RHS=(DIFF INTENSITY)                        TRAN5740
C                                                                       TRAN5750
  181 X8(I)=X(K)/C(I)*TG(I)                                             TRAN5760
      HD = (X(K-1) - X(K)) * H(I)
C                                                                       TRAN5780
C               REGULAR INTEGRATION STEP(LHS)                           TRAN5790
C                                                                       TRAN5800
      I1 = I + 1
      I2 = I
      R1 = -X(K-1)
      R2 = -X(K)
      IZN = I
      TG1 = -X8(I+1)
      TG2 = -X8(I)
      CALL STEP
C                                                                       TRAN6110
C               SAVE F3 OF LHS IN FM FOR INTEGRATION.                   TRAN6120
C                                                                       TRAN6130
  191 FM(I)=F2                                                          TRAN6140
      FSM(1) = FS
      IF (ABS(TG(I)) .LT. 1.E-20)  Y2(I) = X6(I-1)
      I=I-1                                                             TRAN6160
      LDF = 2
      K=K+1                                                             TRAN6170
      IF (ABS(TG(I)) .LT. 1.E-20)  Y2(I) = X6(I)
      IF (I-IAX) 239,193,193                                            TRAN6190
  193 IF (X(K)) 195,207,181                                             TRAN6200
C     Y-LINE HAS MADE CLOSEST APPROACH
  195 TEMP(2)=SQRT(DELTAR(I)*(4.0*C(I)+DELTAR(I)))*H(I)                 TRAN6210
      IF (ABS(TEMP(2)) .LT. 1.E-20)  GO TO 223
      HD = X(K-1) * H(I)
      TEMP(1) = HD + HD
      I1 = I + 1
      I2 = I
      R1 = -X(K-1)
      R2 = 0.
      IF (TEMP(1) - .02)  197, 197, 201
C     THIN LHS        XK=0.                                             TRAN6310
  197 TEMP(16)=(Y2(I+1)+X6(I))*0.5*TEMP(1)+(0.667*Y2(I)-0.5*Y2(I+1)     TRAN6290
     1  -0.167*X6(I))*TEMP(2)                                           TRAN6300
      NN = 0
      CALL SCAT
      Q = AMAX1(0., 1. - FMUS / H(I))
      F2 = FS + F2 * (1. - TEMP(1)) + Q * TEMP(16)
      GO TO 223                                                         TRAN6380
  201 H4(I)=FREXP(-TEMP(1))                                             TRAN6390
C     NORMAL LHS    XK=0.                                               TRAN6430
```

```
      NN = 1
      TEMP(7)=FREXP(-TEMP(2))
      TEMP(13)=(X6(I)-Y2(I))/TEMP(2)**2*2.0                              TRAN6400
      TEMP(15)=(X6(I)-Y2(I+1))/(TEMP(1)-TEMP(2))                         TRAN6410
C.VEAT.  H4 IS THE SQUARE OF ITS NORMAL VALUE.                           TRAN6420
      EST = 1. - H4(I)
      CALL SCAT
      Q = AMAX1(0., 1. - FMUS / H(I))
      F2 = FS + F2 * H4(I) + G * (Y2(I) + TEMP(13) + TEMP(7) * (-TEMP
     2 (15) - TEMP(13) * (TEMP(2) + 1.)) + H4(I) * (TEMP(15) - Y2(I+1)))
      GO TO 223
C                                                                        TRAN6490
C                                                                        TRAN6550
C                FIRST TRANSPORT ZONE ON LHS                             TRAN6560
C                                                                        TRAN6570
  205 X8(I)=X(K)/C(I)*TG(I)                                              TRAN6580
      GO TO 191                                                          TRAN6590
C                                                                        TRAN6600
C                X =  ZERO ERROR                                         TRAN6610
C                                                                        TRAN6620
  207 S1=14.0207                                                         TRAN6630
      CALL UNCLE                                                         TRAN6640
  219 S1=14.0219                                                         TRAN6840
      CALL UNCLE                                                         TRAN6850
  221 F2=0.0                                                             TRAN6860
      GO TO 225                                                          TRAN6870
C                                                                        TRAN6880
C                DO Y-INTEGRATION TO X=0                                 TRAN6890
C                                                                        TRAN6900
  223 IF (F2.LT.0.) GO TO 221                                            TRAN6910
  225 FM(I)=F2                                                           TRAN6920
      FSM(I) = FS
C                                                                        TRAN6930
C                FORM TOP SLICE CONTRIBS TO X2                           TRAN6940
C                                                                        TRAN6950
      DO 231 J=IAXP,I                                                    TRAN6960
      TEMP(11)=CSQD(J)-YSQD1
      FNL = SUMX4(J) - SUMX3(J)
      XSQ = OX(J)**2
      X2(J) = X2(J) + FNL * (XSQ + XSQ)
      FU=(TEMP(11)*(FM(I)+F2)+(YSQDP-CSQD(J))*(SUMX4(IAXP)
     1    +SUMX3(IAXP)))/TEMP(5)
      FLX = SUMX3(J) + SUMX4(J)
      FP = FLX + FU
      FPL = FP + FLX
      RHO(J)=RHO(J)+OX(J)*FP
      PR(J) = PR(J) + XSQ * (FPL + FLX) * OX(J)                          TRAN7080
      TR(J) = TR(J) + XSQ**2 * FNL * 4.
  231 CONTINUE
      LRI = 2                                                            TRAN7130
      LDF = 2
      IAXP=I+1
      SUMX3(I)=F2                                                        TRAN7140
      SUMX4(I)=F2                                                        TRAN7150
      I=IAXP                                                             TRAN7160
      K=K-1                                                              TRAN7170
                                                                         TRAN7180
```

```
C     IF(ABS(TEMP(7)).LT.1.E-20)GO TO 257  DELETED 3/16/67, FCT
      I1 = I - 1
      I2 = I
      R1 = 0.
      R2 = X(K)
      IF (TEMP(1) - .02)  233,233,237
C                                                                       TRAN7240
C                SMALL OPTICAL DEPTH EXPANSION (X=0,RHS)                TRAN7250
C                                                                       TRAN7270
  233 NN = 0
      CALL SCAT
      Q = AMAX1(0., 1. - FMUS / H(I-1))
      F2 = FS + F2 * (1. - TEMP(1)) + Q * TEMP(16)
      GO TO 257                                                         TRAN7340
C     NORMAL RHS    (X=0)
  237 NN = 1
C VEAT.  H4 IS THE SQUARE OF ITS NORMAL VALUE.
      EST = 1. - H4(I-1)
      CALL SCAT
      Q = AMAX1(0., 1. - FMUS / H(I-1))
      F2 = FS + F2 * H4(I-1) + Q * (Y2(I) + TEMP(15) + FREXP(-TEMP(1) +
     2 TEMP(2)) * (-TEMP(15) + TEMP(13) * (1. - TEMP(2))) - H4(I-1) *
     3 (Y2(I-1) + TEMP(13)))
  257 IF (F2 .LT. 0.)  F2 = 0.
      GO TO 259
C                                                                       TRAN7430
C                CALCULATE RHS Y-LINE INTEGRATION                       TRAN7440
C                ARRIVE HERE IF Y-LINE INTERSECTS INNER RADIUS          TRAN7450
  239 IAXP=IAX                                                          TRAN7460
      I=IAX                                                             TRAN7470
      K=K-1                                                             TRAN7480
      LRI = 2
      LOF = 1
      IF (IAX .NE. IN .OR. IN .EQ. 1)  GO TO 238
C     BLACKBODY
      F2 = X6(IN-1)
      GO TO 259
  238 IF (X(K+1))  240, 207, 241
C                DIFFUSION BOUNDARY CONDITION WHEN X=0.
  240 X8(I-1) = 0.
      HD = X(K) * H(I-1)
      R1 = 0.
      GO TO 242
  241 X8(I-1)=X(K+1)/C(I-1)*TO(I-1)                                     TRAN7500
      HD = (X(K) - X(K+1)) * H(I-1)
      R1 = X(K+1)
  242 H4(I-1) = FREXP(-HD)
C                                                                       TRAN7530
C                DIFFUSION BOUNDARY CONDITION  AT IAX                   TRAN7540
C                                                                       TRAN7550
      GO TO 250
  249 HD  =   (X(K)-X(K+1))*H(I-1)
      R1 = X(K+1)
  250 I1 = I - 1
      I2 = 1
```

```
      R2 = X(K)
      IZN = I - 1
      TG1 = XB(I-1)
      TG2 = XB(I)
      CALL STEP
C                                                                       TRAN8120
C      ANGULAR INTEGRATION OF X2 USING LINEAR INTERPOLATION             TRAN8130
C                                                                       TRAN8140
  259 FNU = F2 - FM(I)
      FNL = SUMX4(I) - SUMX3(I)
      FXM=OX(I)-X(K)
      X2(I) = X2(I) + ((X(K) + X(K) + OX(I)) * FNU + (OX(I) + OX(I) +
     2 X(K)) * FNL) * FXM
      IF (I .NE. ITUBE)  GO TO 263
      IF (EPSI .GT. Y(JJ))  GO TO 261
      IF (EPSI .LT. TEMP(9))  GO TO 263
      THICK = THICK + ((XTUBE + XTUBE + OX(I)) * F2 + (OX(I) + OX(I) +
     2 XTUBE) * SUMX4(I)) * (OX(I) - XTUBE)
      GO TO 263
  261 THICK = THICK + ((X(K)  + X(K)  + OX(I)) * F2 + (OX(I) + OX(I) +
     2 X(K) ) * SUMX4(I)) * (OX(I) - X(K) )
  263 FU=FM(I)+F2
      FLX = SUMX3(I) + SUMX4(I)
      TEMP(6)=OX(I)*OX(I)
      TEMP(7)=X(K)*X(K)
      FXP=OX(I)+X(K)
      FXP3 = FXP**3
      FMI = FU - FLX
      RHO(I)=RHO(I)+FXM*(FU+FLX)
      PR(I) = PR(I) + FXP * (TEMP(6) + TEMP(7)) * FMI + 4. *
     2 (FLX * OX(I) * TEMP(6) - FU * X(K) * TEMP(7))
      TR(I) = TR(I) + FXM * (FNL * (FXP3 + OX(I) * (3. * TEMP(6) -
     2 TEMP(7))) + FNU * (FXP3 + X(K) * (3. * TEMP(7) - TEMP(6))))
C                                                                       TRAN8340
C                SAVE F2 AND FM FOR NEXT Y-LINE                         TRAN8350
C                                                                       TRAN8360
      SUMX4(I)=F2
      SUMX3(I)=FM(I)                                                    TRAN8380
      FSP(I) = FS
      OX(I)=X(K)                                                        TRAN8390
      IF (ABS(TG(I)) .LT. 1.E-20)  Y2(I) = X6(I)
      I=I+1                                                             TRAN8410
      K=K-1                                                             TRAN8420
      LOF = 2
      IF (ABS(TG(I)) .LT. 1.E-20)  Y2(I) = X6(I-1)
      IF (I-IBXP1) 249,249,283
C                                                                       TRAN8740
C                DEBUG PRINT                                            TRAN8750
C                                                                       TRAN8760
  283 CONTINUE
      DHNU=HNUP-HNU                                                     TRAN8780
      IF (ABS(TRDBG) .LT. 1.E-20)  GO TO 301
      CNTI = SOLID(18) + 1.0
      WRITE (6,307)  HNU, HNUP, IHNU, CNTI
      WRITE (6,309) Y(JJ)
```

```
      WRITE (6,311) JJ,IAX,IBX
      WRITE (6,315)                                                     TRAN8850
      IAXP1=MAX0(IAX,IAXP-1)                                            TRAN8860
      DO 299 I=IAXP1,IBXP1                                              TRAN8870
      IF (JJ.GT.1) GO TO 297                                            TRAN8880
C                                                                       TRAN8890
C               PRINT Y=0 INTEGRATION                                   TRAN8900
C                                                                       TRAN8910
  295 WRITE(6,313)I,C(I),X6(I),X8(I),H4(I),FSM(I),
     2FSP(I),SUMX3(I),SUMX4(I),X2(I)
      GO TO 299                                                         TRAN8930
C                                                                       TRAN8950
C               PRINT REGULAR Y-LINE INTEGRATION                        TRAN8960
C                                                                       TRAN8970
  297 KKK=KK-I+IM+3                                                     TRAN8940
      WRITE(6,313)I,X(KKK),X6(I),X8(I),H4(I),FSM(I),
     2FSP(I),SUMX3(I),SUMX4(I),X2(I)
  299 CONTINUE                                                          TRAN8990
      IF (TRDBG .GT. 68.)  TRDBG = TRDBG - 69.
  301 IF (JJ.EQ.1) GO TO 303                                            TRAN9000
C*****************************************************************TRAN9010
C                                                                     *TRAN9020
C            E D I T   A N D   Y - L I N E   A D V A N C E            *TRAN9030
C                                                                     *TRAN9040
C*****************************************************************TRAN9050
      KK=KK-IFIX(X(KK+1))+2                                             TRAN9060
  303 YSQD1 = YSQUP
      TEMP(9)=Y(JJ)                                                     TRAN9080
      JJ=JJ+1                                                           TRAN9090
      GO TO 87                                                          TRAN9110
  307 FORMAT  (38H1Y-LINE PRINT FOR FREQUENCY BAND FROM F9.3, 5H  TO F9.
     23, 10X7HIHNU = I2, 10X6HCYCLE F5.0)
  309 FORMAT (/5H Y = 1PE10.5)                                          TRAN9130
  311 FORMAT (6H JJ = I3,10X7H IAX = I3,10X7H IBX = I3//)
  313 FORMAT (I4,1P9E14.7)
  315 FORMAT (3X1HI,13X1HX,12X2HX6,12X2HX8,
     212X2HH4,11X3HFSM,11X3HFSP,9X5HSUMX3,
     39X5HSUMX4,12X2HX2)
      END                                                               TRAN9210
```

```
QIT FOR STEP/BL, STEP/BL, STEP/BL1
      SUBROUTINE  STEP                                                  T
COMPILED  JUNE 22, 1967  WBL                                            T
C                                                                      *T
C*                    S P U T T E R   C O M M O N                     **T
C*                                                                     **T
C*                                                                     **T
      COMMON   LMDA(37), NR     , NSMLR , IA     , IB     , ICA    , ICB    ,T
     1   KMAX  , BLANK1, BLANK2, BLANK3, IAP1  , IBP1  , ICAP1 , ICBP1 ,T
     2   II    , IG    , NRAD  , BLANK4, IAM1  , IBM1  , ICAM1 , ICBM1 ,T
     3   IIP1  , IGM1  , IALPHA, BLANK5, TH    , TMAX  , BLANK6, DELPRT,T
     4   FREQ  , CNTMAX, AR    , ASMLR , PUSHA , PUSHB , BOILA , BOILB ,T
     5   CVA   , CVB   , SLUG  , ALPHA , HVA   , HVB   , HCA   , HCB   ,T
     6   EMINA , EMINB , CA    , CB    , GA    , GB    , GL    , GR    ,T
     7   RHOL  , RHOR  , EPIO  , EPSI  , RIA   , RIB   , RDIA  , RDIB  ,T
     8   RPIA  , RPIB  , RPDIA , RPDIB , TPRINT, TA    , TB    , TC     T
      COMMON     TD    , TE    , DTH2  , DTH2P , DTH1  , DTRMIN, DTMAX ,T
     1 * DTMAX1, DTMAX2, DTMAX3, DTR   , SWITCH, CO    , CMIN  , DELTA ,T
     2   GAMA  , WCRIT , SIGMAQ, AC    , ACO3T4, CNVRT , SUMRA , SUMRB ,T
     3   ROIA  , ROIAM1, ROIB  , ROIBP1, GMS   , S1    , S2    , S3    ,T
     4   S4    , S5    , S6    , S7    , S8    , S9    , S10   , S11   ,T
     5   S12   , S13   , S14   , S15   , S16   , S17   , S18   , S19   ,T
     6   S20   , EO    , FO    , TAU   , ZERO  , R    (152), DELTAR(152),T
     7  ASG   (152), RD    (152), VD    (152), RDD   (152), SMLR  (152),T
     8  DELR  ( 37), P     (152), P1    (152), PB    (152), PB1   (152) T
      COMMON         P2    (152), SV    (152), RHO   (152), THETA (152),T
     1  W     (152), E     (152), EI    (152), EK    (152), A     (152),T
     2  V.    (152), G     (152), D     (152), C     (152), X2    (152),T
     3  X3    (152), X4    (152), X5    (152), X6    (152), X7    (152),T
     4  SMLA  (152), SMLB  (152), SMLC  (152), SMLD  (152), SMLE  (152),T
     5  EC    (152), ER    (152), SMLQ  (152), SMLH  (152), BIGA  (152),T
     6  BIGB  (152), CV    (152), BC    (152), BR    (152), CHIC  (152),T
     7  CHIR  (152), CAPAC (152), CAPAR (152), CRTC  (152), CRTR  (152),T
     8  CRTPC (152), GOFR  (152), FEW   (152), CAR   (152), OKLM  ( 37) T
      COMMON         TELM  ( 37), EKLM  ( 37), ELM   ( 37), FCLM  ( 37),T
     1  FRLM  ( 37), WLM   ( 37), QLM   ( 37), AMASNO( 37), CHRNO ( 37),T
     2  ZP1   ( 37), ZP2   ( 37), SOLID ( 37), ECHCK ( 37), RK    (104),T
     3  RL-   ( 37), RHOK  (104), RDK   (104), THETAK(104), TEMP  ( 16),T
     4  HEAD  ( 12), MAXL        , MAXLM                                T
C                                                                      T
C*                                                                     **T
C*********************************************************************T
      COMMON /JIM/ AN, FMU, R1, R2, HD, EST, I1, I2, GMP, A1, A3, FMUS, T
     2 FS, LDF, LRI, IZN, TG1, TG2, F2                                  T
      DIMENSION  CSQU  (1), PR    (1), FM    (1), H     (1), H2    (1),T
     1 H3    (1), H4    (1), FMS   (1), Q1    (1), TG    (1), Q3    (1),T
     2 Q37   (1), Q38   (1), SUMX2 (1), SUMX3 (1), SUMX4 (1), X8    (1),T   550
     3 Y     (1), Y2    (1), OX    (1), FL    (1), TR    (1), FSM   (1),T
     4 FSP   (1)                                                        T
C                                                                      T   570
      EQUIVALENCE          (ACO3T4,TRDBG), (BC   ,SUMX4), (BIGA ,Y    ),T   580
     1        (BIGB , H   ), (BR   ,H3   ), (CAR  ,Q37  ), (CHIC ,SUMX3),T   590
     2        (CHIR ,Q38  ), (CRTR ,SUMX2), (X7   ,PR   ), (GOFR ,Q3   ),T   600
     3        ( PB  ,Q1   ), (S12 ,EDITMF), (EC   ,H2   ), (  W  ,OX   ),T
```

```
     4        (SMLA ,FMS   ), (SMLB ,FL    ), (SMLC ,TR    ), (SMLH ,H4    ),T
     5        (ER   ,FM    ), (V    ,TG    ), (SMLD ,FSM   ), (CRTC ,CSQD  ),T
     6.       (X5   ,Y2    ), (X4   ,X8    ), (SMLE ,FSP   )                 T
C*****************************************************************T     660
C                                                                 *T     670
C                OX CONTAINS X FROM THE PREVIOUS Y LINE           *T     680
C                                                                 *T     690
C                        CSQD    SAME AS   CRTC                   *T     700
C                        EDITMF  SAME AS    S12                   *T     710
C                        Q1      SAME AS     PB                   *T
C                        FM      SAME AS     ER                   *T
C                        H       SAME AS   BIGB                   *T     740
C                        H2      SAME AS     EC                   *T
C                        H3      SAME AS     BR                   *T     760
C                        H4      SAME AS   SMLH                   *T     770
C                        PR      SAME AS     X7                   *T
C                        FMS     SAME AS   SMLA                   *T
C                        FL      SAME AS   SMLB                   *T
C                        TR      SAME AS   SMLC                   *T
C                        FSM     SAME AS   SMLD                   *T
C                        FSP     SAME AS   SMLE                   *T
C                        Y2      SAME AS     X5                   *T
C                        OX      SAME AS      W                   *T
C                        TG      SAME AS      V                   *T
C                        Q3      SAME AS   GOFR                   *T     830
C                        Q37     SAME AS    CAR                   *T     840
C                        Q38     SAME AS   CHIR                   *T     850
C                        SUMX2   SAME AS   CRTR                   *T     860
C                        SUMX3   SAME AS   CHIC                   *T     870
C                        SUMX4   SAME AS     BC                   *T     880
C                        TRDBG   SAME AS AC03T4                   *T     890
C                        Y       SAME AS   BIGA                   *T     910
C                        X8      SAME AS     X4                   *T
C                                                                 *T     940
C*****************************************************************TRAN 930
      GO TO (20, 25), LDF                                         T
C     IF DIFFUSION ZONE, DEFINE STARTING INTENSITY                T
   20 F2 = Y2(I1) - TG1                                           T
   25 IF (HD .GT. 0.01)  GO TO 30                                 T
C     THIN ZONE                                                   T
      NN = 0                                                      T
      GO TO 50                                                    T
C     NORMAL ZONE -- DEFINE EXP(-DELTATAU)                        T
   30 NN = 1                                                      T
      GO TO (35, 40), LRI                                         T
   35 H4(IZN) = FREXP(-HD)                                        T
   40 EST = 1. - H4(IZN)**2                                       T
   50 CALL SCAT                                                   T
      Q = AMAX1(0., 1. - FMUS / H(IZN))                           T
      NN1 = NN + 1                                                T
      GO TO (60, 70), NN1                                         T
   60 F2 = FS + F2 * (1. - HD - HD) + Q * (((Y2(I1) + Y2(I2)) * 0.5 +  T
     2 X6(IZN)) * HD)                                             T
      GO TO 100                                                   T
   70 F2 = FS + F2 * H4(IZN)**2 + Q * (Y2(I2) - TG2 + ((TG1 - Y2(I1)) * T


     2 H4(IZN) + TG2 - TG1) * H4(IZN))                            T
  100 IF (F2 .LT. 0.)  F2 = 0.                                    T
      RETURN                                                      T
      END                                                         T
```

```
@,T  FOR   SCAT/PP,SCAT/PP,SCAT/JP                                      T
      SUBROUTINE SCAT                                                   T
C     GEOMETRY-INDEPENDENT COMPTON SCATTERING                           T
C COMPILED  OCTOBER 9, 1967  WBL
C                                                                      *T
C+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++T
C                                                                       T
C                                                                       T
      COMMON   LMDA(37), NR     , NSMLR , IA     , IB     , ICA    , ICB    ,T
     1   KMAX  , BLANK1, BLANK2, BLANK3, IAP1  , IBP1  , ICAP1 , ICBP1 ,T
     2   II    , IG    , NRAU  , BLANK4, IAM1  , IBM1  , ICAM1 , ICBM1 ,T
     3   IIP1  , IGM1  , IALPHA, BLANK5, TH    , TMAX  , BLANK6, DELPRT,T
     4   FREQ  , CNTMAX, AR    , ASMLR , PUSHA , PUSHB , BOILA , BOILB ,T
     5   CVA   , CVB   , SLUG  , ALPHA , HVA   , HVB   , HCA   , HCB   ,T
     6   EMINA , EMINB , CA    , CB    , GA    , GB    , GL    , GR    ,T
     7   RHOL  , RHOR  , EPIO  , EPSI  , RIA   , RIB   , RDIA  , RDIB  ,T
     8   PPIA  , RPIB  , RPDIA , RPDIB , TPRINT, TA    , TB    , TC     T
      COMMON     TD    , TE    , DTH2  , DTH2P , DTH1  , DTRMIN, DTMAX ,T
     1   DTMAX1, DTMAX2, DTMAX3, DTR   , SWITCH, CO    , CMIN  , DELTA ,T
     2   GAMA  , ACRIT , SIGMAQ, AC    , ACO3T4, CNVRT , SUMRA , SUMRB ,T
     3   ROIA  , ROIAM1, ROIB  , ROIBP1, GMS   , S1    , S2    , S3    ,T
     4   S4    , S5    , S6    , S7    , S8    , S9    , S10   , S11   ,T
     5   S12   , S13   , S14   , S15   , S16   , S17   , S18   , S19   ,T
     6   S20   , EO    , FO    , TAU   , ZERO  , R   (152), DELTAR(152),T
     7  ASQ   (152), RD    (152), VD    (152), RDD   (152), SMLR  (152),T
     8  DELR  ( 37), P     (152), P1    (152), PB    (152), PB1   (152) T
      COMMON         P2    (152), SV    (152), RHO   (152), THETA (152),T
     1  W     (152), E     (152), EI    (152), EK    (152), A     (152),T
     2  V     (152), G     (152), D     (152), C     (152), X2    (152),T
     3  X3    (152), X4    (152), X5    (152), X6    (152), X7    (152),T
     4  SMLA  (152), SMLB  (152), SMLC  (152), SMLD  (152), SMLE  (152),T
     5  EC    (152), ER    (152), SMLQ  (152), SMLH  (152), BIGA  (152),T
     6  BIGB  (152), CV    (152), BC    (152), BR    (152), CHIC  (152),T
     7  CHIR  (152), CAPAC (152), CAPAR (152), CRTC  (152), CRTR  (152),T
     8  CRTPC (152), GOFR  (152), FEW   (152), CAR   (152), OKLM  ( 37) T
      COMMON         TELM  ( 37), EKLM  ( 37), ELM   ( 37), FCLM  ( 37),T
     1  FRLM  ( 37), WLM   ( 37), QLM   ( 37), AMASNO( 37), CHRNO ( 37),T
     2  ZP1   ( 37), ZP2   ( 37), SOLID ( 37), ECHCK ( 37), RK    (104),T
     3  RL    ( 37), RHOK  (104), RDK   (104), THETAK(104), TEMP  ( 16),T
     4  HEAD  ( 12), MAXL        , MAXLM                                T
C                                                                       T
C+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++T
C                                                                      *T
      COMMON /LINDLY/ HNU,SGML,IHNU,NHNU,HNUP,NT,IM,IN,DHNU,THICK,NY    T
C                                                                       T
      COMMON /CNTRL/ SCYCLE, JMULT                                      T
      COMMON /PALMER/  FIG(152), FI1(152), FI2(152), FI3(152), FQ0(152),T
     2 FQ1(152), FQ2(152), FQ3(152), JURUM                              T
      COMMON /JIM/ NN, FMU, R1, R2, HD, EST, I1, I2, GMP, A1, A3, FMUS, T
     2 FS, LDF, LRI, IZN, TG1, TG2, F2                                  T
      DIMENSION   CSQU  (1), PR    (1), FM    (1), H     (1), H2    (1),T
     1 H3    (1), H4    (1), FMS   (1), Q1    (1), TG    (1), Q3    (1),T
     2 Q37   (1), Q38   (1), SUMX2 (1), SUMX3 (1), SUMX4 (1), X8    (1),T     550
     3 Y     (1), Y2    (1), OX    (1), FL    (1), TR    (1), FSM   (1),T
```

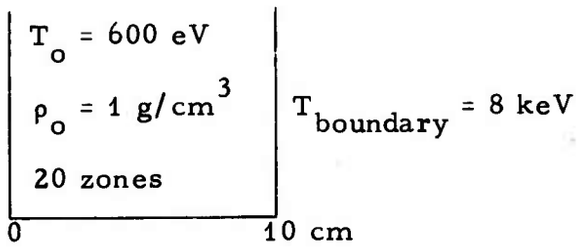
```
     4 FSP    (1)                                                          T
C                                                                          T     570
      EQUIVALENCE          (AC03T4,TRDBG), (BC    ,SUMX4), (BIGA ,Y     ),T     580
     1        (BIGB , H    ), (BR    ,H3    ), (CAR   ,Q37   ), (CHIC ,SUMX3),T     590
     2        (CHIR ,Q38   ), (CRTR ,SUMX2), (X7    ,PR    ), (GOFR ,Q3    ),T     600
     3        ( PB  ,Q1    ), (S12 ,EDITMF), (EC    ,H2    ), (  W  ,OX    ),T
     4        (SMLA ,FMS   ), (SMLB ,FL    ), (SMLC ,TR    ), (SMLH ,H4    ),T
     5        (ER   ,FM    ), (V     ,TG    ), (SMLD ,FSM   ), (CRTC ,CSQD  ),T
     6        (X5   ,Y2    ), (X4    ,X8    ), (SMLE ,FSP   )                T
C*************************************************************************T     660
C                                                                         *T     670
C                 OX CONTAINS X FROM THE PREVIOUS Y LINE                  *T     680
C                                                                         *T     690
C                          CSQD    SAME AS   CRTC                         *T     700
C                          EDITMF  SAME AS    S12                         *T     710
C                          Q1      SAME AS     PB                         *T
C                          FM      SAME AS     ER                         *T
C                          H       SAME AS   BIGB                         *T     740
C                          H2      SAME AS     EC                         *T
C                          H3      SAME AS     BR                         *T     760
C                          H4      SAME AS   SMLH                         *T     770
C                          PR      SAME AS     X7                         *T
C                          FMS     SAME AS   SMLA                         *T
C                          FL      SAME AS   SMLB                         *T
C                          TR      SAME AS   SMLC                         *T
C                          FSM     SAME AS   SMLD                         *T
C                          FSP     SAME AS   SMLE                         *T
C                          Y2      SAME AS     X5                         *T
C                          OX      SAME AS      W                         *T
C                          TG      SAME AS      V                         *T
C                          Q3      SAME AS   GOFR                         *T     830
C                          Q37     SAME AS    CAR                         *T     840
C                          Q38     SAME AS   CHIR                         *T     850
C                          SUMX2   SAME AS   CRTR                         *T     860
C                          SUMX3   SAME AS   CHIC                         *T     870
C                          SUMX4   SAME AS     BC                         *T     880
C                          TRDBG   SAME AS AC03T4                         *T     890
C                          Y       SAME AS   BIGA                         *T     910
C                          X8      SAME AS     X4                         *T
C                                                                         *T     940
C*************************************************************************T
C                                                                         *T
C*************************************************************************T
      CALL DVCHK(IMHAD)
      GO TO (1,2),IMHAD
    1 S1=75.001
      CALL UNCLE
    2 GO TO (100, 102, 102), IALPHA
  100 SQMU = FMU * FMU
      FMUX = FMU
      R1 = R1 / FMU
      R2 = R2 / FMU
      GO TO 106
  102 YSQ = FMU
      XX = R2 * R2
```

```
      XP = R1 * R1
      IF (YSQ .GT. 0.)  GO TO 104
      SQMU = 1.
      FMUX = 1.
      GO TO 106
  104 SQMU = 0.5 * (XP / (XP + YSQ) + XX / (XX + YSQ))
      FMUX = SQRT(SQMU)
  106 DX = R2 - R1
  110 FMUS = FMS(IZN)
      BB = FI0(I2) - FI0(I1) + SQMU * (FI2(I2) - FI2(I1))
      IF (ABS(SOLID(36)) .LT. 1.E-20)  GO TO 115
C     THOMSON SHORT CUT
      IF (NN .NE. 0)  GO TO 112
      FS = .375 * FMUS * DX * ((FI0(I1) + SQMU * FI2(I1)) * (1. - HD) +
     2 .5 * BB)
      GO TO 26
  112 AA = R2 * (FI0(I1) + SQMU*FI2(I1)) - R1 * (FI0(I2) + SQMU*FI2(I2))
      FS = .375 * FMUS / (HD + HD) * (AA * EST + BB * (DX + R1 * EST) -
     2 BB * DX * EST / (HD + HD))
      GO TO 26
C     NORMAL COMPTON PATH
  115 DD = FI3(I2) - FI3(I1) + SQMU * (FI1(I2) - FI1(I1))
      IF (IHNU .EQ. 1)  GO TO 5
      FF = FQ0(I2) - FQ0(I1) + SQMU * (FQ2(I2) - FQ2(I1))
      HH = FQ3(I2) - FQ3(I1) + SQMU * (FQ1(I2) - FQ1(I1))
    5 IF (NN .GT. 0)  GO TO 10
C     THIN RECIPE
      FS1 = (1. - A1) * ((1. - HD) * (FI0(I1) + SQMU * FI2(I1)) + .5*BB)
      FS2 = -A1 * FMUX* ((1. - HD) * (FI3(I1) + SQMU * FI1(I1)) + .5*DD)
      IF (IHNU .EQ. 1)  GO TO 9
      FS3=A3*((1.-HD)*(FQ0(I1)+SQMU*FQ2(I1))+.5*FF)
      FS4 = A3 * FMUX * ((1. - HD) * (FQ3(I1) + SQMU * FQ1(I1)) + .5*HH)
      FS = .375 * FMUS * (FS1 + FS2 + FS3 + FS4) * DX
      GO TO 25
    9 FS = .375 * FMUS * (FS1 + FS2) * DX
      GO TO 25
   10 AA = R2 * (FI0(I1) + SQMU*FI2(I1)) - R1 * (FI0(I2) + SQMU*FI2(I2))
      CC = R2 * (FI3(I1) + SQMU*FI1(I1)) - R1 * (FI3(I2) + SQMU*FI1(I2))
      IF (IHNU .EQ. 1)  GO TO 15
      EE=R2*(FQ0(I1)+SQMU*FQ2(I1))-R1*(FQ0(I2)+SQMU*FQ2(I2))
      GG=R2*(FQ3(I1)+SQMU*FQ1(I1))-R1*(FQ3(I2)+SQMU*FQ1(I2))
   15 TERM2 = DX + EST * (R1 - DX / (HD + HD))
      FS1 = (1. - A1) * (AA * EST + BB * TERM2)
      FS2 = -A1 * FMUX * (EST * CC + DD * TERM2)
      IF (IHNU .EQ. 1)  GO TO 20
      FS3=A3*(EE*EST + FF*TERM2)
      FS4 = A3 * FMUX * (EST * GG + HH * TERM2)
      FS=.375*FMUS/(HD+HD)*(FS1+FS2+FS3+FS4)
      GO TO 25
   20 FS=.375*FMUS/(HD+HD)*(FS1+FS2)
   25 FMUS = FMUS * GMP
   26 IF (FS .GT. (-1.E-20))  GO TO 29
      IF (ABS(HVB) .LT. 1.E-20)  GO TO 128
      WRITE (6, 27)  FS, IZN, IHNU, FMUX
   27 FORMAT  (6H FS = 1PE13.6, 7X6HIZN = I3, 7X7HIHNU = I2, 7X6HFMU = 1
     2PE13.6)
      WRITE (6,28)  R1, R2, HD, EST, FS1, FS2, FS3, FS4, AA, BB, CC, DD,
     2 EE, FF, GG, HH, FI0(I1), FI0(I2), FI1(I1), FI1(I2), FI2(I1),
     3 FI2(I2), FI3(I1), FI3(I2)
   28 FORMAT  (1P8E15.6)
      IF (TRDBG .LT. 68.)  TRDBG = TRDBG + 69.
  128 FS=0.
      IF (ABS(CVB) .LT. 1.E-20)  GO TO 29
      S1=75.008
      CALL UNCLE
   29 CALL DVCHK(IMHAD)
      GO TO (30,40),IMHAD
   30 S1=75.0009
      CALL UNCLE
   40 RETURN
      END
```

APPENDIX IV

APPLICATIONS OF THE PLANE GEOMETRY CODE

The plane geometry code was applied in conjunction with the standard SPUTTER code to several one-dimensional problems. The problem definition can be summarized as follows:



The only physical process considered was radiation transport, i.e., no hydrodynamics. The equation of state for the material was that of CH_2. The opacity used was that of a hypothetical material in which $\kappa_R = 0.2$ at all frequency groups.

The results of the calculations are shown in figures 8 through 13. Figure 8 shows the flux as a function of $u = h\nu/kT$ for the Thomson scattering, i.e., $1/m_o c^2 = 0$. The difference between the curves at 0 and 2 mfp represents the energy deposited into the material. However, in the case of Thomson scattering, no material heating should occur. One should look at this discrepancy as a convergence problem. The results of figure 8 are plotted for cycle 20. Extending the calculation further would improve the accuracy at the cost of further computer time.

Figure 9 is the same calculation with Compton scattering. One should note the spectrum changes at the high-frequency end. This reduction in the spectrum for the Compton case is qualitatively in agreement with theory.

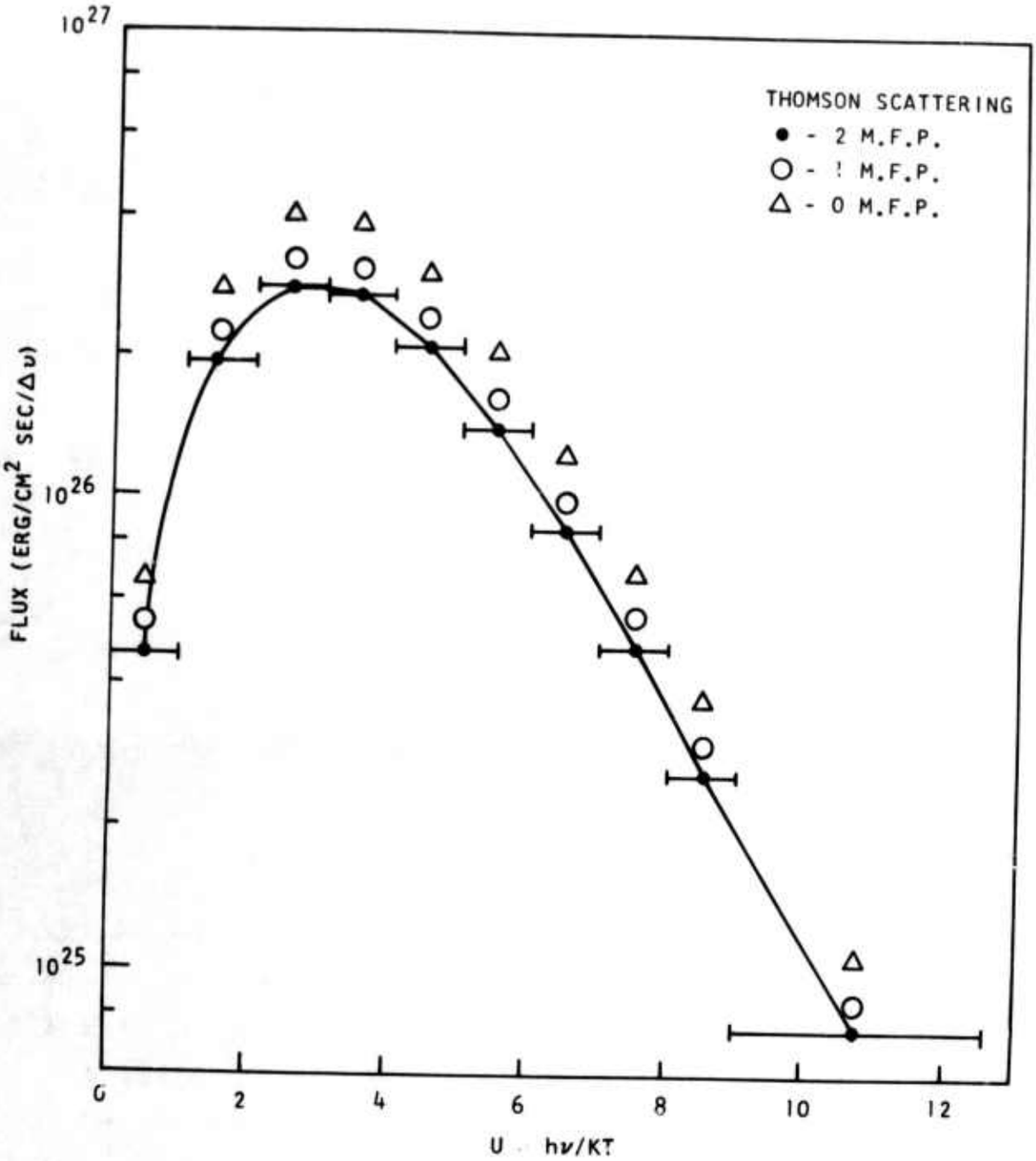


Figure 8. Spectrum at Various Optical Depths Employing Thomson Scattering

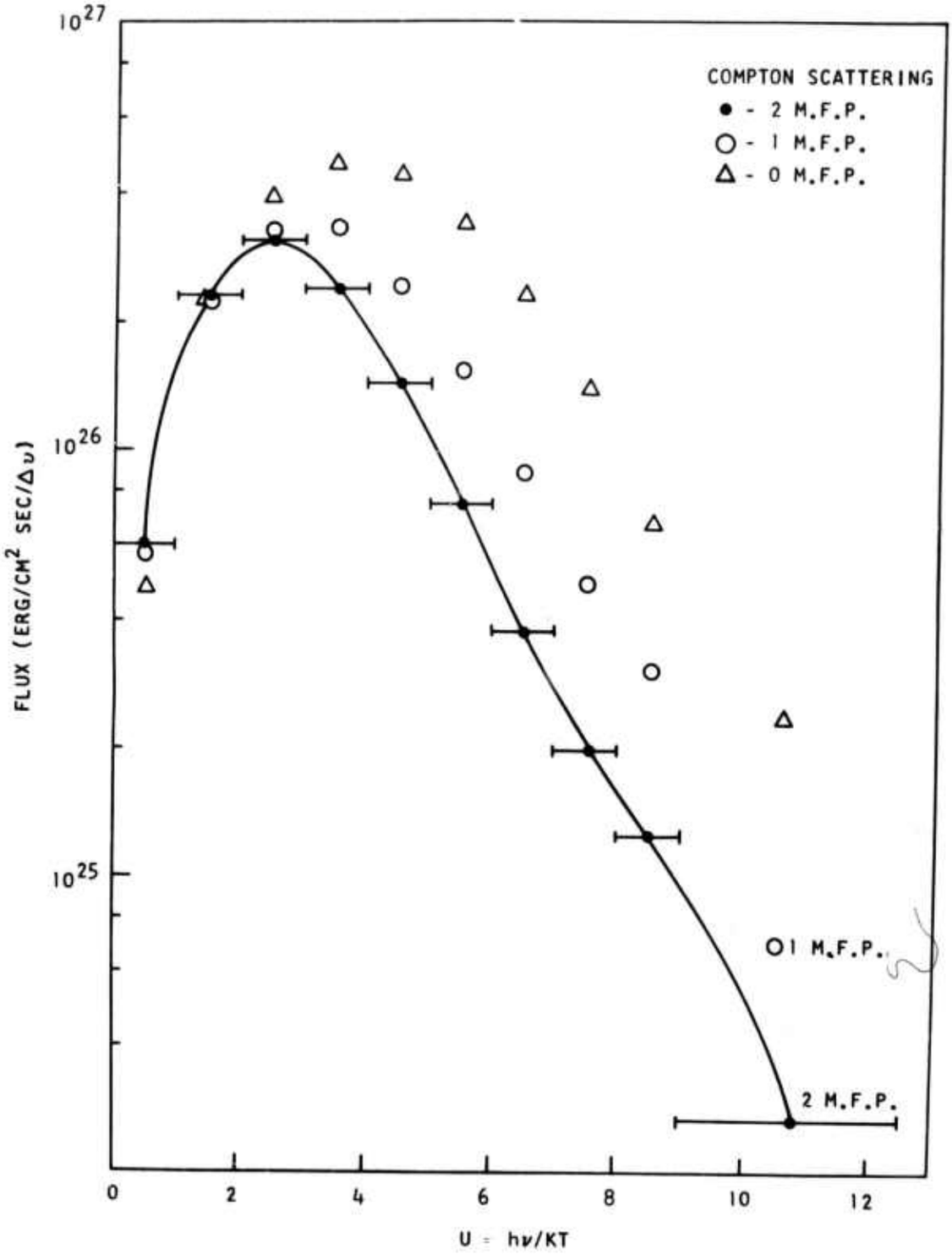


Figure 9. Spectrum at Various Optical Depths Employing Compton Scattering

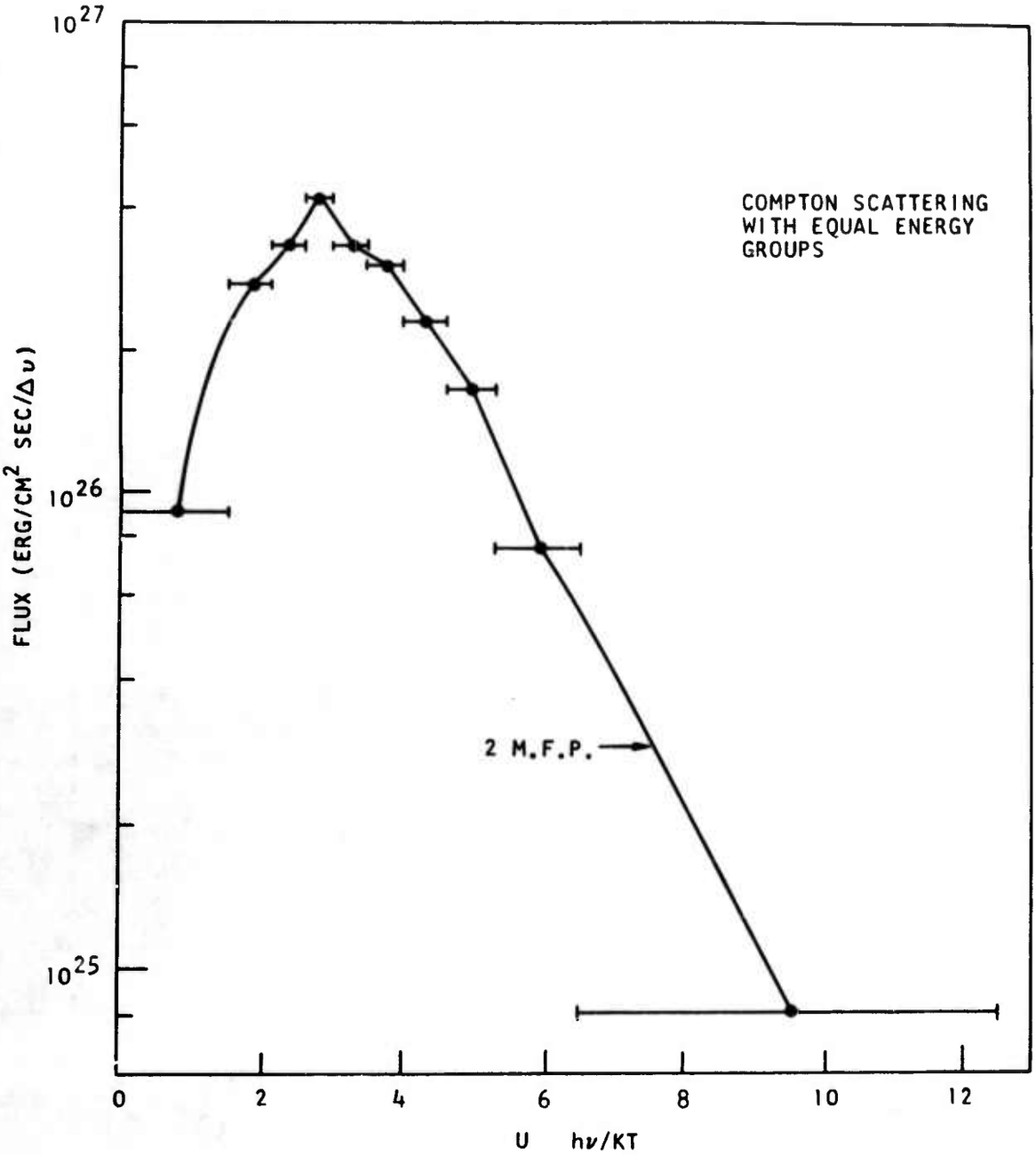


Figure 10. Exit Spectrum for Compton Scattering

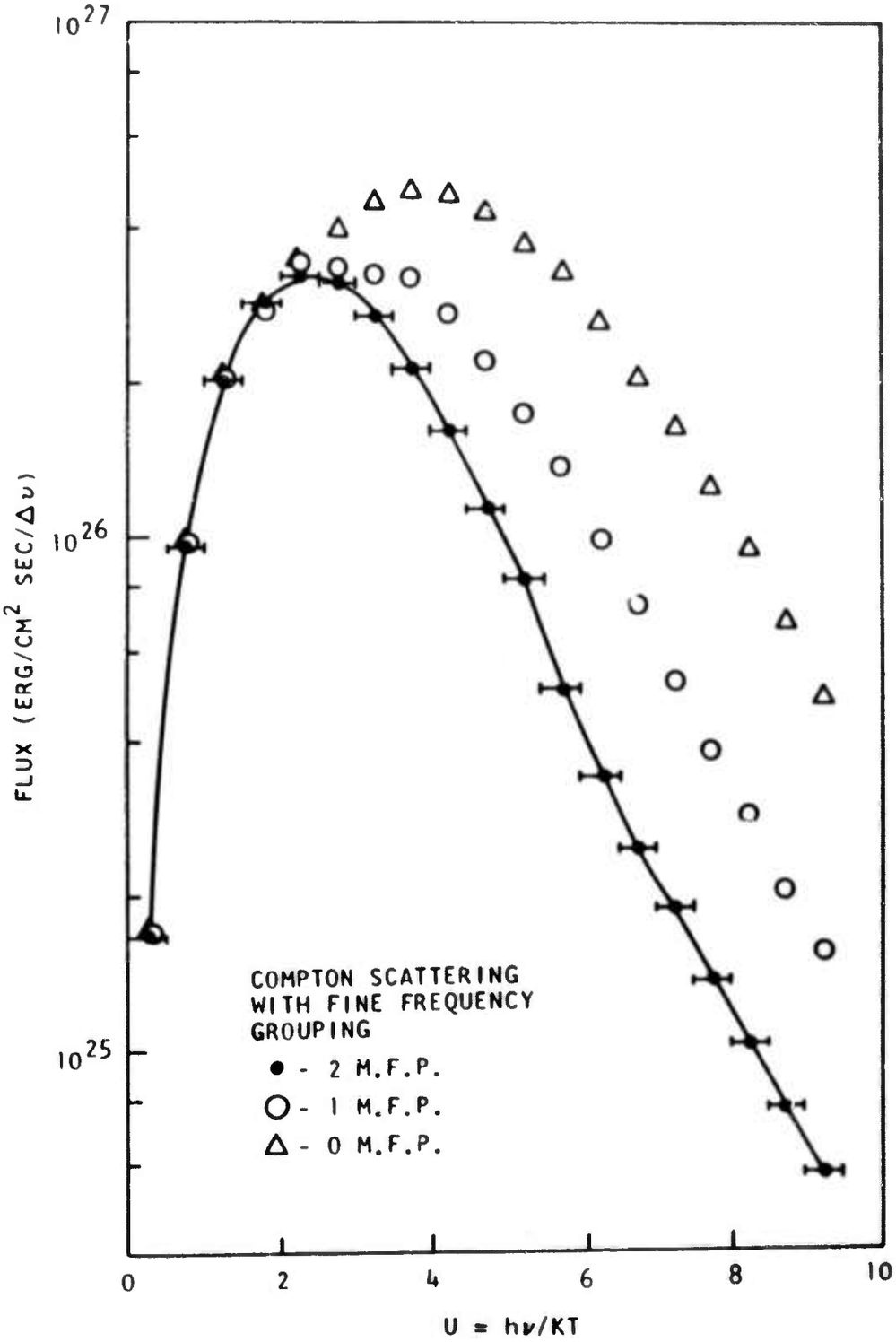


Figure 11. Spectrum using Compton Scattering

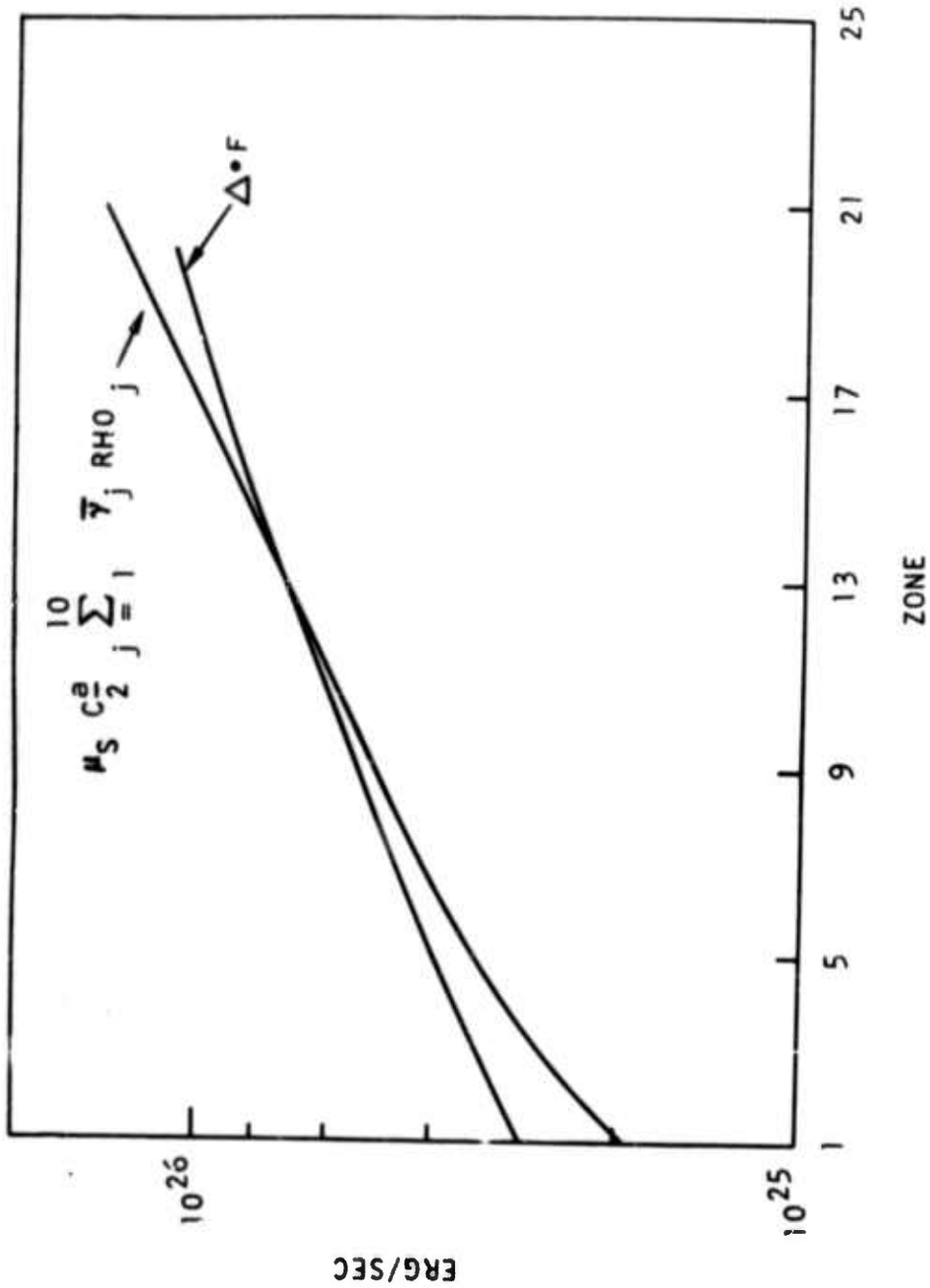


Figure 12. Comparison of Theoretical and Computed Heating Rates

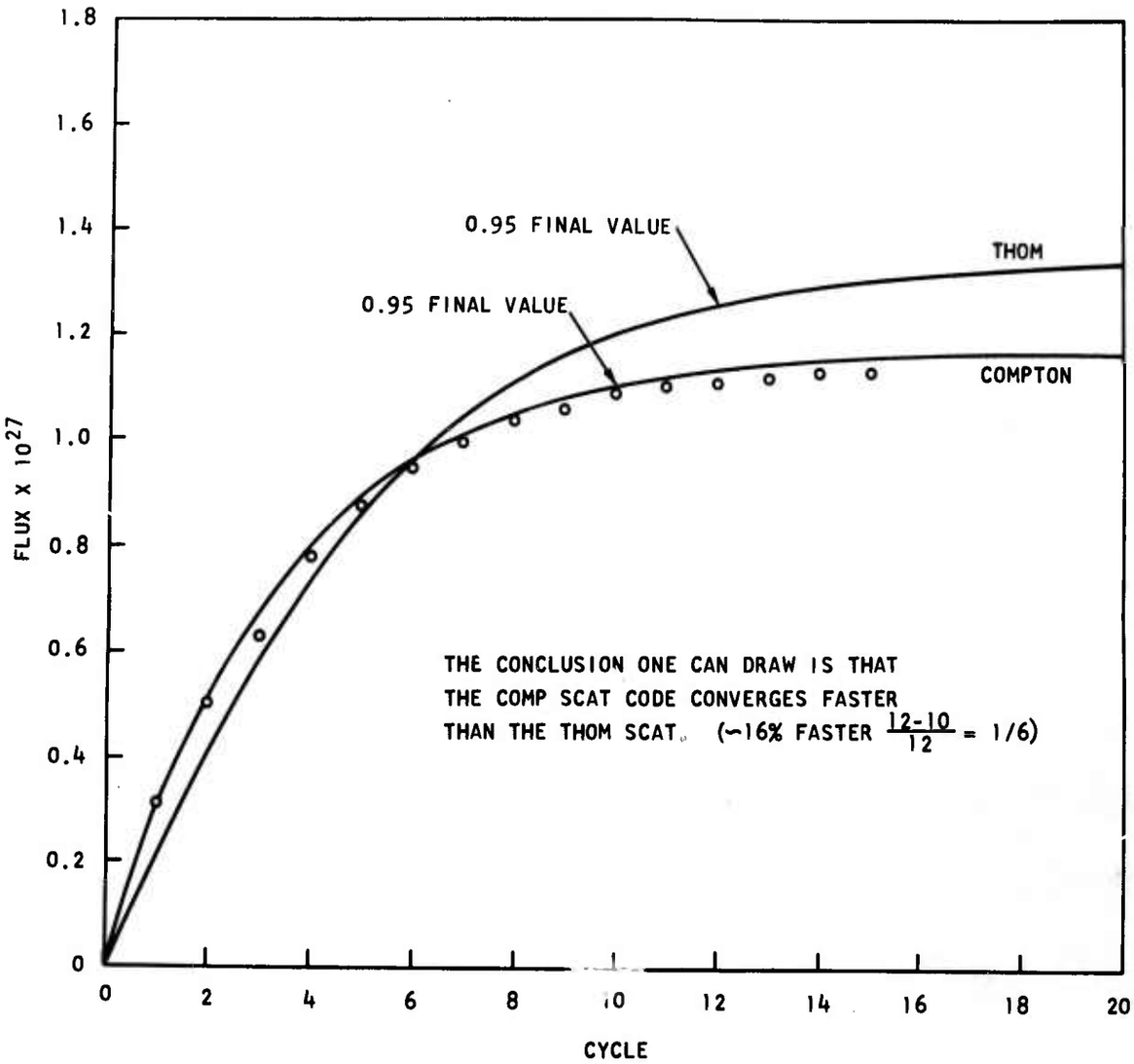


Figure 13. Comparison of Convergence Rates for Thomson and Compton Scattering

In the first two problems, illustrated in figures 8 and 9, the frequency groups were (0 to 8 keV), (8 to 16 keV), (16 to 24 keV), (24 to 32 keV), (32 to 40 keV), (40 to 48 keV), (48 to 56 keV), (56 to 64 keV), (64 to 72 keV), and (72 to 100 keV). The question arises as to how dependent is the solution on the number and definition of these groups. In figures 9 and 10, two different groupings were considered. In figure 10, the frequency groups were chosen to include 10 percent of the energy in an 8-keV blackbody. It is apparent from figure 10 that the spectrum has been distorted by unequal frequency groups. This conclusion was also supported by the fourth problem, i.e., the case in which the number of frequency groups was doubled. Initially, the first nine frequency groups were halved, whereas the (72 to 100 keV) group remained constant. This problem was unsuccessful. The unequal frequency grouping caused discontinuities to be propagated through the spectrum. This difficulty was eliminated by changing the (72 to 100 keV) group to (72 to 76 keV), where all the groups were then 4 keV wide. The results of this problem are shown in figure 11. Notice that figures 9 and 11 have converged to approximately the same solution. With the previous remarks in mind, one should be hesitant about solving problems in which the frequency groupings are unequal.

In figure 9, the difference between the curve at 2 and 0 mfp is the amount of energy used to heat the material. To determine if this is a reasonable estimate, a comparison of the material heating ratio (SMLE) and the theoretical heating rates

$$\left(\mu_s c \sum_{j=1}^{N} \bar{\gamma}_j E_j\right)$$

as a function of zone is presented in figure 12. The difference between these two curves can be used as a criterion for convergence.

A further point of interest is how fast the solution converges to its steady-state value at the edge of the window away from the source. Figure 13 graphically displays this convergence.

For comparative purposes, a plot of the flux from an 8-keV blackbody as a function of frequency is presented in figure 14.

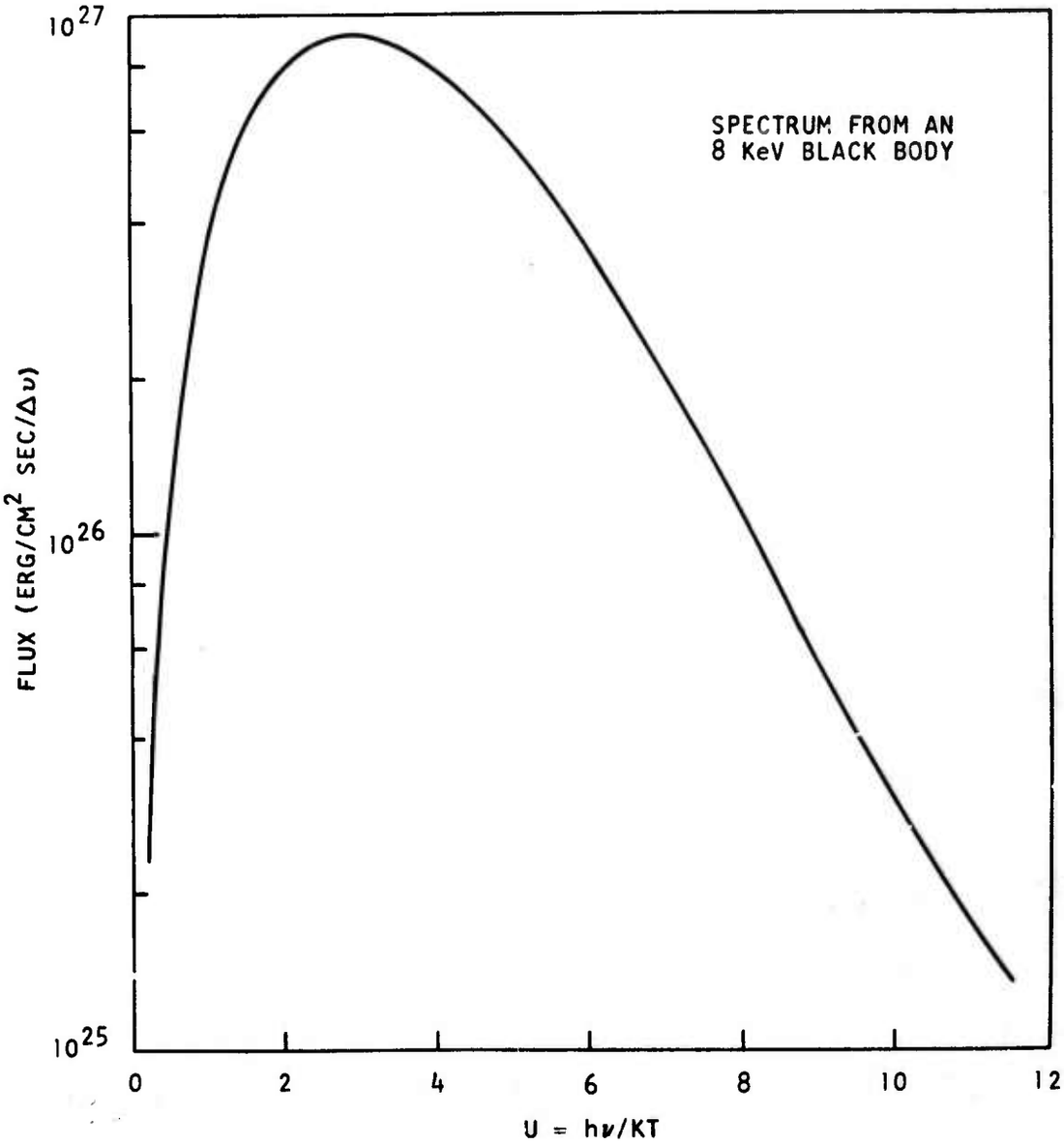


Figure 14. Spectrum from 8-keV Blackbody

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APPENDIX V

COMPTON AND INVERSE COMPTON SCATTERING

INTRODUCTION

Scattering of photons by free electrons in the Compton scattering process results in a modification of the radiative intensity in angular distribution and spectrum by virtue of the resulting energy and momentum exchange. This rate of change of intensity is described by the equation of radiative transfer, a Boltzmann equation for the photons. The objective here is to derive an approximation to the radiative-transfer equation which is valid when the scattering takes place from electrons in a Maxwellian distribution having temperature θ_e. For this temperature to be maintained, it is necessary for electrons to undergo numerous energy-exchanging collisions between each photon scattering event. These collisions are then sufficient to maintain a Maxwellian distribution at the same temperature. Compton collisions with moving electrons may result in gain of photon energy (inverse Compton collisions) as well as energy loss. Both of these processes in the general case are necessary to describe the events which take place in a Compton scattering medium. In particular, the realization of a state of equilibrium between the photons and the electrons requires the inclusion of inverse Compton collisions and the direct Compton collisions to a consistent degree of approximation.

SCATTERING EQUATIONS

The equation for the transfer of photons in a scattering medium has been given in general form by Sampson (Ref. 8) and by Bond, Watson, and

Welch (Ref. 9). This equation has been applied by Freeman (Ref. 4) to the Compton scattering of photons by electrons at rest. In that work the equations are derived for photons having energies which are small compared with mc^2. An expansion is performed of the Klein-Nishina cross section through second order in the quantity $\gamma = h\nu/mc^2$. A further Taylor series expansion in frequency of the scattered intensity about the frequency of the photon beam in question is performed to obtain an "agelike" approximation. A similar treatment of the equation of transfer for scattering has been given by Fraser (Ref. 5). He takes into account the Compton scattering to first order in γ and, in addition, includes terms to first order in the quantity $\alpha = \theta_e/mc^2$, thereby including the inverse Compton effect in first order. The objective in this appendix is to reduce the results of Fraser to a form more suitable for calculation and to test his results in certain known limiting cases. The equation of scattering transfer will be derived first in a form suitable for application to a general geometric situation. The equations are then simplified by specialization to the plane and spherically symmetric geometries, and finally the diffusion approximation is derived.

The equations for the Compton scattering are contained in Fraser's expressions for Γ_1, Γ_2, and Γ_3 as given in his Eqs. (31), (32), and (33). When the drift velocity u_e is zero, these equations become

$$\Gamma_1 = -N\phi_o\, I(\nu,\Omega)(1 - 2\gamma)$$

$$\Gamma_2 = -N\phi_o \frac{3c^2}{16\pi h\nu^3} I(\nu,\Omega)\, \gamma\left(1 - \nu\frac{\partial}{\partial\nu}\right)\int d\Omega'\, I(\nu,\Omega')(1 - \mu + \mu^2 - \mu^3)$$

$$\begin{aligned}\Gamma_3 = -N\phi_o \frac{3}{16\pi} \Bigg\{ & \gamma\left(1 - \nu\frac{\partial}{\partial\nu}\right)\int d\Omega'\, I(\nu,\Omega)(1+\mu^2)(1-\mu) \\ & -\left[1 + \alpha\left(2 - 2\nu\frac{\partial}{\partial\nu} + \nu^2\frac{\partial^2}{\partial\nu^2}\right)\right]\int d\Omega'\, I(\nu,\Omega) + \alpha\left(4 - 2\nu\frac{\partial}{\partial\nu} + \nu^2\frac{\partial^2}{\partial\nu^2}\right)\int d\Omega'\, I(\nu,\Omega')\mu \\ & -\left[1 - \alpha\left(6 + 2\nu\frac{\partial}{\partial\nu} - \nu^2\frac{\partial^2}{\partial\nu^2}\right)\right]\int d\Omega'\, I(\nu,\Omega')\mu^2 - \alpha\left(4 + 2\nu\frac{\partial}{\partial\nu} - \nu^2\frac{\partial^2}{\partial\nu^2}\right)\int d\Omega' I(\nu,\Omega')\mu^3 \quad (68)\end{aligned}$$

where N is the total number density of electrons and $\phi_o = 8\pi/3\ (r_o^2) = 6.65 \times 10^{-25}\ cm^2$ is the Thomson scattering. In Eq. (68), the values of M_o, $\underline{M}_1$, $\underline{M}_2$, and $\underline{M}_3$ have been substituted for as follows:

$$M_o = \frac{3}{16\pi} \int d\Omega'\ I(\nu, \Omega')$$

$$\underline{\Omega} \cdot \underline{M}_1 = \frac{3}{16\pi} \int d\Omega'\ I(\nu, \Omega')\mu$$

$$\underline{\Omega} \cdot \underline{M}_2 = \frac{3}{16\pi} \int d\Omega'\ I(\nu, \Omega')\mu^2 \tag{69}$$

$$\underline{\Omega} \cdot \underline{M}_3 = \frac{3}{16\pi} \int d\Omega'\ I(\nu, \Omega')\mu^3$$

$$M_o - \Omega \cdot (\underline{M}_1 - \underline{M}_2 + \underline{M}_3) = \frac{3}{16\pi} \int d\Omega'\ I(\nu, \Omega')(1 + \mu^2)\ (1 - \mu)$$

where the cosine of the angle of scattering is $\underline{\Omega} \cdot \underline{\Omega}' = \mu$. These terms represent the scattering contributions to the equation of radiative transfer for the intensity $I(\nu, \Omega)$. The first term represents the scattering out of the beam proportional to the total Klein-Nishina cross section expanded to first order in γ. The second term represents the contribution of stimulated scattering to both of the processes of scattering from the beam and scattering into the beam. The quantity Γ_3 describes the scattering of photons into the beam by all of the electrons contained in the Maxwell distribution.

A comparison shows that the α-independent terms are the same as Freeman's first order in γ terms. These terms can be regrouped to display the order of the terms more effectively. Their sum, comprising the scattering contributions to the radiative transfer equation, is

$$- \mu_s \Bigg[(1 - 2\gamma)\, I(\nu,\Omega) - \frac{3}{16\pi} \Bigg\{ \int d\Omega'\, I(\nu,\Omega')(1 + \mu^2)$$

$$- \gamma \left(1 - \nu \frac{\partial}{\partial \nu}\right) \int d\Omega'\, I(\nu,\Omega')\, (1 + \mu^2)(1 - \mu)$$

$$+ \alpha \Bigg[2 \int d\Omega'\, I(\nu,\Omega')(1 - 2\mu - 3\mu^2 + 2\mu^3)$$

$$+ \left(\nu^2 \frac{\partial^2}{\partial \nu^2} - 2\nu \frac{\partial}{\partial \nu}\right) \int d\Omega'\, I(\nu,\Omega')(1 + \mu^2)(1 - \mu) \Bigg]$$

$$- \frac{c^2}{h\nu^3} I(\nu,\Omega)\, \gamma \left(1 - \nu \frac{\partial}{\partial \nu}\right) \int d\Omega'\, I(\nu,\Omega')(1 + \mu^2)(1 - \mu) \Bigg\} \Bigg] \qquad (70)$$

where $\mu_s = \phi_o N$.

In order to place the equation in conservative form in anticipation of formation of difference equations for numerical work, it is desirable to reformulate the frequency derivative terms. This reformulation corresponds to isolating those terms which contribute to exchange of energy within the photon distribution from the terms which contribute to exchange of energy between the electrons and photons. The desired substitutions are as follows:

$$\gamma \left(1 - \nu \frac{\partial}{\partial \nu}\right) I = \frac{h}{mc^2} \left[3\nu I - \frac{\partial(\nu^2 I)}{\partial \nu} \right]$$

$$\nu^2 \frac{\partial^2 I}{\partial \nu^2} - 2\nu \frac{\partial I}{\partial \nu} = \frac{\partial^2 (\nu^2 I)}{\partial \nu^2} - 6 \frac{\partial(\nu I)}{\partial \nu} + 4I \qquad (71)$$

For the case of spherical or plane geometry, symmetry of the radiative intensity about the polar direction can be assumed. This symmetry permits the integration of the azimuthal component of the solid angle in the photon scattering terms. If the results of Freeman (Ref. 4, p. 10) are used, the scattering terms become

$$- \mu_s \Bigg[(1 - 2\gamma)\, I(\nu, \Omega) - \frac{3}{16} \Bigg(\int d\mu_3\, I_3\, [3 - \mu_1^2 + (3\mu_1^2 - 1)\, \mu_3^2]$$

$$- \gamma \left(1 + \frac{c^2}{h\nu^3} I(\nu, \Omega) \right) \left(1 - \nu \frac{\partial}{\partial \nu} \right) \int d\mu_3\, I_3\, f(\mu_1, \mu_3)$$

$$+ \alpha \Bigg\{ 2 \int d\mu_3 I_3\, [(3\mu_1^2 - 1)(1 - 3\mu_3^2) + 2\mu_1 (1 - 3\mu_1^2)\, \mu_3 + 2\mu_1 (5\mu_1^3 - 3)\mu_3^3]$$

$$+ \left(\nu^2 \frac{\partial^2}{\partial \nu^2} - 2\nu \frac{\partial}{\partial \nu} \right) \int d\mu_3 I_3\, f(\mu_1, \mu_3) \Bigg\} \Bigg) \Bigg] \tag{72}$$

where

$$f(\mu_1, \mu_3) = 3\mu_1^2 - 1 + \mu_1 (3\mu_1^2 - 5)\, \mu_3 + (3\mu_1^2 - 1)\, \mu_3^2 + \mu_1\, (3 - 5\mu_1^2)\mu_3^3$$

In Eq. (72), the inclusion of the additional terms for induced emission and inverse Compton scattering is not appreciably more difficult than for the Compton scattering term already considered. The same angular integrals enter as in Freeman's Eq. (18) (Ref. 4). The main difference arises in the presence of the second derivative with respect to frequency in addition to the first derivative occurring in the Compton formulation.

The diffusion approximation can also be carried out in parallel fashion to the derivation of Compton scattering for cold electrons. In this case two equations result, which are obtained from the zeroth and first moments of the equation of transfer. The Compton terms entering in the zeroth-moment equation are

$$- \mu_s \Bigg[-\gamma \left(I_o + \nu \frac{\partial I_o}{\partial \nu} \right) + \frac{c^2}{h\nu^3} \gamma \left(I_o^2 - \frac{2}{15} I_1^2 - \nu I_o \frac{\partial I_o}{\partial \nu} + \frac{2}{15} \nu I_1 \frac{\partial I_1}{\partial \nu} \right)$$

$$- \alpha \left(\nu^2 \frac{\partial^2 I_o}{\partial \nu^2} - 2\nu \frac{\partial I_o}{\partial \nu} \right) \Bigg] \tag{73}$$

and those for the first-moment equation are

$$- \mu_s \left[I_1 \left(1 - \frac{12}{5}\gamma\right) + \frac{2}{5}\gamma\nu \frac{\partial I_1}{\partial \nu} + \frac{c^2}{h\nu^3}\gamma \left(\frac{3}{5} I_o I_1 + \frac{2}{5}\nu I_o \frac{\partial I_1}{\partial \nu} \right.\right.$$

$$\left.\left. - \nu I_1 \frac{\partial I_o}{\partial \nu}\right) + \frac{2}{5}\alpha \left(I_1 + \nu^2 \frac{\partial^2 I_1}{\partial \nu^2} - 2\nu \frac{\partial I_1}{\partial \nu}\right)\right] \tag{74}$$

TESTS OF THE EQUATIONS

The equations derived above can be subjected to a number of tests to determine whether known results are obtained. Consider a scattering medium containing a weak radiation field for which the stimulated emission terms can be neglected. Integrations can then be carried out over the solid angle and the entire frequency spectrum. The resultant integrated radiative-transfer equation becomes an equation for the rate of change of radiation energy within a particular volume element. The Compton contributions to the rate of change represent the rate of loss or gain of energy from the radiation field. They also correspond to the gain or loss of energy by the electrons. These terms are

$$\int d\nu \int d\Omega (\Gamma_1 + \Gamma_3) = \mu_s c \left[\int \gamma E_\nu \, d\nu + \int \gamma^2 \frac{\partial E_\nu}{\partial \gamma} d\nu + \alpha \int \left(\nu^2 \frac{\partial^2 E_\nu}{\partial \nu^2} - 2\nu \frac{\partial E_\nu}{\partial \nu}\right) d\nu \right]$$

$$= \frac{\mu_s}{mc} \left(4\theta_e \int E_\nu \, d\nu - \int h\nu E_\nu \, d\nu \right) \tag{75}$$

where $E_\nu = 1/c \int d\Omega I(\nu, \Omega)$ is the spectral radiation energy. This is precisely the result given by Grasberger (Ref. 10).

The terms taking account of the stimulated scattering can also be included provided the radiation is isotropic. The contribution to the heating rate is

$$\int d\nu \int d\Omega \Gamma_2 = -\mu_s \frac{4\pi}{2m} \int I^2 \frac{d\nu}{\nu^2} = -\frac{\mu_s}{2m} \frac{c^2}{4\pi} \int E_\nu^2 \frac{d\nu}{\nu^2} \tag{76}$$

If, in addition, the radiation energy is given by a Planck distribution having a temperature θ_r, as given by

$$I = B = \frac{2h}{c^2} \frac{\nu^3}{e^{h\nu/\theta_r} - 1} \tag{77}$$

the frequency integrations can be performed. The total resulting heating rate of the electrons is

$$\frac{dE_e}{dt} = \frac{16\mu_s}{mc^2} \sigma \theta_r^4 (\theta_r - \theta_e) \tag{78}$$

where σ is the Stefan-Boltzmann constant. This rate is applicable to a blackbody enclosure in which the radiation intensity is somehow maintained in a Planck distribution corresponding to a radiation temperature which is different from the temperature of the electrons within the enclosure. The derived electron heating rate is a well-known result (Ref. 10) which displays the characteristic that the radiation and electron temperatures will approach each other by virtue of this scattering interaction, yielding an equilibrium state in which the temperatures are equal.

These results test all of the Compton terms, including the induced scattering terms. Consequently, they constitute a strong confirmation of the correctness of these equations.

APPROXIMATIONS

Several approximations have been made in deriving these equations which limit their applicability. First, the neglect of high-order terms in γ and α restricts validity of the transfer equation to $h\nu$ and θ_e of the order of 100 kV. The inclusion of the terms corresponding to γ^2 given in reference 4 would allow application of the equations to somewhat higher photon energies.

The second approximation, resulting from the expansion of the frequency dependence of the intensity and omission of quadratic terms in the frequency difference, implies that I_μ must be a smooth function of frequency. Near a photoelectric edge or in the neighborhood of a line profile, these conditions may not be satisfied. An investigation of the validity of this approximation has been carried out by Chandrasekhar (Ref. 11), who evaluated the transmission of line radiation through a cold scattering atmosphere. His result shows that even in the case of a δ-function source of radiation, a relatively small error, as measured by the fraction of energy erroneously scattered to higher frequencies (see Fig. 33, Ref. 11, p. 334), results (approximately 15 percent for an atmosphere containing two-thirds of a mean free path).

The neglect of the specific effects of polarization may also be of some consequence. Chandrasekhar (Ref. 12) has compared the diffuse reflection resulting from radiation incident on a semi-infinite scattering medium when the correlation of photon polarization after scattering is followed or neglected. Differences of the order of 5 percent in the scattered intensity are obtained (see Figs. 24 and 25, Ref. 12, pp. 262 and 263).

Scattering in the treatment of this report results from electrons which are free. Effects of binding of the electrons and the localization of the electrons within the atom give rise to modifications of the incoherent scattering Klein-Nishina formula for free-electron scattering and produce additional scattering which is coherent with the incident radiation. These effects are small when the energy of the photon is much greater than the binding energy of the atom and when the temperature of the material is sufficiently high that the probability of bound electrons being present is small.

EQUILIBRIUM SPECTRA

In this subsection, the solutions to the above equations corresponding to scattering of radiation in a homogeneous enclosure are examined. The equation for the spectral energy density is

$$\frac{1}{c}\frac{\partial I_o}{\partial t} = \mu_a' (B - I_o) - \mu_s \left[- 2\gamma I_o + \left(1 + \frac{c^2}{h\nu^3} I_o\right)\left(I_o - \nu \frac{\partial I_o}{\partial \nu}\right) - \alpha\left(\nu^2 \frac{\partial^2 I_o}{\partial \nu^2} - 2\nu \frac{\partial I_o}{\partial \nu}\right)\right] \tag{79}$$

The steady-state solution of these equations should admit a Planck function for the radiation intensity corresponding to the temperature of the electrons. Substitution of the Planck function into Eq. (79) shows that such is the case. For the Planck function to satisfy this equation, however, it is necessary that the correct number density of photons be present. This condition will not in general be satisfied, however, if only the scattering interaction is present. More generally, the equilibrium will be achieved with too few or too many photons for the thermodynamic equilibrium solution to apply. If too few photons are present, the induced scattering-terms quadratic in I_o will be negligible, giving the steady-state equation

$$\nu^2 \frac{\partial^2 I_o}{\partial \nu^2} + \left(\frac{\gamma}{\alpha} - 2\right) \nu \frac{\partial I_o}{\partial \nu} + \frac{\gamma}{\alpha} I_o = 0 \ . \tag{80}$$

This equation is satisfied by the function $I_o = A\nu^3 e^{-h\nu/\theta_e}$, the Wien approximation to the Planck function, but it has an arbitrary normalization, depending on the number of photons present.

If, on the other hand, there are too many photons for the thermodynamic equilibrium solution, only the quadratic terms need be retained,

$$- \gamma \frac{c^2}{h\nu^3} I_o \nu \frac{\partial I_o}{\partial \nu} + \gamma \frac{c^2}{h\nu^3} I_o^2 = 0 \quad \text{or} \quad I_o = \nu \frac{\partial I_o}{\partial \nu} \tag{81}$$

In this case, the solution is $I_o = B\nu$, where B depends on the photon number density. However, this solution is valid only for frequencies such that $\nu^2 \leq (c^2/h)\, B$.

CRITERIA FOR COMPTON HEATING

The inclusion of the Compton and inverse Compton scattering contributions to the heating rate is required only when the heating by pure absorption is negligible by comparison. In order to estimate the conditions where the Compton terms must be included, an estimate of the absorption contribution to the heating is derived and is then compared with the corresponding Compton scattering formula. As shown above, if the radiation intensity can be characterized by a Planck distribution with θ_r, the electron heating rate from Compton scattering is

$$\left.\frac{dE}{dt}\right)_c = 2.1 \times 10^{-17} N_e \theta_r^4 (\theta_r - \theta_e) \quad (\text{ergs/cm}^3\ \text{sec}) \tag{82}$$

when temperatures are measured in eV and N_e in cm^{-3}.

At high temperatures, the pure absorption mechanism giving the largest contribution will be that from the free-free absorption. By using the absorption coefficient for the free-free process (Ref. 13), it is possible to derive a formula for the rate at which electrons exchange energy with the photons:

$$\left.\frac{dE_e}{dt}\right)_{ff} = 1.5 \times 10^{-25} Z^2 N_e N_i \theta_e^{-1/2} (\theta_r - \theta_e) \quad (\text{ergs/cm}^3\ \text{sec}) \tag{83}$$

where Z^2 is the effective square of the ionic charge and N_i is the ionic number density.

The ratio R of the absorption heating rate to the scattering heating rate is given by

$$R = \frac{7.2 \times 10^{-9} Z^2 N_i}{\theta_e^{1/2} \theta_r^4} \tag{84}$$

A large value of R implies that scattering can be neglected in the electron heating rate. As an illustration of the application of this formula, one can obtain the temperature and density conditions at which heating due to scattering and absorption are equal. Figure 15 displays the temperature-density dependence of this condition, R = 1, for several typical materials, assuming that $\theta_e = \theta_r$. In applying this result, it should be kept in mind that deviations of the radiation spectrum from Planckian will strongly affect the answer.

The above criterion for the electron heating rate does not directly apply to the relative importance of absorption and scattering on the spectrum itself, since the frequency dependence of the absorption and scattering terms is quite different. If $R \geq 1$, the low-frequency portion of the spectrum will be dominated completely by absorption. The high-frequency portion of the spectrum will be modified predominantly by direct Compton scattering if $\theta_r \gg \theta_e$ and by inverse Compton scattering when $\theta_r \ll \theta_e$.

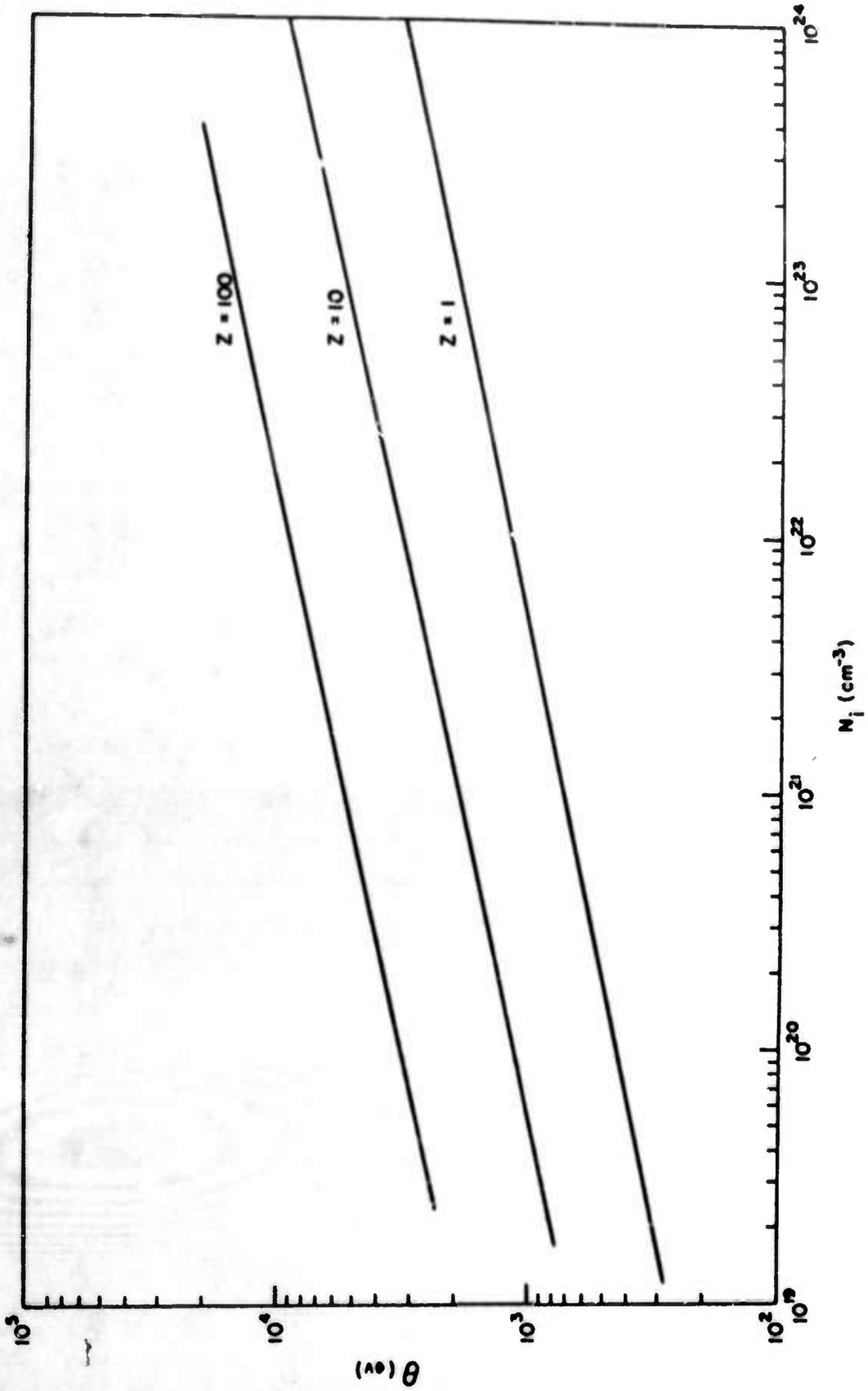

Figure 15. Temperature and Density at Which Heating Rates Due to Absorbtion and Scattering are Equal

APPENDIX VI

A MODIFIED METHOD OF CHARACTERISTICS FOR RADIATIVE TRANSFER

In references 14 and 15, quantities termed "transmission functions" are proposed for use in the analysis of radiative transfer by the method of characteristics. These functions are mean values of the monochromatic attenuation factor $\exp(-\rho\kappa_\nu \Delta x)$ for a range of frequencies $\Delta\nu$, where Δx is an interval along a ray within which the density ρ and opacity κ_ν are assumed to be uniform. The frequency average of this exponential is taken with two different weighting functions B_ν and $dB_\nu/d\theta$. In an idealized problem with uniform temperature only the first of these averages, denoted by $S(\Delta x)$, is needed. This function, defined by

$$S_{ij}(\Delta x_i) = \frac{\int_{\nu_j}^{\nu_{j+1}} B(\nu, \theta_i) \exp[-\rho_i \kappa_i(\nu, \rho_i, \theta_i)\Delta x_i]\, d\nu}{\int_{\nu_j}^{\nu_{j+1}} B(\nu, \theta_i) d\nu} \tag{85}$$

has a limiting form for very small Δx_i given by

$$S_{ij}(\Delta x_i) \sim \exp(-\rho\kappa_{ij}^{P} \Delta x_i) \tag{86}$$

where κ_{ij}^{P} is the usual Planck mean. For larger Δx (in most cases still rather small) the function flattens out rapidly; i.e., $-(1/\rho\, \Delta x) \log S$ is a decreasing function of Δx, eventually limiting to the minimum value of κ_ν in the frequency group at sufficiently large Δx, plus terms of order Δx^{-1}.

In a medium with uniform composition, temperature, and density, the transport equation for the intensity in group j at a point x_n along a ray $x_o < x < x_n$ due to radiation moving in the positive x direction is given in references 14 and 15 as

$$I_j(x_n) = B_j(x_n) + [I(x_o) - B(x_o)]\, S_j(x_n - x_o) \tag{87}$$

If the interval (x_o, x_n) is now subdivided into n zones of width $\Delta x = (x_n - x_o)/n$, the intensity at each of the subdivision points is

$$I_j(x_i) = B_j(x_i) + [I(x_{i-1}) - B(x_{i-1})]\, S_j(\Delta x)$$

$$= B_j(x_i) + [I(x_{i-2}) - B(x_{i-2})]\, S_j^2(\Delta x), \text{ etc.} \tag{88}$$

By repeated application of Eq. (88), one readily obtains

$$I_j(x_n) = B_j(x_n) + [I(x_o) - B(x_o)]\, S_j^n(\Delta x) \tag{89}$$

which, with Eq. (87), implies that

$$S_j(n\Delta x) = S_j^n(\Delta x) \tag{90}$$

a condition which is satisfied if S is an exponential function, but is unfortunately violated by functions of the type described in references 14 and 15. With sufficiently fine subdivision of the medium in this example, the attenuation would in fact be that given by the Planck opacity, an incorrect result apart from the limiting case in which $\rho\kappa^P(x_n - x_o) << 1$.

This example exhibits the limitations resulting from one of the assumptions made in references 14 and 15, and in Eq. (87), namely that the frequency dependence of $I(\nu)$ within each group is proportional to that of $B(\nu)$ at every point along the ray. Actually, the frequency dependence of $I(\nu)$ depends inherently upon conditions along the entire ray, and no method of frequency averaging based only upon locally evaluated temperature and density can be expected to be valid.

A second and unrelated difficulty occurs in spherical geometry, namely that consistent and simple models for the spatial dependence of the source function do not reduce to the correct diffusion limit, and other models which limit correctly are somewhat inconsistent and have a tendency to yield negative values for the intensity (Ref. 2, Vol III).

In this appendix a formulation is proposed which employs (1) nonlocal "transmission functions" of exponential form and (2) an apparently consistent model for the source function which has the correct diffusion limit. The method utilizes only the currently available Planck and Rosseland group mean opacities, but is capable of generalization to a formulation which, by describing the frequency dependence of opacity within each group in more detail, may allow use of fewer groups to attain the needed accuracy.

For monochromatic radiation, the intensity along a ray at optical depth τ_n is given by

$$I(\tau_n) = I(\tau_o)\, e^{-(\tau_n - \tau_o)} + \int_{\tau_o}^{\tau_n} B e^{-(\tau_n - \tau)}\, d\tau \tag{91}$$

with integration by parts,

$$I(\tau_n) = B(\tau_n^+) + [I(\tau_o) - B(\tau_o^+)]\, e^{-(\tau_n - \tau_o)} - \int_{\tau_o}^{\tau_n} \frac{dB}{d\tau}\, e^{-(\tau_n - \tau)}\, d\tau \tag{92}$$

The last term, representing source gradient contributions to the intensity, may be represented as a sum of individual zone contributions:

$$\int_{\tau_o}^{\tau_n} \frac{dB}{d\tau}\, e^{-(\tau_n - \tau)}\, d\tau = \sum_{k=1}^{n} Q_{kn} \tag{93}$$

where

$$Q_{kn} = \int_{\tau_{k-1}}^{\tau_k} \frac{dB}{d\tau} e^{-(\tau_n - \tau)} d\tau + (B_k^+ - B_k^-) e^{-(\tau_n - \tau_k)}$$

$$= e^{-(\tau_n - \tau_k)} \left[\int_{s_{k-1}}^{s_k} \frac{dB}{ds} e^{-\sigma_k (s_k - s)} ds + B_k^+ - B_k^- \right] \tag{94}$$

Here s is the geometric distance along the ray, $\sigma_k = \rho_k \kappa_k$ is assumed constant in each interval $s_{k-1} < s < s_k$, and the possibility of discontinuous B(s) at interval boundaries is allowed for.

It is now necessary to represent the source gradient dB/ds in an explicit manner. Let the direction cosines of a ray with respect to Cartesian axes x, y, and z be denoted respectively by ξ, η, and ζ; then

$$ds = \frac{1}{\xi} dx = \frac{1}{\eta} dy = \frac{1}{\zeta} dz \tag{95}$$

The quadratic form

$$B(x,y,z) = B(x_k, y_k, z_k) + \alpha_k (z - z_k) + \beta_k (x^2 + y^2 - x_k^2 - y_k^2)$$

$$+ \gamma_k (x^2 + y^2 + z^2 - x_k^2 - y_k^2 - z_k^2)$$

$$x_{k-1} < x < x_k$$

$$y_{k-1} < y < y_k$$

$$z_{k-1} < z < z_k \tag{96}$$

has plane symmetry if $\beta_k = \gamma_k = 0$, cylindrical symmetry if $\alpha_k = \gamma_k = 0$, spherical symmetry if $\alpha_k = \beta_k = 0$, and two-dimensional (finite) cylindrical symmetry if just $\gamma_k = 0$. This form may be simplified somewhat if the Cartesian axes can be chosen independently for each ray, so that, for example, the x-axis is parallel to the direction of the ray in spherical

geometry, or to the projection of the ray on the plane $z = 0$ in cylindrical geometry.

From Eqs. (95) and (96) the source gradient along the ray is

$$\frac{dB}{ds} = \alpha_k \zeta + 2\beta_k(\xi x + \eta y) + 2\gamma_k(\xi x + \eta y + \zeta z) \tag{97}$$

so that

$$Q_{kn} = \left[\frac{\alpha_k}{\sigma_k}\zeta + 2\frac{\beta_k}{\sigma_k^2}(\xi\sigma_k x_k + \eta\sigma_k y_k - \xi^2 - \eta^2) + 2\frac{\gamma_k}{\sigma_k^2}(\xi\sigma_k x_k + \eta\sigma_k y_k + \zeta\sigma_k z_k - 1) + B_k^+ - B_k^-\right] e^{-(\tau_n - \tau_k)}$$

$$- \left[\frac{\alpha_k}{\sigma_k}\zeta + 2\frac{\beta_k}{\sigma_k^2}(\xi\sigma_k x_{k-1} + \eta\sigma_k y_{k-1} - \xi^2 - \eta^2) + 2\frac{\gamma_k}{\sigma_k^2}(\xi\sigma_k x_{k-1} + \eta\sigma_k y_{k-1} + \zeta\sigma_k z_{k-1} - 1\right] e^{-(\tau_n - \tau_{k-1})} \tag{98}$$

On comparing Eqs. (97) and (98), it is apparent that when $\tau_n - \tau_{n-1} >> 1$ the intensity limits to the value

$$I(\tau_n) = B(\tau_n) - \frac{dB}{d\tau}\Big|_{\tau = \tau_n'} \tag{99}$$

where for plane geometry $\tau_n' = \tau_n$ and otherwise $\tau_n' = \tau_n - 1$. This is essentially consistent with the diffusion approximation.

So far, the analysis has been restricted to the single-frequency case. Equation (92) contains several types of terms, each with a different frequency dependence, corresponding to a variety of different materials, temperatures, and densities. Since frequency averaging destroys the separability of these contributions (as discussed above), approximation methods of a nonlocal character are needed.

The transmission functions of reference 15 can easily be generalized to nonlocal form. For example, the Planck transmission function defined

for a single zone by Eq. (85) is to be replaced by the kernel

$$S_j(s_i, s_n) = \int_{\nu_j}^{\nu_{j+1}} \sigma_i B(\theta_i, \nu) \exp \sum_{k=i}^{n-1} [-\sigma_k(\nu, \rho_k, \theta_k)\Delta s_k] d\nu \Big/ \int_{\nu_i}^{\nu_{j+1}} \sigma_i B(\theta_i, \nu) d\nu \tag{100}$$

which describes the attenuation of radiation emitted at s_i between s_i and a field point s_n. Of course, the direct evaluation of the terms in Eq. (100) is scarcely feasible in practice. Instead, a representation of the entire function is required which can be readily evaluated and which preserves some of the characteristics of Eq. (100), in particular, the thin limit

$$\lim_{s_n \to s_i} S_j(s_i, s_n) = 1 - (s_n - s_i)\, \sigma_j^P(s_n) \tag{101}$$

where $\sigma_j^P(s_n)$ is the group Planck mean. A necessary condition for the diffusion limit is that for opacity independent of position

$$\lim_{s_i \to -\infty} \sigma_j^R(s_n) \int_{s_i}^{s_n} S_j(s, s_n)\, ds = 1 \tag{102}$$

where $\sigma_j^R(s_n)$ is the group Rosseland mean. In general, S_j as a function of s_n should be uniformly positive, while the first derivative should be uniformly negative; also, the function should be short-range in the sense that for

$$s_i \to -\infty\,, \quad S_j(s_i, s_n) \sim (s_n - s_i)^{-m}\,, \quad m > 1 \tag{103}$$

where if m is not infinite, as for an exponential, it is at least large enough to restrict the significant contributions to the integral in Eq. (102) to source positions within a very few Rosseland mean free paths of the field point in all except pathologically nongrey cases.

The following construction is a nonlocal "picket-fence" (Refs. 16 and 17) transmission function of this type. It is assumed that the group

Planck and Rosseland means are known at each point, and that a parameter b_{kj} characteristic of the opacity distribution within group j at point s_k can be chosen. (For brevity, the group index j will be suppressed in the following formulas.) The first step is to construct the following composite opacities for each point:

$$\sigma^A = \frac{\sigma^P + b\sigma^R - \mathrm{sgn}(1 - b^2)\left[(\sigma^P - \sigma^R)(\sigma^P - b^2\sigma^R)\right]^{1/2}}{1 + b} \tag{104}$$

$$\sigma^B = \frac{\sigma^P - b\sigma^R + \mathrm{sgn}(1 - b^2)\left[(\sigma^P - \sigma^R)(\sigma^P - b^2\sigma^R)\right]^{1/2}}{1 - b} \tag{105}$$

where b is to be chosen so that σ^A and σ^B are real, and

$$0 < \sigma^A \leq \sigma^B \tag{106}$$

These conditions are satisfied if $\sigma^P = \sigma^R$, or if $\mathrm{sgn}(1 - b^2) = \mathrm{sgn}(\sigma^P - \sigma^R)$, i.e.,

$$b^2 < 1 < \sigma^P/\sigma^R \tag{107}$$

or

$$b^2 > 1 > \sigma^P/\sigma^R \tag{108}$$

Equation (108) only applies to cases which are nearly grey, or which have substantial scattering contributions in the Rosseland mean. Values of σ^A and σ^B for two ratios σ^P/σ^R are shown in figure 16.

The second step is to define the optical distances

$$\tau^A(s_i, s_n) = \int_{s_i}^{s_n} \sigma^A(s)\, ds \tag{109}$$

$$\tau^B(s_i, s_n) = \int_{s_i}^{s_n} \sigma^B(s)\, ds \tag{110}$$

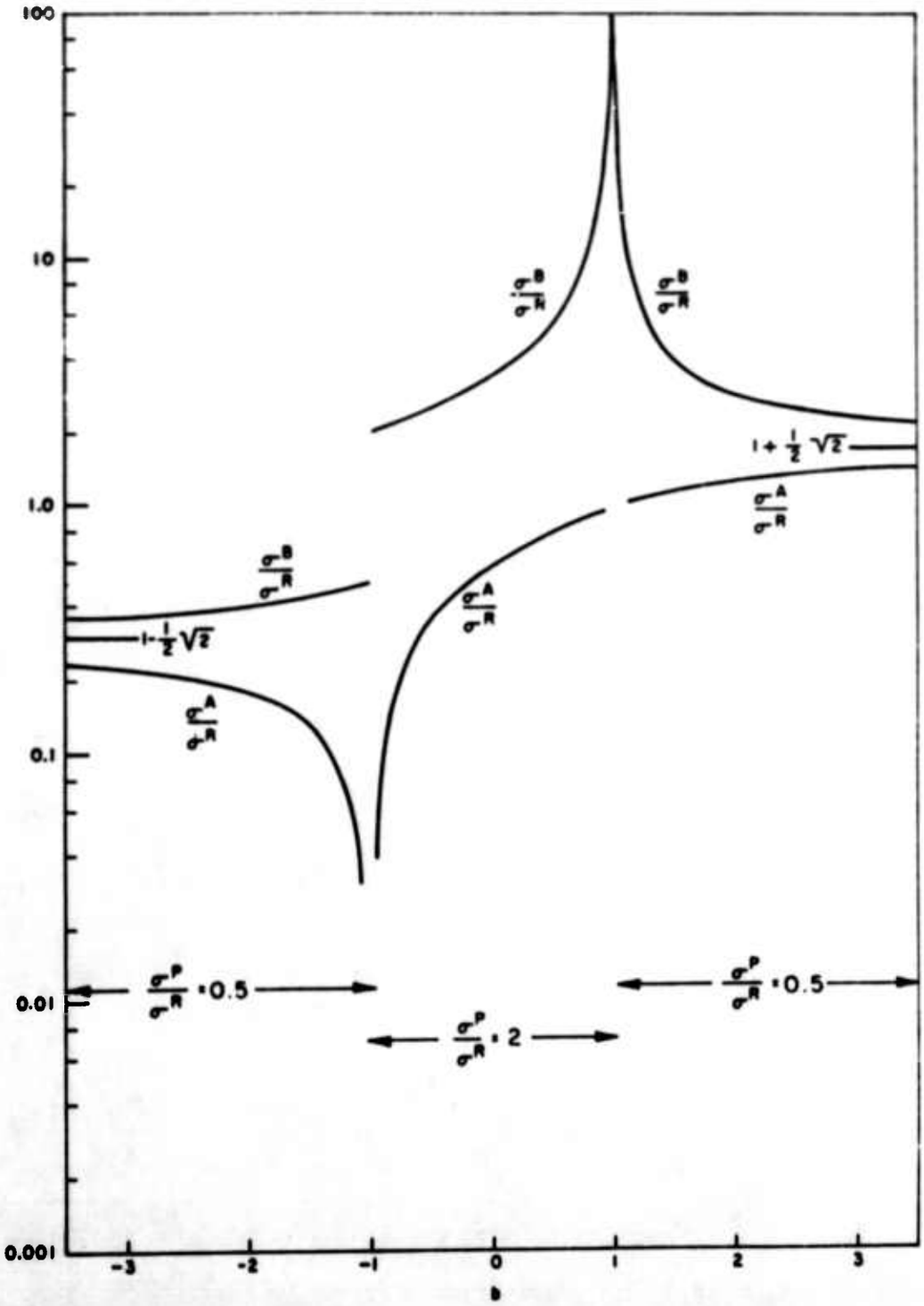

Figure 16. Dependence of Component Opacities on the Parameter b

Next, the transmission function is represented by

$$S(s_i, s_n) = \frac{1}{2}(1 + b_n)\, e^{-\tau^A(s_i, s_n)} + \frac{1}{2}(1 - b_n)\, e^{-\tau^B(s_i, s_n)} \tag{111}$$

and, finally, the "nonlocal opacity" by

$$\sigma(s_i, s_n) = -\frac{d}{ds_n} \log S(s_i, s_n)$$

$$= \frac{1}{S(s_i, s_n)} \left[\frac{1}{2}(1 + b_n)\sigma^A(s_n)\, e^{-\tau^A(s_i, s_n)} + \frac{1}{2}(1 - b_n)\sigma^B(s_n)\, e^{-\tau^B(s_i, s_n)}\right] \tag{112}$$

The significance of the parameter b is now clearer. Assuming σ^P to be considerably larger than σ^R along the ray, two limiting cases can be distinguished. The nongrey character may be due to the presence within the group of a few strong line components, with the absorption minima, or windows, occupying most of the group width. The appropriate values of b will then be those near 1, so that according to Eq. (105) the "line" opacity σ^B is large compared with σ^P. The transmission, as shown in figure 17, attenuates at the Planck rate for a very short distance, with most of the contributions attenuated at a rate σ^A which is slightly less than the Rosseland mean. At the other extreme, there is the less probable situation in which the absorption maxima are broad, with the nongrey character due to the presence of isolated narrow but deep windows. For $b \to -1$, $\sigma^A \to 0$, and $\sigma^B \to \sigma^P$. The transmission attenuates at nearly the Planck mean rate for perhaps several Planck mean free paths, but then levels out in such a way that small contributions are transmitted with little attenuation from remote sources. For intermediate cases, values of b near zero may be used. In particular, for b = 0,

$$\left.\begin{matrix}\sigma^A \\ \sigma^B\end{matrix}\right\} = \sigma^P \pm [\sigma^P(\sigma^P - \sigma^R)]^{1/2} \tag{113}$$

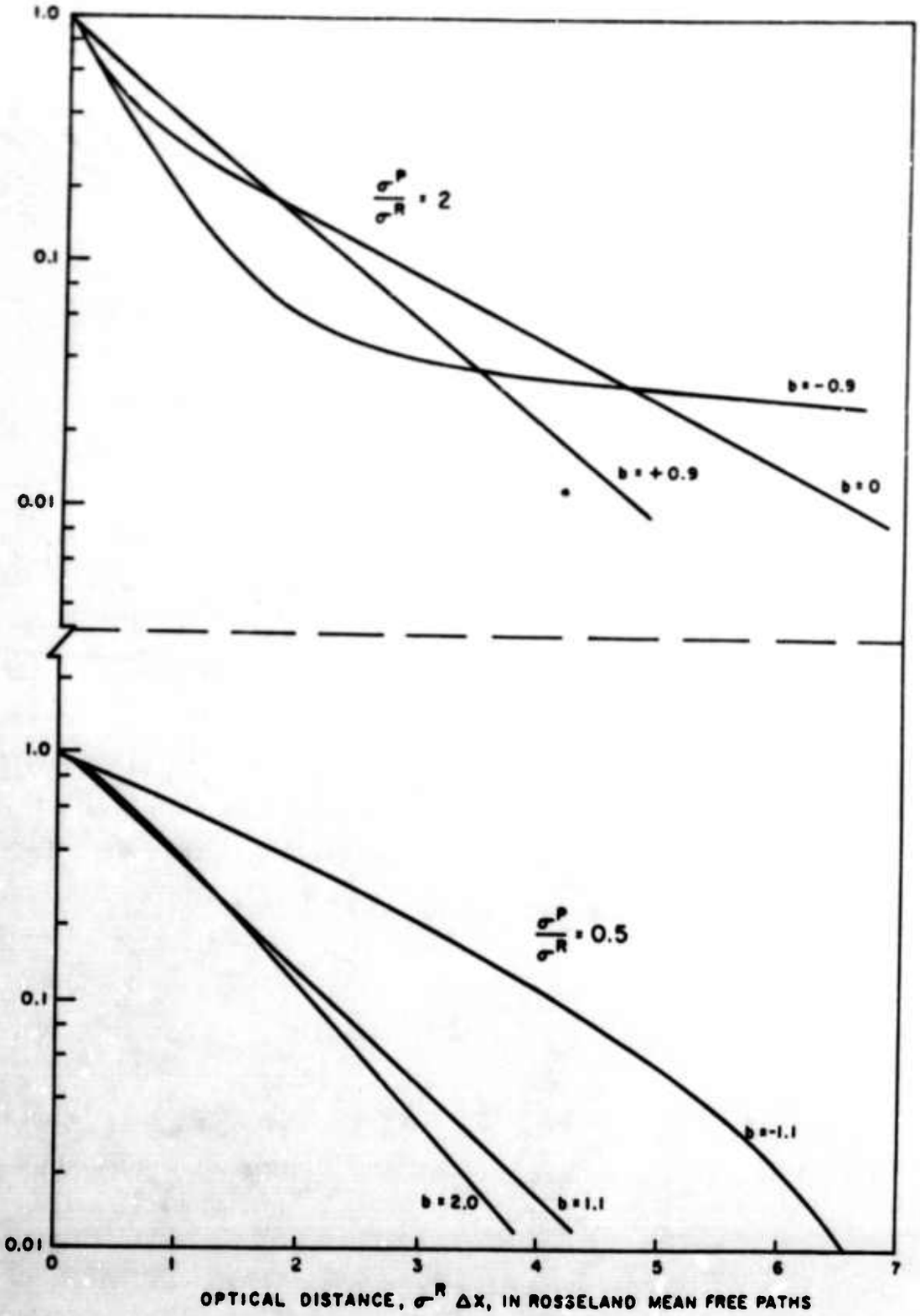

Figure 17. Transmission Function $S(\Delta x)$

and just half of the emitted radiation attenuates by each of the rates σ^A and σ^B. For $\sigma^P < \sigma^R$, in order that the S function defined by Eq. (111) be positive at large distances, b must be restricted to positive values $b > 1$. The transmission functions also have a more appropriate shape near the source for $b > 1$, as shown in figure 17.

The evaluation of the parameter b will be discussed in a subsequent report, in terms of a distribution function for mean free paths at each point (Ref. 17). In the absence of such information, a "defined" value such as 0 may be used. It should be noted that the Milne-Eddington model is not explicitly assumed; however, b is not treated as a function of position in the definitions of the derivative and integral of the transmission function, Eqs. (112) and (102).

The quantities of the form $e^{-(\tau_n - \tau_k)}$ and σ_k appearing in Eqs. (92) and (98) may then be evaluated by the expressions given in Eqs. (111) and (112), respectively, to obtain a computationally feasible frequency-averaged form.

The source gradient coefficients α_k, β_k, γ_k in Eqs. (96), (97), and (98) are readily defined by Rosseland optical depth interpolation. The index k may be regarded as ordering the intersections of the ray with successive surfaces, which are alternately boundary surfaces and midsurfaces for each cell; furthermore, k and s are assumed to increase in the direction of the ray. Thus, if k indexes a boundary point and k-1 a zone midpoint, for one-dimensional cases

$$\alpha_k = \frac{B_k^- - B_{k-1}}{z_k - z_{k-1}}, \quad \beta_k = \frac{B_k^- - B_{k-1}}{r_k^2 - r_{k-1}^2}, \quad \gamma_k = \frac{B_k^- - B_{k-1}}{R_k^2 - R_{k-1}^2} \tag{114}$$

where r^2 and R^2 are, respectively, $x^2 + y^2$ and $x^2 + y^2 + z^2$, and

$$B_k^- = B_{k-1} + \epsilon_k \frac{(B_{k+1} - B_{k-1})\, \sigma_k^R (z_k - z_{k-1})}{\sigma_k^R (z_k - z_{k-1}) + \sigma_{k+1}^R (z_{k+1} - z_k)} \tag{115}$$

for plane geometry, and

$$B_k^- = B_{k-1} + \epsilon_k \frac{(B_{k+1} - B_{k-1})(\sigma_k^R)^2 (R_k^2 - R_{k-1}^2)}{(\sigma_k^R)^2 (R_k^2 - R_{k-1}^2) + (\sigma_{k+1}^R)^2 (R_{k+1}^2 - R_k^2)} \tag{116}$$

for spherical geometry. One-dimensional cylindrical geometry may employ an interpolation formula like Eq. (116) with R replaced by r. The coefficient ϵ_k is 1 unless the step model is to be used, in which case $\epsilon_k = 0$ and consequently $\alpha_k = \beta_k = \gamma_k = 0$. In two-dimensional cylindrical geometry, the corresponding formulae for bilinear Rosseland optical depth interpolation in the variables z and r^2 are left as an exercise for the reader. If k indexes a midpoint, similar formulae apply, with

$$\alpha_k = \frac{B_k - B_{k-1}^+}{z_k - z_{k-1}}, \text{ etc.} \tag{117}$$

A final remark is that for the plane case, the integration over ray orientation should be performed analytically. The exponentials in Eq. (111) are then to be replaced by E-functions. The detailed evaluation of this approach is left for a subsequent report.

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UNCLASSIFIED
Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY *(Corporate author)*
Gulf General Atomic Incorporated
San Diego, California 92112

2a. REPORT SECURITY CLASSIFICATION
UNCLASSIFIED

2b. GROUP

3. REPORT TITLE
NUCLEAR EXPLOSION INTERACTION STUDIES, Vol III, The OUTPUT Code

4. DESCRIPTIVE NOTES *(Type of report and inclusive dates)*
29 September 1966-27 October 1967

5. AUTHOR(S) *(First name, middle initial, last name)*
J. R. Triplett et al.

6. REPORT DATE
April 1968

7a. TOTAL NO. OF PAGES
206

7b. NO. OF REFS
17

8a. CONTRACT OR GRANT NO.
F29601-67-C-0014

b. PROJECT NO.
5710

c. Subtask No. 07.017
ARPA Order No. 313

d.

9a. ORIGINATOR'S REPORT NUMBER(S)
AFWL-TR-67-131, Vol III

9b. OTHER REPORT NO(S) *(Any other numbers that may be assigned this report)*
Contractor's report No. GA-7764, Vol III

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11. SUPPLEMENTARY NOTES

12. SPONSORING MILITARY ACTIVITY
AFWL (WLRT)
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13. ABSTRACT

(Distribution Limitation Statement No. 2)
The OUTPUT code is designed for the analysis of early-time nuclear explosions. The equations for radiative transfer (characteristic method) and conservation of total (fluid and radiation) momentum and energy are solved in one-dimensional (plane or spherical) geometry. The radiation equations include first-order Compton scattering, and the hydrodynamic equations are treated in explicit Lagrangian form. The code is undergoing continuing development; the formulation, flow charts, glossary, and listings presented represent its status as of 27 October 1967.

DD FORM 1 NOV 65 1473

UNCLASSIFIED
Security Classification

UNCLASSIFIED
Security Classification

14. KEY WORDS	LINK A ROLE	LINK A WT	LINK B ROLE	LINK B WT	LINK C ROLE	LINK C WT
Radiative hydrodynamics codes						
Compton scattering						
Early-time nuclear explosions						

AFSC (KAFB NM)

UNCLASSIFIED
Security Classification