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67-131,
Vol III

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.

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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 $a = 137 \text{ ergs/cm}^3/\text{eV}^4$ 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. $h\nu / m_0 c^2 \leq 0.2$, $m_0 c^2$ = 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 $I(\mu) \equiv \frac{2\pi}{c} I(\vec{\Omega})$:

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

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

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

is the linear absorption coefficient corrected for induced emission;

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

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

$$\begin{aligned} S = & -\mu_s \left[I - \frac{3}{16} \int_{-1}^1 d\mu' I(\mu') [3 - \mu^2 + (3\mu^2 - 1)(\mu')^2] \right. \\ & + \gamma \left\{ -2I + \frac{3}{16} \int_{-1}^1 d\mu' \left(I(\mu') - \gamma \frac{dI(\mu')}{d\gamma} \right) [3 - \mu^2 + \mu'\mu(3\mu^2 - 5) \right. \\ & \left. \left. + (3\mu^2 - 1)(\mu')^2 + \mu(3 - 5\mu^2)(\mu')^3] \right\} \right] + O(\gamma^2) \end{aligned} \quad (4)$$

where

$$\mu_s = \frac{8}{3} \pi r_o^2 N_e \quad (5)$$

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

$$\gamma = \frac{h\nu}{m_o c^2} \quad (6)$$

Examination of the form of the scattering source term reveals that the low-energy limit, i. e., $\gamma \rightarrow 0$, 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

$$-\nabla \cdot \vec{F} = -c \int_0^\infty \mu_a' (2B_\nu - E_\nu) d\nu + \mu_s \frac{hc}{m_0 c^2} \int_0^\infty \nu E_\nu d\nu \quad (7)$$

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

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

Thus, I_0 , I_1 , and I_2 are proportional to the radiation energy density, the flux, and the radiation pressure, respectively. Now,

$$\begin{aligned}
S = & -\mu_s \left\{ I(1 - 2\gamma) - \frac{3}{16} [(3 - \mu^2) I_0 + (3\mu^2 - 1) I_2] \right. \\
& + \frac{3}{16} \gamma [(3 - \mu^2) I_0 + \mu(3\mu^2 - 5) I_1 + (3\mu^2 - 1) I_2 + \mu(3 - 5\mu^2) I_3] \\
& \left. - \frac{3}{16} \gamma^2 \frac{\partial}{\partial \gamma} [(3 - \mu^2) I_0 + \mu(3\mu^2 - 5) I_1 + (3\mu^2 - 1) I_2 + \mu(3 - 5\mu^2) I_3] \right\}
\end{aligned} \tag{9}$$

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

$$\begin{aligned}
S = & -\mu_s \left\{ I(1 - 2\gamma) - \frac{3}{16} [(3 - \mu^2) I_0 + (3\mu^2 - 1) I_2] \right. \\
& + \frac{9}{16} \gamma [(3 - \mu^2) I_0 + \mu(3\mu^2 - 5) I_1 + (3\mu^2 - 1) I_2 + \mu(3 - 5\mu^2) I_3] \\
& \left. - \frac{3}{16} \frac{\partial \gamma^2}{\partial \gamma} [(3 - \mu^2) I_0 + \mu(3\mu^2 - 5) I_1 + (3\mu^2 - 1) I_2 + \mu(3 - 5\mu^2) I_3] \right\}
\end{aligned} \tag{11}$$

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

$$\begin{aligned}
 S_j = & -\mu_s \left\{ I_j (1 - 2\bar{\gamma}_j) - \frac{3}{16} [(3 - \mu^2) I_{0j} + (3\mu^2 - 1) I_{2j}] \right. \\
 & + \frac{9}{16} \bar{\gamma}_j [(3 - \mu^2) I_{0j} + \mu(3\mu^2 - 5) I_{1j} + (3\mu^2 - 1) I_{2j} + \mu(3 - 5\mu^2) I_{3j}] \\
 & - \frac{3}{16} \frac{h}{m_o c^2} \nu_{j+1}^2 [(3 - \mu^2) I_{0j}(\nu_{j+1}) + \mu(3\mu^2 - 5) I_{1j}(\nu_{j+1}) \\
 & \quad \quad \quad + (3\mu^2 - 1) I_{2j}(\nu_{j+1}) + \mu(3 - 5\mu^2) I_{3j}(\nu_{j+1})] \\
 & + \frac{3}{16} \frac{h}{m_o c^2} \nu_j^2 [(3 - \mu^2) I_{0j}(\nu_j) + \mu(3\mu^2 - 5) I_{1j}(\nu_j) + \mu(3 - 5\mu^2) I_{3j}(\nu_j) \\
 & \quad \quad \quad \left. + (3\mu^2 - 1) I_{2j}(\nu_j)] \right\} \quad (15)
 \end{aligned}$$

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

$$I_{xj} = \int_{\nu_j}^{\nu_{j+1}} I_x(\nu) d\nu \quad (16)$$

Moreover,

$$\bar{\gamma}_j I_{xj} = \int_{\nu_j}^{\nu_{j+1}} \gamma I_x(\nu) d\nu \quad (17)$$

One should note that in Eq. (15) the quantities $I_{0j}(\nu_j)$, $I_{1j}(\nu_j)$, 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

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

Thus,

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

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

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

where

$$A_1 = 3\bar{\gamma}_j + \frac{h}{m_0 c^2} \frac{v_j^2}{\Delta v_j} \quad (21)$$

$$A_2 = 1 - A_1, \quad (22)$$

$$A_3 = \frac{h}{m_0 c^2} \frac{v_{j+1}^2}{\Delta v_{j+1}} \quad (23)$$

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

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

where

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

Using

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

as an integrating factor, one finds

$$\begin{aligned} I_j(x_2) = I_j(x_1) e^{-\alpha_j(x_2 - x_1)} &+ \frac{\mu_{a_j}}{\mu} \int_{x_1}^{x_2} B_j(x') e^{-\alpha_j(x_2 - x')} dx' \\ &+ \frac{\mu_s}{\mu} \int_{x_1}^{x_2} \{ \} e^{-\alpha_j(x_2 - x')} dx' \end{aligned} \quad (27)$$

where

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

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_{0j} , I_{0j+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

$$\begin{aligned}
 & \frac{\mu_s}{\mu} \int_{x_1}^{x_2} \{ \} e^{-\alpha_j(x_2-x')} dx' \\
 &= \frac{\mu_s}{\mu} \frac{3}{16} A_2 \left[\left(\frac{1 - e^{-\alpha_j \Delta}}{\alpha_j} \right) A + B \left(\frac{x_2 - x_1 e^{-\alpha_j \Delta}}{\alpha_j} - \frac{1 - e^{-\alpha_j \Delta}}{\alpha_j^2} \right) \right] \\
 & - \frac{\mu_s}{\mu} \frac{3}{16} \mu A_1 \left[\left(\frac{1 - e^{-\alpha_j \Delta}}{\alpha_j} \right) C + D \left(\frac{x_2 - x_1 e^{-\alpha_j \Delta}}{\alpha_j} - \frac{1 - e^{-\alpha_j \Delta}}{\alpha_j^2} \right) \right] \\
 & + \frac{\mu_s}{\mu} \frac{3}{16} A_3 \left[\left(\frac{1 - e^{-\alpha_j \Delta}}{\alpha_j} \right) E + F \left(\frac{x_2 - x_1 e^{-\alpha_j \Delta}}{\alpha_j} - \frac{1 - e^{-\alpha_j \Delta}}{\alpha_j^2} \right) \right] \\
 & + \frac{\mu_s}{\mu} \frac{3}{16} A_3 \mu \left[\left(\frac{1 - e^{-\alpha_j \Delta}}{\alpha_j} \right) G + H \left(\frac{x_2 - x_1 e^{-\alpha_j \Delta}}{\alpha_j} - \frac{1 - e^{-\alpha_j \Delta}}{\alpha_j^2} \right) \right] \quad (29)
 \end{aligned}$$

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

$$A = \frac{1}{\Delta x} \{ x_2 (F10(J, x_1) + \mu^2 F12(J, x_1)) - x_1 (F10(J, x_2) + \mu^2 F12(J, x_2)) \}$$

$$B = \frac{1}{\Delta x} \{ F10(J, x_2) - F10(J, x_1) + \mu^2 (F12(J, x_2) - F12(J, x_1)) \}$$

$$C = \frac{1}{\Delta x} \{x_2 FI3(J, x_1) - x_1 FI3(J, x_2) + \mu^2 (x_2 FI4(J, x_1) - x_1 FI4(J, x_2))\}$$

$$D = \frac{1}{\Delta x} \{FI3(J, x_2) - FI3(J, x_1) + \mu^2 (FI4(J, x_2) - FI4(J, x_1))\}$$

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

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

$$G = \frac{1}{\Delta x} \{x_2 FI3(J+1, x_1) - x_1 FI3(J+1, x_2) + \mu^2 (x_2 FI4(J+1, x_1) - x_1 FI4(J+1, x_2))\}$$

$$H = \frac{1}{\Delta x} \{FI3(J+1, x_2) - FI3(J+1, x_1) + \mu^2 (FI4(J+1, x_2) - FI4(J+1, x_1))\} \quad (30)$$

$$\text{with } FI0(J, x_i) = 3I_{0j}(x_i) - I_{2j}(x_i)$$

$$FI2(J, x_i) = 3I_{2j}(x_i) - I_{0j}(x_i)$$

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

$$FI4(J, x_i) = 3I_{4j}(x_i) - 5I_{3j}(x_i)$$

$$A_1 = 3\bar{\gamma}_j + \frac{h}{m_0 c^2} \frac{v_j^2}{\Delta v_j}$$

$$A_2 = 1 - A_1$$

(31)

$$A_3 = \frac{h}{m_0 c^2} \frac{v_{j+1}^2}{\Delta v_{j+1}}$$

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:

$$\begin{aligned}
 & \frac{\mu_s}{\mu} \int_{x_1}^{x_2} \{ \} e^{-\alpha_j(x_2 - x')} dx' \\
 &= \frac{\mu_s}{\mu} \frac{3}{16} A_2 \Delta \left[(FI0(J, x_1) + \mu^2 FI2(J, x_1)) \left(1 - \frac{1}{2} \alpha_j \Delta \right) + \frac{\Delta}{2} B \right] \\
 &- \frac{\mu_s}{\mu} \Delta \frac{3}{16} \mu A_1 \left[\left(1 - \frac{1}{2} \alpha_j \Delta \right) (FI3(J, x_1) + \mu^2 FI1(J, x_1)) + \frac{\Delta}{2} D \right] \\
 &+ \frac{\mu_s}{\mu} \Delta \frac{3}{16} A_3 \left[\left(1 - \frac{1}{2} \alpha_j \Delta \right) (FI0(J+1, x_1) + \mu^2 FI2(J+1, x_1)) + \frac{\Delta}{2} F \right] \\
 &+ \frac{\mu_s}{\mu} \Delta \frac{3}{16} \mu A_3 \left[\left(1 - \frac{1}{2} \alpha_j \Delta \right) (FI3(J+1, x_1) + \mu^2 FI1(J+1, x_1)) + \frac{\Delta}{2} H \right] \quad (32)
 \end{aligned}$$

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

$$\begin{aligned}
 \frac{1}{c} \nabla \cdot \mathbf{F}_j &= \mu_{a_j} (2B_j - E_j) - \mu_s E_j (1 - 2\bar{\gamma}_j) + \mu_s E_j \left(1 - 3\bar{\gamma}_j - \frac{h}{m_0 c^2} \frac{v_j^2}{\Delta v_j} \right) \\
 &+ \mu_s \frac{h}{m_0 c^2} \frac{v_{j+1}^2}{\Delta v_{j+1}} E_{j+1} \quad (33)
 \end{aligned}$$

Summing on j , one obtains

$$\frac{1}{c} \nabla \cdot \mathbf{F} = \sum_{j=1}^N \mu_{a_j} (2B_j - E_j) - \mu_s \sum_{j=1}^N \bar{\gamma}_j E_j - \mu_s \frac{h}{m_o c^2} \sum_{j=1}^N \left(E_j \frac{v_j^2}{\Delta v_j} - E_{j+1} \frac{v_{j+1}^2}{\Delta v_{j+1}} \right) \quad (34)$$

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

$$\sum \left(E_j \frac{v_j^2}{\Delta v_j} - E_{j+1} \frac{v_{j+1}^2}{\Delta v_{j+1}} \right) = E_1 \frac{v_1^2}{\Delta v_1} - E_{N+1} \frac{v_{N+1}^2}{\Delta v_{N+1}} \quad (35)$$

Now, by definition, $v_1 = 0$ and $E_{N+1} = 0$. Thus, the calculated heating rate due to Compton scattering is

$$\mu_s c \sum_{j=1}^N \bar{\gamma}_j E_j \quad (36)$$

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

$$\mu_s \frac{hc}{m_o c^2} \int_0^\infty v E_v dv \quad (37)$$

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_{0j} , I_{1j} , 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., $\gamma \rightarrow 0$. For this case, the transport equation becomes

$$\mu \frac{dI^{n+1}}{dx} = \mu_a' (B - I^{n+1}) - \mu_s I^{n+1} + \frac{3}{16} \mu_s [(1 - \mu^2) I_0^n + (3\mu^2 - 1) I_2^n] \quad (38)$$

If spatial homogeneity is assumed, then

$$I^{n+1}(\mu) = \frac{\mu_a}{\bar{\mu}} B + \frac{3}{16} \frac{\mu_s}{\bar{\mu}} [(1 - \mu^2) I_0^n + (3\mu^2 - 1) I_2^n] \quad (39)$$

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

To find I_0^{n+1} and I_2^{n+1} , integrate over $d\mu$. Thus,

$$I_0^{n+1} = \frac{2\mu_a}{\bar{\mu}} B + \frac{\mu_s}{\bar{\mu}} I_0^n \quad (40)$$

and

$$I_2^{n+1} = \frac{2}{3} \frac{\mu_a}{\bar{\mu}} B + \frac{3}{10} \frac{\mu_s}{\bar{\mu}} I_0^n + \frac{1}{10} \frac{\mu_s}{\bar{\mu}} I_2^n \quad (41)$$

Solving these recursion equations, one finds that

$$I_0^n = 2B \left[1 - \left(\frac{\mu_s}{\bar{\mu}} \right)^n \right] \quad (42)$$

and

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

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

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

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

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

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

Integrating over frequency, one finds

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

where

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

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

$$I_{0k}^n = B_k \frac{2\mu_{a_k}}{\left[\mu_{a_k} + \mu_s \left(\bar{\gamma}_k + \frac{h}{m_0 c^2} \frac{\nu_k^2}{\Delta \nu_k} \right) \right]} \left\{ 1 - \left[\frac{\mu_s}{\bar{\mu}_k} \left(1 - 3\bar{\gamma}_k - \frac{h}{m_0 c^2} \frac{\nu_k^2}{\Delta \nu_k} \right) \right]^n \right\} \quad (48)$$

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

$$\frac{dI}{dx} = \mu'_a (B_\nu - I) + S \quad (49)$$

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

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

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/cm² 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

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

The momentum equation can be written as

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

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

$$\sigma_{ij} = -P_m \delta_{ij} - P_{ij} \quad (53)$$

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

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

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

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

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

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

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

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

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

$$(P) = \frac{1}{2\pi} \int_{-1}^1 d\mu \int_0^{2\pi} d\phi I(\mu) \begin{bmatrix} \mu^2 & \mu\sqrt{1 - \mu^2} \cos \phi & \mu\sqrt{1 - \mu^2} \sin \phi \\ \mu\sqrt{1 - \mu^2} \cos \phi (1 - \mu^2) \cos^2 \phi & (1 - \mu^2) \cos \phi \sin \phi \\ \mu\sqrt{1 - \mu^2} \sin \phi (1 - \mu^2) \sin \phi \cos \phi & (1 - \mu^2) \sin^2 \phi \end{bmatrix} \quad (58)$$

On evaluating the integrals, one obtains

$$P_{ij} = 0 \quad i \neq j \quad (59)$$

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

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

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

$$E_r = \int_{-1}^1 I d\mu \quad (62)$$

Eq. (52) for the spherical case is

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

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

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

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

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

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

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

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

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

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 PROGRAMMINGLOGIC 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 sub-cycling 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,

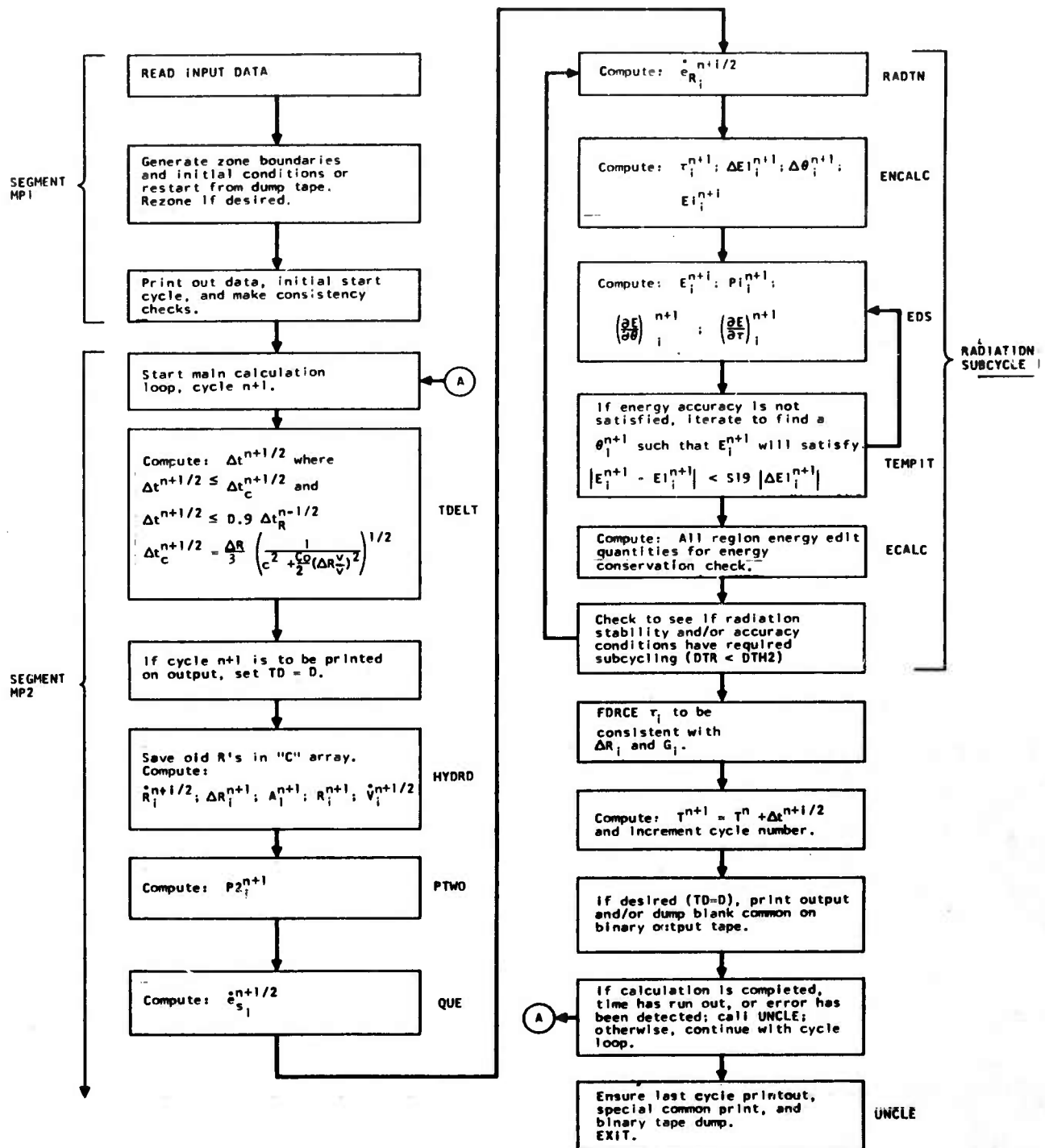


Figure 1. The OUTPUT code: Summary Flow Logic

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 P_1 , and the two partial derivatives of E , $\partial E / \partial \theta$ and $\partial E / \partial \tau$. The difference between the first-law internal energy E_{I_1} and the equation-of-state energy E_i is compared to the change in internal energy ΔE_{I_1} 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		Definition
Term	Code	
$\Delta t^{n+1/2}$	= 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)	= $R(i + 1/2) - R(i)$
A_i^{n+1}	= A(i)	= area of zone ($\propto r_i^{\alpha-1}$)
$\dot{V}_i^{n+1/2}$	= VD(i)	= rate of change of zone volumes
P_2^{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
ΔE_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
E_i^{n+1}	= EI(i)	= first-law internal energy
E_i^{n+1}	= E(i)	= equation-of-state internal energy
P_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

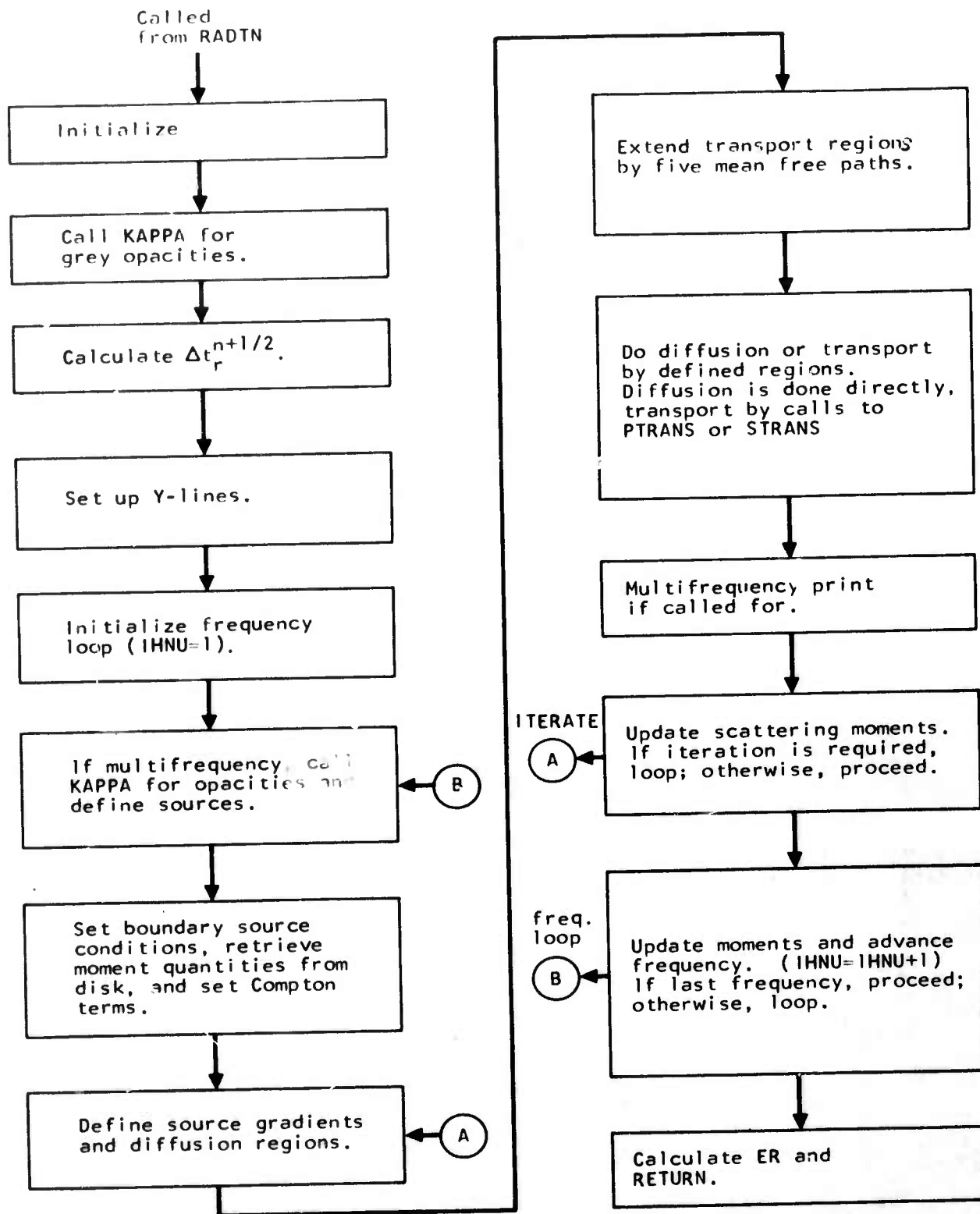


Figure 2. RAD

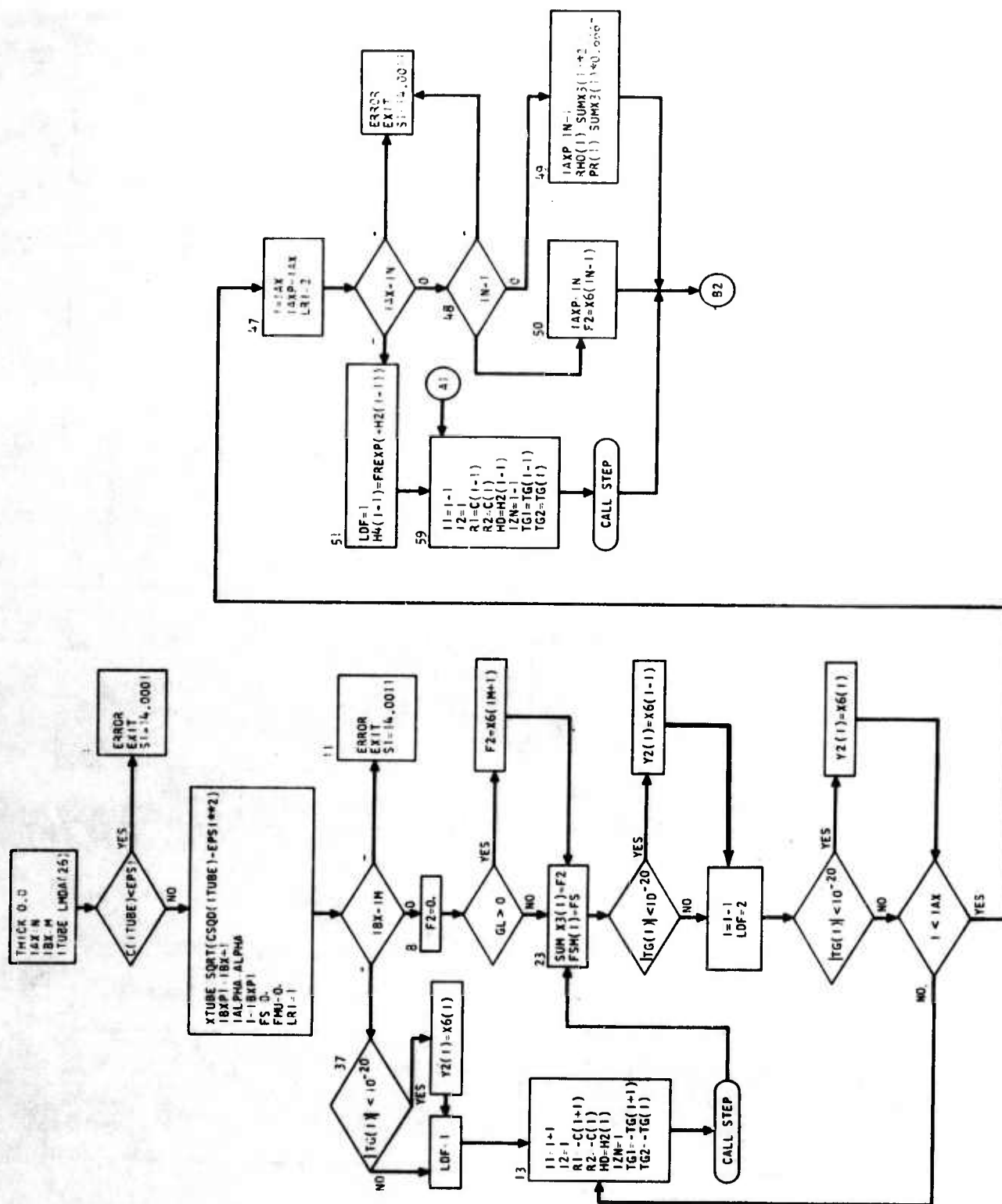


Figure 3. STRANS(N, M)

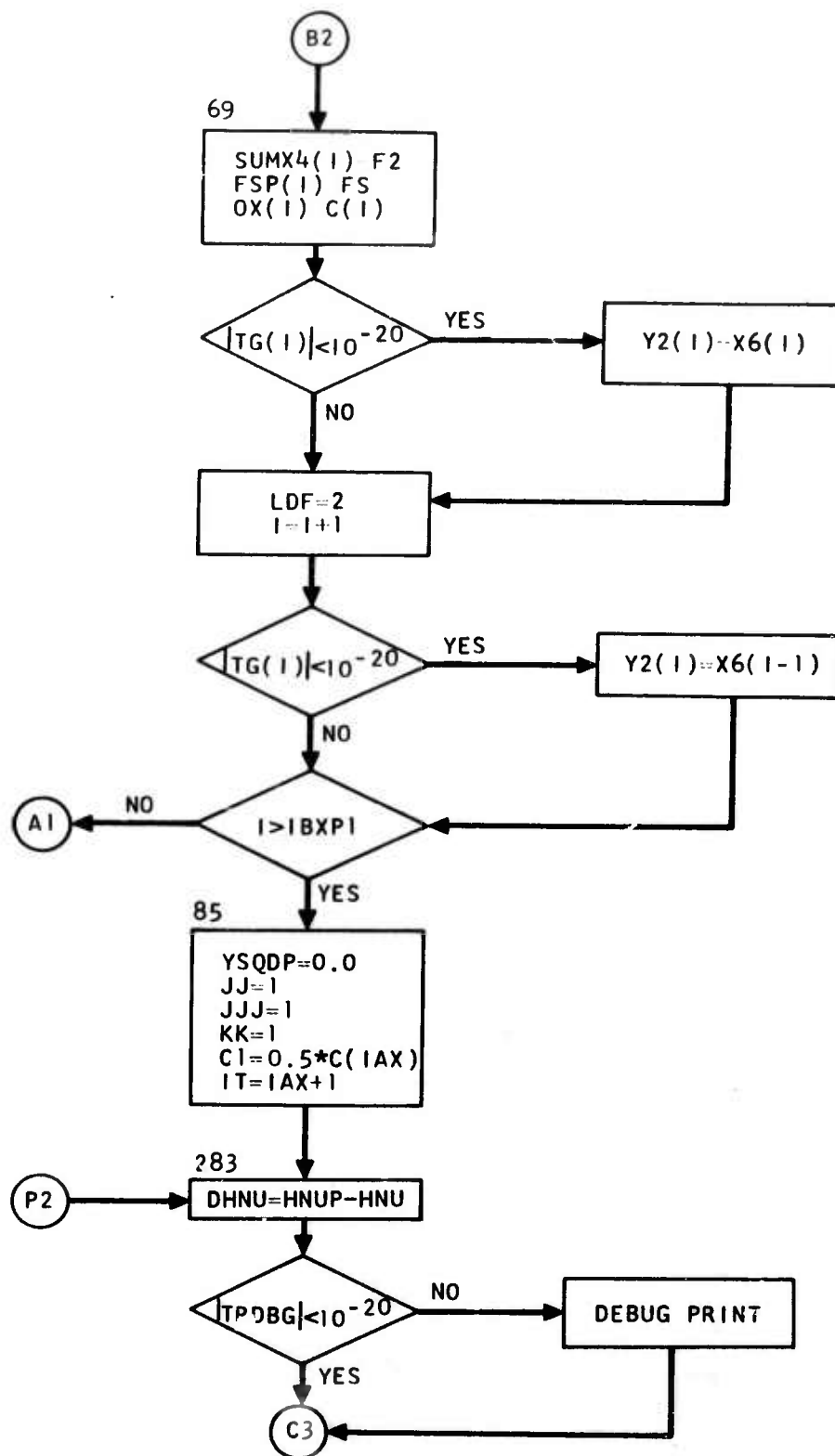


Figure 3 (continued). STRANS(N, M)

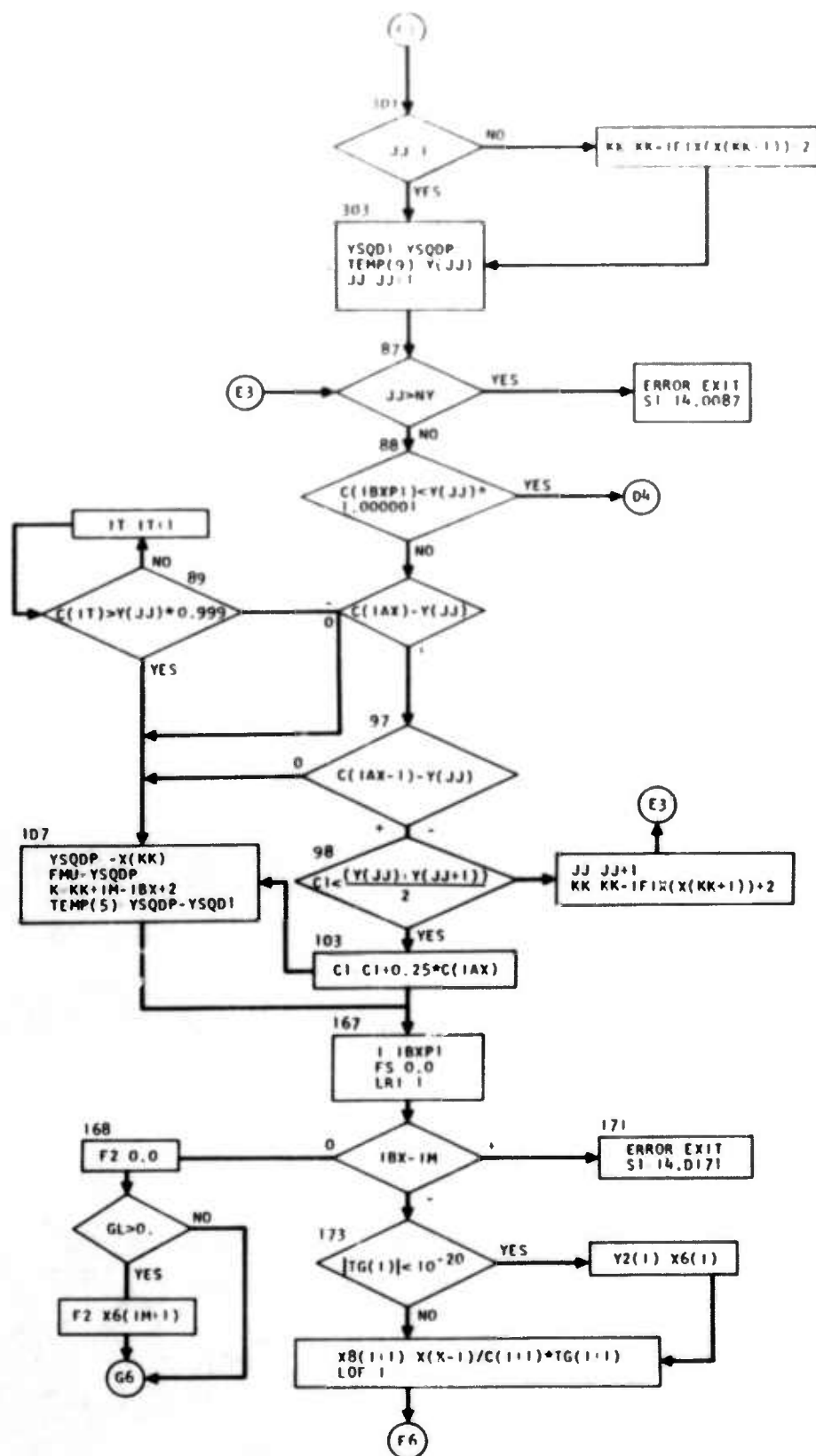


Figure 3 (continued). STRANS(N, M)

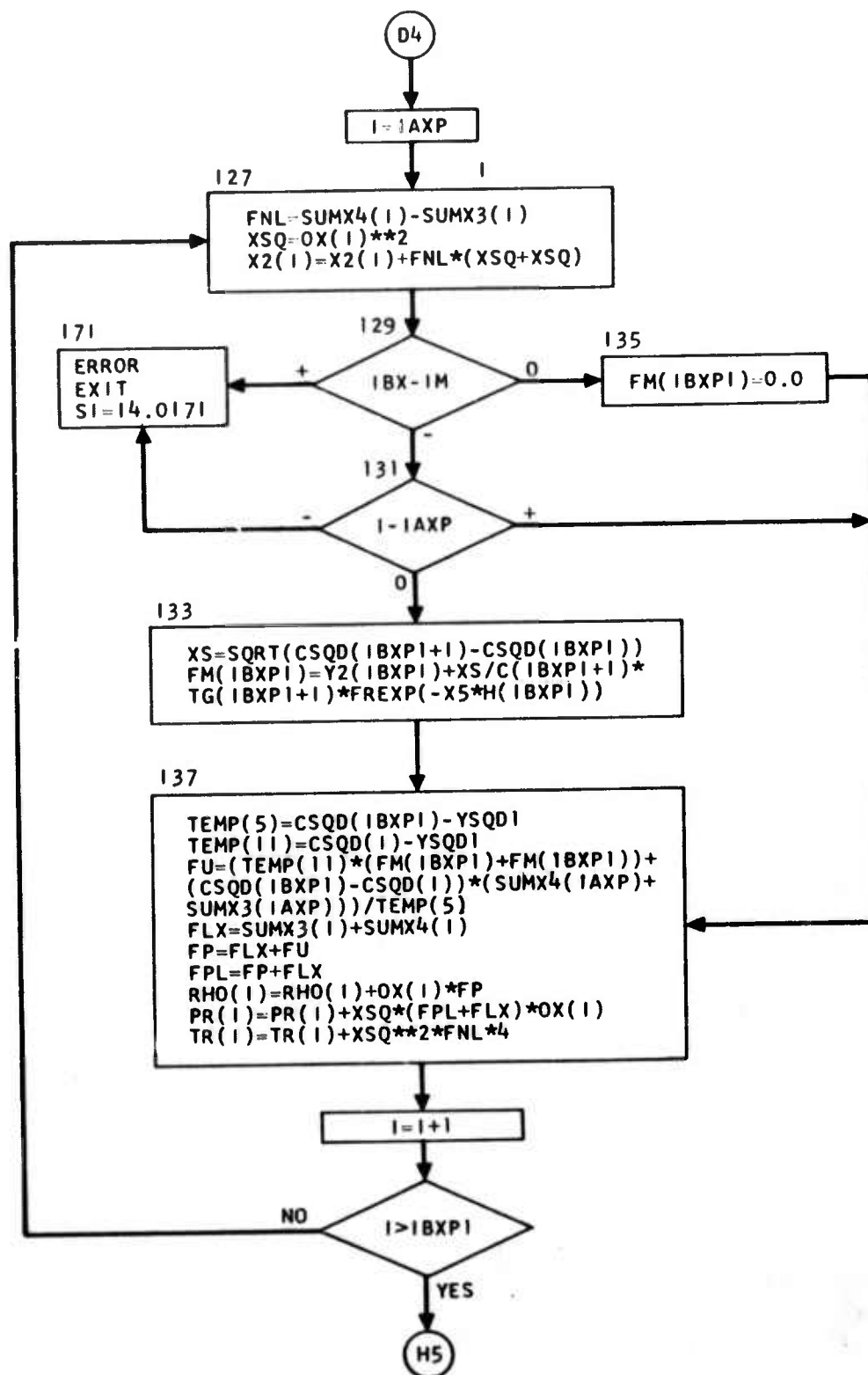


Figure 3 (continued). STRANS(N, M)

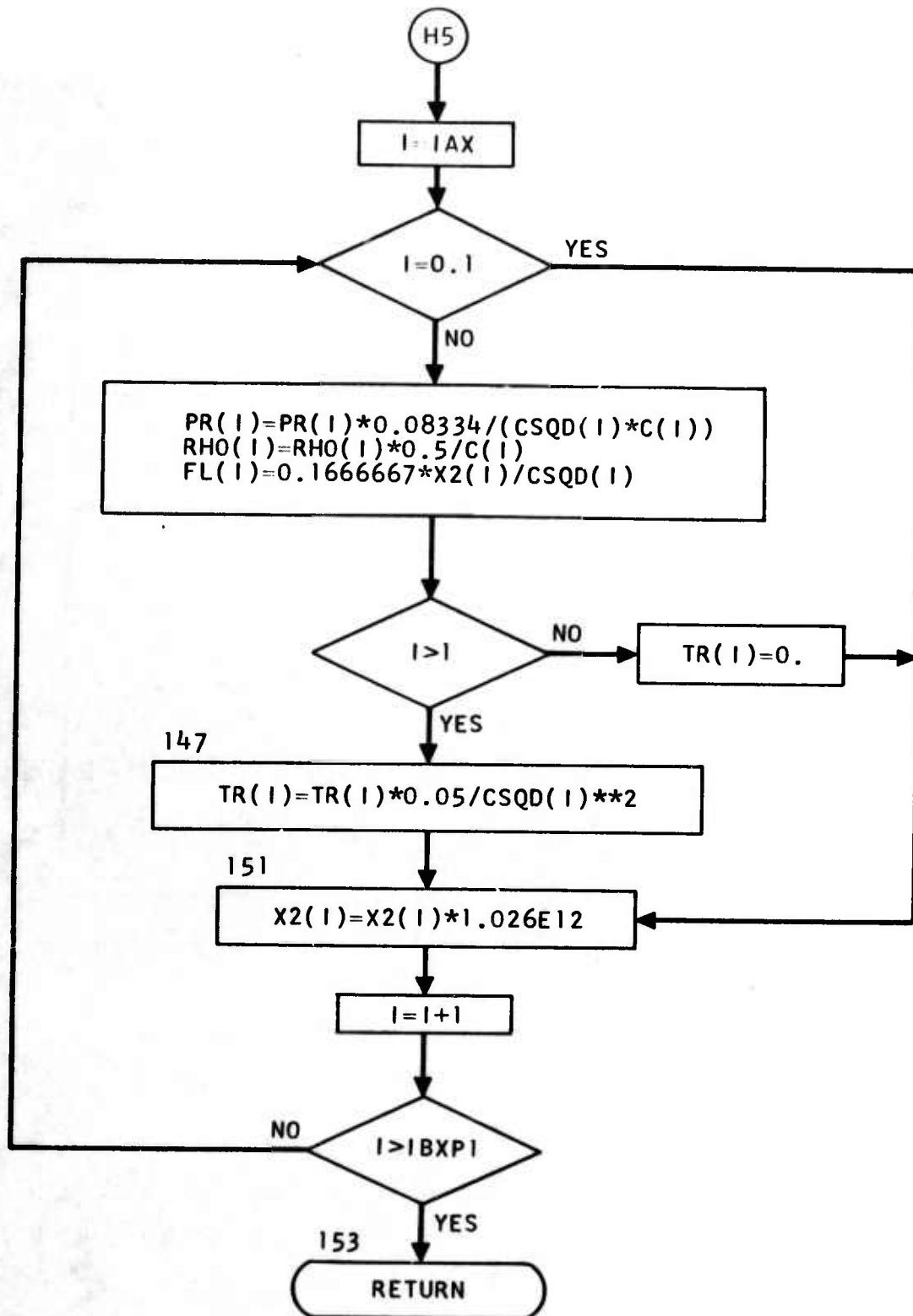


Figure 3 (continued). STRANS(N, M)

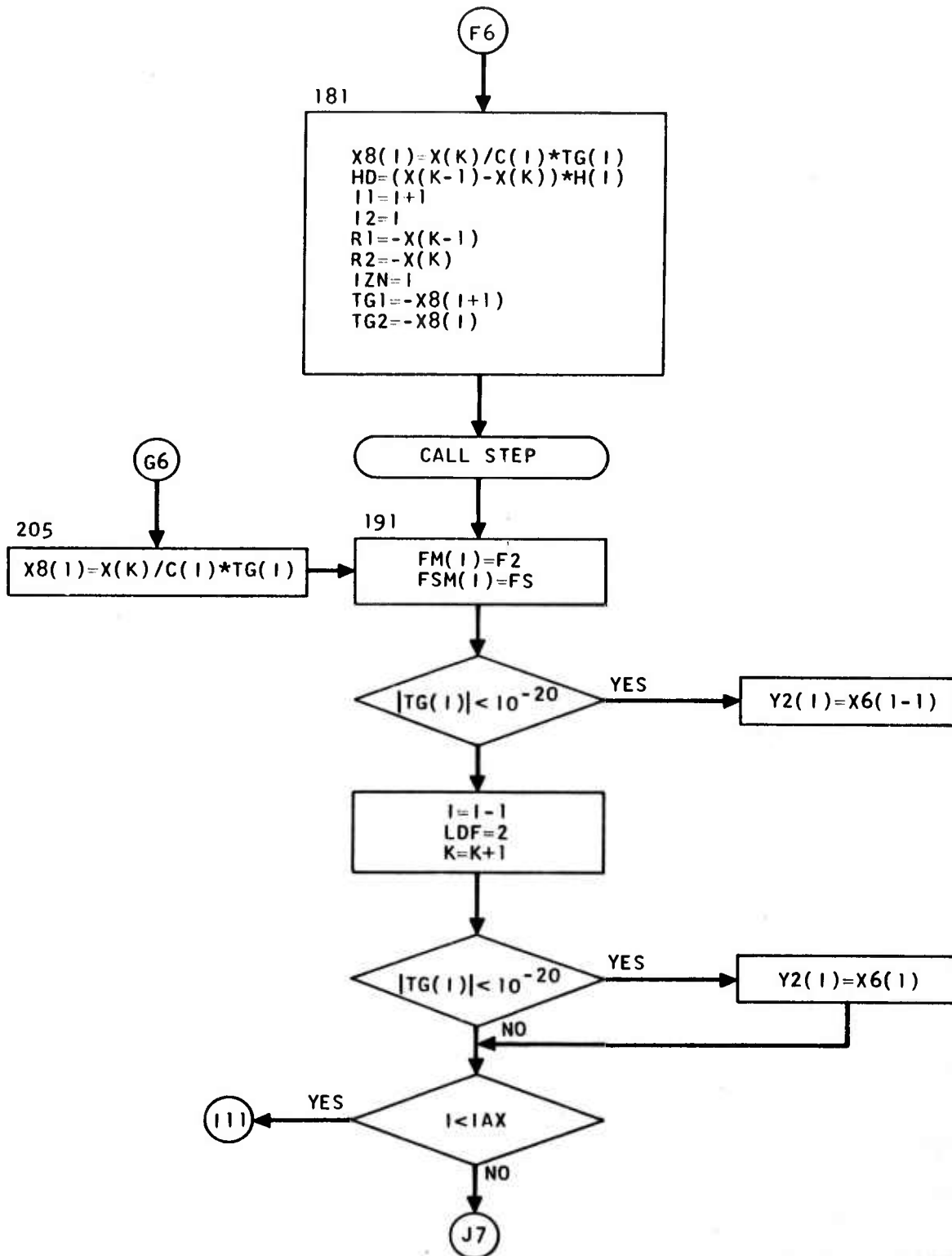


Figure 3 (continued). STRANS(N, M)

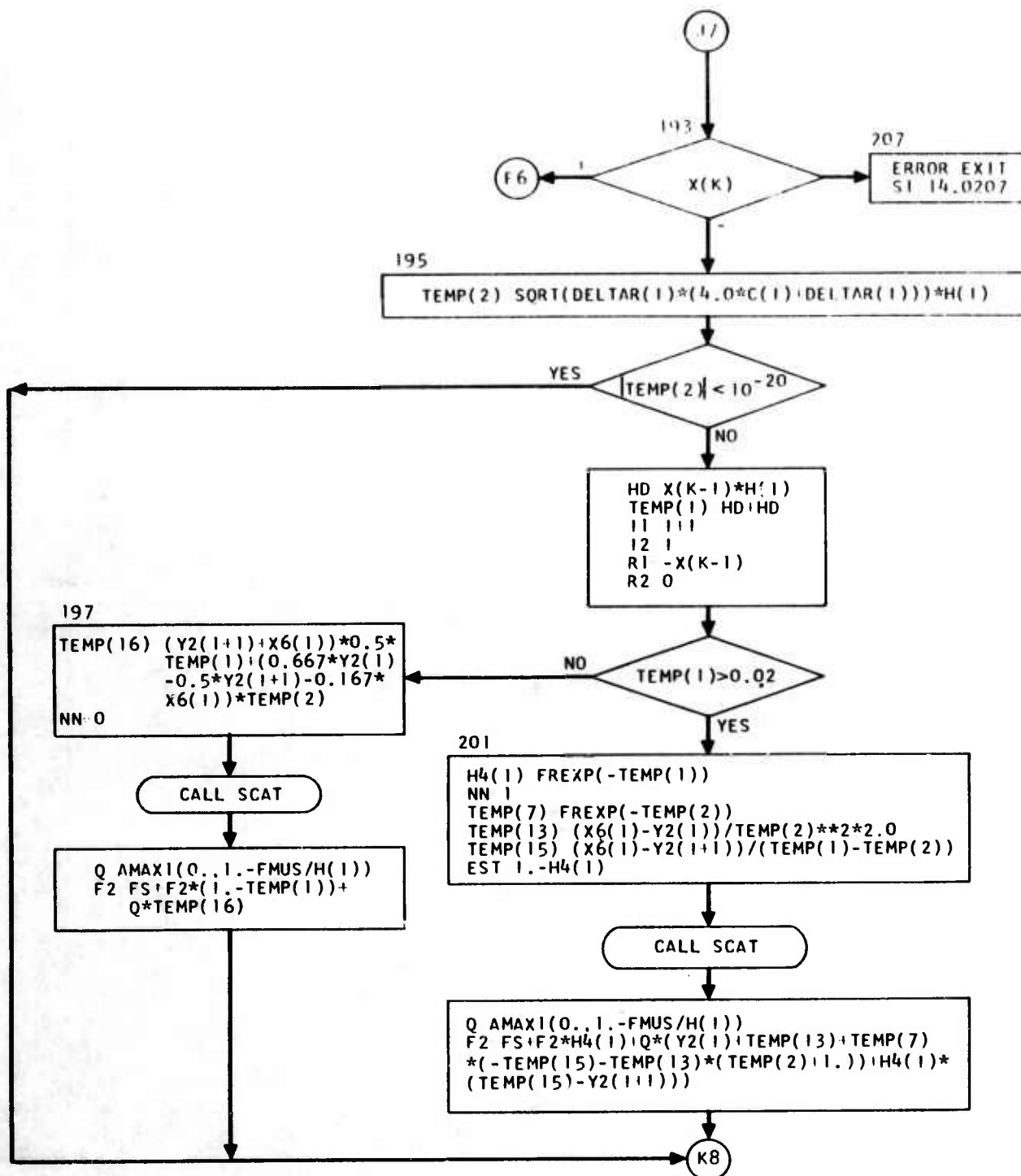


Figure 3 (continued). STRANS(N, M)

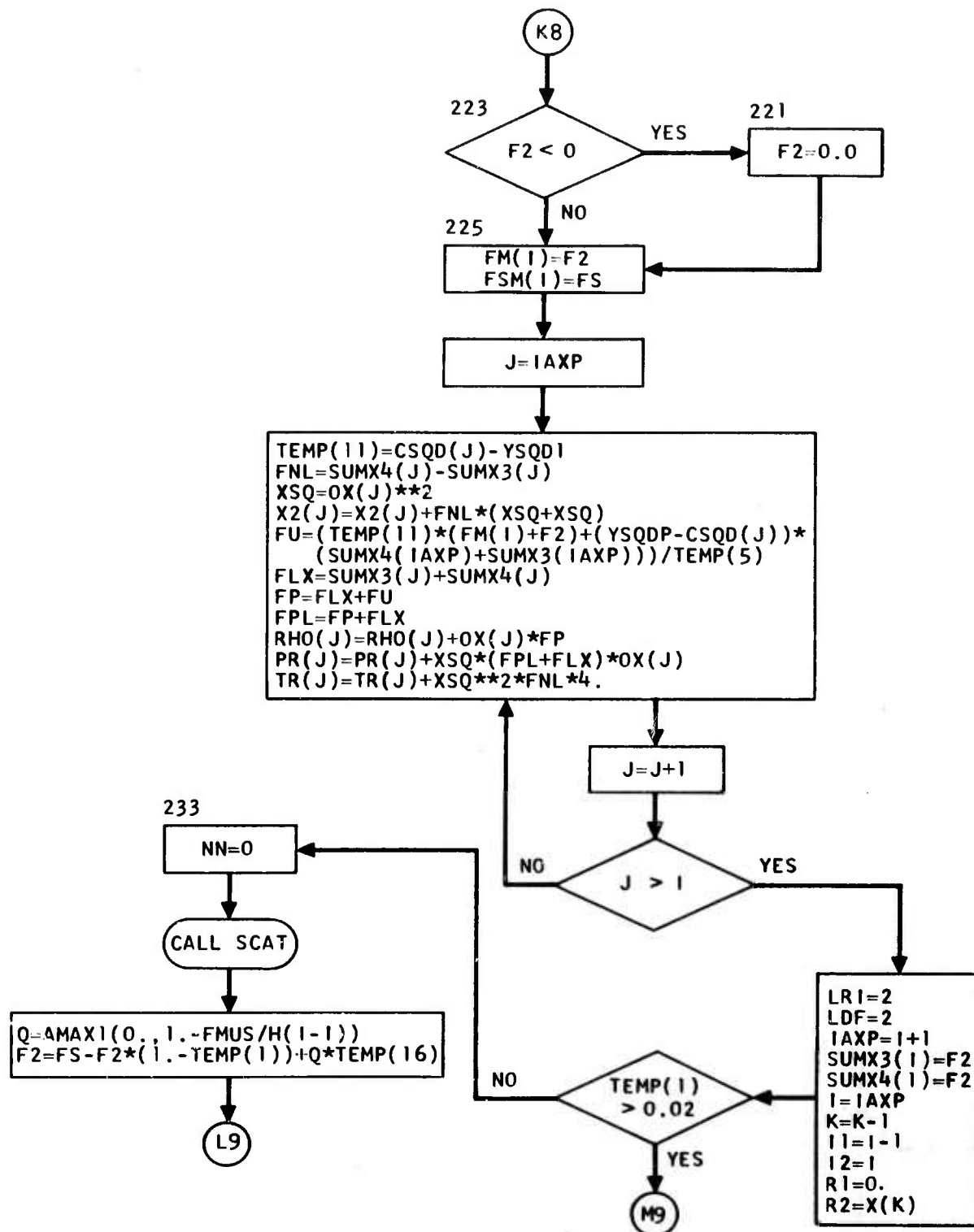


Figure 3 (continued). STRANS(N, M)

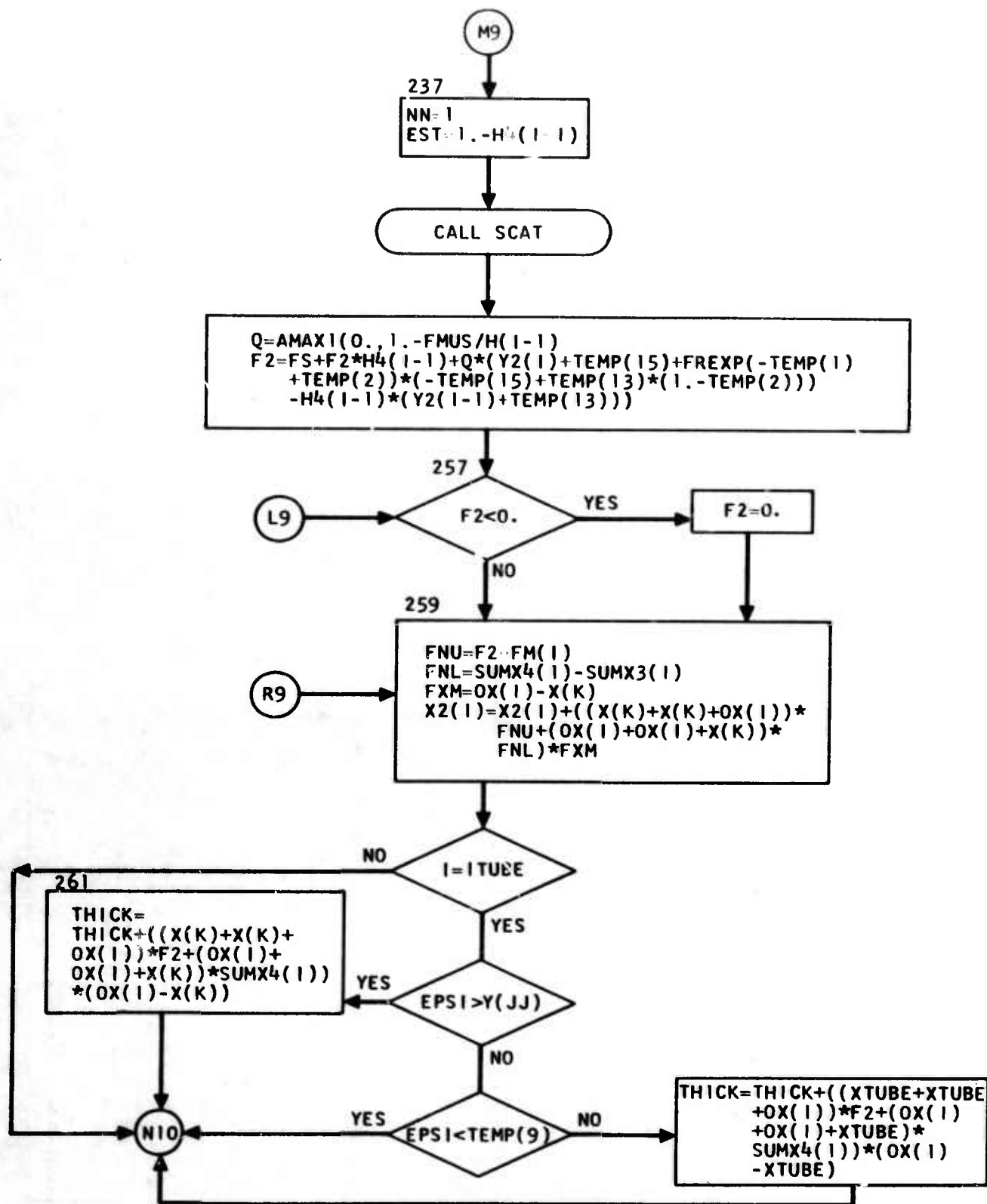


Figure 3 (continued). STRANS(N, M)

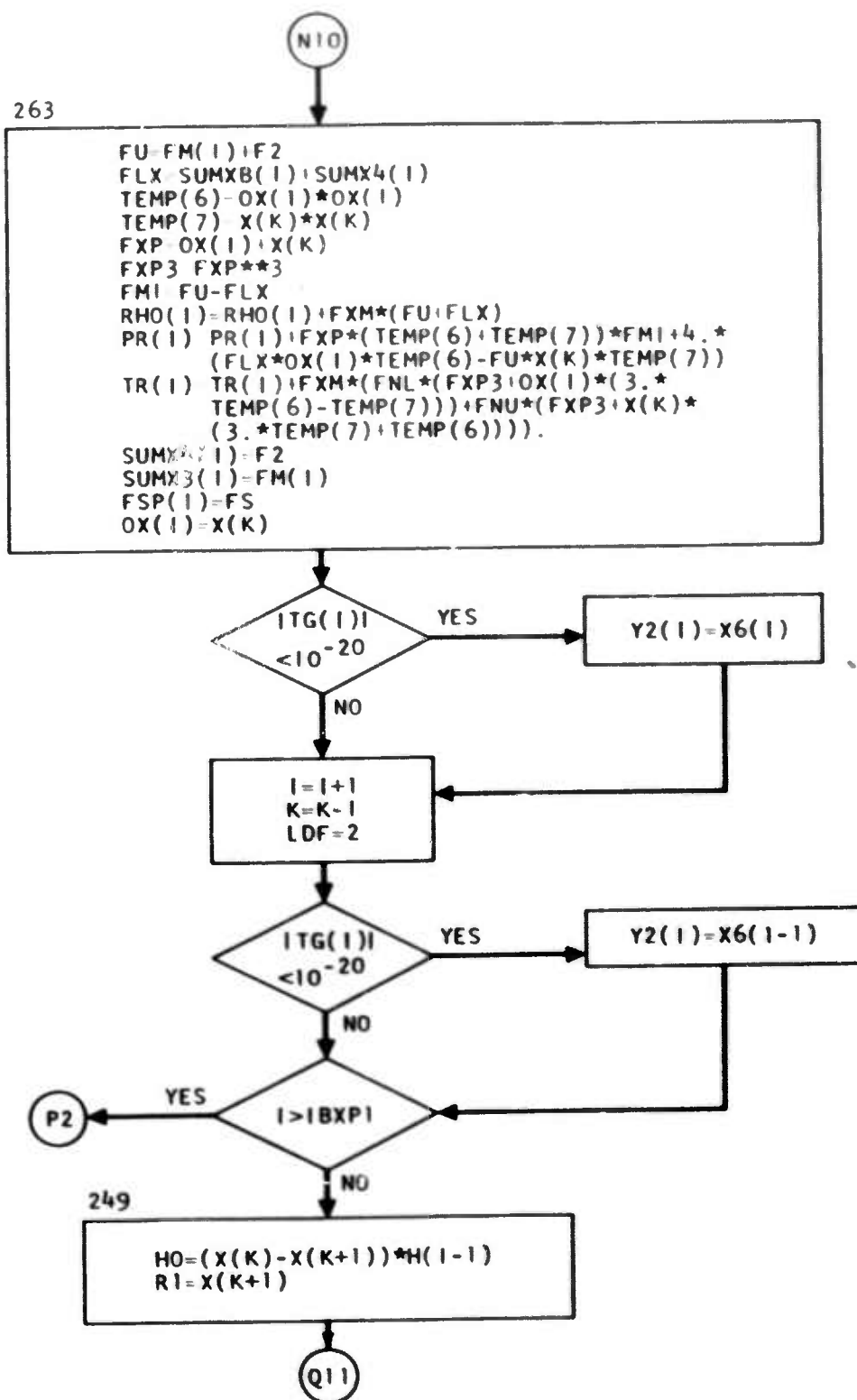


Figure 3 (continued). STRANS(N, M)

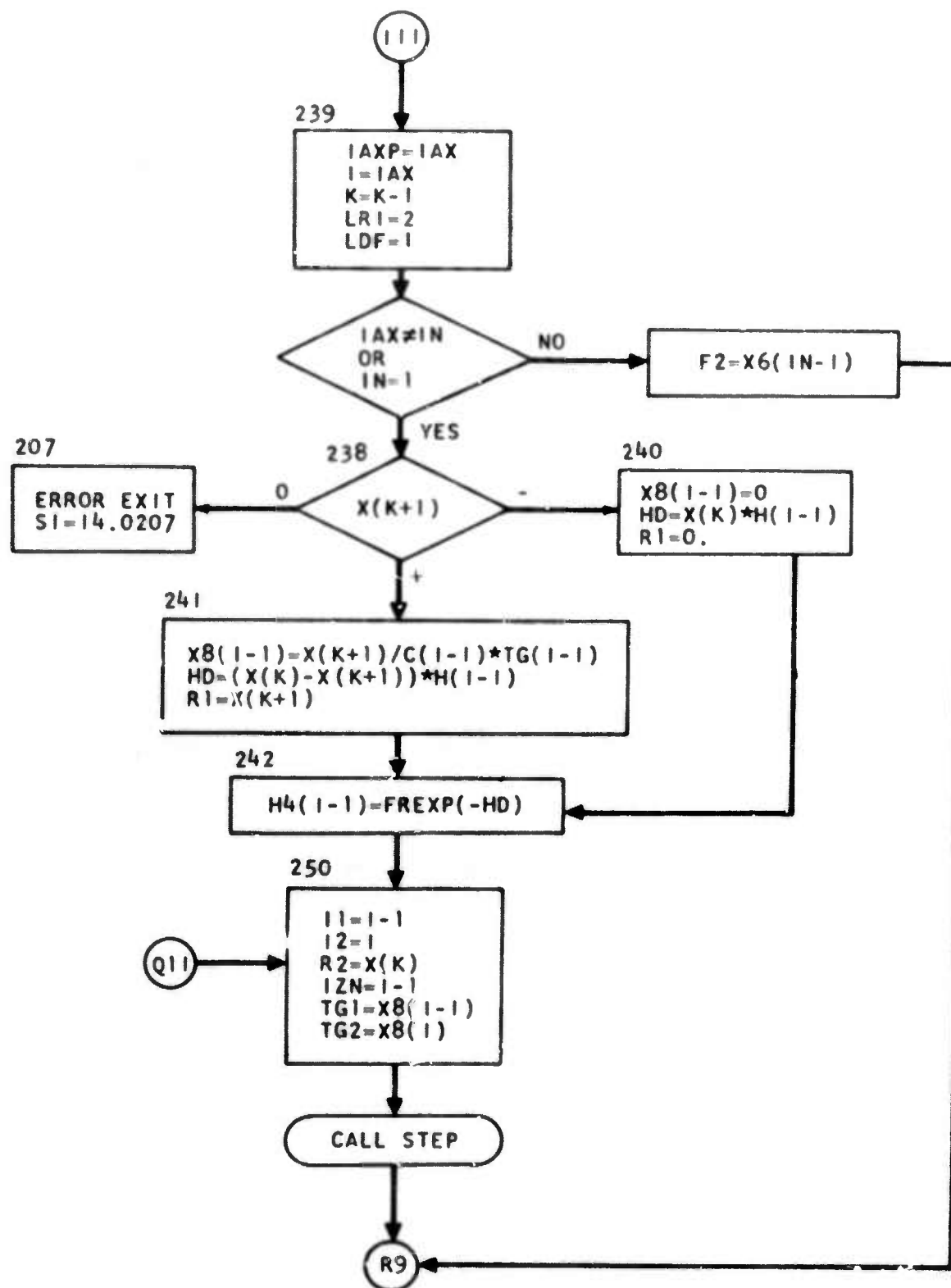


Figure 3 (concluded). STRANS(N, M)

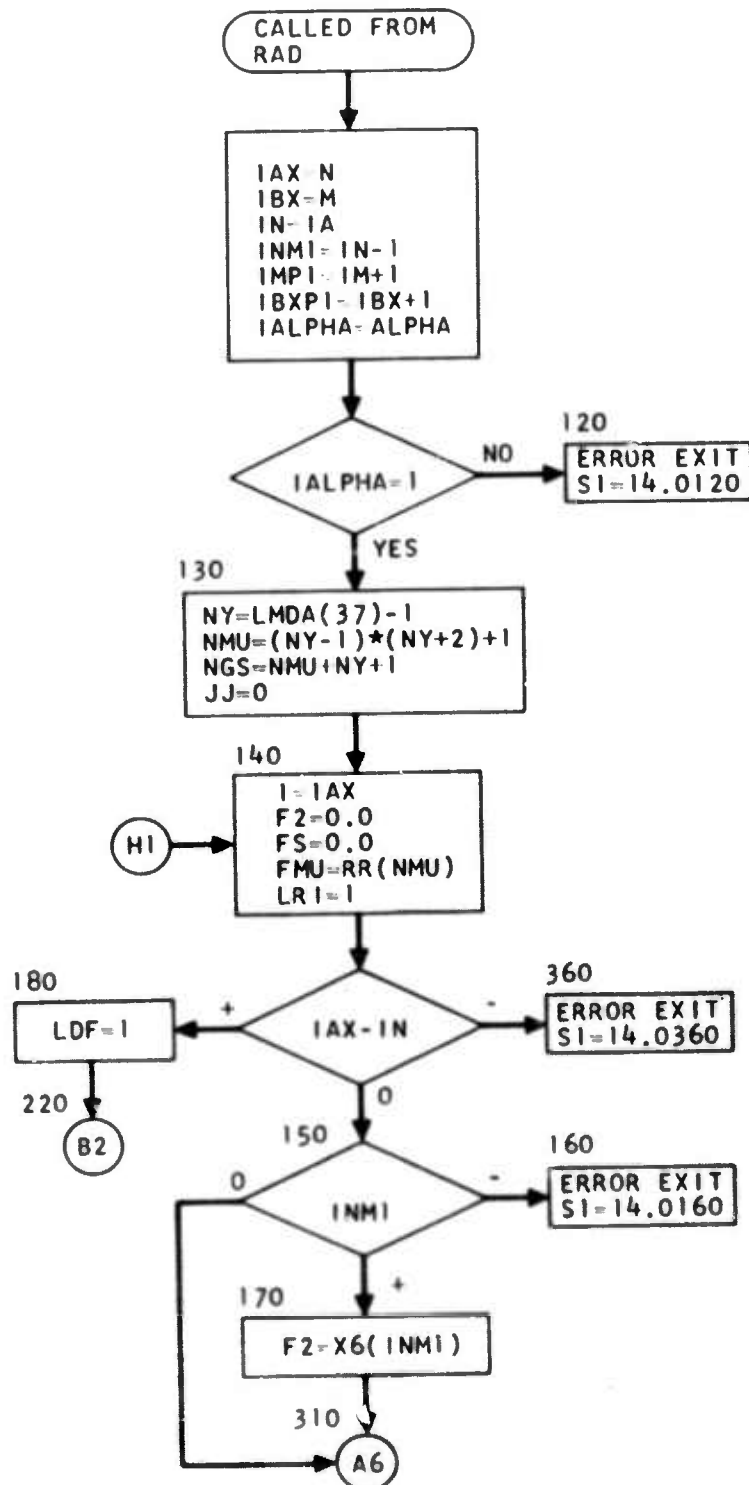


Figure 4. PTRANS

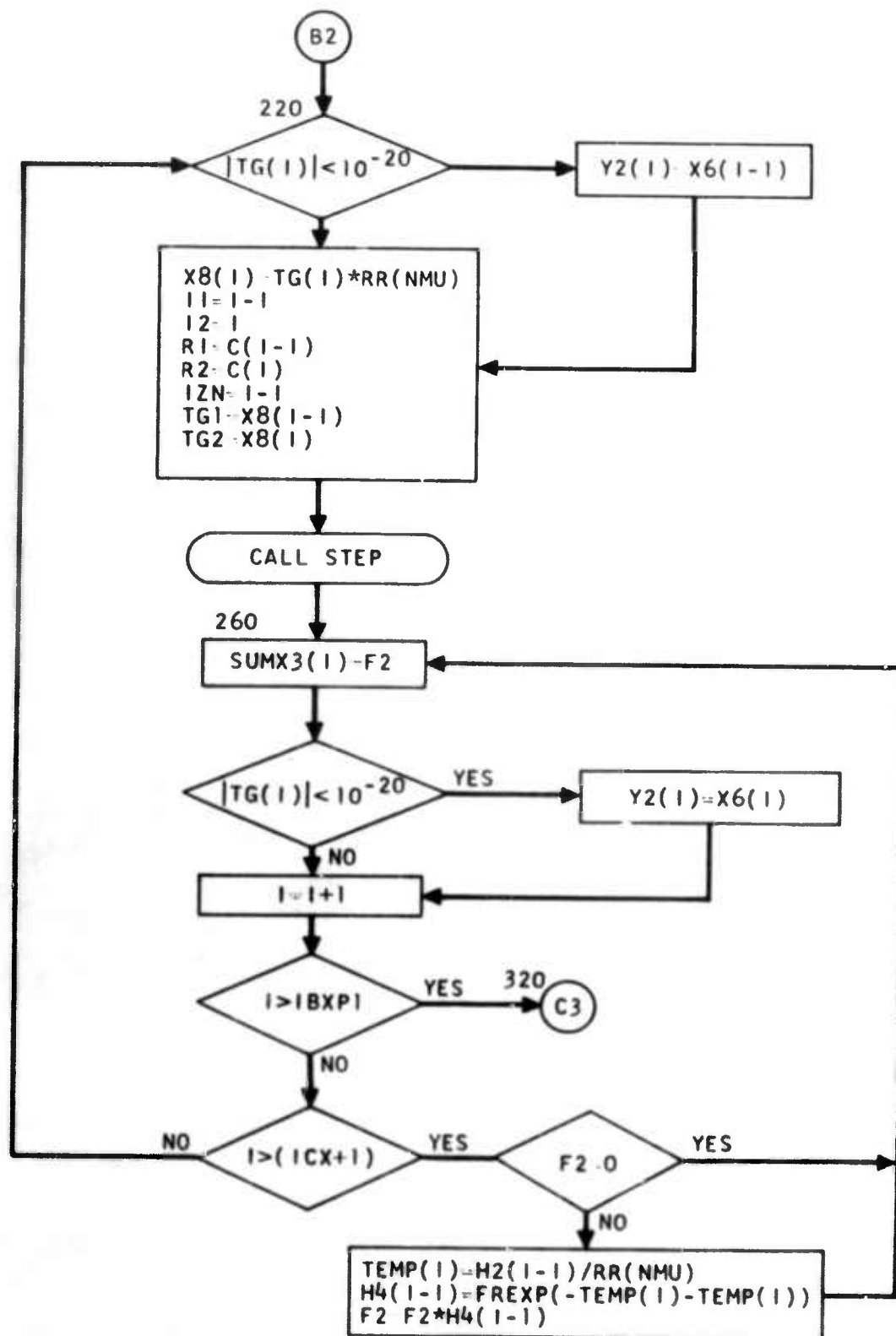


Figure 4 (continued). PTRANS

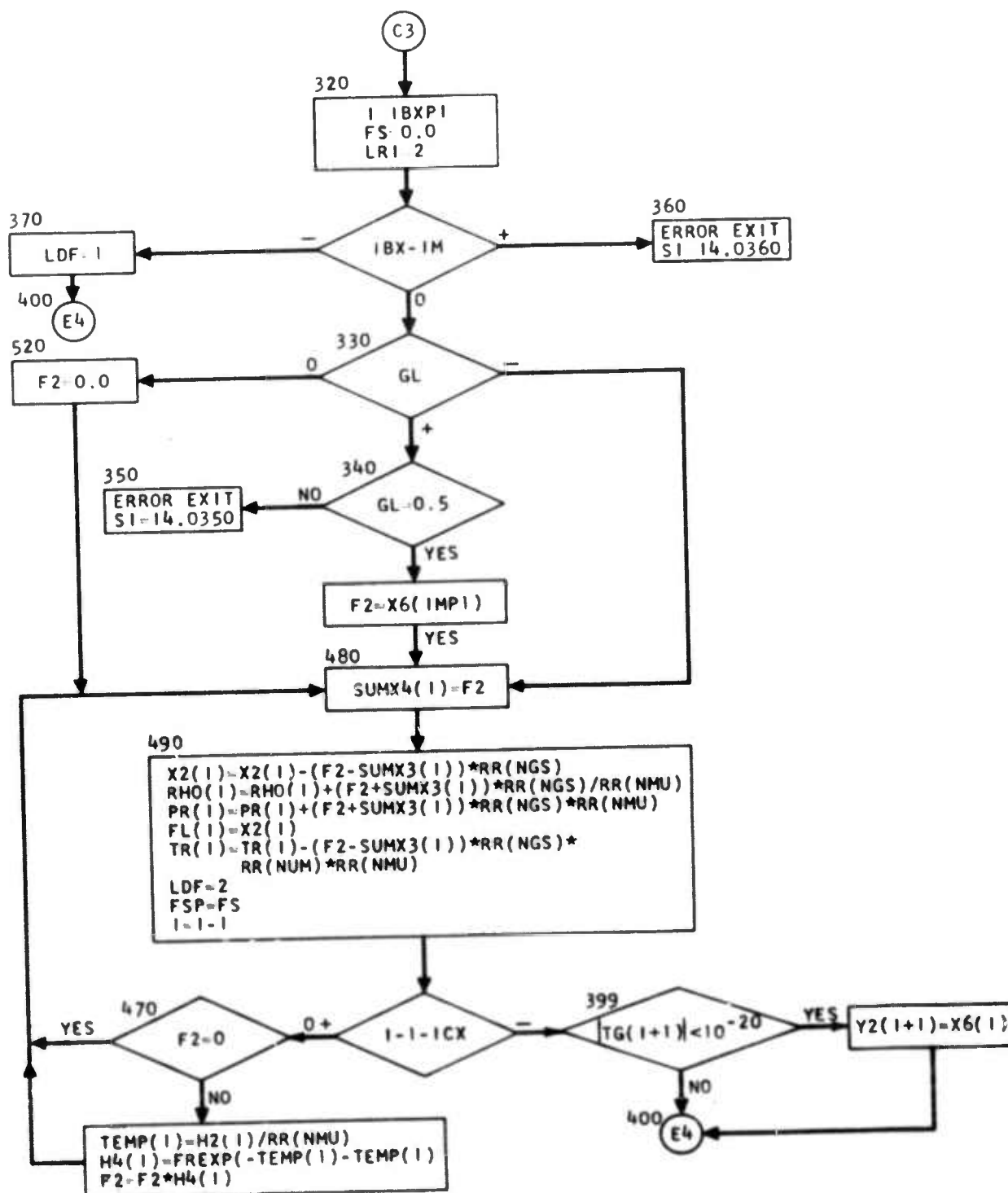


Figure 4 (continued). PTRANS

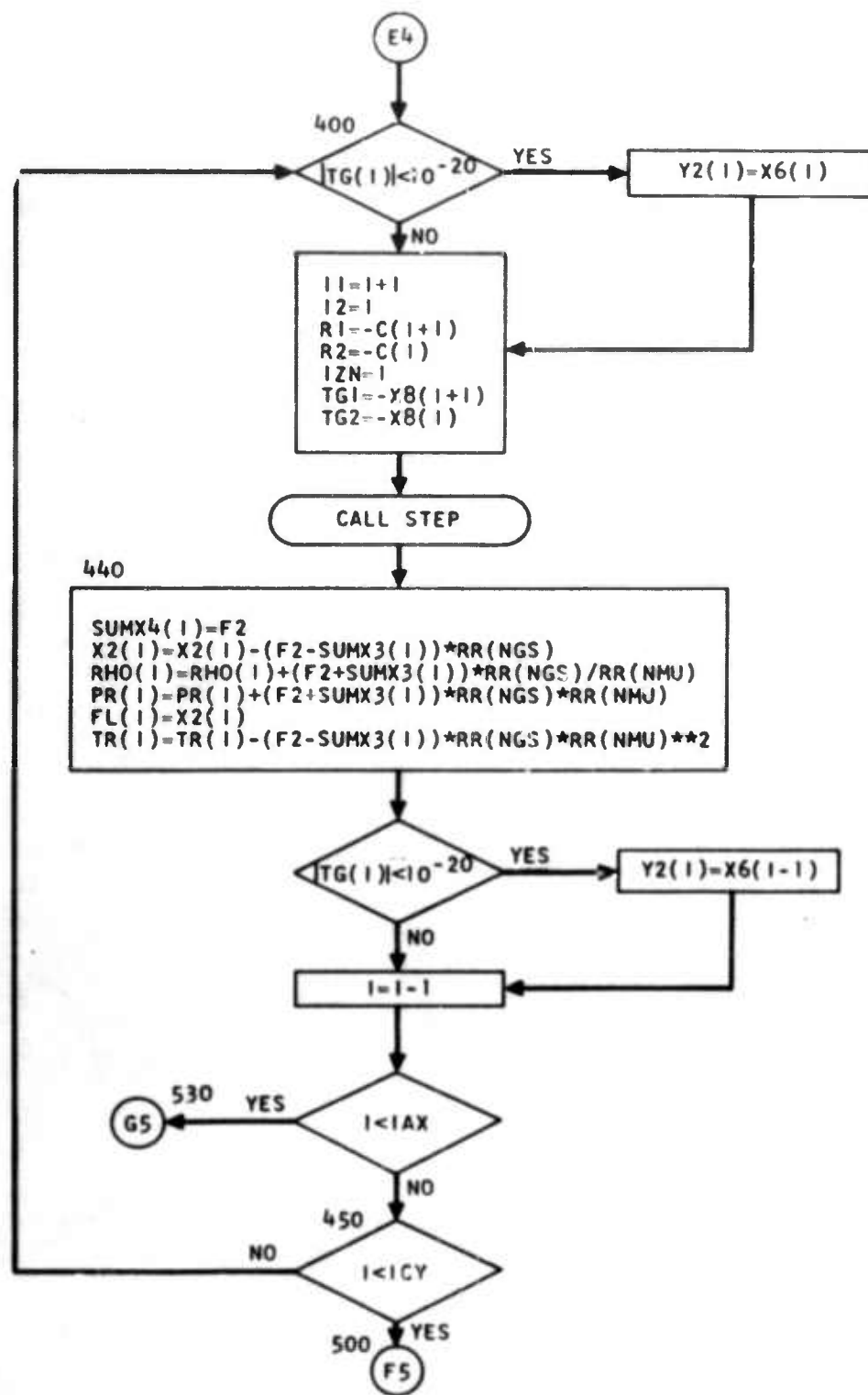


Figure 4 (continued). PTRANS

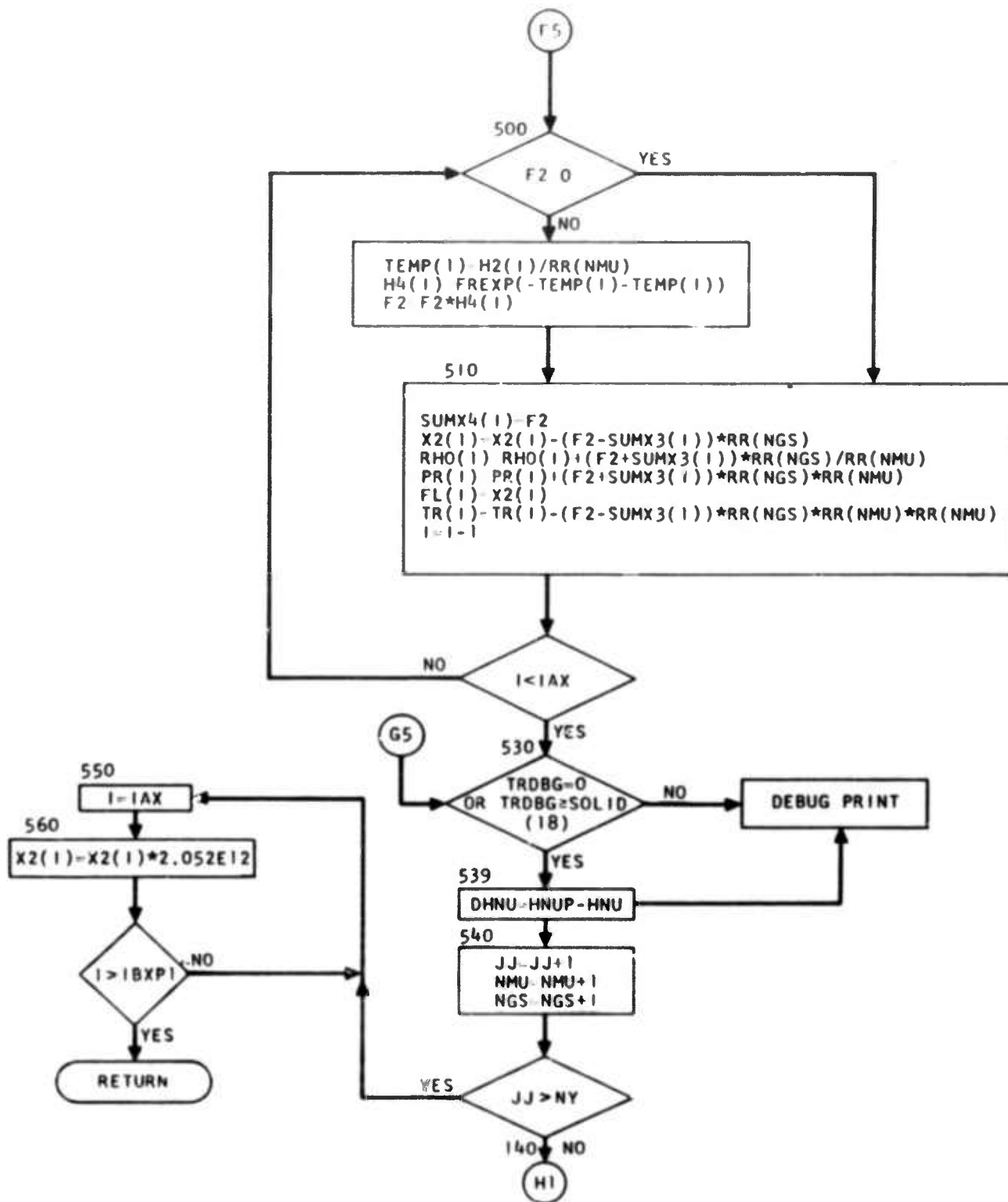


Figure 4 (continued). PTRANS

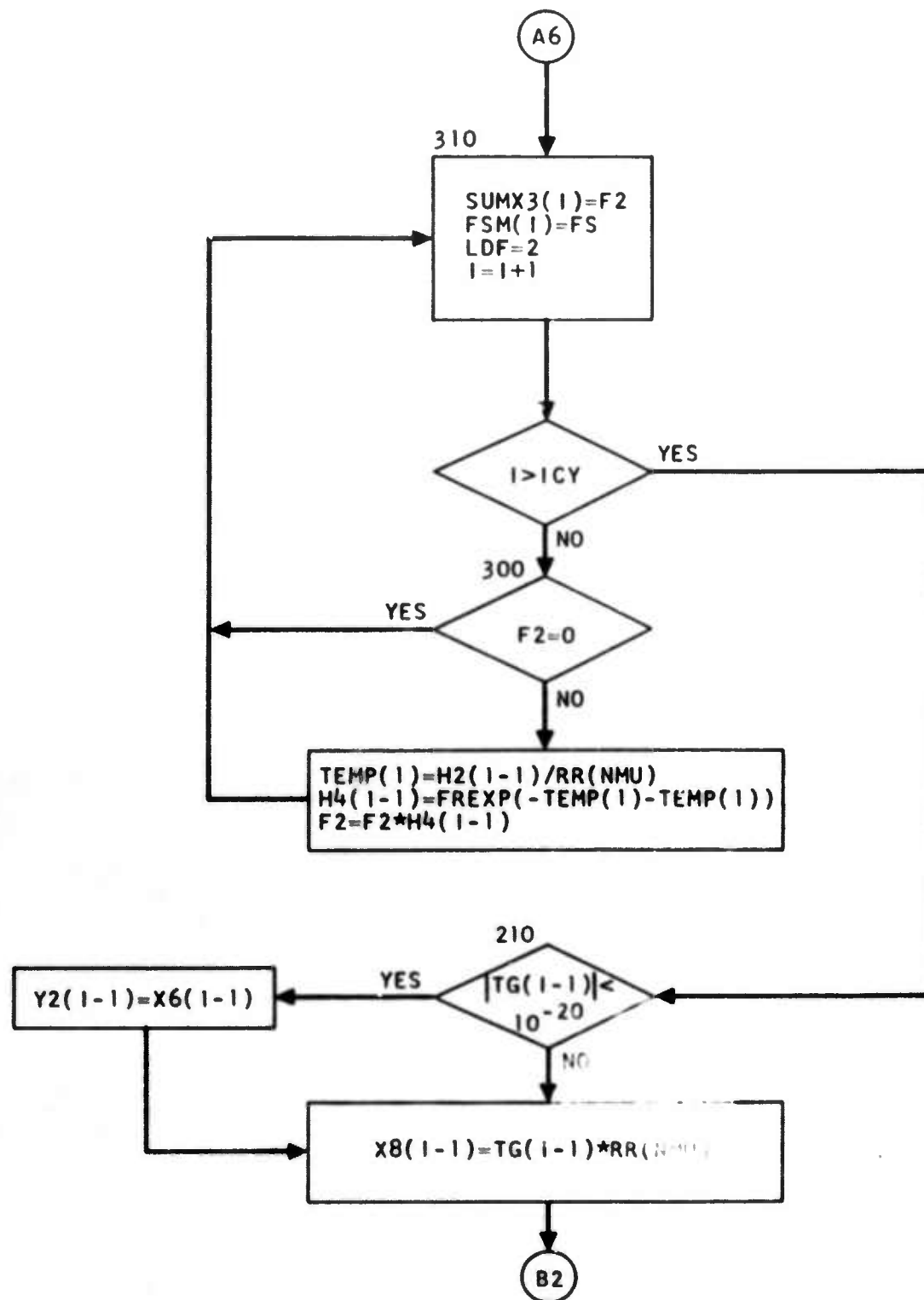


Figure 4 (concluded). PTRANS

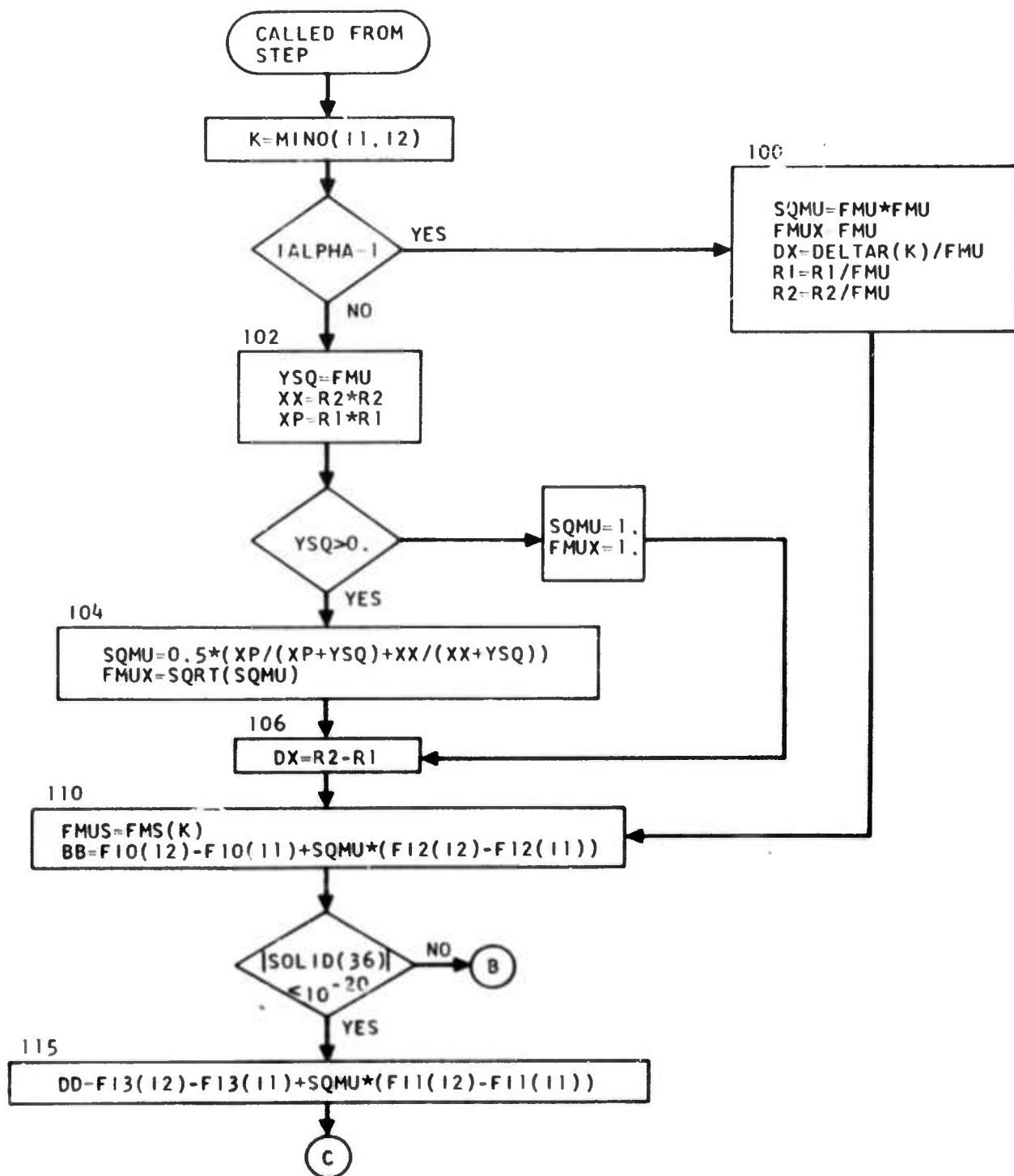


Figure 5. SCAT

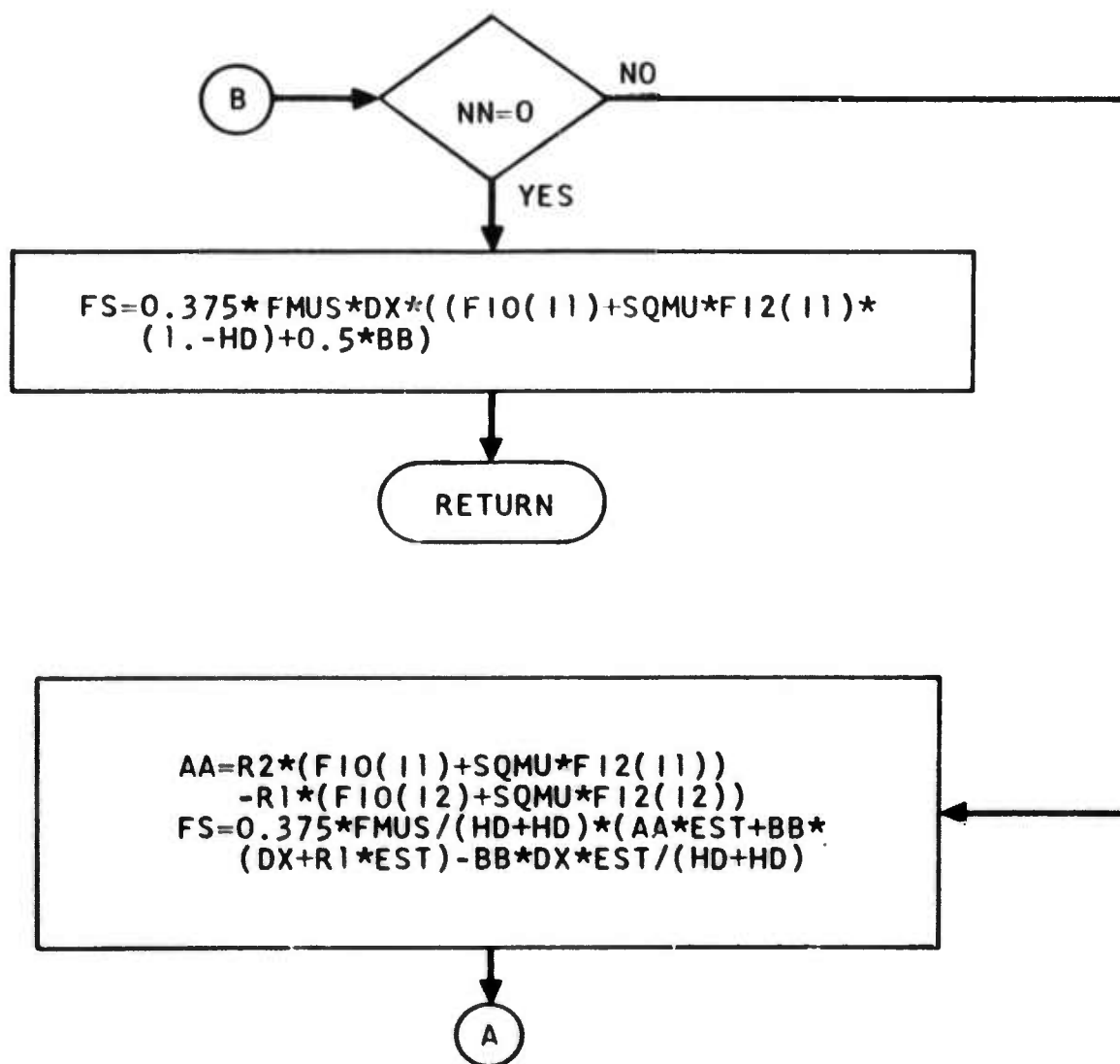


Figure 5 (continued). SCAT

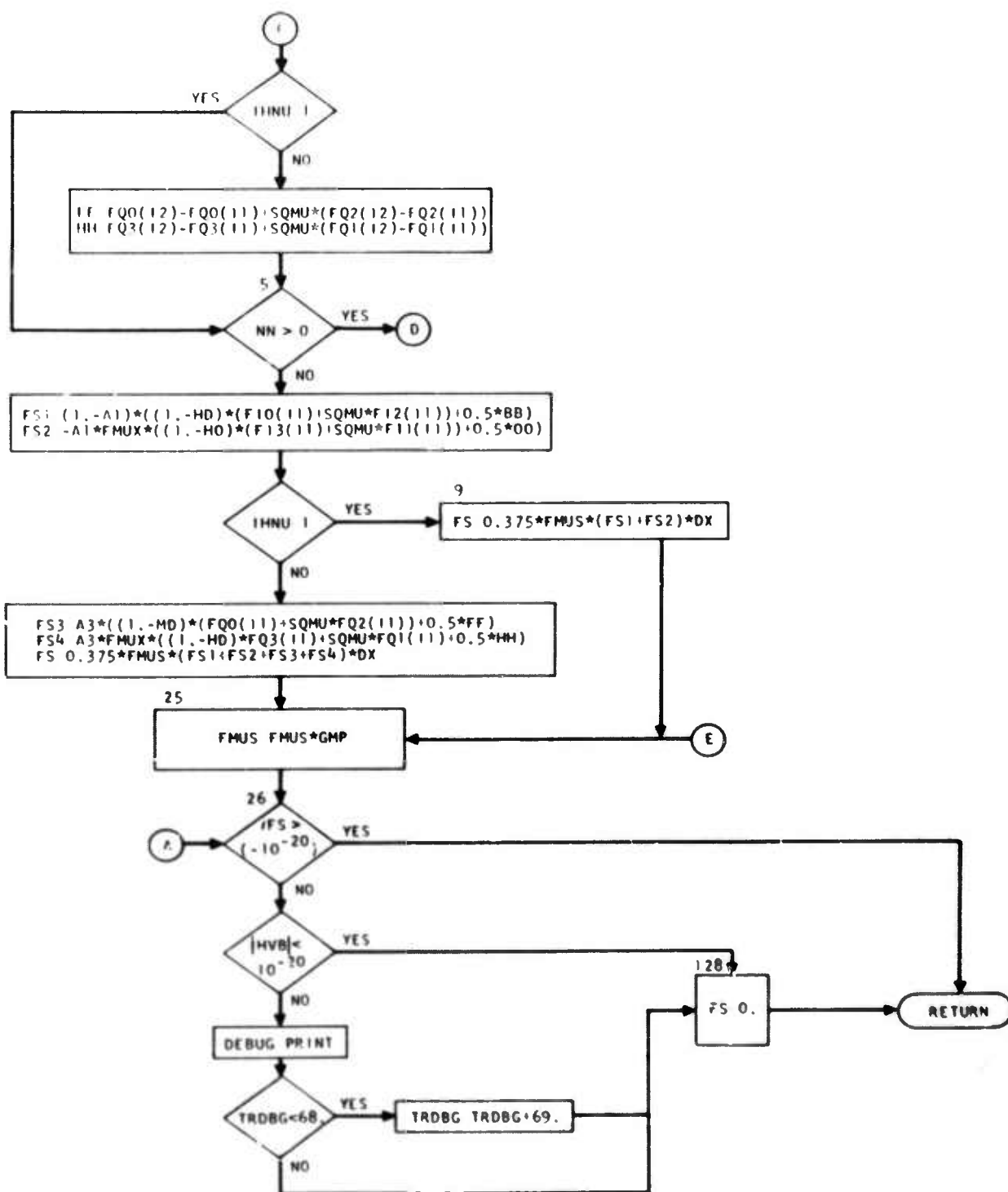


Figure 5 (continued). SCAT

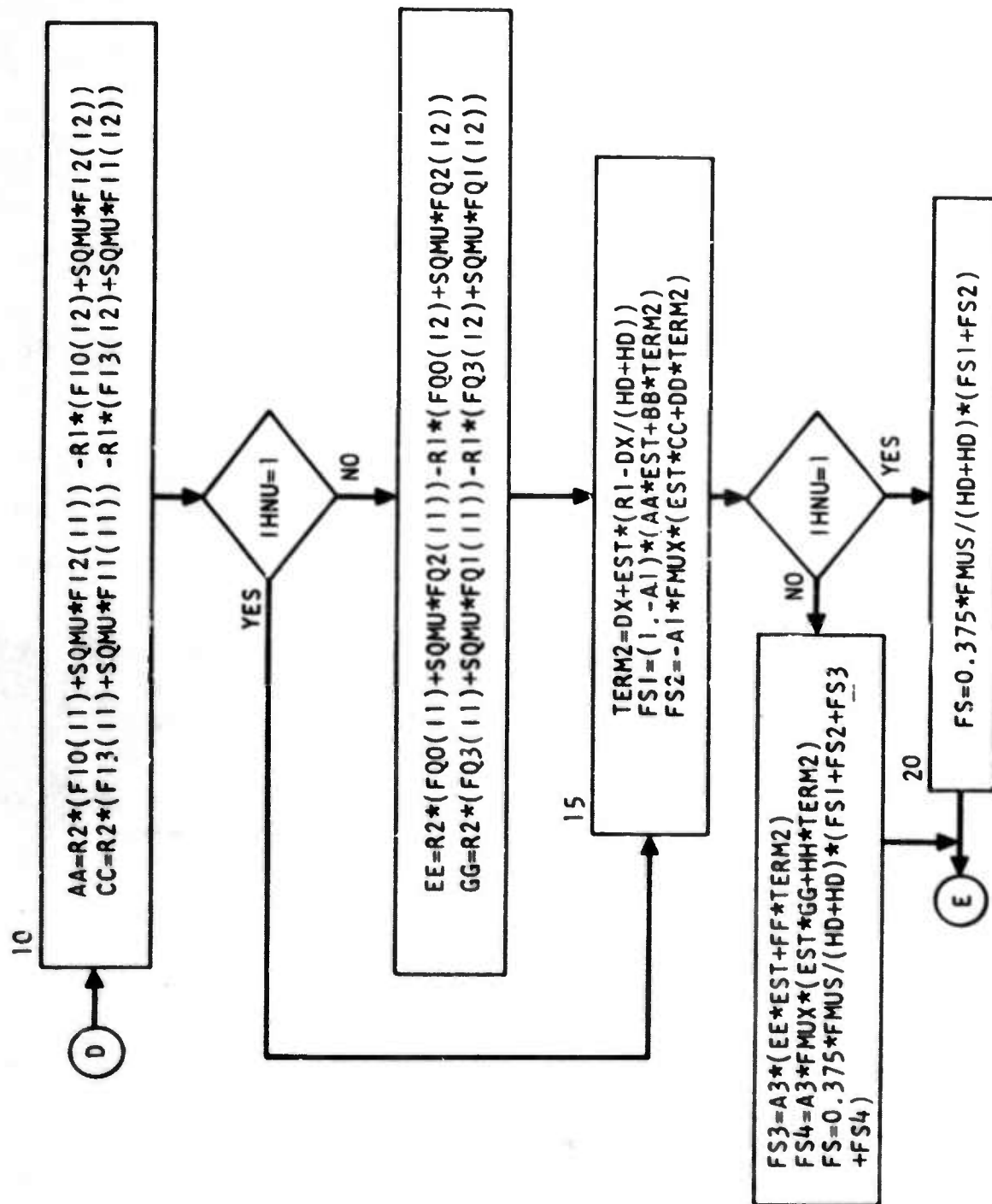


Figure 5 (concluded). SCAT

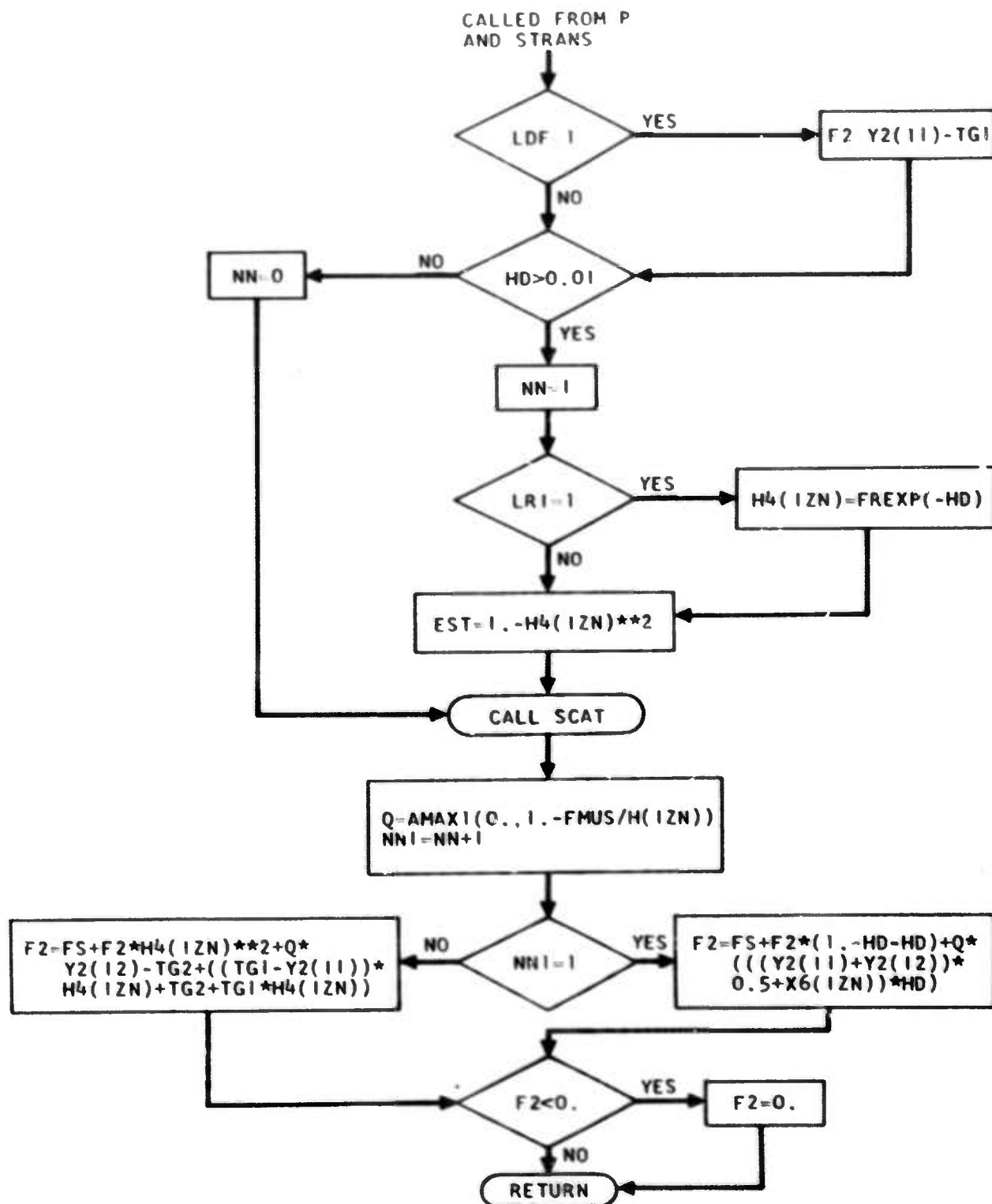


Figure 6. STEP

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 is $r_{i+1}^{n+1} - r_i^{n+1}$, 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 $ \mu $, 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 $F_{I0}(J + 1, x)$ used in Eq. (30). That is, it is the F_{I0} 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 F_{I1} . PALMER Common.
FQ2	The array corresponding to F_{I2} . PALMER Common.
FQ3	The array corresponding to F_{I3} . 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 $\mu_s/\mu = 3/16$, 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 $H \cdot \Delta x$ 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, $\int_{-1}^1 \mu d\mu$, 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 $(I_+ - I_-)$ 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 KOOOFX 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, $\int_{-1}^1 \mu^2 d\mu$. 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 sub-routines 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 $r_{IBXP1}^2 - y_j^2$, 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 $r_i^2 - y_j^2$, 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, $\int_{-1}^1 \mu^3 d\mu$. Used in calculating the scattering moment quantities. Equivalenced to SMLC in Blank Common.
X	This is an array of all the values of $\sqrt{r_i^2 - y_j^2}$ 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 $r_{IBXP1+1}^2 - r_{IBXP1}^2$. 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 $\sqrt{r_{ITUBE}^2 - EPSI^2}$, 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, $TG \cdot x/r$. 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⁾	LALPHA ⁽¹⁾	RHO ⁽³⁾	
FMS ⁽¹⁾	LAX ⁽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 sub-routines and used in RAD. CAPAC(150-152) is reserved for special input quantities. See p. 86 of this report. Blank Common.
CAPAR	$\kappa_{\text{Rosseland}}$ evaluated in KAPPA or one of its sub-routines 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 subcyclng 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 sub-routines. 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 $\bar{\gamma}$ 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 $2 \kappa_s \bar{\gamma}$, 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 K000FX ⁽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 $\log \theta$, used in linear-in-log interpolation for multifrequency absorption coefficients in DIANA. Equivalenced to CAR in Blank Common.
Q38	Zone array for $-\log \rho$, 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.
TS1	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 Processor) 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 sub-routines) 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

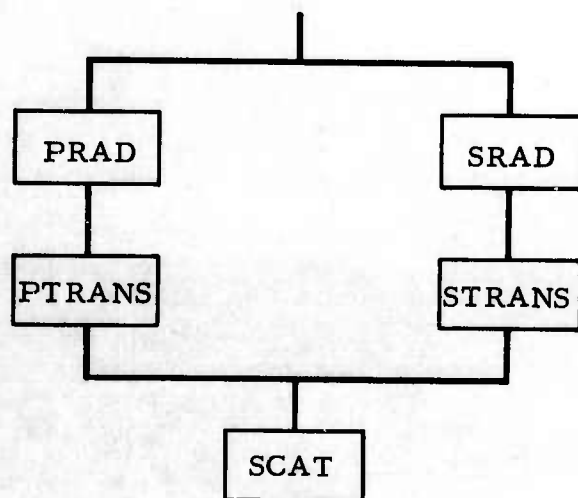
It has been convenient in several instances to write dummy subroutines with the same name as standard SPUTTER subroutines, since outright deletion of the latter would require extensive changes elsewhere in the code. The standard subroutines and the reasons why they are undesirable are as follows:

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.

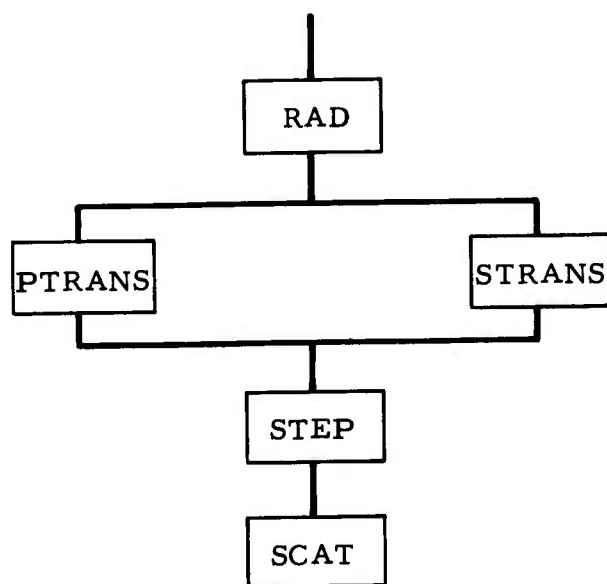
CHANGES IN RADIATION ROUTINES

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:

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

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

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

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 $I_x(v_j)$. 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/dv .

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/dv 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/dv , 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/dv , 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/dv . 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 ($x_{ij} = \sqrt{x_i^2 - y_j^2}$) 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 $3/8\text{-}\mu\text{sec}$ fetch from opposite bank versus a $3/4\text{-}\mu\text{sec}$ 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.

FORTTRAN 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, $\kappa(\text{DIANE})$ is assumed to be κ_a only, and $\kappa_s = \text{SOLID}(37)$ 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 non-standard 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 $t > \text{RDK}(52)$ 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

<u>S1 Flag</u>	<u>Immediate Cause</u>	<u>Probable Remote Causes and Comments</u>
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.

<u>S1 Flag</u>	<u>Immediate Cause</u>	<u>Probable Remote Causes and Comments</u>
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

<u>S1 Flag</u>	<u>Immediate Cause</u>	<u>Probable Remote Causes and Comments</u>
14.0001	Divide check	Same as 13.0150.
14.0005	IALPHA $\neq$ 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 $\neq$ 0	Negative scattering intensity with abort flag set. If HVB also $\neq$ 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

<u>S1 Flag</u>	<u>Immediate Cause</u>	<u>Probable Remote Causes and Comments</u>
----------------	------------------------	--

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 $0.2 \text{ cm}^2/\text{g}$ 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 CAPAC	C(151) =	-0.2	SEPTEMB	FR	18, 1967	
Column											
1	2-6	7	8-16	17-25	26-34	35-43	44-52	53-61	62-70	71-80	
2	68	3	5.0	20.							FREQCNTMAX
2	12	1.		31.							LMDA(19)
2	19	1	1.0								LMDA(36)
2	36	1	20.								IG
2	40	5	1.	31.	1.	31.	1.				TMAX
2	53	1	31.								CVB
	65	1	1.0								SLUG
	77	1	0.								ALPHA
	78	1	1.								HVB
	79	1	3.0								HC
	81	1	0.								GL
	83	1	0.								RHOR
	90	1	0.0								JC
	93	1	1.								TE
	100	1									DTMAX1-2-3
	107	1	1.0								TRDBG
	109	1	9.0								S2
	115	3	1.0	5.0	-10	1.0	-09				S3 NO COND
	127	1	0.								S4 NO BOIL
	137	1	3.								S5
	138	1	1.0								EDITMF
	139	1	-1.0								
	140	1	10.0								
	147	1	1.0								
	151	1	0.0								
	160	7	0.	1.	2.	3.	4.	5.	6.		

(Table continued on next page)

TABLE III (continued)

COMPTON 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
1677	7.		3.	9.	10.	10.5	11.	11.5	
1747	12.		12.5	13.	13.5	14.	14.5	15.	
1817	15.5		16.	16.5	17.	17.5	18.	18.5	
1883	19.		19.5	20.					
2021	1.		1.	1.	1.	1.	1.	1.	
2028	1.		1.	1.	1.	1.	1.	1.	
2035	1.		1.	1.	1.	1.	1.	1.	
2042	1.		1.	1.	1.	1.	1.	1.	
2049	1.		1.						
2325	8000.		8000.	8000.	8000.	8000.	8000.	8000.	
2332	8000.		8000.	8000.	600.	600.	600.	600.	
2339	600.		600.	600.	600.	600.	600.	600.	
2346	600.		600.	600.	600.	600.	600.	600.	
2353	600.		600.						
7338	3.01		-0.2	8.					CAPAC150-2
8405	1.								
8681	1206.								
9405	1.								
9332	776000.		72000.	68000.	64000.	60000.	56000.	52000.	
9339	748000.		44000.	40000.	36000.	32000.	28000.	24000.	
9346	620000.		16000.	12000.	8000.	4000.	1000.		
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	.2	
9372	320.		.2	80000.					
8466	10.5								TELM(25)
8853	110.0								SOLID(10)
8884	10.								SOLID(36)
8885	1--1999								SOLID(37)
8882	10.								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 $\bar{\kappa} > \kappa_s$ 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 $0 < r < 15 \text{ cm}$
 $\rho = 1.$
 $Q = 8-.433 \text{ r keV}$
 $\Delta r = 1. \text{ cm}$
- Region 2 $15 < r < 150 \text{ cm}$
 $\rho = 31/r^3$
 $\theta = 600 \text{ eV}$
 $g = 10 \text{ (i. e. , total mass of each zone is } 4/3 \pi \times 10 \text{ g)}$

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 $r > 4 \text{ cm}$ 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.

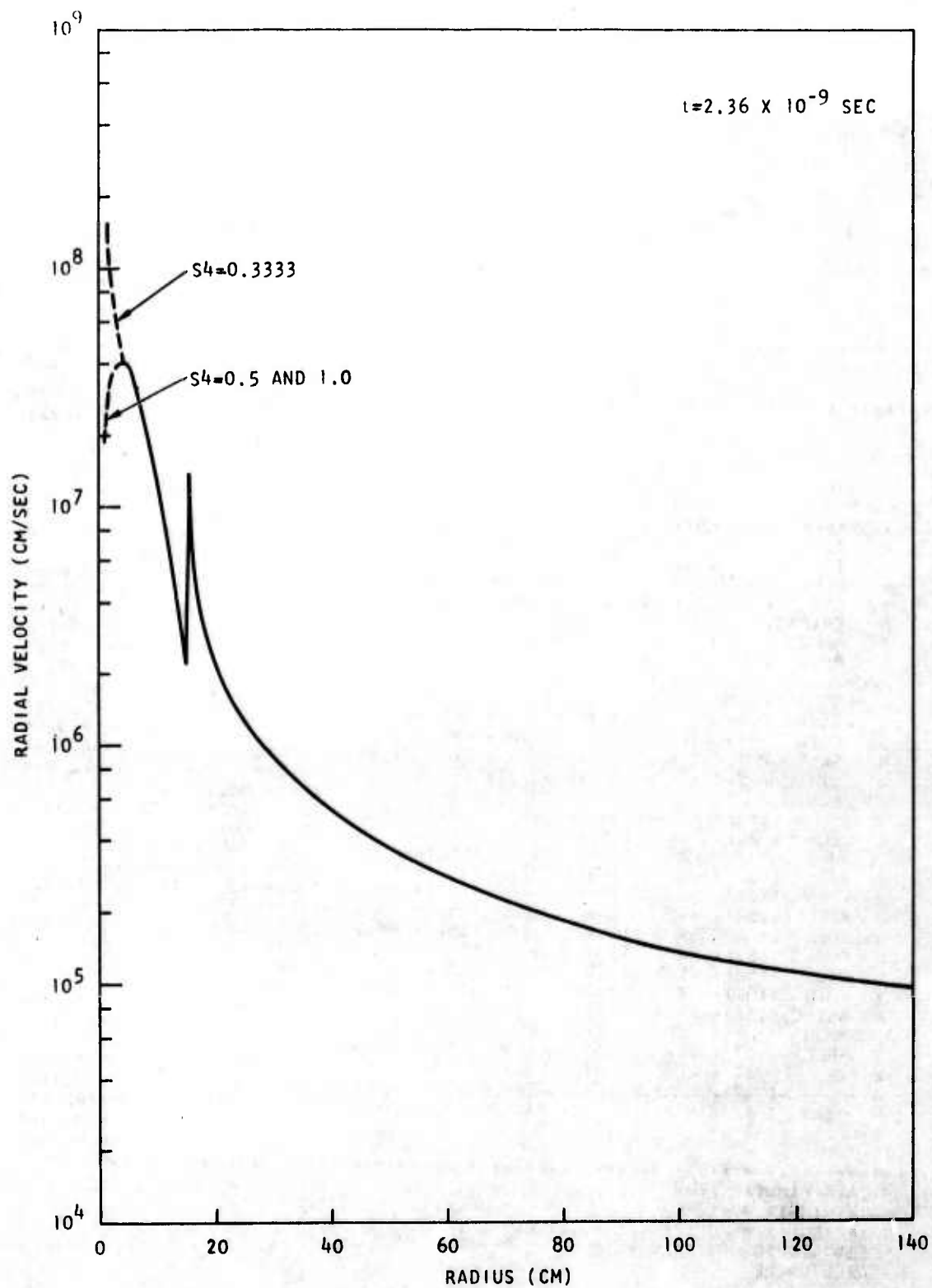


Figure 7. Dependence of Radial Velocity on Parameter $S4$

APPENDIX III

LISTING OF OUTPUT CODE ROUTINES

WIT FOR QUEB/OUT, QUEB/OUT, QUEB/OUT1

SUBROUTINE QUEB

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**KAP20090

C**KAP20100

C**KAP20110

C**KAP20120

C**KAP20130

C**KAP20140

C**KAP20150

C**KAP20160

C**KAP20170

C**KAP20180

C**KAP20190

C**KAP20200

C**KAP20210

C**KAP20220

C**KAP20230

C**KAP20240

C**KAP20250

C**KAP20260

C**KAP20270

C**KAP20280

C**KAP20290

C**KAP20300

C**KAP20310

C**KAP20320

C**KAP20330

C**KAP20340

C**KAP20350

C**KAP20360

C**KAP20370

C**KAP20380

C**KAP20390

C**KAP20400

C**KAP20410

C**KAP20420

C**KAP20430

C**KAP20440

C**KAP20450

C**KAP20460

C**KAP20470

C**KAP20480

C**KAP20490

C**KAP20500

C**KAP20510

C**KAP20520

C**KAP20530

C**KAP20540

C**KAP20550

C**KAP20560

C**KAP20570

C**KAP20580

C**KAP20590

C**KAP20600

C**KAP20610

C**KAP20620

C**KAP20630

C**KAP20640

C**KAP20650

C**KAP20660

C**KAP20670

C**KAP20680

C**KAP20690

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)
SUMS=0.
DO 30 I=IL,IR

```

30 SUMG=SUMG+G(I)
40 DO 50 I=1,152
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
   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 SMLQ(I) = TEMP(1) * G(I)
1000 FIRST= 1.
   RETURN
   END

```

BI 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 LMOA(37), NR , NSMLR , IA , IB , ICA , ICB ,
1 KMAX , BLANK1, BLANK2, BLANK3, IAP1 , IBP1 , ICAP1 , ICBP1 ,
2 II , IG , NRAU , 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, JTR , SWITCH, CO , CMIN , DELTA ,
2 GAMA , WCRIT , SIGMAQ, AC , ACOST4, 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 DELK ( 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), EH (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), GOFER (152), FEW (152), CAR (152), OKLM ( 37)
COMMON TELM ( 37), EKLM ( 37), ELM ( 37), FCLM ( 37),
1 FRLM ( 37), WLM ( 37), GLM ( 37), AMASNO( 37), CHRNO ( 37),
2 ZP1 ( 37), ZP2 ( 37), SOLID ( 37), ECHCK ( 37), RK (104),
3 KL ( 37), RHOK (104), RDK (104), THETAK(104), TEMP ( 16),
4 HEAD ( 12), MAXL , MAXLM
```

C
C* **
C*****

```
DATA FIRST/0./
N=ROK(101)
IF(FIRST.GT..5) GO TO 25
DO 20 K=1,N
IL=ROK(K)
IR=ROK(K+1)-1.
ROK(94+K)=0.
DO 10 I=IL,IR
10 ROK(94+K)=ROK(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. 12) 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 BURY 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

```

Q,T FOR QUE10/OUT, QUE10/OUT, QUE10/OUT1
SUBROUTINE QUE10
C MP1ED JULY 18, 1967 JEZ
C SPECIAL SOURCE FOR J. PALMER
C SOURCE VARIES AS R**H
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 , EPS1 , RIA , RIB , RDIA , RDIB ,KAP20190
8 RPIA , RPIB , RPU1A , RPD1B , TPRINT, TA , TB , TC ,KAP20200
COMMON TU , TE , DTH2 , DTH1 , DTRMIN, DTMAX ,KAP20210
1 DTMAX1, DTMAX2, DTMAX3, DTR , SWITCH, CO , CMIN , DELTA ,KAP20220
2 GAMA , WCRIT , SIGMAG, AC , AC03T4, CNVRT , SUMRA , SUMRB ,KAP20230
3 RO1A , RO1AM1, RO1B , RO1BP1, 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 ASU (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 CHIN (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-I
   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)-I.
   SUMQ = 0.
   SUMS = -.5*G(IL-1)
   DO 90 I=IL,IR
   SUMS = SUMS+.5*(G(I-I)+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
   SMLQ(I) = SMLQ(I)*(SOLID(8)/SUMQ)
95  FIRST= 1.
1000 RETURN
    END

```

```
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
```

C KAPP0430
C **KAPP0440
C *****KAPP0450
C COMMON /LINDLY/ HNU,SGHL,IHNU,NHNU,MNUP,NT,IM,IN,DHNU,THICK,NY KAPP0460
C KAPP0470
C KAPP0480

106

```

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=MINU(LMDA(J)-1,M)
      J= J - 1
      IF(QLM(J+17))400,350,400
350   QLM(J+17)=ADS(OKLM(J))
400   CONTINUE
      SOLID(20)= IL
      SOLID(21)=IR
      SOLID(22)=J
      IF(AMASHO(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=1
      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
      GO TO 700
      2 CALL KAP2
      GO TO 700
      3 CALL KAP3
      GO TO 700
      4 CALL KAP4
      GO TO 700
      5 CALL KAP5
      GO TO 700
      6 CALL KAP6
      GO TO 700
      7 CALL KAP7
      GO TO 700
      8 CALL KAP8
      GO TO 700
      9 CALL KAP9
      GO TO 700
      10 CALL KAP10
      GO TO 700
      11 CALL KAP11
      GO TO 700
      12 CALL KAP12
      GO TO 700
600   CALL UIANA(J)
700   DO 800 I=IL,IR
      CAPAR(I) = AKIN1(CAPAR(I), 2.620E6/THETA(I))
800   CONTINUE
      CALL UVCHK(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

```

KAPP1170

KAPP1190

KAPP1210

KAPP1230

KAPP1250

KAPP1270

KAPP1290

KAPP1310

KAPP1330

KAPP1350

KAPP1370

KAPP1390

Q, 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

C

```
COMMON LMDA(37), NH , NSMLR , IA , IB , ICA , ICB ,
1 KMAX , BLANK1, BLANK2, BLANK3, IAP1 , IBP1 , ICAP1 , ICBP1 ,
2 II , IG , NKAU , BLANK4, IAM1 , IBM1 , ICAM1 , ICBM1 ,
3 IIP1 , IGM1 , IALPHA, BLANK5, IN , TMAX , BLANK6, DELPRT,
4 FREQ , CNTMAX, AN , ASMLR , PUSHA , PUSHB , HOILA , BOILH ,
5 CVA , CVB , SLUG , ALPHA , HVA , HVB , HCA , HCB ,
6 EMINA , EMINB , CA , CB , GA , GB , GL , GR ,
7 RMOL , RMOR , EPIO , EPSI , RIA , RID , ROIA , ROIB ,
8 RPIA , RPIB , RPDIA , RPDIB , TPRINT, TA , TB , TC
COMMON TD , TE , UTH2 , UTH2P , UTH1 , DTRMIN, DTMAX ,
1 UTHAX1, UTHAX2, DTMAX3, UTR , 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), HU (152), VD (152), RDO (152), SMLR (152),
8 UELM ( 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 CHIN (152), CAPAC (152), CAPAH (152), CRTC (152), CRTR (152),
8 CRTPC (152), GOFH (152), FEW (152), CAR (152), OKLM ( 37),
COMMON TELM ( 37), EKLM ( 37), ELM ( 37), FCLM ( 37),
1 FRLM ( 37), WLM ( 37), OLM ( 37), AMASNO( 37), CHRNO ( 37),
2 ZP1 ( 37), ZP2 ( 37), SOLID ( 37), ECHCK ( 37), RK (104),
3 NL ( 37), NHOK (104), ROK (104), THETAK(104), TEMP ( 16),
4 HEAD ( 12), MAXL , MAXLM
```

C

C

C.....

COMMON /LINDLY/ HNU,SGNL,IMNU,NHNU,MNUP,NT,IM,IN,DMNU,THICK,NY

IF (IMNU.EQ. 1) NHNU = THETAK(101)

HNU = THETAK(IMNU+60)

IK = SOLID(20)

IL = SOLID(21)

DO 10 I = IK, IL

IF (IMNU.GT. 0) GO TO 6

C GREY KAPPA

CAPAH(1) = THETAK(102)

GO TO 10

C MULTIFREQUENCY KAPPA

6 CAPAH(I) = THETAK(IMNU+80)

10 CAPAC(I) = CAPAH(I)

RETURN

END

W,T FOR KAP12/JP, KAP12/JP, KAP12/JP1
SUBROUTINE KAP12

KAP10010
KAP10020
ES3 0040

C
C
C
C
C
C
C

SPUTTER COMMON

```

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, AK , 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 , RHOB , EP10 , EPSI , RIA , RIB , ROIA , ROIB ,
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 , SIGMAJ, AC , AC03T4, 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), HU (152), VD (152), RDO (152), SMLR (152),
8 DELK ( 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), GUFH (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 HL ( 37), RHOK (104), ROK (104), THETAK(104), TEMP ( 16),
4 HEAD ( 12), MAXL , MAXLM
IL=SOLID(21)

```

KAP10050

C
C
C
C

```

IK=SOLID(20)
J=SOLID(22)
CHRN=92.0
AMASH=4.017E+9
ZPA=2.408E-03
ZPB=3.821E+04
DO 1000 I=IK,IL
IF(THETA(I).NE.0.) GO TO 1

```

KAP10030
KAP10040
KAP10060
KAP10070
KAP10080
KAP10090
KAP10100
KAP10110

```

CAPAK(1)=.2
CAPAC(1)=.2
GO TO 1000
1 IAT=1
TEMP(3)=THETA(1)**2
TEMP(4)=TEMP(3)**2
TEMP(5)=THETA(1)**1.5
C * * * * *
IF(SV(1).GE.10.) GO TO 200
IF(SV(1).LE.1.) GO TO 10
IXI=2
SVI=SV(1)
SV(1)=10.
DYDY=ALOG(10./SVI)/(2.3025851)
GO TO 200
5 SV(1)=1.
TEMP(6)=CAPAK(1)
C * * * * *
10 IF(THETA(1)-1000.0) 12,12,14
12 CAPAK(1)=5.49E+6/(TEMP(5)*(1.0+1.E-6*SV(1)*TEMP(3)))+13.1*
1 SORT(SV(1))
CAPAK(1) = AMAX1(OKLM(J+17) * CAPAK(1), .2)
GO TO 20
14 CAPAK(1)=(1.0+1.75E12/TEMP(4))*(.0789+2.784E21/(TEMP(3)*(7.6E13*
1 SORT(SORT(SV(1))) + TEMP(4)*SV(1))))
CAPAK(1) = AMAX1(OKLM(J+17) * CAPAK(1), .2)
20 GO TO (350,340),IXI
C * * * * *
200 CONTINUE
IF(THETA(1)-20.0) 201,201,202
201 EFF=1.E2
GO TO 300
202 IF(THETA(1)-20.0) 203,203,204
203 EFF=9.E2/(THETA(1)+1.0)**2+2.5E-5*THETA(1)**5
GO TO 300
204 IF(THETA(1)-100.0) 205,205,206
205 EFF=6.56E5/THETA(1)**3+5.E-5*THETA(1)**3
GO TO 300
206 EFF=6.0+4.4E5/THETA(1)**2
300 CONTINUE
WS=SQRT(THETA(1))
WSA = FEW(1)**2/SV(1)
IF(FLA(1).LT.1.) GO TO 330
WSA=WSA*FEW(1)
GO TO 335
330 WSA = AMIN1(WSA, 1.E10/AMASN*THETA(1)*WS*EXP(-8.0/THETA(1)))
335 CAPAK(1) = AMASN**2*9.06E-14/THETA(1)**3*WSA/WS
CAPAK(1)=AMAX1(OKLM(J+17)*EFF*CAPAK(1),.2)
GO TO (350,3),IXI
C * * * * *
340 CAPAK(1)=EXP(ALOG(TEMP(6))+(ALOG(CAPAK(1))-ALOG(TEMP(6)))*DYDY)
SV(1)=SVI
C * * * * *
C * * * * *
350 WSB=13.0/THETA(1)*(CHRN**2)
IF(FEW(1).EQ.0.) GO TO 370
360 WSC=1.E+10/AMASN*TEMP(5)/FEW(1)*SV(1)
GO TO 380
370 WSC= 1.
380 CONTINUE
CAPAC(1)=.87*CAPAK(1)*AMIN1(1.0*WSB,1.0*ALOG(WSC))
CAPAC(1)=AMAX1(CAPAC(1),CAPAK(1))
.000 CONTINUE
RETURN
END

```

KAP10200
KAP10210
KAP10220

KAP10200
KAP10270
KAP10280

KAP10300
KAP10310
KAP10320

KAP10410
KAP10420
KAP10430
KAP10440
KAP10450
KAP10460
KAP10470
KAP10480
KAP10490
KAP10500
KAP10510

KAP10600
KAP10610

KAP10630
KAP10640
KAP10650
KAP10660
KAP10670

Q1 FOR RTAPE/ORIG, RTAPE/ORIG, RTAPE/A1
SUBROUTINE RTAPE(NTAPE,CYCLE)

RTAP0010

C

C,MPILED 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

C

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 , ICRM1 , RTAP0090

3 IIP1 , IGM1 , IALPHA, BLANK5, TH , TMAX , BLANK6, DELPRT, RTAP0100

4 FREQ , CNTMAX, AR , ASMLR , PUSHA , PUSHB , HOILA , BOILB , RTAP0110

5 CVA , CVB , SLUG , ALPHA , MVA , MVB , HCA , HCB , RTAP0120

6 EMINA , EMINB , CA , CB , GA , GB , GL , GR , RTAP0130

7 RHOL , RHOR , EP10 , EPSI , RIA , RIB , RDIA , RDIB , RTAP0140

8 RPIA , RPIB , RPDIA , RPDIB , TPRINT, TA , TB , TC , RTAP0150

COMMON TU , TE , UTH2 , DTH2P , DTH1 , DTRMIN, DTMAX , RTAP0160

1 DTMAX1, DTMAX2, DTMAX3, DTR , SWITCH, CO , CMIN , DELTA , RTAP0170

2 GAMA , WCRIT , SIGMAJ, AC , ACO3T4, CNVPT , SUMRA , SUMRB , RTAP0180

3 ROIA , ROIAM1, HOIB , HOIBP1, 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), RU (152), VD (152), ROD (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), BK (152), CHIC (152), RTAP0310

7 CHIR (152), CAPAC (152), CAPAR (152), CHTC (152), CRTR (152), RTAP0320

8 CRIPC (152), GUFH (152), FEW (152), CAR (152), OKLM (37), RTAP0330

COMMON TELM (37), EKLM (37), ELM (37), FCLM (37), RTAP0340

1 FRLM (37), WLM (37), GLM (37), AMASNO(37), CHRNO (37), RTAP0350

2 ZP1 (37), ZP2 (37), SOLID (37), ECHCK (37), RK (104), RTAP0360

3 HL (37), RHOK (104), RUK (104), THETAK(104), TEMP (16), RTAP0370

4 HEAD (12), MAXL , MAXLM , RTAP0380

C*****RTAP0390

C*****RTAP0400

C*****RTAP0410

COMMON /LINDLY/ HNU,SGIL,IMNU,NHNU,HNUF,NT,IM,IN,OHNU,THICK,NY

COMMON /PALMER/ F10(152), F11(152), F12(152), F13(152), F00(152),

2 F01(152), F02(152), F03(152), JDRUM

C RTAPE DEFINES JDRUM ON RESTARTS. RTAPE DEFINES IT ON INITIAL STARTS.

NHNU = LHOA(36)

REWIND RTAPE

10 READ (NTAPE) COUNT

IF (COUNT.LT.0..OR.COUNT.GT.CYCLE) GO TO 30

IF (ABS(F0) .GT. 1.E-20) READ (NTAPE)

RTAP0420

RTAP0430

RTAP0440

IF (ABS(COUNT - CYCLE) .LT. 1.E-20) GO TO 20	
WRITE (6,50) COUNT	
50 FORMAT (1H0 5X, 6HCYCLE F6.0, 8H SKIPPED)	RTAP0460
READ (NTAPE)	
DO 15 I = 1, NHNU	
15 READ (NTAPE)	RTAP0470
GO TO 10	RTAP0480
20 READ (NTAPE)(LMUA(I),I=1,9405)	
JURUM = 25	
LMUA(36) = NHNU	
DO 25 I = 1, NHNU	
READ (NTAPE) F10, F11, F12, F13	
25 WRITE (JURUM) F10, F11, F12, F13	RTAP0490
RETURN	RTAP0500
30 S1 = 40.	
WRITE (6, 40) SOLID(34)	
40 FORMAT (1H0 5X 6HCYCLE F6.0, 17H NOT ON DUMP TAPE)	
CALL EX17	RTAP0520
END	

AFWL TR 67-131, Vol III

Q1 FOR WTAPE/SP, WTAPE/SP, WTAPE/SP1

SUBROUTINE WTAPE

COMPILED APRIL 27, 1967 WBL

SPECIAL VERSION FOR COMPTON SCATTERING CODES

```

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      , IRAD      , 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      , KIA      , RIR      , RDIA      , ROIB      ,
8  RPIA      , RPIB      , RPOIA      , RPOIB      , TPRINT, TA      , TB      , TC      ,
COMMON  ID      , TE      , DTH2      , DTH2P      , DTH1      , DTRMIN, DTMAX      ,
1  DTMAX1, DTMAX2, DTMAX3, DTR      , SWITCH, CO      , CMIN      , DELTA      ,
2  GAMA      , WCRIT      , SIGMAU, AC      , ACOST4, CNVRT      , SUMRA      , SUMRB      ,
3  ROIA      , NOIAM1, 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      , DELTA(152),
7  ASG      (152), RU      (152), VD      (152), RUD      (152), SMLR      (152),
8  DELR      (37), P      (152), P1      (152), PB      (152), PB1      (152),
COMMON  P2      (152), SV      (152), RMO      (152), THETA      (152),
1  W      (152), E      (152), EI      (152), EK      (152), A      (152), X2      (152),
2  V      (152), G      (152), D      (152), C      (152), X7      (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), GOFK      (152), FEW      (152), CAR      (152), OKLM      (37),
COMMON  TELM      (37), EKLM      (37), ELM      (37), FCLM      (37),
1  FRLM      (37), WLM      (37), QLM      (37), AMASHO(37), CHRNO      (37),
2  ZP1      (37), ZP2      (37), SOLID      (37), ECHCK      (37), RK      (104),
3  RL      (37), RHOK      (104), RDK      (104), THETA(104), TEMP      (16),
4  HEAD      (12), MAXL      , MAXLM
C
C*****
C
COMMON /LINDLY/ HM,SG,L,IMNU,NHNU,MNUP,NT,IM,IN,OHNU,THICK,NY
COMMON /PALMER/ FIU(152), F11(152), F12(152), F13(152), F00(152),
2 F01(152), F02(152), F03(152), JORUM
COMMON /CNTML/ SCYCLE, J4ULT
C
N=55
WS=-3.0
WRITE (N) SOLID(18)
IF (ABS(FO) .GT. 1.E-20) WRITE (N) TH
C
WRITE (N)(LMDA(I),I=1,9405)
NHNU = LMDA(36)
IF (SOLID(18) .GT. SCYCLE) REWIND JORUM
DO 10 I = 1, NHNU
IF (SOLID(18) .GT. SCYCLE) READ (JORUM) FI0, F11, F12, F13
10 WRITE (N) FI0, F11, F12, F13
WTAPE DEFINES JORUM ON INITIAL STARTS. WTAPE DOES IT ON RESTARTS.
IF (SOLID(34) .GT. 0. .OR. SOLID(14) .GT. 0.) GO TO 20
JORUM = 25
REWIND JORUM
DO 15 I = 1, NHNU
15 WRITE (JORUM) FI0, F11, F12, F13
20 WRITE (N) WS
BACKSPACE N
RETURN
END

```

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BI   FOR      MP2/XX,MP2/XX,MP2/XXX
      SUBROUTINE MP2
      OUTPUT VERSION -- BOIL, CNDOCTN DELETED
C
C
C
C*****3MAI0010
C*****3MAI0030
C*****3MAI0040
C*****3MAI0050
C*****3MAI0060
C*****3MAI0070
C*****3MAI0080
C*****3MAI0090
C*****3MAI0100
C*****3MAI0110
C*****3MAI0120
C*****3MAI0130
C*****3MAI0140
C*****3MAI0150
C*****3MAI0160
C*****3MAI0170
C*****3MAI0180
C*****3MAI0190
C*****3MAI0200
C*****3MAI0210
C*****3MAI0220
C*****3MAI0230
C*****3MAI0240
C*****3MAI0250
C*****3MAI0260
C*****3MAI0270
C*****3MAI0280
C*****3MAI0290
C*****3MAI0300
C*****3MAI0310
C*****3MAI0320
C*****3MAI0330
C*****3MAI0340
C*****3MAI0350
C*****3MAI0360
C*****3MAI0370
C*****3MAI0380
C*****3MAI0390
C*****3MAI0400
C*****3MAI0410
C*****3MAI0420
C*****3MAI0430
C*****3MAI0440
C*****3MAI0450
C*****3MAI0460
C*****3MAI0470
C*****3MAI0480
C*****3MAI0490
C*****3MAI0570

      COMMON /SPUTTER COMMON/
      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 FRLQ, CNTMAX, AR, ASMLR, PUSHA, PUSHB, HOILA, BOILB,
5 CVA, CVB, SLUG, ALPHA, HVA, HVB, HCA, HCB,
6 EMINA, EMINB, CA, CB, GA, GB, GL, GR,
7 RHOL, RHOB, EPIO, EPSI, RIA, RIB, RDIA, RDIB,
8 RPIA, RPIB, RPDIA, RPDIB, TPRINT, TA, TB, TC,
      COMMON TU, TE, UTH2, DTH2P, DTH1, DTRMIN, DTMAX,
1 DTMAX1, DTMAX2, DTMAX3, UTR, SWITCH, CO, CMIN, DELTA,
2 GAMA, WCHIF, SIGMAQ, AC, ACOST4, CNVRT, SUMRA, SUMRB,
3 ROIA, ROIAM1, ROIB, ROIBP, 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, FAU, ZERO, R, DELTAR,
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), GOFK (152), FEW (152), CAR (152), OKLM (37),
      COMMON TELM (37), EKLM (37), ELM (37), FCLM (37),
1 FRLH (37), WLM (37), OLM (37), AMASNO (37), CHRHO (37),
2 ZP1 (37), ZP2 (37), SOLID (37), ECHCK (37), RK (104),
3 RL (37), RHOK (104), HDK (104), THETAK (104), TEMP (16),
4 HEAD (12), MAXL, MAXLM,
      COMMON /CNTRL/ SCYCLE, JMULT,
      EQUIVALENCE (S12,ED1TMF),
      HYDRO SUB-CYCLE VERSION 9/25/63
      TO=0.
      IF (BLANK2 .GT. 1.E-15) TPRINT=TH + BLANK2
      5 IF (WARN(IHR)) 10, 600, 600

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10 IF (EKLM(19)) 501, 520, 501	3MAI0580
501 CONTINUE	3MAI0590
CALL AUT0RZ	3MAI0600
520 IF (GMS) 530, 201, 530	3MAI0610
530 CALL DEZONE	3MAI0620
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=IHM1	
GO TO 2010	
2001 IBD = IA	
2010 CONTINUE	3MAI0720
204 CALL HYDRO	3MAI0730
202 CALL PTWO	3MAI0740
	3MAI0750
	3MAI0760
C	
C SELECT SOURCE	
IF (ABS(S6) .LT. 1.E-20) GO TO 80	
CALL QUE	
C	3MAI0950
80 CONTINUE	3MAI0960
DTH=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-DTH+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)/DTH).LT.1.5) GO TO 110	
105 CALL SSNTCH (6, K000FX)	3MAI1150
GO TO (106, 107), K000FX	3MAI1160
106 S1 = 1.0106	3MAI1170
GO TO 610	3MAI1180
107 CONTINUE	3MAI1190
IF (WARN(IHM)) 108, 605, 605	3MAI1200
108 ZP1(18)=ZP1(18)-DTH	3MAI1210
ZP1(19)=ZP1(19)+1.0	3MAI1220

	GC TO 84	3MAI1230
	110 CONTINUE	3MAI1240
C	FORCE SV TO BE CONSISTENT WITH R AND G	
	DO 111 I=IA, IUM1	
	SV(I)=DELTAR(I)/G(I)	
	IF (IALPHA.EQ.1) GO TO 111	
	TEMP(1)=R(I+1)+R(I)	
	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(I*8)	
	BLANK4 = BLANK4 + SOLID(28)*DTH2	
909	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. THAX) 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, KU00FX)	3MAI1390
	GO TO (250, 5), KU00FX	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	


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      IR = IB
      CALL UVCHK(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  DELTA(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(I), 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 UVCHK(KP)
      IF(KP.LT. 2) X=SQRT(-KP)
30  CONTINUE
      R(IA) = R(IA)+RD(IA)*DTH2
      DO 50 I=IA,IBM1
      TEMP(1) = DELTA(I)+(RD(I+1)-RD(I))*DTH2
      R(I+1) = R(I)+TEMP(1)
      IF(S10)41,42,43
41  A(I) = 1.
      VD(1) = 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.1.E-6)GO T
10 45
VD(I) = (TEMP(1)*(R(I+1)*(R(I+1)+R(I))+R(I)*R(I))-DELTAR(I)*(C(I+1
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+1)+R(I)))*(RD(I+1)-RD(I))
50 DELTAR(I) = TEMP(1)
A(IH) = ALPHA*R(IH)**(ALPHA-1.)
CALL DVCHK(KP)
IF(KP.GT. 1) GO TO 70
SI=7.129
X=-1.
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 PHAGEN, 18 APRIL 1967

C COMPILED JUNE 3, 1966

C COMPILED 1 NOV 1965

ECAL0020

C INCLUDES INTEGRATED FLUX THRU NK SURFACE
C (FRLM(19)).

ECAL0030

ECAL0040

ECAL0050

ECAL0060

ECAL0070

C *****

ECAL0080

C *****

ECAL0090

S P U T T E R C O M M O N

ECAL0100

C *****

ECAL0110

C *****

ECAL0120

COMMON LMUA(37), NR , NSMLR , IA , IB , ICA , ICB , ECAL0130

1 KMAX , BLANK1, BLANK2, BLANK3, IAP1 , IBP1 , ICAP1 , ICBP1 , ECAL0140

2 I1 , IG , NHAD , BLANK4, IAM1 , IBM1 , ICAP1 , ICBM1 , ECAL0150

3 IIP1 , IGM1 , IALPHA, BLANK5, TH , TMAX , BLANK6, DELPHT, ECAL0160

4 FREQ , CNTMAX, AH , ASMLR , PUSHA , PUSHB , BOILA , BOILD , ECAL0170

5 CVA , CVB , SLUG , ALPHA , HVA , HVB , HCA , HCB , ECAL0180

6 EMINA , EMINB , CA , CB , GA , GB , GL , GR , ECAL0190

7 RHUL , RHOR , EPIO , EPSI , RIA , RIR , RDIA , RDIB , ECAL0200

8 RPIA , RPIB , RPDIA , RPDIB , TPRINT, TA , TB , TC , ECAL0210

COMMON TU , TE , DTH2 , DTH2P, DTH1 , DTRMIN, DTMAX , ECAL0220

1 DTMAX1, DTMAX2, DTMAX3, DTH , SWITCH, CO , CMIN , DELTA , ECAL0230

2 GAMA , WCRIT , SIGMA0, 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 ASW (152), RU (152), VD (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 CHIM (152), CAPAC (152), CAPAR (152), CRTC (152), CRTR (152), ECAL0380

8 CRTPC (152), GOFK (152), FEW (152), CAH (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

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ECAL0460

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ECAL0470

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ECAL0480

EQUIVALENCE (LMUA(24), IBB)

DIMENSION ERLM(1)
EQUIVALENCE (FCLM, ERLM)

ECAL0490
ECAL0500

C
C

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      IF (PUSHA) 1, 5, 5
1    IC = IB
      FRLM(18) = FRLM(18) + DTR*X2(1A)
      IF (EMINA - E1(ICBM1)) 2, 2, 10
2    IF (ICB - 10) 3, 3, 10
3    ICBM1 = ICB
      ICB = ICBP1
      ICBP1 = ICB + 1
      CALL EOS (ICBM1)
      GO TO 10
5    IC = 1A
      FRLM(18) = FRLM(18) + DTR*X2(1U)
      IF (IFIX(PUSHA) .EQ. 0) GO TO 10
      IF (S3) 10, 6, 10
6    IF (EMINA .GT. E1(ICA)) GO TO 10
      IF (ICA .EQ. 1) GO TO 10
      ICAP1 = ICA
      ICA = ICAM1
      ICAM1 = ICA - 1
      CALL EOS (ICA)
10   CONTINUE
      DO 180 J = 1, MAXL
      ELM(J) = 0.
      IL = LMDA(J)
      NVAP = 0
      IF (IL .GE. 1A .AND. IL .LE. 1B) 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(1)
      IF (S10) 104, 103, 102
102  TEMP(1) = TEMP(1) * (.5. + R(1) * (H(1) + TEMP(1)) + TEMP(1)**2)
      GO TO 104
103  TEMP(1) = TEMP(1)*(2.*R(1) + TEMP(1))
104  ERLM(J) = ERLM(J) + RHO(1) * TEMP(1)
      IF (IFIX(S2) .NE. 3) GO TO 105
      ELM(J) = ELM(J) + RHO(1) * TEMP(1)
105  IF (IFIX(S6) .EQ. 0) GO TO 110
      QLM(J) = QLM(J) + SMLQ(1)*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. 1C) GO TO 160
      GX = SOLID(24)*G(18B)
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 160
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 (IS) 180, 175, 160
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, IMM1
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(HR)
    P(152) = MAX1(P(152), SOLID(28))
    RETURN
    END

```

ECAL1110
ECAL1120

W,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

C COMPILED SEPTEMBER 17, 1967 RUL

C COMPILED FEB. 15, 1967 H. 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 2-3

C COMPILED MAY 18, 1966 BY G. A. LANE

C COMPILED MAY 10, 1965. RSE TAKES ADVANTAGE OF NEW PATH (-3.) IN
EIONX.

EOS 0030

C COMPILED ON MARCH 31, 1966 ADDING COMMON FOR NHAR (GE)

EOS 0040

C

C S P U T T E R C O M M O N

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COMMON/LMS/ EION(20)
EQUIVALENCE(EION(3),ZHA)
EQUIVALENCE(EION(16),ZLEH)
COMMON/LMSE/MATERL,ILEMIT,SNAFU,(1,12,13,14,15,16,(17,18,19,110,J1,
2 J2,J3,J4,J5,J6,J7)
DATA MATERL,ILEMIT,SNAFU,(1,12,13,14,15,16,17,18,19,110,J1,J2,J3,
2 J4,J5,J6,J7/2*0.0,0.0,17*0.
EQUIVALENCE (L,MATERL)
EQUIVALENCE (SNAFU,PATII)
COMMON/LMSC/ M(51)
DIMENSION Z(51),PART(1)
EQUIVALENCE(M(1),NOLMIT), (M(2),Z(2)),(M(3),PART(3))
COMMON/LMSD/ TLMS(30)
EQUIVALENCE(TLMS(15),DZDTAU )
EQUIVALENCE(TLMS(16),DZDHT)

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C
COMMON/CNTRL/SCYCLE,OMULT
COMMON/GE/NUAR
REAL NUAR
NUAR= 1.
IF(SOLID(18).EQ.SCYCLE) I10=0
I = JJ
IX = NR - 1
NX = 1
IF (PUSHA) 303,2,302
302 IF (I - IAMI) (1,2
303 IX = NR
NX = -1
IF (I - IB) 2,1,1
1 E(I)=CVA*(THETA(I)-.025)
CV(I)=CVA
PB1(I)=0.0
P1(I)=0.0
GO TO 500
2 CONTINUE
DO 100 J=1, MAXLM
IF (I-LMDA(J+1)) 5,6,6
5 SOLID(20)=I
SOLID(21)=I
SOLID(22)=J
EOS 1070
EOS 1120
EOS 1130
EOS 1140
EOS 1150
EOS 1170
EOS 1180
EOS 1190
EOS 1200
EOS 1210
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

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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 ((1-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
  TO AVOID 'EIONX', SET RHOR.EQ.1.E38.
C
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
  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 = FEN(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 5
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

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P1(I) = EION(7)
E(I) = EION(8)
IF ((I-IX)*NX.GT.0 .AND. ZP1(26).NE.0.) GO TO 203
CV(I) = EION(9)
ASQ(I) = EION(11)
FEW(I) = EION(13)
PB1(I) = EION(10)
IF (H1B.EQ.0.) GO TO 199
IF (SV(I).GE.SOLID(17)) GO TO 199
P1(I) = P1(I) + 1.E12*(SOLID(17)/SV(I)-1.)*2
ASQ(I) = SQRT(ASQ(I)**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
11 CALL ES1
GO TO 200
12 CALL ES2
GO TO 200
13 CALL ES3
GO TO 200
14 CALL ES4
GO TO 200
15 CALL ES5
GO TO 200
16 CALL ES6
GO TO 200
17 CALL ES7
GO TO 200
18 CALL ES8
GO TO 200
19 CALL ES9
GO TO 200
20 CALL ES10
GO TO 200
21 CALL ES11
GO TO 200
22 CALL ES12
GO TO 200
6 CONTINUE
100 CONTINUE
C
ASQ IS SPEED OF SOUND
200 ASQ(I) = SQRT(.25*GAMA*P1(I)*SV(I))
199 IF (IFIX(S2).EQ. 3) GO TO 404
GO TO 150
404 P1(I) = RHO(I) * 0.3333333 + P1(I)
GO TO 400
150 IF(RPIA)400,201,400
201 TEMP(I)=THETA(I)**4
P1(I)=P1(I)+.5*(SMLR(I)+SMLR(I+1))
PB1(I)=137.0*TEMP(I)+PB1(I)
E(I)=E(I)+137.0*TEMP(I)*SV(I)
CV(I)=CV(I)+548.0*TEMP(I)/THETA(I)*SV(I)

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./HVAR + FEW(I))
401 E(I) = E(I) + ECHCK(J+17)
500 RETURN
END

```

EOS 1240
EOS 1250
EOS 1260
EOS 1270
EOS 1280
EOS 1290
EOS 1300
EOS 1310
EOS 1320
EOS 1330
EOS 1340
EOS 1350
EOS 1360
EOS 1370
EOS 1380
EOS 1390
EOS 1400
EOS 1410
EOS 1420
EOS 1430
EOS 1440
EOS 1450
EOS 1460
EOS 1470
EOS 1480
EOS 1490
EOS 1500

EOS 1520
EOS 1540
EOS 1550
EOS 1560

EOS 1580

9, 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.....**PRAD 70

C.....**PRAD 80

C.....**PRAD 90

COMMON LMUA(37), NR, NSMLR, IA, IB, ICA, ICB, PRAD 100

1 KMAX, BLANK1, BLANK2, BLANK3, IAP1, IBP1, ICAP1, ICBP1, PRAD 110

2 II, IG, HRAD, BLANK4, IAM1, IBM1, ICAM1, ICBM1, PRAD 120

3 IIP1, IGM1, IALPHA, BLANK5, ITH, TMAX, BLANK6, DELPRT, PRAD 130

4 FREQ, CNTMAX, AK, ASMLR, PUSHA, PUSHB, BOILA, BOILB, PRAD 140

5 CVA, CVB, SLUG, ALPHA, HVA, HVH, MCA, MCB, PRAD 150

6 EMINA, EMIB, CA, CB, GA, GB, GL, GR, PRAD 160

7 RHOL, RHOR, EPIO, EPSI, RIA, RIB, ROIA, ROIB, PRAD 170

8 RPIA, RPIB, RPOIA, RPOIB, TPRINT, TA, TB, TC, PRAD 180

COMMON TD, TE, DTH2, DTH2P, DTH1, DTRMIN, DTMAX, PRAD 190

1 DTMAX1, DTMAX2, DTMAX3, UTR, SWITCH, CO, CMH, DELTA, PRAD 200

2 GAMA, WCRIT, SIGMAJ, AC, ACOJ4, CNVRT, SUMRA, SUMRB, PRAD 210

3 ROIA, ROIAM1, ROIB, ROIBP1, GMS, S1, S2, S3, PRAD 220

4 S4, S5, S6, S7, S8, S9, S10, S11, PRAD 230

5 S12, S13, S14, S15, S16, S17, S18, S19, PRAD 240

6 S2U, EO, FO, TAU, ZERO, R (152), DELTAR(152), PRAD 250

7 ASQ (152), RD (152), VD (152), RDD (152), SMLR (152), PRAD 260

8 DELR (37), P (152), P1 (152), PB (152), PB1 (152), PRAD 270

COMMON P2 (152), SV (152), RHO (152), THETA (152), PRAD 280

1 W (152), E (152), E1 (152), EK (152), A (152), PRAD 290

2 V (152), G (152), D (152), C (152), X2 (152), PRAD 300

3 X3 (152), X4 (152), X5 (152), X6 (152), X7 (152), PRAD 310

4 SMLA (152), SMLB (152), SMLC (152), SMLD (152), SMLE (152), PRAD 320

5 EC (152), ER (152), SMLQ (152), SMLH (152), RIGA (152), PRAD 330

6 BIGU (152), CV (152), BC (152), BR (152), CHIC (152), PRAD 340

7 CHIK (152), CAPAC (152), CAPAR (152), CRTC (152), CRTR (152), PRAD 350

8 CRTPC (152), GOFR (152), FEW (152), CAR (152), OKLM (37), PRAD 360

COMMON TELM (37), EKLM (37), ELM (37), FCLM (37), PRAD 370

1 FRLM (37), WLM (37), OLM (37), AMASNO (37), CHRNO (37), PRAD 380

2 ZP1 (37), ZP2 (37), SOLID (37), ECHCK (37), RK (104), PRAD 390

3 RL (37), RHOK (104), ROK (104), THETAK(104), TEMP (16), PRAD 400

4 HEAD (12), MAXL, MAXLM, PRAD 410

C.....**PRAD 420

C.....PRAD 460

COMMON /LINDLY/ HNU,SGNL,IHNU,NHNU,HNUP,NT,IM,IN,DHNU,THICK,NY PRAD 470

COMMON /CNTRL/ SCYCLE, JMUL

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, HO, EST, I1, I2, GMP, A1, A3, FMUS,

2 FS, LDF, LRI, IZN, TG1, TG2, F2 PRAD 500

C.....PRAD 500

DIMENSION CSOD (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
EQUIVALENCE (AC03T4,TRDBG), (BC ,SUMX4), (BIGA ,Y ),P 570
1 (BIGA ,H ), (H1 ,H3 ), (CAR ,Q37 ), (CHIC ,SUMX3),P 580
2 (CHIR ,Q38 ), (CRTR ,SUMX2), (X7 ,PR ), (GOFR ,Q3 ),P 590
3 (PB ,Q1 ), (S12 ,EDITMF), (EC ,H2 ), ( W ,OX ),P 600
4 (SMLA ,FMS ), (SMLB ,FL ), (SMLC ,TR ), (SMLH ,H4 ),P
5 (ER ,FM ), (V ,TG ), (SMLD ,FSM ), (CRTC ,CS00 ),P
6 (X5 ,Y2 ), (X4 ,X8 ), (SMLE ,FSP ) P
C .....P 660
C OX CONTAINS X FROM THE PREVIOUS Y LINE P 670
C P 680
C CS00 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 BIGA 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
C IUMX = 4000 P
C T4 = 1. P
C TAX = ABS(SOLID(37)) * 1.95692E-6 P
C IF (ABS(SOLID(36)) .GT. 1.E-20) TAX = 0. P
C JDRUM1 = 51 - JDRUM P
C REWIND JDRUM P

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C C C
      RE=100 JORUM1
      IM=IM+1
      IN=IA
      IMPI=IM+1
      INMI=IN-1
      CALL UVCHK (KOUFA)
      CALL      UVCKON
      IF (IMPI-IN) 30,30,40

      NO VAPOR ZONES

30  X2(IMPI) = 1.0283E12 * A(IMPI) * (THETA(IM)**4 - THETA(IMPI)**4)
      EX(IM)=-X2(IMPI)
      GO TO 1320
40  THTAMX = .025
      DO 100 I=IN,IM

          SET UP FOR KAPPA INTERPOLATION

          Q1(I)=THETA(I)**4
          Q37(I)=ALOG(THETA(I))
          Q38(I)=ALOG(SV(I))
          FMS(I) = ABS(SOLID(37)) * 0.5 / SV(I)
          CSQD(I) = C(I)**2
          IF (THETA(I) .GT. THTAMX) THTAMX = THETA(I)
100  CONTINUE
          IF (THTAMX .LT. THETA(IMPI)) THTAMX = THETA(IMPI)
          IF (INMI .GT. 0 .AND. THTAMX .LT. THETA(INMI)) THTAMX=THETA(INMI)
          IF (THTAMX .LT. 0.05 .AND. GL .LT. 1.-30 .AND. INMI .LE. 0)
2    GO TO 1320
          CSQD(IMPI) = C(IMPI)**2
          IF (ABS(SOLID(37)) .GT. 1.E-20) IM = IM
          INMU=0
          CALL KAPPA(IN,IM)
          MINIMUM RADIATION TIME STEP
          #SB=0.
          DO 101 I=1,MAXLM
101  #SB=#SB+ELM(I)
          DTR1=1.E10
          DTR2=1.E10
          DO 107 I=IN,IM
          IF (AMIN1(CAPAC(I),CAPAR(I)).GT.0.) GO TO 102
          S1=13.0102
          CALL UNCLE
102  IF (ABS(SOLID(10)) .LT. 1.E-20) GO TO 103
          TEMP(1)=CAPAR(I)
          TEMP(3)=CAPAR(I)
          GO TO 104
103  TEMP(1)=CAPAC(I)
          TEMP(3)=CAPAC(I)
104  IF (THETA(I).LT..001) GO TO 107
          H(I) = .5*TEMP(1)/SV(I)*DELTAR(I)
          TEMP(1)=1.E10
          TEMP(2)=1.E10
          #SUB=E(I)*G(I)

```

```

      IF (ABS(ER(1)) .LT. 1.E-20 .OR. WSDU .LT. .001 * WSD) GO TO 105
C      ACCURACY CRITERION
      TEMP(1)=SLUG*WSDU/ABS(ER(1))
C      STABILITY CRITERION
105  TEMP(2) = TELM(25) * (AMIN1(TEMP(1), (.5 + 1.5 * H(1))*.2) * CV(1)/
      1 (4.1132E12*TEMP(3)*THETA(1)**3)))
      IF (TEMP(2) .LT. 1.E-20) GO TO 107
      IF (TEMP(2).GT.UTR1) GO TO 106
      DTH2=UTR1
      IMN2=IMN1
      UTR1=TEMP(2)
      IMN1=1
      GO TO 107
106  IF (TEMP(2).GT.UTR2) GO TO 107
      DTR2=TEMP(2)
      IMN2=1
107  CONTINUE
      DTRMIN=UTR1
      EO=IMN1
      IF (DTR1.GT.TELM(26)) GO TO 108
      TELM(26)=DTR1
      TELM(27)=IMN1
      TELM(28)=DTR2
      TELM(29)=IMN2
      TELM(30)=SGLID(16)*1.
108  IF (DTRMIN-UTR) 111,112,109
109  ULANKJ=TH+AMIN1(DTRMIN*GR*DTH2)
      GO TO 112
111  NHAD=2P1(18)/DTRMIN + 1.
      UTR=2P1(18)/FLOAT(NHAD)
      IF (NHAD .LE. 50) GO TO 112
      S1=13.0112
      CALL UNCLE
112  CALL UVCHK(KX)
      GO TO (150,160), KX
150  S1 = 13.0150
      CALL UNCLE
160  IF (GL .GT. 0.) IR = IM
      GO TO (128, 113, 113), IALPHA
C
C CHARACTERISTICS IN NONPLANE GEOMETRY -- SET UP X AND Y OUTSIDE FREQ LOOP
C
113  K = 0
C      DETERMINE WHETHER TO SKIP ZONES WITH Y-LINES
114  K1=K
      Y(1)=0.0
      X4(1) = 0.0
      JK=1
C*****
C      SET UP Y LINES
C*****
      DRAW Y LINES---ONE FOR EACH LARGE TEMPERATURE CHANGE
      FORCE Y LINE ON SURFACE OF SOLID IF ANY

```

C	NO Y GREATER THAN C(IR+1)	P	1630
C	IF (IN .LE. 1) GO TO 115	P	
	JK = 2	P	
	Y(2) = C(IN)	P	
	X4(2) = CSQD(111)	P	
115	DO 118 I = IN, IR	P	
	IF (ABS(Q37(I+1) - Q37(1)) - 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. 1 .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	FIND COMPLETE SET OF X VALUES	*P	1790
C	(INTERSECTIONS OF RADII WITH Y LINES)	*P	1800
C	*****	*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	
	K2=K2+2	P	1910
	KK=1	P	1920
121	TS1 = CSQD(I) - X4(J)	P	
	IF (TS1) 124, 124, 122	P	
122	X(K2)=SQRT(TS1)	P	
	K2=K2+1	P	1960
	IF (K2-IDMX) 123, 123, 119	P	
123	I=I-1	P	
	KK=KK+1	P	1990
	GO TO 121	P	
124	KKK=K2-KK	P	
	X(KKK)=-X(KK-1)	P	2020
125	CONTINUE	P	
C	FINISH X-BLOCK WITH A NEGATIVE NUMBER	P	2070
	X(K2)=-1.0	P	
C	*****	PRAD1420	
C	*****	PRAD1430	
C	BEGIN FREQUENCY LOOP	PRAD1440	
C	*****	PRAD1460	
C	*****	PRAD1480	

C	SET UP MAX FREQ BOUNDARY	PRAD1490
C	COMPTON SCATTERING FORBIDS VERY HIGH FREQUENCIES.	PRAD1500
C	THETAK(103) CHOSEN TO BE COMPATIBLE WITH KAP6/JP	P
	128 HNUP = THETAK(103)	P
	HNUP=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	MONOFREQUENCY CALCULATION	PRAD2070
C		PRAD2080
C		PRAD2090
	210 HNUP=1	PRAD2100
	DO 220 I=IN,IM	PRAD2120
	220 X6(I)=Q1(I)	PRAD2140
	240 DFB = 1.0	PRAD2180
	HNUP = .001	PRAD2190
	DHNUP = THETAK(103)	
	ICX = IM	
	ICY=IN	
	GO TO 460	
C	TYPICAL GROUP CALCULATION OF SOURCES	PRAD2220
C		PRAD2230
C		PRAD2450
	310 CALL KAPPA(IN,IM)	PRAD2460
	ZZ = 0.	PRAD2470
	DHNUP = DHNU	PRAD2480
	DHNUP=HNUP-HNU	
	350 ICX = IM	PRAD2490
	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,IK	PRAD2680
	BETA=HNU/THETA(I)	PRAD2690
C	AVOID CALCULATION OF DFB LESS THAN 1E-5	PRAD2700
C		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	FORM SOURCE X6	PRAD2890
C		

C	440 DFB=PLNKUT(BETA*BETAP)	PRAD2910
	X6(I)=DFB*Q1(I)	PRAD2920
	450 CONTINUE	PRAD2930
	CALL DVCHK(KX)	PRAD2980
	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, 0.97646E-6 * (HNU + HNUX))	
	A1P = HNU**2 / DHNU * 1.95692E-6	
	IF (IHNU .EQ. 1) GO TO 512	
	A3 = HNUX**2 / DHNU * 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 QJ1 = (C(I+1) - C(I)) / SV(I)
546 CPA = CPC - HHTAX
H3(I) = CPA * QJ1
CHOOSE ALL ROSSELAND IF SOLID(10) IS NONZERO
IF (ABS(SOLID(10)) .LT. 1.E-20) GO TO 550
H2(I) = H3(I)
H(I) = CPA / SV(I)
GO TO 560
550 CPB = AMAX1(CAPAC(I) + TAUX, 0.2)
H2(I) = CPB * QJ1
H(I) = CPB / SV(I)
560 QJ1=QJ1+H3(I)
Q3(I+1)=QJ1
H(I) = 0.5 * H(I)
H2(I)=0.5*H2(I)
H3(I)=0.5*H3(I)
X2(I)=0.0
X3(I)=0.0
X4(I)=0.0
Y2(I) = 0.
TG(I) = 0.
RHO(I) = 0.
PR(I) = 0.
FL(I) = 0.
570 TR(I) = 0.
X2(IMP1)=0.0
X3(IMP1)=0.0
X4(IMP1)=0.0
TG(IMP1) = 0.
RHO(IMP1) = 0.
PR(IMP1) = 0.
FL(IMP1) = 0.
TR(IMP1) = 0.
Y2(IN)=X6(IN)
TG(IN)=0.0
C
C FORM Y2 AND TG SET X3=-1 IF A DIFFUSION CRITERION MET USING HCB
C
600 ICXM1=ICX-1
IF (ICY.GT.ICXM1) GO TO 650
DO 640 I=ICY,ICXM1
TEMP(1)=H3(I+1)+H3(I)
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
GO TO 640
620 TG(I+1)=(X6(I+1)-X6(I))/TEMP(1)
Y2(I+1)=(X6(I+1)*H3(I)+X6(I)*H3(I+1))/TEMP(1)
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
640 CONTINUE
C FORCE DIFFUSION FOR NEGATIVE HCB
650 IF (HCB) 651, 655, 655

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PRAD3280

PRAD3290

PRAD3310

PRAD3320

PRAD3330

PRAD3340

PRAD3380

PRAD3390

PRAD3400

PRAD3420

PRAD3430

PRAD3440

PRAD3520

PRAD3570

PRAD3580

PRAD3590

PRAD3600

PRAD3610

PRAD3620

PRAD3630

PRAD3680

PRAD3690

PRAD3700

PRAD3740

PRAD3760

PRAD3770

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651 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
C LAST ZONE MUST BE TRANSPORT IF EXTERNAL INPUT INTENSITIES PROVIDED
C 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)
    TG(IMP1)=0.0
C
C EXTEND TRANSPORT REGION BOUNDARIES TO PROVIDE 5 MEAN FREE PATHS
C
690 I=IN+1
    CALL DVCHK(KX)
    GO TO (692, 700), KX
692 S1 = 13.0692
    CALL UNCLE
700 IF (X3(I)) 710,730,720
710 I=I+1
    IF (I-ICX-1) 700,730,820
720 S1=13.0720
    CALL UNCLE
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
    J=J-1
    IF (J-IN) 760,740,740
760 I=I+1
    IF (I-ICX-1) 770,770,820
770 IF (X3(I)) 780,760,720
780 J=I
790 IF (Q3(J)-Q3(I-1)- 5.) 800,800,710
800 X3(J) = 0.0
    J=J+1
    IF (J-ICX-1) 790,810,810
810 I = J
    GO TO 710
820 I=IN+1
C
C TEST TO FORM TRANSPORT REGIONS
C
    IF (X3(IN)) 890,830,720
830 IAX=IN
840 IF (X3(I)) 860,850,720

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PRAD3780

PRAD3910
PRAD3920
PRAD3930

PRAD3960
PRAD3970

PRAD3980
PRAD3990
PRAD4000

PRAD4020

PRAD4050
PRAD4060
PRAD4070
PRAD4080
PRAD4090
PRAD4100
PRAD4110

PRAD4130
PRAD4140
PRAD4150
PRAD4160
PRAD4170
PRAD4180
PRAD4190
PRAD4200
PRAD4210

PRAD4230
PRAD4240

C			
C	REMOVE ONE ZONE DIFFUSION REGION		
C			
	850 I=I+1		PRAD4250
	IF (I-ICX-1) 840,950,950		PRAD4260
	860 I=I+1		PRAD4270
	IF (I-ICX-1) 870,950,950		PRAD4280
	870 IF (X3(I)) 880, 875, 720		PRAD4290
	875 X3(I-1) = 0.		PRAD4300
	GO TO 840		PRAD4310
	880 IBX=I-3		
	IF (IBX.LT.IAX) GO TO 970		PRAD4330
	GO TO 960		PRAD4340
	890 IF (IN.GT.1) GO TO 910		PRAD4350
C	ASSUME C(1) = 0.		PRAD4360
	900 X2(1) = 0.0		
	FL(1) = 0.		
	GO TO 920		
	910 X2(IN) = 1.0283E12 * A(I,I) * (X6(IN-1) - X6(IN))		PRAD4380
	FL(IN) = 0.5 * (X6(I,I-1) - X6(IN))		PRAD4390
	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		
	IF (I - ICX - 1) 925, 980, 980		PRAD4430
C			
C	DO TRANSPORT TO IM IN REGION OF NO SOURCE		
C			
	940 IAX=I		PRAD4450
	GO TO 850		PRAD4460
	950 IBX=IM		PRAD4470
	960 IF (IAX .GT. ICX) GO TO 965		PRAD4480
	GO TO (961, 962, 963), 1ALPHA		PRAD4490
	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
C VEAT. MAY NEED RHO, FL, TR HERE.
990 IF (GL) 1000,1010,1020
1000 X2(IMP1) = 0.
      GO TO 1030
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
C      OPTIONAL EDIT OF X2 ETC.
C
1030 IF (ABS(EDITMF) .LT. 1.E-20 .OR. ZZ .GT. 1.E-20) GO TO 1040
      CNT1=SOLID(18)+1.0
      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, 10X3HICX14, 10X3HICY14/)
      4 FORMAT (3X1HI, 1UX1HR, 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 - FI0(I)
      QD = FIOSV + FI0(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 FI0(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

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PRAD4580

PRAD4590

PRAD4600

PRAD4610

PRAD4650

PRAD4660

PRAD4670

PRAD4690

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      WRITE (6,8) CNT1, IHNU, T4, GEM, IGEM
      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)
      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(JDRUM1) FI0, FI1, FI2, FI3
C
C      ADVANCE FREQ, STORE EMERGENT FLUX, TEST FOR COMPLETION OF GROUPS
C
      HNUP = HNNU
      DHNU = DHNU
      IHNU = IHNU + 1
      T4 = 1.
      IF (IHNU - NHNU) 1060, 1060, 1060
1060 CALL DVCHK (K000FX)
      GO TO (1070, 310), K000FX
C*****
C
C      END FREQUENCY LOOP
C*****
C*****
1070 S1 = 13.1070
      CALL UNCLE
1080 SUMX2(INM1) = 0.0
      JURUM = JDRUM1
      REWIND JDRUM
      DO 1090 I = IN, IM
      EC(I) = 0.
      X2(I) = SUMX2(I)
      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, 10X7H TIME = 1PE13.6)
      7 FORMAT (1P10E12.5)
1320 RETURN
      END

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C*IT FOR PTRANS/P, PTRANS/P, PTRANS/P1
C*SUBROUTINE PTRANS(N,M)
C*COMPILED OCTOBER 9, 1967 WBL
C*PLANE CHARACTERISTIC TRACE WITH DOUBLE GAUSSIAN INTEGRATION PTRAO030
C*USES THE RADIATION TRANSPORT 'STEP' SUBROUTINE
C*****PTRAO050
C*SPUTTER COMMON
C**PTRAO060
C**PTRAO070
COMMON LMDA(37), NR , HSMR , IA , IB , ICA , ICB , PTRAO080
1 KMAX , BLANK1, BLANK2, BLANK3, IAP1 , IAP2 , ICAP1 , ICBP1 , PTRAO090
2 II , IG , NRAD , BLANK4, IAM1 , IBM1 , ICAM1 , ICBM1 , PTRAO100
3 IIP1 , IGM1 , IALPHA, BLANK5, TH , TMAX , BLANK6, DELPRT, PTRAO110
4 FREQ , CNTMAX, AR , ASMLR , PUSHA , PUSHB , BOILA , BOILB , PTRAO120
5 CVA , CVB , SLUG , ALPHA , HVA , HVB , HCA , HCB , PTRAO130
6 EMINA , EMINB , CA , CB , GA , GB , GL , GR , PTRAO140
7 RHOL , RHOR , EP10 , EPS1 , RIA , RIB , RDIA , RDIB , PTRAO150
8 RPIA , RPIB , RPDIA , RPDIB , TPRINT, TA , TB , TC , PTRAO160
COMMON TD , TE , DTH2 , DTH2P , DTH1 , DTRMIN, DTMAX , PTRAO170
1 DTMAX1, DTMAX2, DTMAX3, DTR , SWITCH, CO , CMIN , DELTA , PTRAO180
2 GAMA , WCRIT , SIGMAQ, AC , ACOST4, CNVRT , SUMRA , SUMRB , PTRAO190
3 ROIA , ROIAM1, ROIB , ROIBP1, GMS , S1 , S2 , S3 , PTRAO200
4 S4 , S5 , S6 , S7 , S8 , S9 , S10 , S11 , PTRAO210
5 S12 , S13 , S14 , S15 , S16 , S17 , S18 , S19 , PTRAO220
6 S20 , EO , FO , TAU , ZERO , R (152), DELTAR(152), PTRAO230
7 ASQ (152), RD (152), VD (152), RDD (152), SMLR (152), PTRAO240
8 DELR ( 37), P (152), P1 (152), PB (152), PB1 (152), PTRAO250
COMMON P2 (152), SV (152), RHO (152), THETA (152), PTRAO260
1 W (152), E (152), EI (152), EK (152), A (152), PTRAO270
2 V (152), G (152), D (152), C (152), X2 (152), PTRAO280
3 X3 (152), X4 (152), X5 (152), X6 (152), X7 (152), PTRAO290
4 SMLA (152), SMLB (152), SMLC (152), SMLD (152), SMLE (152), PTRAO300
5 EC (152), ER (152), SMLQ (152), SMLH (152), BIGA (152), PTRAO310
6 BIGB (152), CV (152), BC (152), BR (152), CHIC (152), PTRAO320
7 CHIR (152), CAPAC (152), CAPAR (152), CRTC (152), CRTR (152), PTRAO330
8 CRTPC (152), GOFRC (152), FEW (152), CAR (152), OKLM ( 37), PTRAO340
COMMON TELM ( 37), EKLM ( 37), ELM ( 37), FCLM ( 37), PTRAO350
1 FRLM ( 37), WLM ( 37), QLM ( 37), AMASNO( 37), CHRNO ( 37), PTRAO360
2 ZP1 ( 37), ZP2 ( 37), SOLID ( 37), ECHK ( 37), RK (104), PTRAO370
3 RL ( 37), RHOK (104), ROK (104), THETAK(104), TEMP ( 16), PTRAO380
4 HEAD ( 12), MAXL , MAXLM
PTRAO390
C**PTRAO400
C*****PTRAO410
COMMON /LINDLY/ HNU,SGNL,IHNU,NHNU,HNUP,NT,IM,IN,DHNU,THICK,NY PTRAO450
COMMON /CNTRL/ SCYCLE, JMUL PTRAO460
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*****PTRAO540
DIMENSION NR(40) PTRAO550
DATA RR/2.113248E-01,7.886752E-01,1.056624E-01,3.943376E-01, PTRAO560
1 1.127017E-01,5.000000E-01,8.872983E-01,3.130600E-02, PTRAO570
2 2.222222E-01,2.464718E-01,6.943180E-02,3.300095E-01, PTRAO580
3 6.699905E-01,9.305682E-01,1.207610E-02,1.076071E-01, PTRAO590
4 2.184655E-01,1.618513E-01,4.691010E-02,2.307653E-01, PTRAO600

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5      5.000000E-01,7.092347E-01,9.530899E-01,5.557100E-03, PTRAO610
6      5.522540E-02,1.422222E-01,1.840889E-01,1.129063E-01, PTRAO620
7      3.376520E-02,1.093953E-01,3.806903E-01,6.193096E-01, PTRAO630
8      8.306047E-01,9.662348E-01,2.892400E-03,3.055570E-02, PTRAO640
9      8.906520E-02,1.448918E-01,1.498251E-01,8.276980E-02/ PTRAO650
C      PTRAO660
C *****PTRAO900
C 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 EQUIVALENCE (AC03T4,TRDBG), (BC ,SUMX4), (BIGA ,Y ),P 570
1 (BIGB , H ), (BR ,H3 ), (CAR ,Q37 ), (CHIC ,SUMX3),P 580
2 (CHIR ,Q38 ), (CRTR ,SUMX2), (X7 ,PR ), (GOFR ,Q3 ),P 590
3 ( PB ,Q1 ), (S12 ,EDITMF), (EC ,H2 ), ( W ,OX ),P 600
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 670
C *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 *****PTRAJ910
C *****PTRAO920
C *****PTRAO930

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C		PTRA0940
	IAX=N	PTRA0950
	IBX=M	PTRA0960
	INMI=IN-1	PTRA0980
	IMP1 = IM + 1	PTRA0990
	CALL DVCHK(KDOOFX)	PTRA1000
	GO TO (100,110), KDOOFX	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
	NOS = 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	
	FNU = 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 (INMI) 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(INMI)	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)	
C		PTRA1500
C	REGULAR INTEGRATION STEP FOR F2, POSITIVE MU	PTRA1510
C		PTRA1520
220	IF (ABS(TG(I)) .LT. 1.E-20) Y2(I) = X6(I-1)	PTRA1530

X8(I)=T6(I)*RR(NMU)	PTRA1550
I1 = 1 - 1	
I2 = 1	
R1 = C(I-1)	
R2 = C(I)	
I2H = 1 - I	
T61 = X8(I-1)	
T62 = X8(I)	
HU = H2(I-1)/RR(NMU)	
CALL STEP	
260 SUMX3(I)=F2	PTRA1640
IF (ABS(T6(I)) .LT. 1.E-20) Y2(I) = X6(I)	
I=I+1	PTRA1660
IF (I .GT. IUXP1) GO TO 320	
IF (I .LE. ICX + 1) GO TO 220	
C	
C	
NO SOURCE IN ZONE GREATER THAN ICX	PTRA1740
CAVEAT. 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)=FEXP(-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(I-1)/RR(NMU)	PTRA1820
H4(I-1)=FEXP(-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-1CY) 300,300,210	PTRA1870
C	PTRA1880
C	PTRA1890
DO NEGATIVE ANGLES SECOND	PTRA1900
C	PTRA1910
320 I=IBXP1	PTRA1920
FS = 0.0	
LRI = 2	
IF (IBX-1M) 370,330,360	
330 IF (GL) 480,520,340	PTRA1930
C	PTRA1940
GL = 1/2 MEANS BLACKBODY CONDITION SET AT IMP1	PTRA1950
C	
GL = POSITIVE INTEGER INPUT OPTION DELETED	
C	
GL = 0 MEANS VACUUM AT IMP1	PTRA1970
C	PTRA1980
GL NEGATIVE MEANS REFLECTIVE CONDITION AT IMP1	PTRA1990
340 IF (GL.NE.0.5) GO TO 350	PTRA2000
F2 = X6(IMP1)	PTRA2010
GO TO 480	
350 S1 = 14.0350	
CALL UNCLE	
C	
C	
ERROR IF INDEX EXCEEDS NORMAL RANGE	PTRA2050
C	PTRA2060
360 S1=14.0360	PTRA2070
CALL UNCLE	PTRA2080
C	PTRA2090
	PTRA2100

C C 370 LDF = 1 GO TO 400 399 IF (ABS(TG(I+1)) .LT. 1.E-20) Y2(I+1) = X6(I) C C C C 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) H2 = H2(I)/RR(NMU) CALL STEP 440 SUMX4(I)=F2 C C C C X2(I)=X2(I)-(F2-SUMX3(I))*RR(NGS) RHO(I) = RHO(I) + (F2 + SUMX3(I)) * RR(NGS) / RR(NMU) 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-IA) 530,450,450 450 IF (I-IC) 500,400,400 C C C C NO SOURCE IN ZONE LESS THAN ICY 470 IF (F2.EQ.0.0) GO TO 480 TEMP(1)=H2(I)/RR(NMU) H4(I)=FREXP(-TEMP(1)-TEMP(1)) F2=F2+H4(I) 480 SUMX4(I)=F2 490 X2(I)=X2(I)-(F2-SUMX3(I))*RR(NGS) RHO(I) = RHO(I) + (F2 + SUMX3(I)) * RR(NGS) / RR(NMU) 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 C C C C NO SOURCE IN ZONE LESS THAN ICY 500 IF (F2.EQ.0.0) GO TO 510 TEMP(1)=H2(I)/RR(NMU) H4(I)=FREXP(-TEMP(1)-TEMP(1)) F2=F2+H4(I)	PTRA2110 PTRA2120 PTRA2230 PTRA2240 PTRA2250 PTRA2330 PTRA2340 PTRA2350 PTRA2360 PTRA2370 PTRA2420 PTRA2430 PTRA2440 PTRA2470 PTRA2480 PTRA2490 PTRA2500 PTRA2510 PTRA2520 PTRA2530 PTRA2540 PTRA2550 PTRA2560 PTRA2570 PTRA2580 PTRA2590 PTRA2600 PTRA2610 PTRA2620 PTRA2630 PTRA2640
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510 SUMX4(I)=F2
    X2(I)=X2(I)-(F2-SUMX3(I))*RR(NGS)
    RHO(I) = RHO(I) + (F2 + SUMX3(I)) * RR(NGS) / RR(NMU)
    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-1) 530,500,500
520 F2=0.0
    GO TO 480
530 CONTINUE
    IF (ABS(TRDBG) .LT. 1.E-20) GO TO 539
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
65  WRITE (6,5) I, SUMX3(I), SUMX4(I)
    5 FORMAT (I4, 1PE11.4, E14.7 )
    8 FORMAT (28HIPLANE TRANSPORT DEBUG PRINT/)
    9 FORMAT (7X1HI, 7X7HI RIGHT, 8X6HI LEFT)
10  FORMAT (27H GAUSSIAN QUADRATURE ANGLE I2, 17H WHOSE COSINE IS F11
    2.8/)
    IF (TRDBG .GT. 68.) TRDBG = TRDBG - 69.
539 DHNU=HNUP-HNU
540 JJ = JJ + 1
    NMU = NMU + 1
    NGS = NGS + 1
    IF (JJ-NY) 140,140,550
550 DO 560 I=IAX,IBXP1
560 X2(I) = X2(I)* 2.052E12
    RETURN
    END

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PTRA2650
PTRA2660

PTRA2670
PTRA2680
PTRA2690
PTRA2700
PTRA2710

RED10920

RED10640
RED10650
RED10660
RED10670

PTRA2810
PTRA2820
PTRA2830
PTRA2840
PTRA2850
PTRA2860
PTRA2870
PTRA2880
PTRA2890

Q,T 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

C CONNECTED LINEAR-QUADRATIC INTERPOLATION AT X=0.

C EPSI IS Y LIMIT OF EDIT TUBE

C LMDA(26) IS INTERFACE INDEX OF EDIT TUBE APERTURE

C

C*****

C

S P U T T E R C O M M O N

C*

C*

C*

C*

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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 , IGN1 , 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 , RHOB , EPIO , EPSI , RIA , RIB , ROIA , ROIB ,
8 RPIA , RPIB , RPOIA , RPOIB , TPRINT, TA , TB , TC ,
COMMON TU , 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 ASG (152), RU (152), VD (152), ROU (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), CHTC (152), CRTR (152),
8 CRTPC (152), GOFK (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 HEAU ( 12), MAXL , MAXLM

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C

C

C*

C*

C

COMMON /LINDLY/ HNU,SGNL,IHNU,NHNU,HNUP,NT,IM,IN,DHNU,THICK,NY

C

COMMON /DAVIS/ X(4000), ICX, ICY

TRAN 20

TRAN 30

TRAN 430

TRAN 440

TRAN 450

TRAN 480

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COMMON /JIM/ NH, FMU, R1, R2, HD, EST, I1, I2, GMP, A1, A3, FMUS,
2 FS, LUF, LRI, L2N, 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
EQUIVALENCE (AC03T4,TRDBG), (BC ,SUMX4), (BIGA ,Y ),P 570
1 (BIGB , H ), (BR ,H3 ), (CAR ,Q37 ), (CHIC ,SUMX3),P 580
2 (CHIR ,Q38 ), (CRTR ,SUMX2), (X7 ,PR ), (GOFR ,Q3 ),P 590
3 ( PB ,Q1 ), (S12 ,EDITMF), (EC ,H2 ), ( W ,OX ),P 600
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 940
C .....TRAN 930
C .....TRAN 940
C .....TRAN1040
C .....TRAN1050
C .....TRAN1060

IAX=N
IBX=M
THICK = 0.0
ITUBE = LMDA(26)
IF (C(ITUBE) .LT. EPSI) GO TO 1
XTUBE = SQRT(CSQD(ITUBE) - EPSI**2)
CALL DVCHK(KX)

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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, 6, 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 CALCULATE Y=0 RAY	*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	
LDF = 2	
IF (ABS(TG(I)) .LT. 1.E-20) Y2(I) = X6(I)	
IF (I-IA) 47,13,13	
C	TRAN1750
	TRAN1770
	TRAN1990

```

C          DIFFUSION BOUNDARY CONDITION AT IBXP1
C
37 IF (ABS(TG(I)) .LT. 1.E-20) Y2(I) = X6(I)
   LDF = 1
   GO TO 13
C
C          RHS OF RAY
C
47 I=IAX
   IAXP=IAX
   LRI = 2
   IF (IAX - IN) 11, 48, 51
48 IF (IN - 1) 11, 49, 50
49 IAXP=IN+1
   RHO(1)=SUMX3(1)*2.
   PR(1)=SUMX3(1)*.6667
   GO TO 69
50 IAXP = IN
   F2 = X6(1N-1)
   GO TO 69
C
C          DIFFUSION BOUNDARY CONDITION AT IAX
C
51 LDF = 1
   H4(I-1) = FREXP(-H2(I-1))
   GO TO 59
C
C          REGULAR INTEGRATION STEP (Y=0,RHS)
C
59 I1 = I - 1
   I2 = I
   R1 = C(I-1)
   R2 = C(I)
   HU = H2(I-1)
   IZN = I - 1
   TG1 = TG(I-1)
   TG2 = TG(I)
   CALL STEP
C
C          SAVE RHS INTENSITIES IN SUMX4
C
69 SUMX4(I) = F2
   FSP(I) = F5
   OX(I)=C(I)
   IF (ABS(TG(I)) .LT. 1.E-20) Y2(I) = X6(I)
   LDF = 2
   I=I+1
   IF (ABS(TG(I)) .LT. 1.E-20) Y2(I) = X6(I-1)
   IF (I-IBXP1) 59, 59, 85
C *****
C          COMPLETE Y = 0 RAY
C *****
C *****
85 YSQDP=0.0

```

TRAN2000
TRAN2010

TRAN2380
TRAN2390
TRAN2400
TRAN2410
TRAN2420

TRAN2440
TRAN2450
TRAN2460
TRAN2490

TRAN2500
TRAN2510
TRAN2520

TRAN2830
TRAN2840
TRAN2850

TRAN3120
TRAN3130
TRAN3140
TRAN3140

TRAN3160

TRAN3180

TRAN3470
*TRAN3480
*TRAN3490
*TRAN3500
*TRAN3510

```

      JJ=1
      JJJ=1
      KK=1
C
C      SEARCH FOR Y-LINE NEAR HALF OF C(IAX)
C
      C1=0.50*C(IAX)
      IT = IAX + 1
      GO TO 283
C*****
C      SET UP Y-LINES
C*****
C      FIRST, TEST IF Y LIES OUTSIDE OF ACTIVE MESH.
C
      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
          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
      98 IF (C1 .LT. 0.5 * (Y(JJ) + Y(JJ+1))) GO TO 103
          JJ=JJ+1
          KK=KK-IFIX(X(KK+1))+2
          GO TO 87
C
C      SEARCH FOR Y-LINE NEAR THREE QUARTERS OF C(IAX)
C
      103 C1=C1+0.25*C(IAX)
C      CALCULABLE Y-LINE FOUND -- PROCEED
      107 YSQDP=-X(KK)
          FMU = YSQDP
          K=KK+IM-IX+2
          TEMP(5)=YSQDP-YSQD1
          GO TO 167
C
C      COMPLETE X2 INTEGRATION WHEN LAST Y-LINE USED
C*****
      127 DO 139 I=IAXP,IBXP1
C
C      ANGULAR INTEGRATION OF X2 USING LINEAR INTERPOLATION
C
          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
      133 AS=SQRT(CSQD(IBXP1+1)-CSQD(IBXP1))

```

TRAN3530
 TRAN3540
 TRAN3550
 TRAN3560
 TRAN3570
 TRAN3580
 TRAN3590

TRAN3620
 *TRAN3630
 *TRAN3640
 *TRAN3650
 *TRAN3660
 TRAN3670
 TRAN3680
 TRAN3690

TRAN3730

TRAN3790
 TRAN3800
 TRAN3810
 TRAN3820
 TRAN3830
 TRAN3840

TRAN3870

TRAN3880
 TRAN3890
 TRAN3900
 *TRAN4170
 *TRAN4180
 *TRAN4190
 *TRAN4200
 TRAN4210
 TRAN4220
 TRAN4230
 TRAN4240

TRAN4290
 TRAN4300
 TRAN4310

```

      FM(IXP1) = Y2(IXP1) + XS / C(IXP1+1) * TG(IXP1+1) *
      2 FHEXP(-XS * H(IXP1))
      GO TO 137
135 FM(IXP1)=0.0
137 TEMP(5)=CSQD(IXP1)-YSQD1
      TEMP(11)= CSQD(1)-YSQD1
      FU=(TEMP(11)+(FM(IXP1)+FM(IXP1))+(CSQD(IXP1)-
      1 CSQD(1))*(SUMX4(IAXP)+SUMX3(IAXP)))/TEMP(5)
      FLX = SUMX3(1) + SUMX4(1)
      FP = FLX + FU
      FPL = FP + FLX
      RHO(1)=RHO(1)+OX(1)*FP
      PR(1) = PR(1) + XSD * (FPL + FLX) * OX(1)
      TR(1) = TR(1) + XSD**2 * FNL * 4.
139 CONTINUE
C*****TRAN4500
C      COMPLETION OF X2 INTEGRATION AT *TRAN4510
C      END OF TRANS REGION *TRAN4520
C      *TRAN4530
C      *TRAN4540
C*****TRAN4550
      DO 151 I=IAX,IXP1
      IF (I.EQ.1) GO TO 151
      PR(I)=PR(I)*.08334/(CSQD(I)*C(I))
      RHO(I)=RHO(I)*0.50/C(I)
      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
      CALL DVCHK(KX)
      GO TO (152, 153), KX
152 S1 = 14.0152
      CALL UNCLE
153 RETURN
C*****TRAN4740
C      *TRAN5230
C      *TRAN5240
C      *TRAN5250
C      *TRAN5260
C      *TRAN5270
C      *TRAN5280
C      *TRAN5290
C      *TRAN5300
C      *TRAN5310
      TYPICAL Y-LINE INTEGRATION
C*****TRAN5270
C      LHS CALCULATION FIRST-STOKE F2 IN FM
C*****TRAN5280
C      *TRAN5290
C      *TRAN5300
C      *TRAN5310
167 I=IXP1
      FS = 0.0
      LRI = 1
      IF (IHX - IM) 173, 168, 171
168 F2 = 0.0
      IF (GL.GT. 0.) F2 = Xb(IM+1)
      GO TO 205
C*****TRAN5340
C      *TRAN5350
C      *TRAN5360
C      *TRAN5370
      ERROR IF INDEX EXCEEDS NORMAL RANGE
171 S1=14.0171

```

C	CALL UNCLE	TRAN5380
C		TRAN5390
C	DIFFUSION BOUNDARY CONDITION AT IBXP1	TRAN5400
	173 IF (ABS(TG(I)) .LT. 1.E-20) Y2(I) = X6(I)	TRAN5410
	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(I) = 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-IAK) 239,193,193	TRAN6190
	193 IF (X(K)) 195,207,181	TRAN6200
C	Y-LINE HAS MADE CLOSEST APPROACH	
	195 TEMP(2)=SQRT(DELTA(I)*(4.0*C(I)+DELTA(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	
	201 H4(I)=FREXP(-TEMP(1))	TRAN6380
C	NORMAL LHS XK=0.	TRAN6390
		TRAN6430

```

      NN = 1
      TEMP(7)=FREXP(-TEMP(2))
      TEMP(13)=(X6(I)-Y2(I))/TEMP(2)**2*2.0
      TEMP(15)=(X6(I)-Y2(I+1))/(TEMP(1)-TEMP(2))
C_AVEAT. H4 IS THE SQUARE OF ITS NORMAL VALUE.
      EST = 1. - H4(I)
      CALL SCAT
      Q = AMAX1(0., 1. - FMUS / H(I))
      F2 = FS + F2 * H4(I) + Q * (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
C          FIRST TRANSPORT ZONE ON LHS
C
205 X8(I)=X(K)/C(I)*TG(I)
      GO TO 191
C
C          X = ZERO ERROR
C
207 S1=14.0207
      CALL UNCLE
219 S1=14.0219
      CALL UNCLE
221 F2=0.0
      GO TO 225
C
C          DO Y-INTEGRATION TO X=0
C
223 IF (F2.LT.0.) GO TO 221
225 FM(I)=F2
      FSM(I) = FS
C
C          FORM TOP SLICE CONTRIBS TO X2
C
      DO 231 J=IAXP,I
      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)=KHO(J)+OX(J)*FP
      PR(J) = PR(J) + XSQ * (FPL + FLX) * OX(J)
      TR(J) = TR(J) + XSQ**2 * FNL * 4.
231 CONTINUE
      LRI = 2
      LDF = 2
      IAXP=I+1
      SUMX3(I)=F2
      SUMX4(I)=F2
      I=IAXP
      K=K-1

```

TRAN6400
TRAN6410
TRAN6420

TRAN6490
TRAN6550
TRAN6560
TRAN6570
TRAN6580
TRAN6590
TRAN6600
TRAN6610
TRAN6620
TRAN6630
TRAN6640
TRAN6640
TRAN6840
TRAN6850
TRAN6860
TRAN6870
TRAN6880
TRAN6890
TRAN6900
TRAN6910
TRAN6920

TRAN6930
TRAN6940
TRAN6950
TRAN6960

TRAN7080

TRAN7130

TRAN7140
TRAN7150
TRAN7160
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
C      SMALL OPTICAL DEPTH EXPANSION (X=0,RHS)
C
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
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) + ( * (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
C      CALCULATE RHS Y-LINE INTEGRATION
C      ARRIVE HERE IF Y-LINE INTERSECTS INNER RADIUS
239 IAXP=IAX
   I=IAX
   K=K-1
   LRI = 2
   LUF = 1
   IF (IAX .NE. IIN .OR. IN .EQ. 1) GO TO 238
C      BLACKBODY
   F2 = X6(IIN-1)
   GO TO 259
238 IF (X(K+1)) 240, 207, 241
C      DIFFUSION BOUNDARY CONDITION WHEN X=0.
240 XB(I-1) = 0.
   HD = X(K) * H(I-1)
   R1 = 0.
   GO TO 242
241 XB(I-1)=X(K+1)/C(I-1)*TG(I-1)
   HD = (X(K) - X(K+1)) * H(I-1)
   R1 = X(K+1)
242 H4(I-1) = FREXP(-HD)

C
C      DIFFUSION BOUNDARY CONDITION AT IAX
C
   GO TO 250
249 HD = (X(K)-X(K+1))*H(I-1)
   R1 = X(K+1)
250 I1 = I - 1
      I2 = 1

```

TRAN7240
TRAN7250
TRAN7270

TRAN7340

TRAN7430
TRAN7440
TRAN7450
TRAN7460
TRAN7470
TRAN7480

TRAN7500

TRAN7530
TRAN7540
TRAN7550

```

R2 = X(K)
IZN = I - 1
TG1 = XB(I-1)
TG2 = XB(I)
CALL STEP

C
C   ANGULAR INTEGRATION OF X2 USING LINEAR INTERPOLATION
C
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 (EPS1.GT. Y(JJ)) GO TO 261
    IF (EPS1.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
    FM1 = FU - FLX
    RH0(I)=RH0(I)+FXM*(FU+FLX)
    PR(I) = PR(I) + FXP * (TEMP(6) + TEMP(7)) * FM1 + 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
C   SAVE F2 AND FM FOR NEXT Y-LINE
C
    SUMX4(I)=F2
    SUMX3(I)=FM(I)
    FSP(I) = FS
    OX(I)=X(K)
    IF (ABS(TG(I)) .LT. 1.E-20) Y2(I) = X6(I)
    I=I+1
    K=K-1
    LDF = 2
    IF (ABS(TG(I)) .LT. 1.E-20) Y2(I) = X6(I-1)
    IF (I-IBXP1) 249,249,283

C
C   DEBUG PRINT
C
/83 CONTINUE
    DHNU=HNUP-HNU
    IF (ABS(TRDBG) .LT. 1.E-20) GO TO 301
    CNT1 = SOLIU(18) + 1.0
    WRITE (6,307) HNU, HNUP, IHNU, CNT1
    WRITE (6,309) Y(JJ)

```

TRAN8120
TRAN8130
TRAN8140

TRAN8340
TRAN8350
TRAN8360

TRAN8380

TRAN8390

TRAN8410
TRAN8420

TRAN8740
TRAN8750
TRAN8760

TRAN8780

```

WRITE (6,311) JJ,IAX,IBX
WRITE (6,315)
IAXP1=MAX0(IAX,IAXP-1)
DO 299 I=IAXP1,IBXP1
IF (JJ.GT.1) GO TO 297
C
C      PRINT Y=0 INTEGRATION
C
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
C
C      PRINT REGULAR Y-LINE INTEGRATION
C
297 KKK=KK-I+IM+3
WRITE(6,313) I,X(KKK),X6(I),X8(I),H4(I),FSM(I),
2FSP(I),SUMX3(I),SUMX4(I),X2(I)
299 CONTINUE
IF (TROBG .GT. 68.) TROBG = TROBG - 69.
301 IF (JJ.EQ.1) GO TO 303
C *****
C
C      EDIT AND Y - LINE ADVANCE
C
C *****
C      KK=KK-IFIX(X(KK+1))+2
303 YSQD1 = YSQUP
TEMP(9)=Y(JJ)
JJ=JJ+1
GO TO 67
307 FORMAT (38H1Y-LINE PRINT FOR FREQUENCY BAND FROM F9.3, 5H TO F9.
23, 10X7H1HNU = I2, 10X6HCYCLE F5.0)
309 FORMAT (/5H Y = 1PE10.5)
311 FORMAT (6H JJ = I3,10X7H IAX = I3,10X7H IBX = I3//)
313 FORMAT (I4,1P9E14.7)
315 FORMAT (3X1HI,13X1HX,12X2HX6,12X2HX8,
21X2HH4,11X3HFSM,11X3HFSP,9X5HSUMX3,
39X5HSUMX4,12X2HX2)
END

```

TRAN8850
 TRAN8860
 TRAN8870
 TRAN8880
 TRAN8890
 TRAN8900
 TRAN8910

TRAN8930
 TRAN8950
 TRAN8960
 TRAN8970
 TRAN8940

TRAN8990

TRAN9000

*****TRAN9010

*TRAN9020

*TRAN9030

*TRAN9040

*****TRAN9050

TRAN9060

TRAN9080

TRAN9090

TRAN9110

TRAN9130

TRAN9210

QIT FOR STEP/BL, STEP/BL, STEP/BLI

SUBROUTINE STEP

COMPILED JUNE 22, 1967 WDL

C
C*
C*
C*

SPUTTER COMMON

T
T
*T
*T
*T
*T

```
COMMON LMDA(37), NK , 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 TU , TE , UTH2 , DTH2P , DTH1 , DTRMIN, DTMAX , T
1 DTMAX1, DTMAX2, DTMAX3, UTR , SWITCH, CO , CMIN , DELTA , T
2 GAMMA , WCRIT , SIGMAJ, AC , ACO3T4, CNVRT , SUMRA , SUMRB , T
3 ROIA , ROIAM1, ROIH , ROIHP1, 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), RU (152), VD (152), RDU (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), U (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), THETA(104), TEMP ( 16), T
4 HEAD ( 12), MAXL , MAXLM
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C
C*
C*

T
T
*T

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*****T
COMMON /JIM/ NN, FMU, R1, R2, HD, EST, I1, I2, GMP, A1, A3, FMUS, T
2 FS, LDF, LRI, IZN, TG1, TG2, F2
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
3 Y (1), Y2 (1), OX (1), FL (1), TR (1), FSM (1), T
4 FSP (1)
```

550

C

T

```
EQUIVALENCE (ACO3T4,TRDBG), (BC ,SUMX4), (BIGA ,Y ),T
1 (BIGB , H ), (BR ,H3 ), (CAR ,Q37 ), (CHIC ,SUMX3),T
2 (CHIR ,Q38 ), (CRTR ,SUMX2), (X7 ,PR ), (GOFR ,Q3 ),T
3 ( PB ,Q1 ), (S12 ,EDITMF), (EC ,H2 ), ( W ,OX ),T
```

570
580
590
600

```

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      OX CONTAINS X FROM THE PREVIOUS Y LINE      *T 670
C      CSQD SAME AS CRTC      *T 680
C      EDITMF SAME AS S12      *T 690
C      Q1 SAME AS PB      *T 700
C      FM SAME AS ER      *T 710
C      H SAME AS BIGB      *T
C      H2 SAME AS EC      *T 740
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 CTRH      *T 860
C      SUMX3 SAME AS CHIC      *T 870
C      SUMX4 SAME AS BC      *T 880
C      TRDBG SAME AS ACOST4      *T 890
C      Y SAME AS BIGA      *T 910
C      X8 SAME AS X4      *T 940
C*****TRAN 930
C      GO TO (20, 25), LDF      T
C      IF DIFFUSION ZONE, DEFINE STARTING INTENSITY      T
C      20 F2 = Y2(I1) - TG1      T
C      25 IF (HD .GT. 0.01) GO TO 30      T
C      THIN ZONE      T
C      NN = 0      T
C      GO TO 50      T
C      NORMAL ZONE -- DEFINE EXP(-DELTATAU)      T
C      30 NN = 1      T
C      GO TO (35, 40), LRI      T
C      35 H4(IZN) = FREXP(-HD)      T
C      40 EST = 1. - H4(IZN)**2      T
C      50 CALL SCAT      T
C      Q = AMAX1(0., 1. - FMUS / H(IZN))      T
C      NN1 = NN + 1      T
C      GO TO (60, 70), NN1      T
C      60 F2 = FS + F2 * (1. - HD - HD) + Q * (((Y2(I1) + Y2(I2)) * 0.5 +      T
C      2 X6(IZN)) * HD)      T
C      GO TO 100      T
C      70 F2 = FS + F2 * H4(IZN)**2 + Q * (Y2(I2) - TG2 + ((TG1 - Y2(I1)) * T

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

```

```

B,T FOR SCAT/PP,SCAT/PP,SCAT/JP          T
SUROUTINE SCAT                            T
C GEOMETRY-INDEPENDENT COMPTON SCATTERING  T
C COMPILED OCTOBER 9, 1967 WOL
C
C*****T
C
C
COMMON LMDA(37), NR , NSMLR , IA , IB , ICA , ICB ,T
1 KMAX , BLANK1, BLANK2, BLANK3, IAP1 , IUP1 , 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, AK , 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 , RPUA , RPOB , TPRINT, TA , TB , TC ,T
COMMON ID , TE , UTH2 , DTH2P , DTH1 , DTRMIN, DTMAX ,T
1 DTMAX1, DTMAX2, DTMAX3, JTR , SWITCH, CO , CMIN , DELTA ,T
2 GAMA , WCHI , SIGMAJ, 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), RU (152), VD (152), ROD (152), SMLR (152),T
8 DELA (37), P (152), PI (152), PB (152), PH1 (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 SKLA (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), UC (152), BR (152), CHIC (152),T
7 CHIR (152), CAPAC (152), CAPAR (152), CRTC (152), CRTR (152),T
8 CRTPC (152), GOFH (152), FEW (152), CAR (152), OKLM (37),T
COMMON TELM (37), EKLM (37), ELM (37), FCLM (37),T
1 FRLM (37), WLM (37), GLM (37), AMASNO(37), CHRHO (37),T
2 ZP1 (37), ZP2 (37), SOLID (37), ECHCK (37), RK (104),T
3 RL (37), RHOK (104), ROK (104), THETA(104), TEMP (16),T
4 HEAD (12), MAXL , MAXLM
C
C*****T
C
COMMON /LINDLY/ HNU,SGHL,IHNU,HNNU,HNUP,NT,IM,IN,DHNU,THICK,NY
C
COMMON /CNTRL/ SCYCLE, JMUL
COMMON /PALMER/ F10(152), F11(152), F12(152), F13(152), F00(152),T
2 F01(152), F02(152), F03(152), JURUM
COMMON /JIM/ NN, FMU, R1, R2, HD, EST, I1, I2, GMP, A1, A3, FMUS, T
2 FS, LUF, LRI, IZIN, TG1, TG2, F2
DIMENSION CSOU (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
3 Y (1), Y2 (1), OX (1), FL (1), TR (1), FSM (1),T

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```

      4 FSP      (1)
C
      EQUIVALENCE      (AC03T4,TRDBG), (BC ,SUMX4), (BIGA ,Y ),T
1      (BIGB , H ), (BR ,H3 ), (CAR ,Q37 ), (CHIC ,SUMX3),T
2      (CHIR ,Q38 ), (CRTR ,SUMX2), (X7 ,PR ), (GOFR ,Q3 ),T
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 )
C*****T
C      OX CONTAINS X FROM THE PREVIOUS Y LINE
C
C      CSQD SAME AS CRTC
C      EDITMF SAME AS S12
C      Q1 SAME AS PB
C      FM SAME AS ER
C      H SAME AS BIGB
C      H2 SAME AS EC
C      H3 SAME AS BR
C      H4 SAME AS SMLH
C      PR SAME AS X7
C      FMS SAME AS SMLA
C      FL SAME AS SMLB
C      TR SAME AS SMLC
C      FSM SAME AS SMLD
C      FSP SAME AS SMLE
C      Y2 SAME AS X5
C      OX SAME AS W
C      TG SAME AS V
C      Q3 SAME AS GOFR
C      Q37 SAME AS CAR
C      Q38 SAME AS CHIR
C      SUMX2 SAME AS CRTR
C      SUMX3 SAME AS CHIC
C      SUMX4 SAME AS BC
C      TRDBG SAME AS AC03T4
C      Y SAME AS BIGA
C      X8 SAME AS X4
C*****T
C      CALL DVCHK(IMHAD)
C      GO TO (1,2),IMHAD
1      S1=75.001
C      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

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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(SQID(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 25
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 (TROBG .LT. 68.) TROBG = TROBG + 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:

$$\begin{array}{|l}
 T_o = 600 \text{ eV} \\
 \rho_o = 1 \text{ g/cm}^3 \\
 20 \text{ zones}
 \end{array}
 \quad T_{\text{boundary}} = 8 \text{ keV}$$

0 10 cm

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.

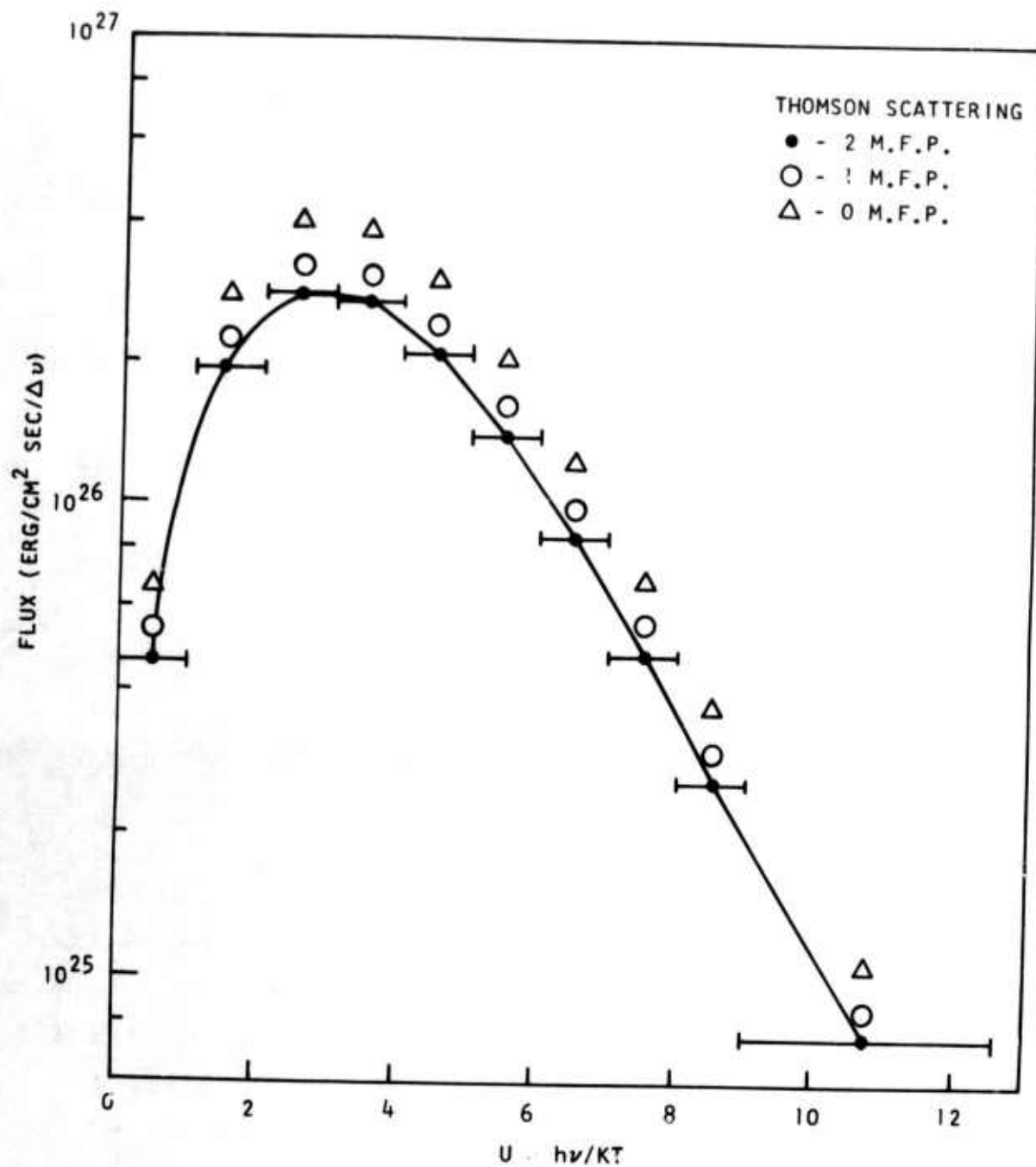


Figure 8. Spectrum at Various Optical Depths Employing Thomson Scattering

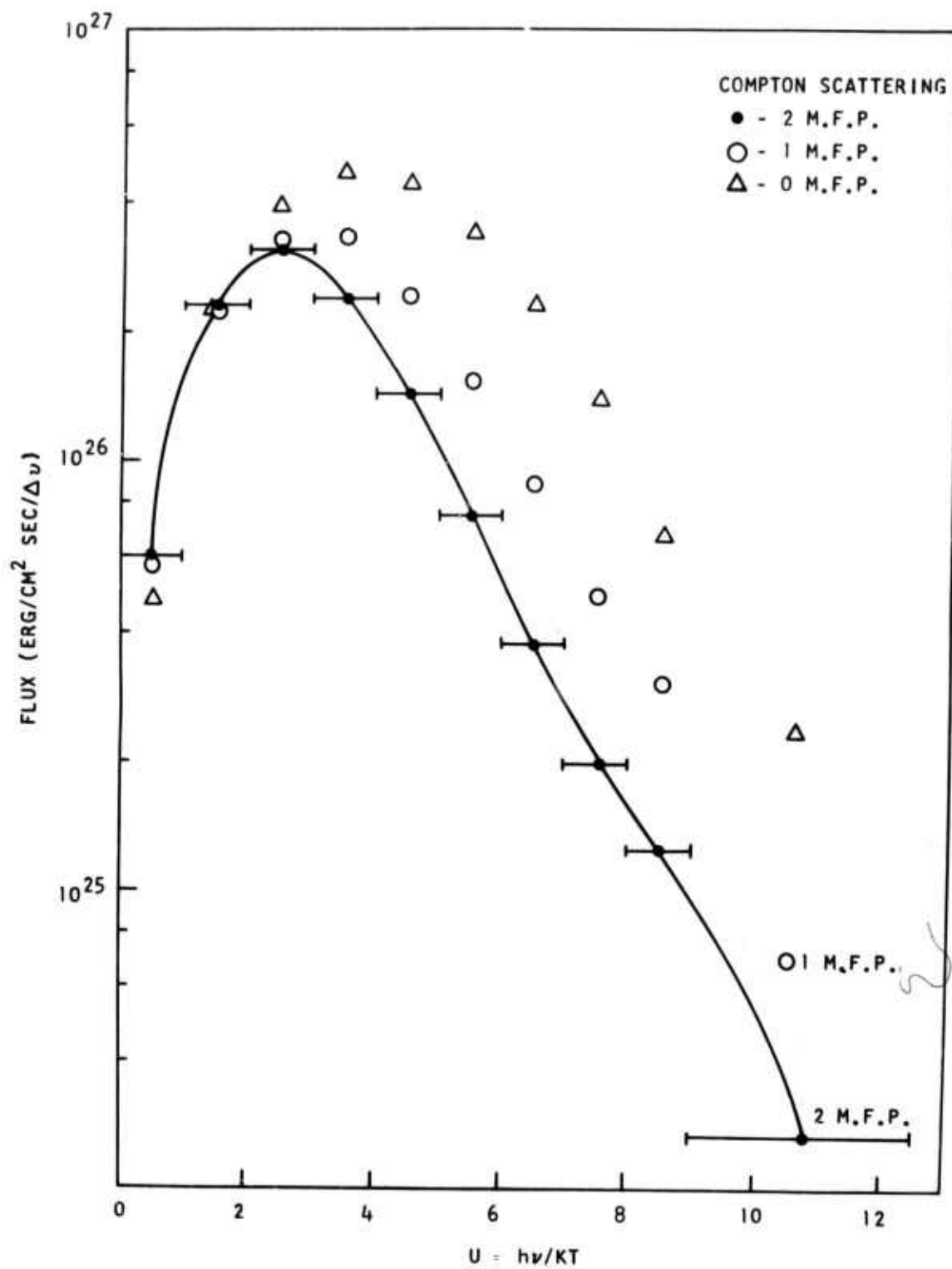


Figure 9. Spectrum at Various Optical Depths Employing Compton Scattering

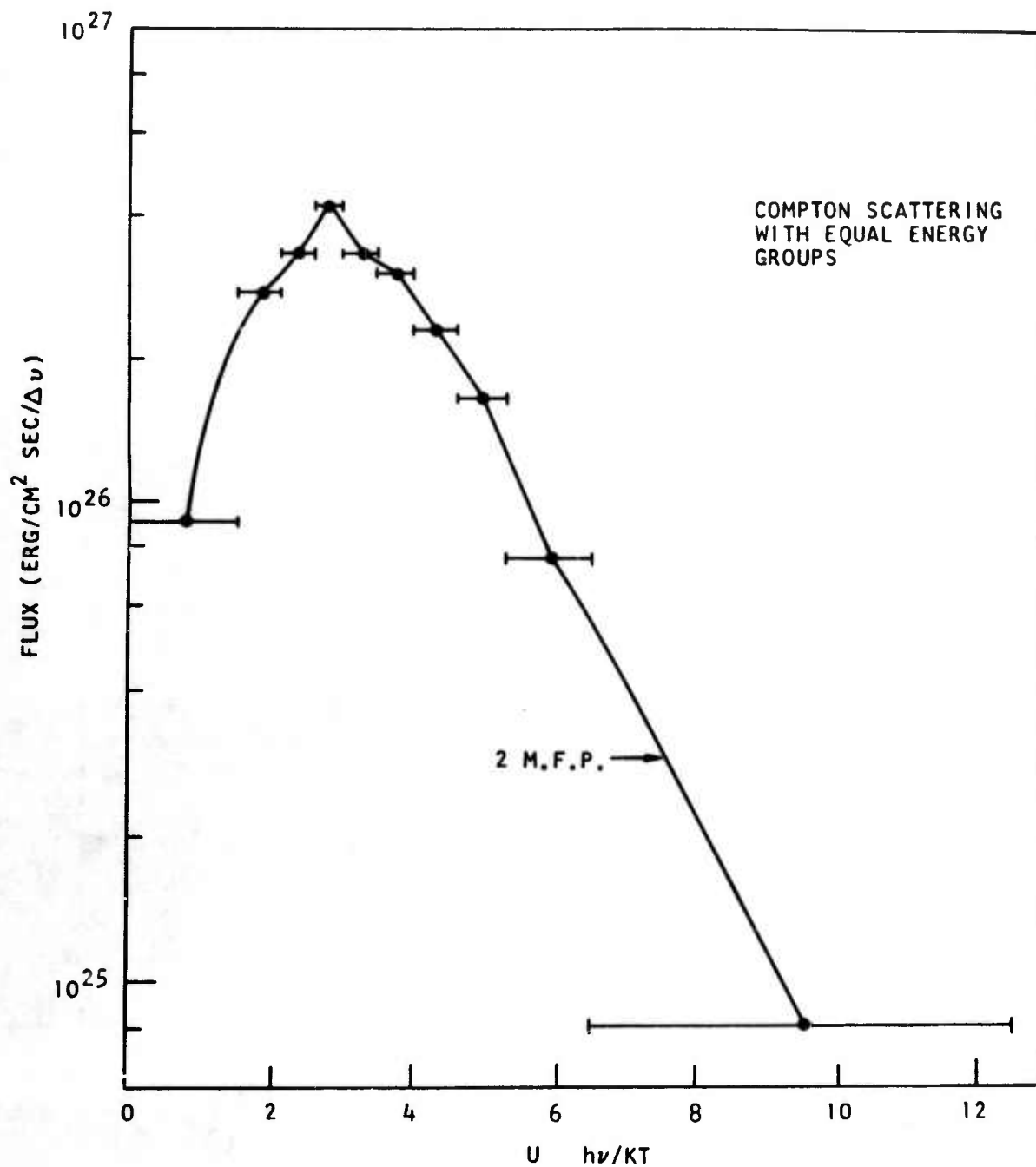


Figure 10. Exit Spectrum for Compton Scattering

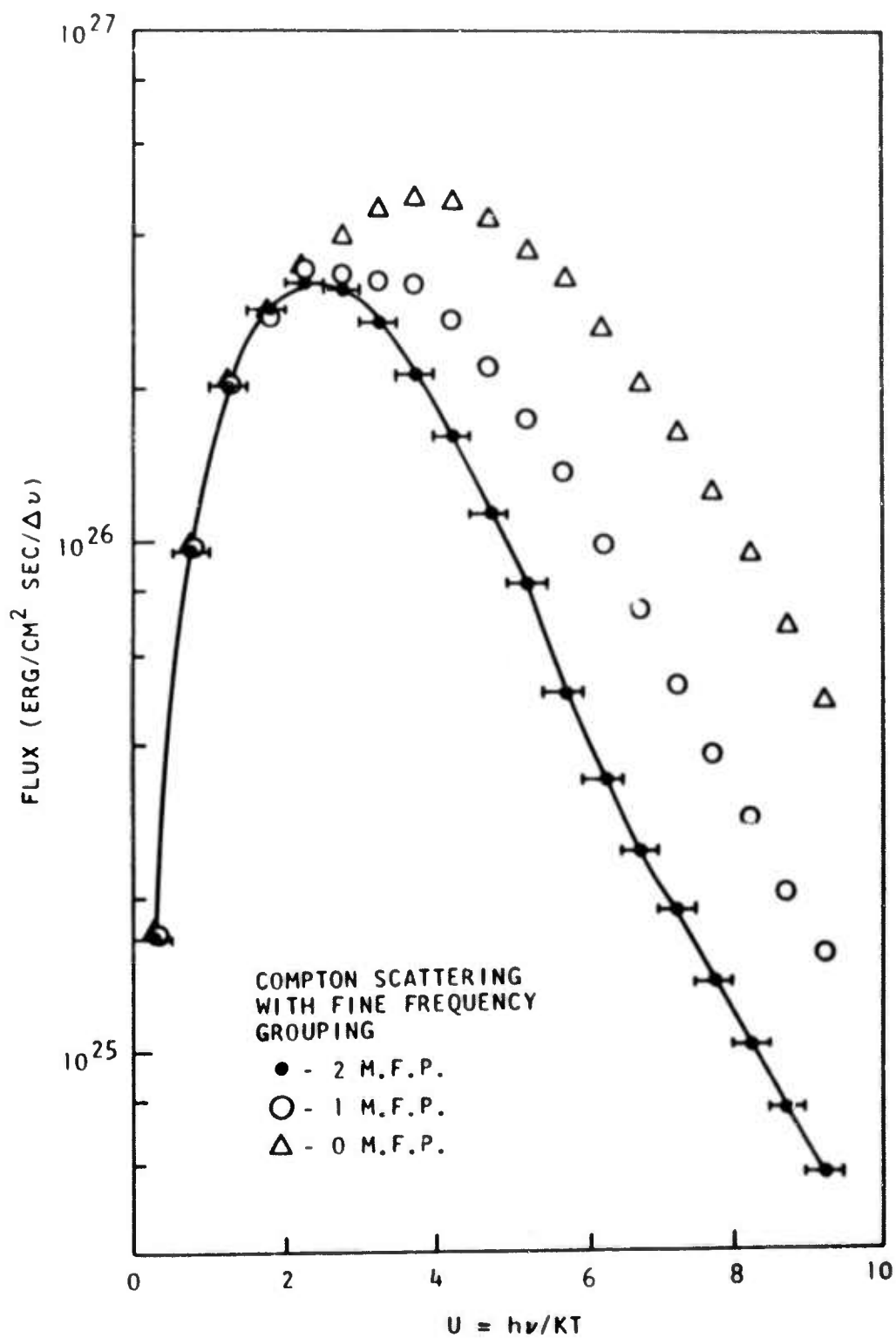


Figure 11. Spectrum using Compton Scattering

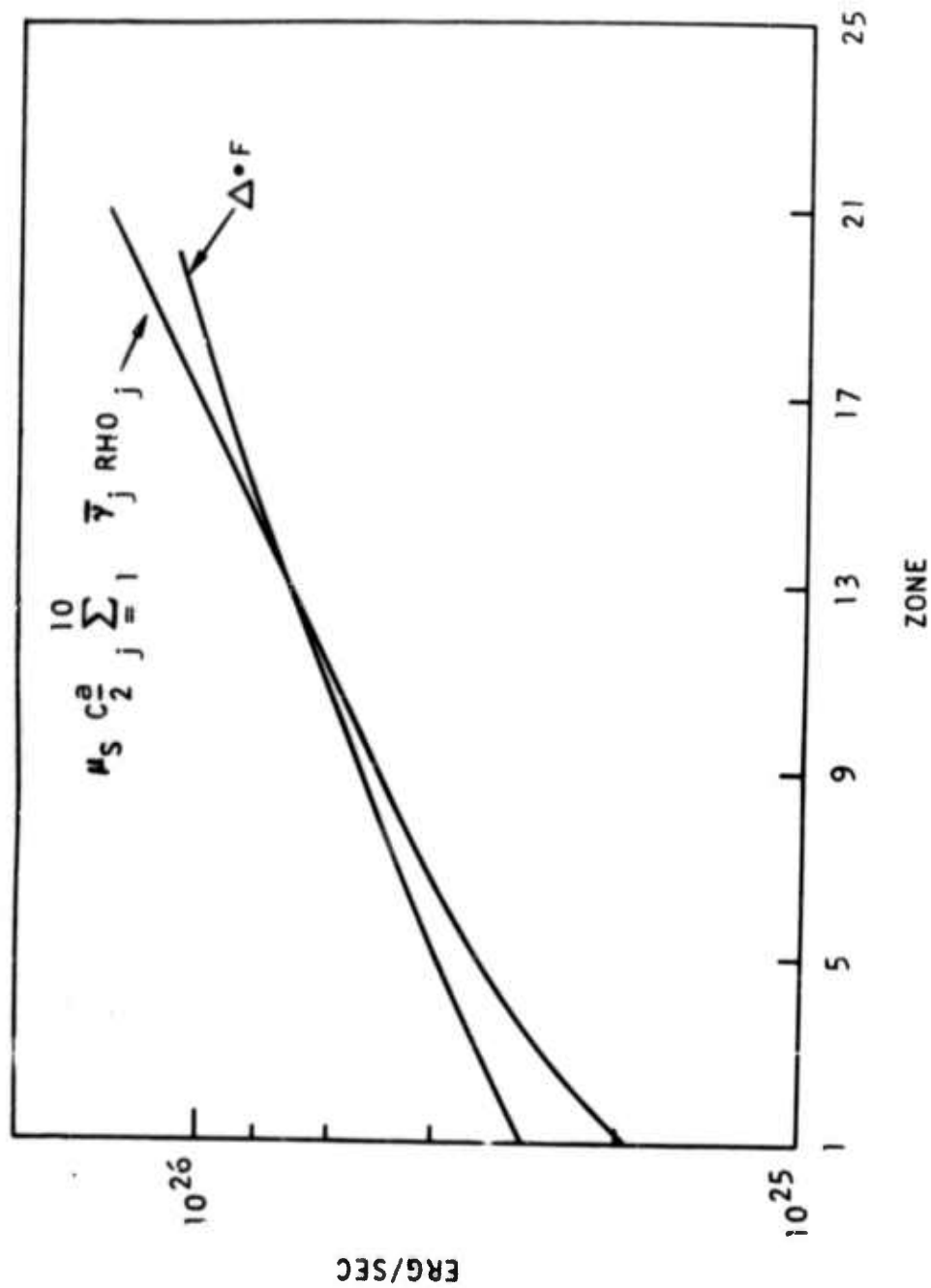


Figure 12. Comparison of Theoretical and Computed Heating Rates

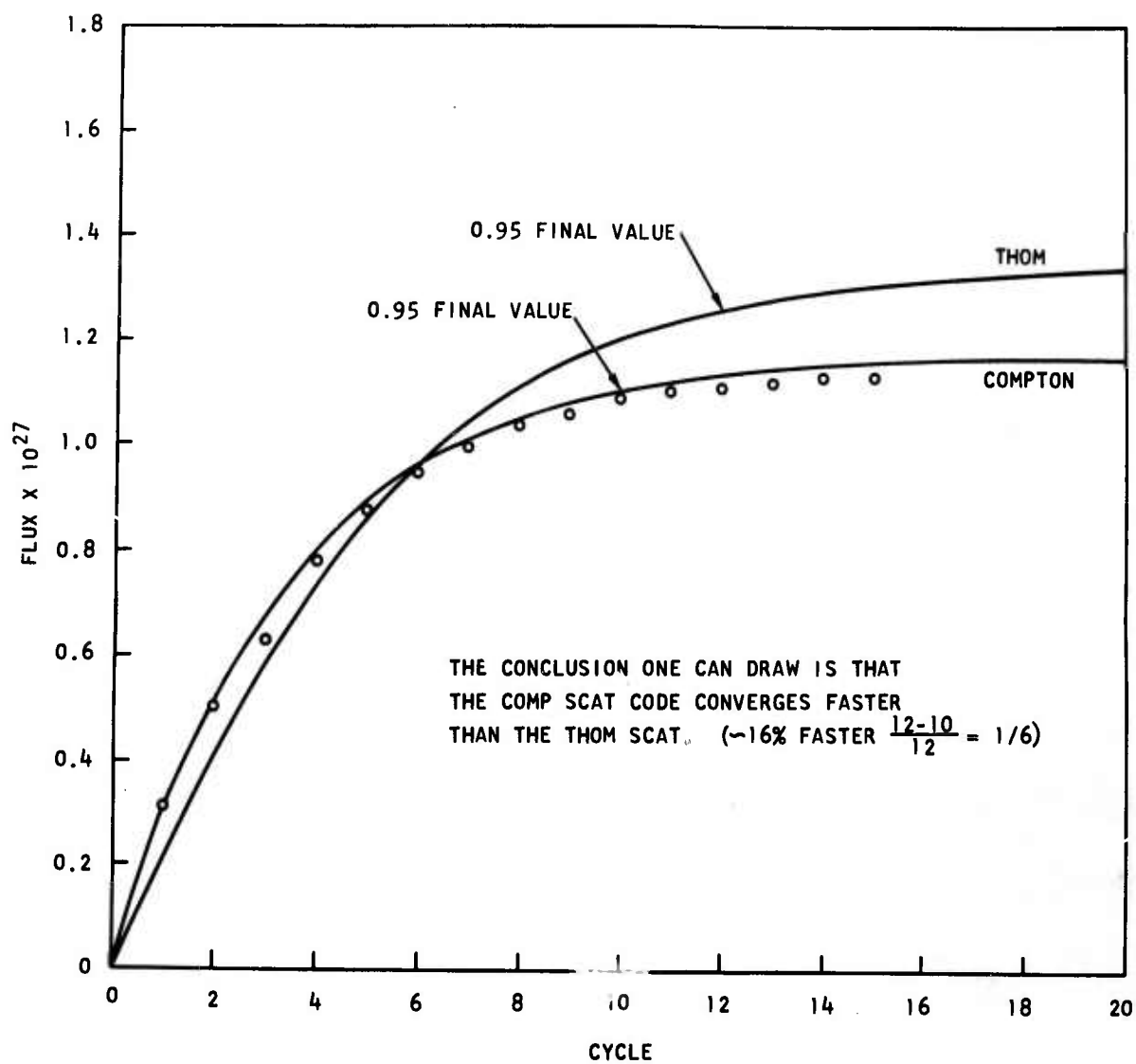


Figure 13. Comparison of Convergence Rates for Thomson and Compton Scattering

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 black-body as a function of frequency is presented in figure 14.

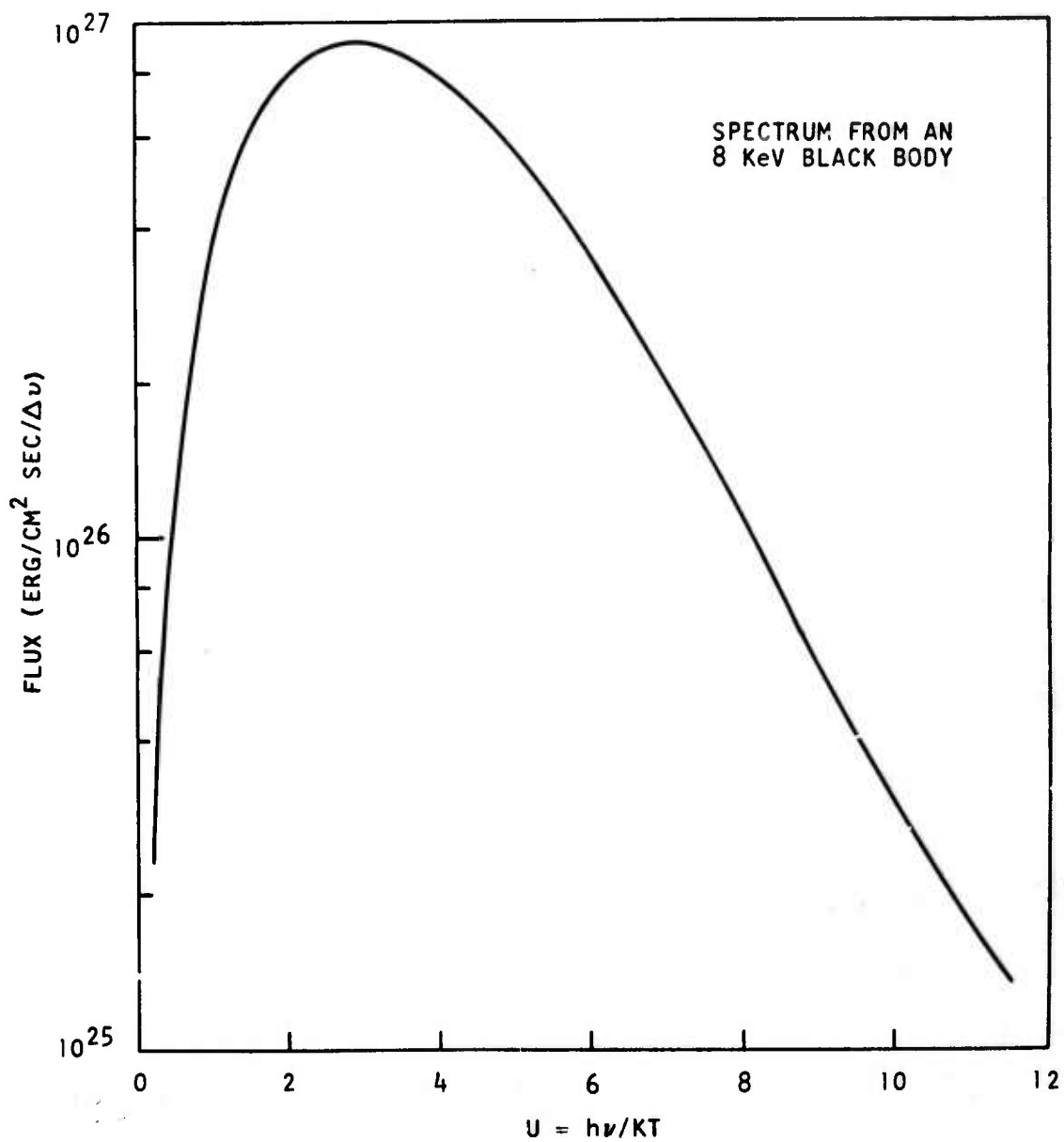


Figure 14. Spectrum from 8-keV Blackbody

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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

$$\Gamma_1 = -N\phi_0 I(\nu, \Omega)(1 - 2\gamma)$$

$$\Gamma_2 = -N\phi_0 \frac{3c^2}{16\pi h\nu} I(\nu, \Omega) \gamma \left(1 - \nu \frac{\partial}{\partial \nu}\right) \int d\Omega' I(\nu, \Omega')(1 - \mu + \mu^2 - \mu^3)$$

$$\Gamma_3 = -N\phi_0 \frac{3}{16\pi} \left\{ \gamma \left(1 - \nu \frac{\partial}{\partial \nu}\right) \int d\Omega' I(\nu, \Omega)(1 + \mu^2)(1 - \mu) \right.$$

$$\begin{aligned} & - \left[1 + \alpha \left(2 - 2\nu \frac{\partial}{\partial \nu} + \nu^2 \frac{\partial^2}{\partial \nu^2} \right) \right] \int d\Omega' I(\nu, \Omega) + \alpha \left(4 - 2\nu \frac{\partial}{\partial \nu} + \nu^2 \frac{\partial^2}{\partial \nu^2} \right) \int d\Omega' I(\nu, \Omega') \mu \\ & \left. - \left[1 - \alpha \left(6 + 2\nu \frac{\partial}{\partial \nu} - \nu^2 \frac{\partial^2}{\partial \nu^2} \right) \right] \int d\Omega' I(\nu, \Omega') \mu^2 - \alpha \left(4 + 2\nu \frac{\partial}{\partial \nu} - \nu^2 \frac{\partial^2}{\partial \nu^2} \right) \int d\Omega' I(\nu, \Omega') \mu^3 \right\} \quad (68) \end{aligned}$$

where N is the total number density of electrons and $\phi_0 = 8\pi/3 (r_0^2) = 6.65 \times 10^{-25} \text{ cm}^2$ is the Thomson scattering. In Eq. (68), the values of M_0 , $\underline{M}_1$, $\underline{M}_2$, and $\underline{M}_3$ have been substituted for as follows:

$$\begin{aligned} M_0 &= \frac{3}{16\pi} \int d\Omega' I(\nu, \Omega') \\ \underline{\Omega} \cdot \underline{M}_1 &= \frac{3}{16\pi} \int d\Omega' I(\nu, \Omega') \mu \\ \underline{\Omega} \cdot \underline{M}_2 &= \frac{3}{16\pi} \int d\Omega' I(\nu, \Omega') \mu^2 \\ \underline{\Omega} \cdot \underline{M}_3 &= \frac{3}{16\pi} \int d\Omega' I(\nu, \Omega') \mu^3 \end{aligned} \tag{69}$$

$$M_0 - \underline{\Omega} \cdot (\underline{M}_1 - \underline{M}_2 + \underline{M}_3) = \frac{3}{16\pi} \int d\Omega' I(\nu, \Omega') (1 + \mu^2) (1 - \mu)$$

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

$$\begin{aligned}
& - \mu_s \left[(1 - 2\gamma) I(\nu, \Omega) - \frac{3}{16\pi} \int d\Omega' I(\nu, \Omega') (1 + \mu^2) \right. \\
& \quad - \gamma \left(1 - \nu \frac{\partial}{\partial \nu} \right) \int d\Omega' I(\nu, \Omega') (1 + \mu^2) (1 - \mu) \\
& \quad + \alpha \left[2 \int d\Omega' I(\nu, \Omega') (1 - 2\mu - 3\mu^2 + 2\mu^3) \right. \\
& \quad \left. + \left(\nu^2 \frac{\partial^2}{\partial \nu^2} - 2\nu \frac{\partial}{\partial \nu} \right) \int d\Omega' I(\nu, \Omega') (1 + \mu^2) (1 - \mu) \right] \\
& \quad \left. - \frac{c^2}{h\nu^3} I(\nu, \Omega) \gamma \left(1 - \nu \frac{\partial}{\partial \nu} \right) \int d\Omega' I(\nu, \Omega') (1 + \mu^2) (1 - \mu) \right] \quad (70)
\end{aligned}$$

where $\mu_s = \phi_0 N$.

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:

$$\begin{aligned}
\gamma \left(1 - \nu \frac{\partial}{\partial \nu} \right) I &= \frac{h}{mc^2} \left[3\nu I - \frac{\partial(\nu^2 I)}{\partial \nu} \right] \\
\nu^2 \frac{\partial^2 I}{\partial \nu^2} - 2\nu \frac{\partial I}{\partial \nu} &= \frac{\partial^2(\nu^2 I)}{\partial \nu^2} - 6 \frac{\partial(\nu I)}{\partial \nu} + 4I
\end{aligned} \quad (71)$$

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

$$\begin{aligned}
& - \mu_s \left[(1 - 2\gamma) I(\nu, \Omega) - \frac{3}{16} \left(\int d\mu_3 I_3 [3 - \mu_1^2 + (3\mu_1^2 - 1) \mu_3^2] \right. \right. \\
& - \gamma \left(1 + \frac{c^2}{h\nu} I(\nu, \Omega) \right) \left(1 - \nu \frac{\partial}{\partial \nu} \right) \int d\mu_3 I_3 f(\mu_1, \mu_3) \\
& + \alpha \left\{ 2 \int d\mu_3 I_3 [(3\mu_1^2 - 1)(1 - 3\mu_3^2) + 2\mu_1(1 - 3\mu_1^2)\mu_3 + 2\mu_1(5\mu_1^3 - 3)\mu_3^3] \right. \\
& \left. \left. + \left(\nu^2 \frac{\partial^2}{\partial \nu^2} - 2\nu \frac{\partial}{\partial \nu} \right) \int d\mu_3 I_3 f(\mu_1, \mu_3) \right\} \right] \quad (72)
\end{aligned}$$

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

$$\begin{aligned}
& - \mu_s \left[-\gamma \left(I_o + \nu \frac{\partial I_o}{\partial \nu} \right) + \frac{c^2}{h\nu} \gamma \left(I_o^2 - \frac{2}{15} I_1^2 - \nu I_o \frac{\partial I_o}{\partial \nu} + \frac{2}{15} \nu I_1 \frac{\partial I_1}{\partial \nu} \right) \right. \\
& \left. - \alpha \left(\nu^2 \frac{\partial^2 I_o}{\partial \nu^2} - 2\nu \frac{\partial I_o}{\partial \nu} \right) \right] \quad (73)
\end{aligned}$$

and those for the first-moment equation are

$$\begin{aligned}
 & -\mu_s \left[I_1 \left(1 - \frac{12}{5} \gamma \right) + \frac{2}{5} \gamma \nu \frac{\partial I_1}{\partial \nu} + \frac{c^2}{h\nu^3} \gamma \left(\frac{3}{5} I_0 I_1 + \frac{2}{5} \nu I_0 \frac{\partial I_1}{\partial \nu} \right. \right. \\
 & \quad \left. \left. - \nu I_1 \frac{\partial I_0}{\partial \nu} \right) + \frac{2}{5} \alpha \left(I_1 + \nu^2 \frac{\partial^2 I_1}{\partial \nu^2} - 2\nu \frac{\partial I_1}{\partial \nu} \right) \right] \quad (74)
 \end{aligned}$$

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

$$\begin{aligned}
 \int d\nu \int d\Omega (\Gamma_1 + \Gamma_3) &= \mu_s c \left[\int \gamma E_\nu d\nu + \int \gamma^2 \frac{\partial E_\nu}{\partial \gamma} d\nu + \alpha \int \left(\nu^2 \frac{\partial^2 E_\nu}{\partial \nu^2} - 2\nu \frac{\partial E_\nu}{\partial \nu} \right) d\nu \right] \\
 &= \frac{\mu_s}{mc} \left(4\theta_e \int E_\nu d\nu - \int h\nu E_\nu d\nu \right) \quad (75)
 \end{aligned}$$

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

$$\int dv \int d\Omega \Gamma_2 = -\mu_s \frac{4\pi}{2m} \int I^2 \frac{dv}{v^2} = -\frac{\mu_s c^2}{2m 4\pi} \int E_v^2 \frac{dv}{v^2} \quad (76)$$

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

$$I = B = \frac{2h}{c} \frac{v^3}{e^{hv/\theta_r} - 1} \quad (77)$$

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

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

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

$$\begin{aligned} \frac{1}{c} \frac{\partial I_o}{\partial t} = \mu'_a (B - I_o) - \mu_s \left[-2\gamma I_o + \left(1 + \frac{c^2}{h\nu^3} I_o\right) \left(I_o - \nu \frac{\partial I_o}{\partial \nu}\right) \right. \\ \left. - \alpha \left(\nu^2 \frac{\partial^2 I_o}{\partial \nu^2} - 2\nu \frac{\partial I_o}{\partial \nu} \right) \right] \end{aligned} \quad (79)$$

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

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

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,

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

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

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

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:

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

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

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

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 $\theta_r \ll \theta_e$.

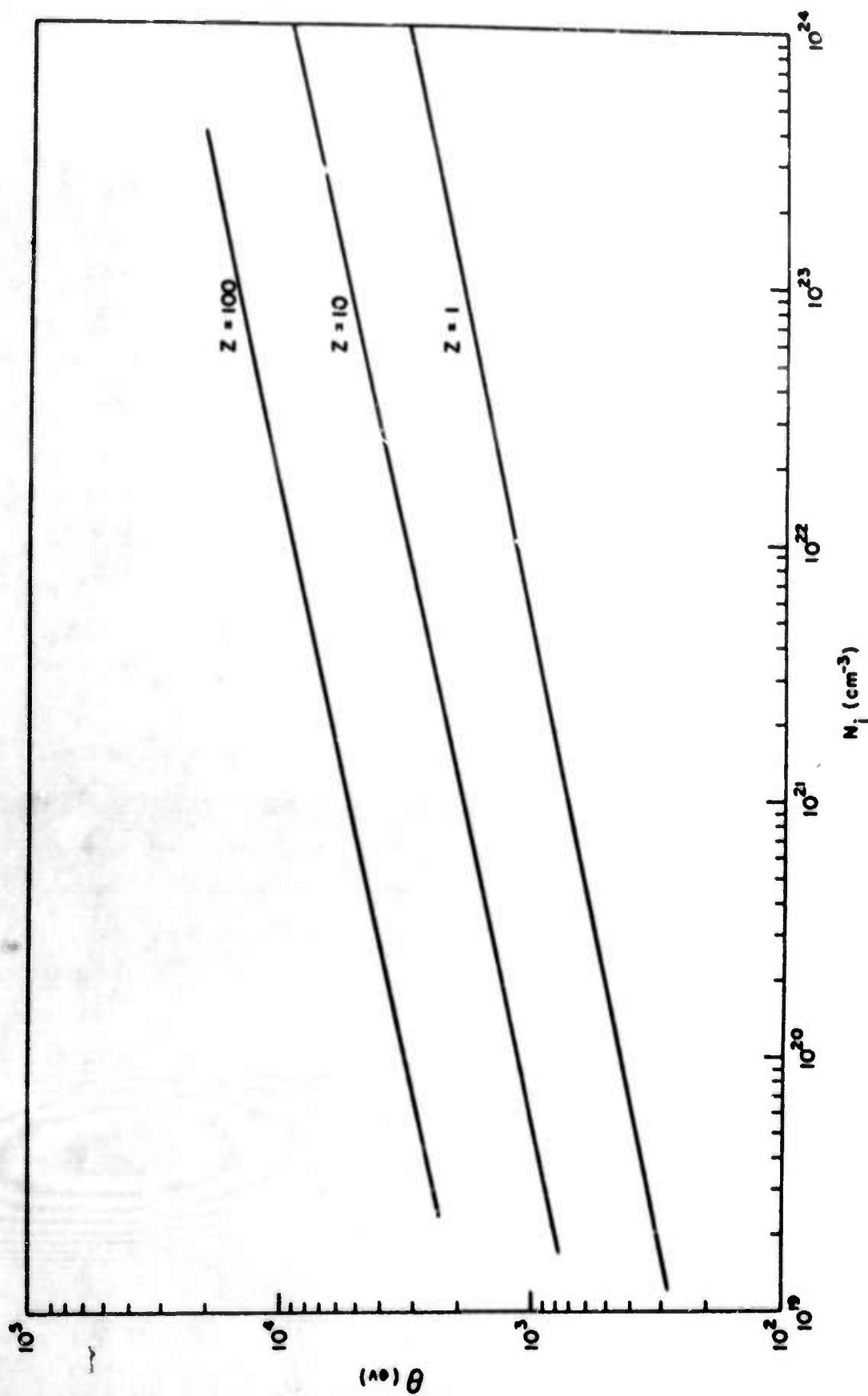


Figure 15. Temperature and Density at Which Heating Rates Due to Absorption and Scattering are Equal

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

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

has a limiting form for very small Δx_i given by

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

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 $x_0 < x < x_n$ due to radiation moving in the positive x direction is given in references 14 and 15 as

$$I_j(x_n) = B_j(x_n) + [I(x_0) - B(x_0)] S_j(x_n - x_0) \quad (87)$$

If the interval (x_0, x_n) is now subdivided into n zones of width $\Delta x = (x_n - x_0)/n$, the intensity at each of the subdivision points is

$$\begin{aligned} I_j(x_i) &= B_j(x_i) + [I(x_{i-1}) - B(x_{i-1})] S_j(\Delta x) \\ &= B_j(x_i) + [I(x_{i-2}) - B(x_{i-2})] S_j^2(\Delta x), \text{ etc.} \end{aligned} \quad (88)$$

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

$$I_j(x_n) = B_j(x_n) + [I(x_0) - B(x_0)] S_j^n(\Delta x) \quad (89)$$

which, with Eq. (87), implies that

$$S_j(n\Delta x) = S_j^n(\Delta x) \quad (90)$$

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 $\rho\kappa^P(x_n - x_0) \ll 1$.

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

$$I(\tau_n) = I(\tau_0) e^{-(\tau_n - \tau_0)} + \int_{\tau_0}^{\tau_n} B e^{-(\tau_n - \tau)} d\tau \quad (91)$$

with integration by parts,

$$I(\tau_n) = B(\tau_n^+) + [I(\tau_0) - B(\tau_0^+)] e^{-(\tau_n - \tau_0)} - \int_{\tau_0}^{\tau_n} \frac{dB}{d\tau} e^{-(\tau_n - \tau)} d\tau \quad (92)$$

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

$$\int_{\tau_0}^{\tau_n} \frac{dB}{d\tau} e^{-(\tau_n - \tau)} d\tau = \sum_{k=1}^n Q_{kn} \quad (93)$$

where

$$\begin{aligned}
 Q_{kn} &= \int_{\tau_{k-1}}^{\tau_k} \frac{dB}{d\tau} e^{-(\tau_n - \tau)} d\tau + (B_k^+ - B_k^-) e^{-(\tau_n - \tau_k)} \\
 &= e^{-(\tau_n - \tau_k)} \left[\int_{s_{k-1}}^{s_k} \frac{dB}{ds} e^{-\sigma_k(s_k - s)} ds + B_k^+ - B_k^- \right] \quad (94)
 \end{aligned}$$

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

$$ds = \frac{1}{\xi} dx = \frac{1}{\eta} dy = \frac{1}{\zeta} dz \quad (95)$$

The quadratic form

$$\begin{aligned}
 B(x, y, z) &= B(x_k, y_k, z_k) + \alpha_k(z - z_k) + \beta_k(x^2 + y^2 - x_k^2 - y_k^2) \\
 &\quad + \gamma_k(x^2 + y^2 + z^2 - x_k^2 - y_k^2 - z_k^2) \\
 &\quad x_{k-1} < x < x_k \\
 &\quad y_{k-1} < y < y_k \\
 &\quad z_{k-1} < z < z_k \quad (96)
 \end{aligned}$$

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

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

so that

$$\begin{aligned} Q_{kn} = & \left[\frac{\alpha_k}{\sigma_k} \zeta + 2 \frac{\beta_k}{\sigma_k} (\xi \sigma_k x_k + \eta \sigma_k y_k - \xi^2 - \eta^2) + 2 \frac{\gamma_k}{\sigma_k} (\xi \sigma_k x_k + \eta \sigma_k y_k \right. \\ & \left. + \zeta \sigma_k z_k - 1) + B_k^+ - B_k^- \right] e^{-(\tau_n - \tau_k)} \\ & - \left[\frac{\alpha_k}{\sigma_k} \zeta + 2 \frac{\beta_k}{\sigma_k} (\xi \sigma_k x_{k-1} + \eta \sigma_k y_{k-1} - \xi^2 - \eta^2) + 2 \frac{\gamma_k}{\sigma_k} (\xi \sigma_k x_{k-1} \right. \\ & \left. + \eta \sigma_k y_{k-1} + \zeta \sigma_k z_{k-1} - 1) \right] e^{-(\tau_n - \tau_{k-1})} \quad (98) \end{aligned}$$

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

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

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

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

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

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

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

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

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

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

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:

$$\sigma^A = \frac{\sigma^P + b\sigma^R - \text{sgn}(1 - b^2) [(\sigma^P - \sigma^R)(\sigma^P - b^2\sigma^R)]^{1/2}}{1 + b} \quad (104)$$

$$\sigma^B = \frac{\sigma^P - b\sigma^R + \text{sgn}(1 - b^2) [(\sigma^P - \sigma^R)(\sigma^P - b^2\sigma^R)]^{1/2}}{1 - b} \quad (105)$$

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

$$0 < \sigma^A \leq \sigma^B \quad (106)$$

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

$$b^2 < 1 < \sigma^P / \sigma^R \quad (107)$$

or

$$b^2 > 1 > \sigma^P / \sigma^R \quad (108)$$

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

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

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

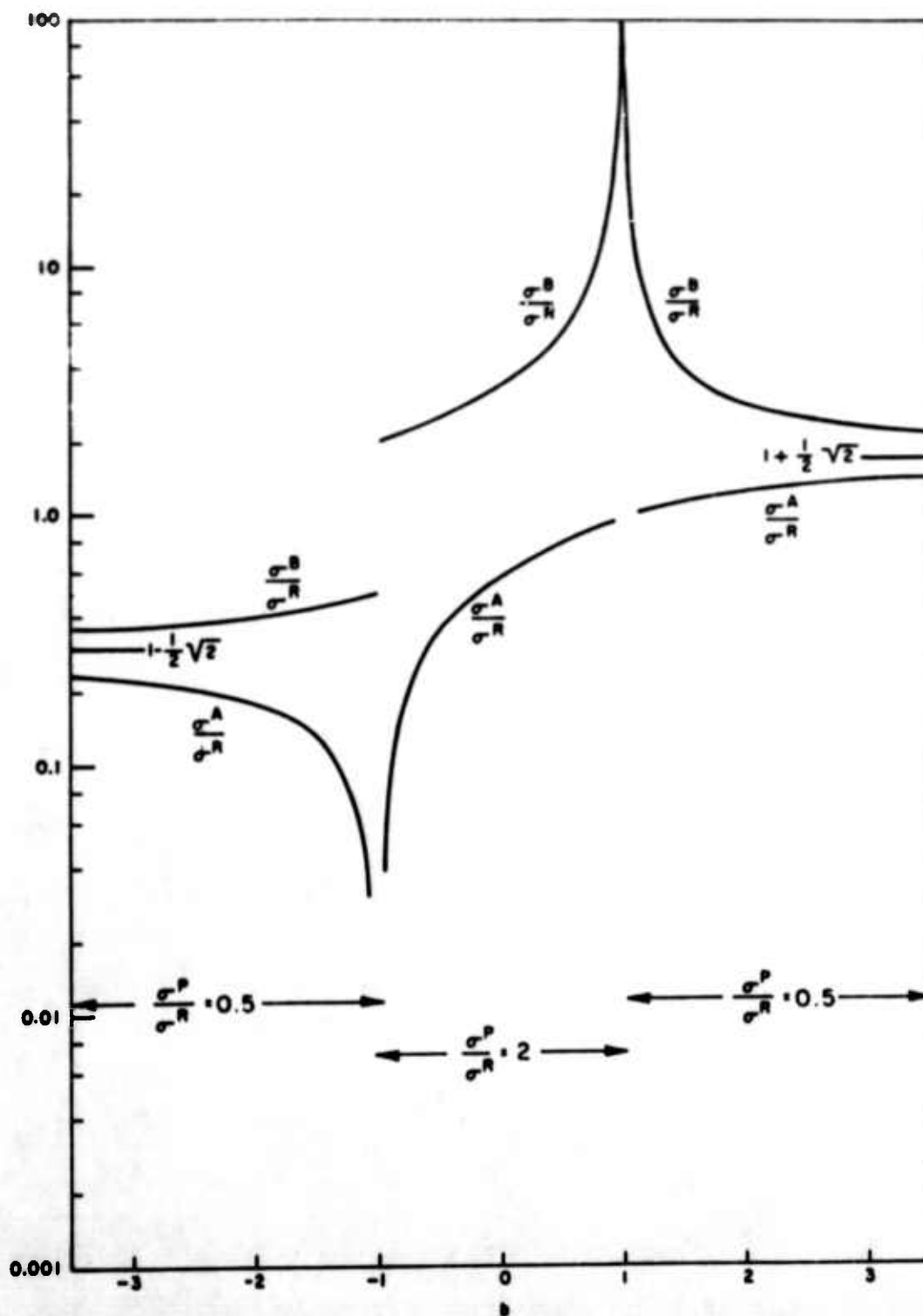


Figure 16. Dependence of Component Opacities on the Parameter b

Next, the transmission function is represented by

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

and, finally, the "nonlocal opacity" by

$$\begin{aligned} \sigma(s_i, s_n) &= -\frac{d}{ds_n} \log S(s_i, s_n) \\ &= \frac{1}{S(s_i, s_n)} \left[\frac{1}{2} (1 + b_n) \sigma^A(s_n) e^{-\tau^A(s_i, s_n)} + \frac{1}{2} (1 - b_n) \sigma^B(s_n) e^{-\tau^B(s_i, s_n)} \right] \end{aligned} \quad (112)$$

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 $b \rightarrow -1$, $\sigma^A \rightarrow 0$, and $\sigma^B \rightarrow \sigma^P$. 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 $b = 0$,

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

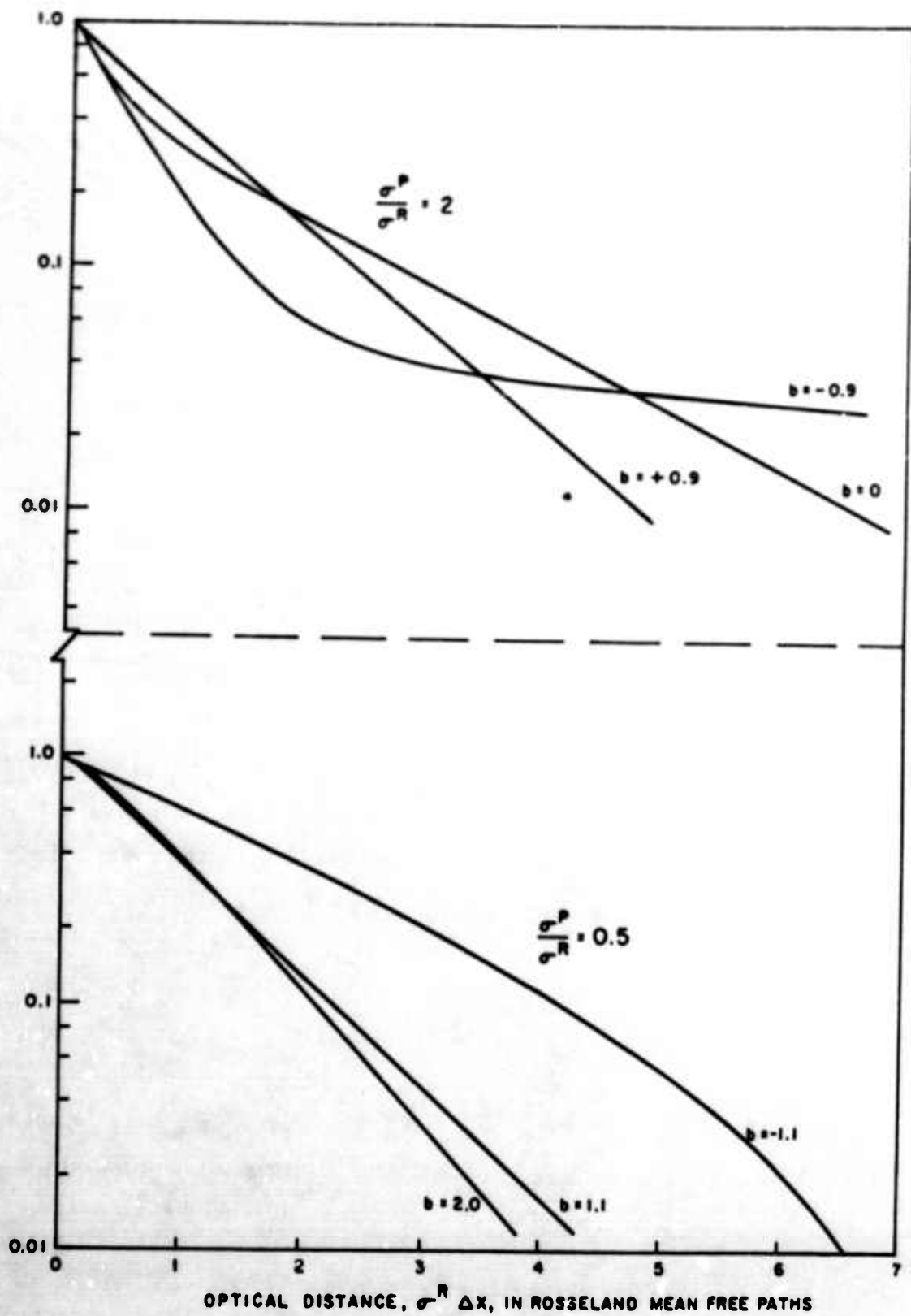


Figure 17. Transmission Function $S(\Delta x)$

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

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

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

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

for plane geometry, and

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

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

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

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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13. ABSTRACT

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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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