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USER'S MANUAL FOR THE PLUME SIGNATURE CODE EAPROF.(U)

JAN 81 S J YOUNG F04701-80-C-0081

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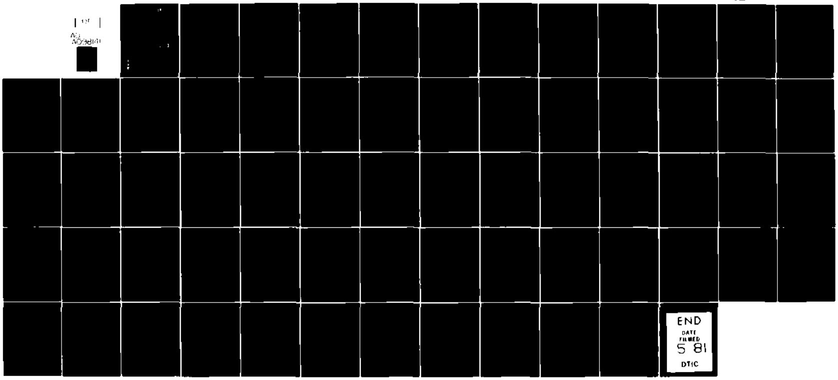

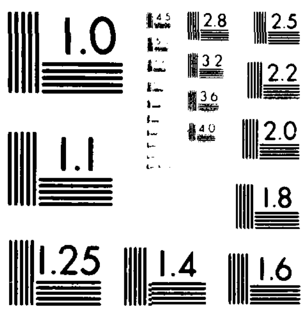


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A description and instructions for use of the plume signature code EAPROF are given. The code computes the transverse profiles of infrared emission and extinction within a fixed bandpass for an axisymmetric, axially uniform, cylindrical two-phase plume. The principal inputs are the radial distributions of gas temperature, pressure, and concentration and particle temperature and number density. An example application is made for a plume containing $H_2O$ as the gas species and $Al_2O_3$ as the particle species.

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## FOREWORD

This report was submitted by the Aerospace Corporation, P.O. Box 92957, Los Angeles, California, 90009, under Procurement Directive AFRPL/SD 81-1, Job Order No. 573010CU with the Air Force Rocket Propulsion Laboratory, Edwards AFB, California 93523.

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CONTENTS

FIGURES

# 1. INTRODUCTION

Program EAPROF (Emission Absorption Profiles) computes the transverse profiles of infrared emission and extinction for an axisymmetric, axially uniform, cylindrical plume from radial profiles of gas temperature, pressure, and concentration and particle temperature and number density. The radiation model treats gas radiation transfer with band model methods and particle radiation transfer with the single-scattering approximation. The radiation model correctly couples the gas and particle components into a single emitting, absorbing and scattering medium. The program treats just one gas species and one particle species at a time. Development of the model is made in Ref. 1.

The gas band model is the Malkmus statistical model and employs either the Curtis-Godson (CG) or derivative (DR) approximations to handle the inhomogeneity and nonisothermality of the plume. Lorentz, Doppler or Voigt line profiles may be used.

The single-scattering geometry used for particle radiation transport is shown in Fig. 1. The s-axis is the primary line of sight (LOS). (The LOS shown in Fig. 1 is the one that goes through the full plume diameter. As the LOS is scanned out across the lateral extent of the plume, it cuts progressively shorter chords of the cylindrical plume). The $\sigma$-axis is the scattering LOS.

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1. S. J. Young, Retrieval of Flow-Field Gas Temperature and Concentration in Low-Visibility Propellant Rocket Exhaust Plumes, U.S. Air Force Rocket Propulsion Laboratory, Edwards Air Force Base, Calif. (to be published).

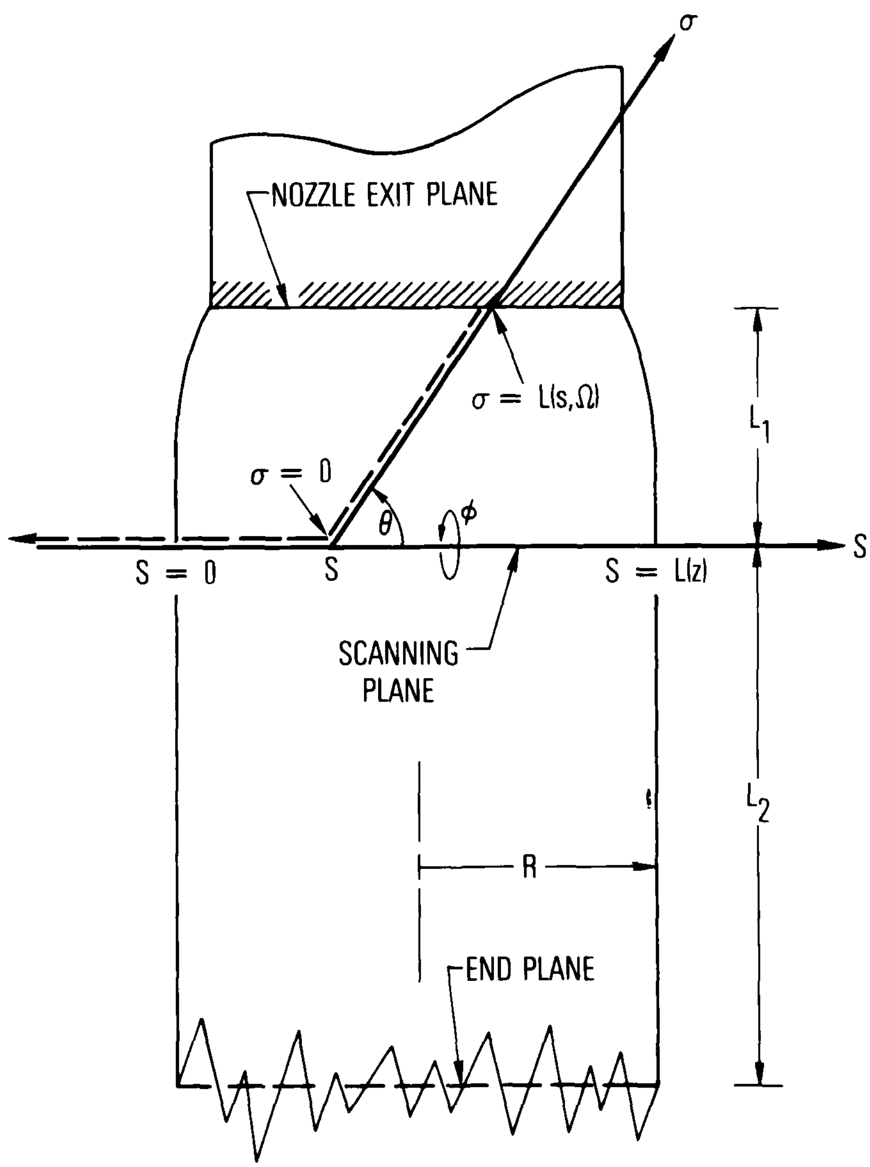


**Fig. 1. Single-Scattering Plume Geometry.**

It is described by the value of $s$ where it branches off the primary LOS and by the scattering angle $\theta$ and the azimuthal angle $\phi$. The single-scattering approximation includes radiation emitted along the primary LOS and radiation that has been scattered once from the scattering LOS into the primary LOS. If the scattering LOS terminates on the nozzle exit plane, motor radiation scattered into the primary LOS is also included. The exit plane is modeled as a solid disc with uniform temperature and emissivity.

Extinction of external radiation shown through the plume is assumed to be caused by gas absorption, particle absorption and particle outscattering. The single-scattering approximation does not allow inscattering to contribute to extinction calculations.

The structure of the code is described in Section 2, and a brief description of the function of each subprogram is given. Preparation of input data for the code is described in Section 3. An example application for a plume containing $H_2O$ and $Al_2O_3$ as the gas and particle species, respectively, is given in Section 4. This example is taken from Ref. 1. A listing of the code is given in the Appendix.

## 2. CODE STRUCTURE

The organization of the code is shown in Fig. 2. EAPROF is the main program. The subroutine INPUT reads all data required for a run and processes it for compatability with the rest of the code. The function ZONEFIT interpolates on input radial profiles and fits the data on a grid of N equal thickness radial zones. The function ANGLFIT interpolates on the input differential scattering cross section and fits the data to the scattering-angle integration grid (also part of input).

With the radial data fitted to a fixed radial grid, further interpolation is performed to fit the data to the primary and scattering lines of sight. These interpolations are performed by subroutines ZLOS and SLOS, respectively.

QTHERM is the main routine for computing the thermal radiation source function along the primary or scattering LOS. This radiation arises from gas and particle emission. The function KDPARAM interpolates for gas band model parameters along a LOS from input tables of these data. PLANCK computes the blackbody function. The remaining functions listed under QTHERM are radiation functions that are variously employed depending on the lineshape and nonuniformity modes selected for the gas radiation band model. They are described in more detail in Refs. 2 and 3.

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2. S. J. Young, Description and Use of the Plume Radiation Code ATLES, SAMSO-TR-77-100, U.S. Air Force Space Division, El Segundo, Calif., 13 May 1977.

3. S. J. Young, Inversion of Plume Radiance and Absorptance Data for Temperature and Concentration, AFRPL-TR-78-60, U. S. Air Force Rocket Propulsion Laboratory, Edwards Air Force Base, Calif., 29 September 1978.

| | |
|---|---|
| EAPROF | main program |
| INPUT<br>ZONEFIT<br>ANGLFIT | data input and preparation |
| ZLOS<br>SLOS | line-of-sight data fitting |
| QTHERM<br>KDPARAM<br>PLANCK<br>F<br>YCGL<br>YDRL<br>YLSL<br>G<br>YCGD<br>YMLD<br>YLSD<br>WMIX<br>YMIX | thermal source function routines |
| QSCAT | scattering source function routine |
| RADNCE | radiance routine |
| OUTPUT | output routine |
| TRNSFR<br>INITIAL<br>STORE | bookkeeping routines |

Fig. 2. Program EAPROF and Associated Subprograms.

The single-scattering source function is computed in QSCAT by an integration over all scattering angles $\theta$ and azimuthal angles $\phi$. Thermal radiation from the nozzle exit plane is also treated here for scattering lines of sight that terminate on this plane.

The thermal source and scattering source functions are integrated over a LOS in subroutine RADNCE. The results are listed by OUTPUT.

The routines TRNSFR, INITIAL and STORE are bookkeeping routines.

## 3. PREPARATION OF INPUT DATA

A computational run of program EAPROF requires a set of program control cards to specify the mode of computation and to supply input data. Some program control cards simply specify a computation mode, some specify a computation mode and supply data, while others signal the code that blocks of auxiliary data are now to be read in. Each type of control card contains an alphanumeric name in the first ten card columns. These names must be spelled correctly and must be left-justified. If data are specified on a program control card, they must be entered in accordance with the format specification indicated in the detailed description of each card given below. All fields of the program control cards are 10 columns wide. In general, integer and alphanumeric data must be right-justified in their fields. Non-integer numerical data may be entered in either F or E formats (with decimal point and, for the latter, the exponential symbol E). E-formatted data must be right-justified in their field. These same rules apply to data entered on auxiliary card decks. The types of control cards and the data contained on them are illustrated in Fig. 3. A description of each type follows.

1. Title Card - The card name is TITLE. Columns 11-80 of this card may be used for any identification title desired.

2. Calculation Data Card - The card name is CALCDATA. SHAPE (format A10) must be one of the alphanumeric values LORENTZ, DOPPLER, or VOIGT. INHOM (format A10) must have either the value CG (for the Curtis-Godson approximation) or DR(for the derivative approximation). NZONES (format I10) is the number of radial and transverse zones used by the spatial numerical integration routines. The maximum value of NZONES is 50. NSIGMA (format I10) is the number of equal-length segments that a scattering LOS is divided into for numerical integration.

| 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 |
|---|---|---|---|---|---|---|---|
| TITLE | | | | | | | |
| CALCDATA | SHAPE | INHOM | NZONES | NSIGMA | SFLAG | | |
| PLMDATA | L1 | L2 | TN | EN | | | |
| SPECIES | GCOL | PCOL | | | | | |
| GPARAM | PRINT | | | | | | |
| GDATA | PRINT | | | | | | |
| PPARAM | PRINT | | | | | | |
| PDATA | PRINT | | | | | | |
| GRID | NPHI | PRINT | | | | | |
| RUN | | | | | | | |

Fig. 3. EAPROF Program Control Card Formats.

If SFLAG (format I10) has the value 1, full gas-particle calculations are carried out. If it has the value 0 (or blank), particle effects are ignored.

3. Plume Data Card - The card name is PLMDATA.
L1 (format E10) is the distance (cm) from the nozzle exit plane to the observation scanning plane. L2 (format E10) is the distance (cm) from the scanning plane to the end of the plume. TN (format E10) is the temperature (K) of the nozzle exit plane disc, and EN (format E10) is its emissivity.

4. Species Card - The card name is SPECIES. The GDATA card described under card type 6 allows the entry of up to four different gas species. The variable GCOL (format I10) on the SPECIES card selects the desired species by assuming a value of 1 to 4. Similarly, PCOL (format I10) selects one of the three particle species read in by the control card type 8 by assuming a value of 1 to 3.

5. Band Model Parameter Card - The card name is GPARAM. This card calls for the read-in of band model parameters for the gas species of interest. These parameters are listed if the variable PRINT (format A10) has the value PRINT. The card deck structure for the parameters is given in Fig. 4.

6. Gas Data Card - The card name is GDATA. This card calls for the read-in of the radial profiles of gas temperature, pressure and concentration. The required deck structure is shown in Fig. 5. If the variable PRINT (format A10) has the value PRINT, these data are listed.

| 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 |
|---|---|---|---|---|---|---|---|
| GPRMID | $\nu$ | $\Delta\nu$ | $\bar{\gamma}$ | $\alpha_1$ | $\alpha_2$ | $\alpha_3$ | |
| T(1) | $\bar{k}(1)$ | D(1) | | | | | |
| T(2) | $\bar{k}(2)$ | D(2) | | | | | |
| ⋮ | ⋮ | ⋮ | | | | | |
| T(40) | $\bar{k}(40)$ | D(40) | | | | | |

All Field formats are E10 or F10 except the GPRMID field which is A10.

GPRMID Identification name.

$\nu$ Spectral position ($cm^{-1}$).

$\Delta\nu$ Spectral resolution ($cm^{-1}$).

$\bar{\gamma}$ Pressure broadening coefficient ($cm^{-1}/atm$) for nonresonant self broadening at STP.

$\alpha_1$ Ratio of resonant self broadeining parameter to $\bar{\gamma}$ at STP.

$\alpha_2$ Ratio of foreign gas broadening parameter to $\bar{\gamma}$ at STP.

$\alpha_3$ Atomic weight of active gas species (amu).

T(i) Temperature array (K). The array must be $T(i) = 100i$, $i = 1, 2, \ldots, 40$.

$\bar{k}(i)$ Absorption coefficient for $\nu$, $\Delta\nu$ and T(i) ($cm^{-1}/atm$).

D(i) Line density parameter for $\nu$, $\Delta\nu$ and T(i) (lines/$cm^{-1}$). Note, $D = 1/\bar{\delta}$.

**Fig. 4. Input Card File Structure for Band Model Parameters.**

| 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 |
|---|---|---|---|---|---|---|---|
| GDTAID | N | R | GNAME1 | GNAME2 | GNAME3 | GNAME4 | |
| r(1) | p(1) | T(1) | $c_1(1)$ | $c_2(1)$ | $c_3(1)$ | $c_4(1)$ | |
| r(2) | p(2) | T(2) | $c_1(2)$ | $c_2(2)$ | $c_3(2)$ | $c_4(2)$ | |
| ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | |
| r(N) | p(N) | T(N) | $c_1(N)$ | $c_2(N)$ | $c_3(N)$ | $c_4(N)$ | |

All field formats are E10 or F10 except the GDTAID, GNAME1, GNAME2, GNAME3 and GNAME4 fields which are A10 and the N field which is I10.

| | |
|---|---|
| GDTAID | Gas data identification name. |
| N | Number of radial points ($N \le 201$). |
| R | Source radius (cm). |
| GNAME1 → GNAME4 | Gas species identification names. |
| r(i) | Radial positions (cm). $0 \equiv r(1) < \ldots < r(N) \equiv R$. |
| T(i) | Temperature (K) at r(i). |
| $c_j(i)$ | Concentration (mole fraction) of species j ($j = 1,\ldots,4$) at r(i). |

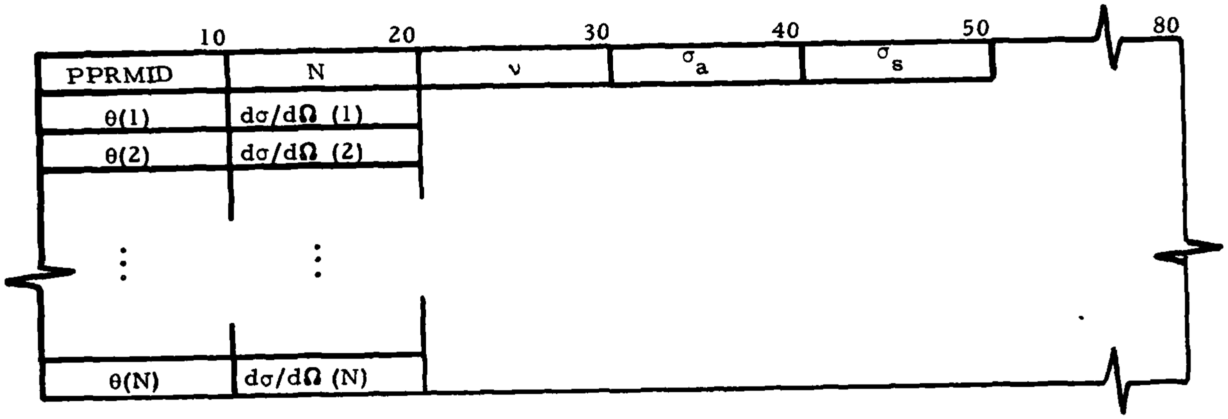
**Fig. 5. Input Card File Structure for Radial Gas Data.**

7. Particle Parameters Card - The card name is PPARAM. This card calls for the read-in of particle scattering data. The required deck structure is shown in Fig. 6. If the variable PRINT (format A10) has the value PRINT, these data are listed.

8. Particle Data Card - The card name is PDATA. This card calls for the read-in of the radial profiles of particle temperature and number density. The required deck structure is shown in Fig. 7. If the variable PRINT (format A10) has the value PRINT, these data are listed.

9. Angle Integration Grid - The card name is GRID. The card supplies and calls for the read in of data defining the grid over which angle integrations are carried out. NPHI (format I10) is the number of intervals over which the $360^{\circ}$ azimuthal integration is carried out. The scattering angle integration over $180^{\circ}$ is carried out on the grid defined in Fig. 8. If the variable PRINT (format A10) on the GRID card has the value PRINT, the scattering angle grid is listed.

10. Execution Card - The card name is RUN. When this card is encountered, computations are begun using the data entered up to that point, and an output listing of the results is made. When the computation and results listing are completed, the program continues to read program control cards until a new RUN card is encountered. A new computation is then begun for all of the conditions and data of the first run except those which have been changed by the intervening program control cards and auxiliary data decks. This process is repeated until an end-of-file card is encountered. With this feature, a large number of related runs can be made with one job submission.




All field formats are E10 or F10 except the PPRMID field which is A10 and the N field which is I10.

| | |
|---|---|
| PPRMID | Particle parameters identification name. |
| $N$ | Number of scattering angles ($N \le 181$). |
| $\nu$ | Spectral position ($cm^{-1}$). |
| $\sigma_a$ | Absorption cross section ($cm^2$). |
| $\sigma_s$ | Total scattering cross section ($cm^2$). |
| $\theta(i)$ | Scattering angle array (deg). $0 \le \theta(1) < \theta(2) < \ldots < \theta(N) \le 180^\circ$. |
| $d\sigma/d\Omega(i)$ | Differential scattering cross section for $\theta(i)$ ($cm^2/sr$). |

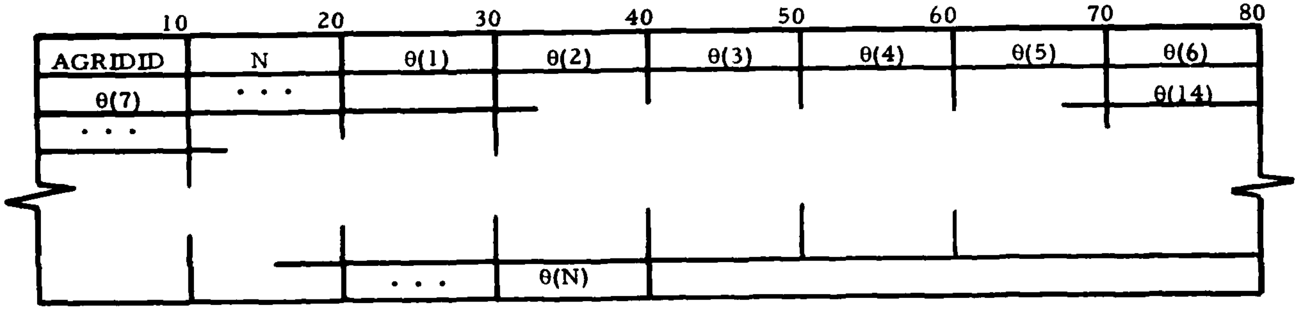
Fig. 6. Input Card File Structure for Particle Scattering Parameters.

| 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 |
|---|---|---|---|---|---|---|---|
| PDTAID | N | R | PNAME1 | PNAME2 | PNAME3 | | |
| r(1) | $T_1(1)$ | $c_1(1)$ | $T_2(1)$ | $c_2(1)$ | $T_3(1)$ | $c_3(1)$ | |
| r(2) | $T_1(2)$ | $c_1(2)$ | $T_2(2)$ | $c_2(2)$ | $T_3(2)$ | $c_3(2)$ | |
| ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | |
| r(N) | $T_1(N)$ | $c_1(N)$ | $T_2(N)$ | $c_2(N)$ | $T_3(N)$ | $c_3(N)$ | |

All field formats are E10 or F10 except the PDTAID and PNAME1 through PNAME3 fields which are A10, and the N field which is I10.

| | |
|---|---|
| PDTAID | Particle data identification name. |
| N | Number of radial points ($N \leq 201$). |
| R | Source radius (cm). |
| PNAME1 → PNAME3 | Particle species identification names. |
| r(i) | Radial positions (cm). $0 \leq r(1) < \ldots < r(N) = R$. |
| $T_j(i)$ | Temperature (K) of species j ($j = 1, \ldots, 4$) at r(i). Note, if $T_j(1) < 0$, the particle temperature profile for the jth species is set equal to the gas temperature profile. |
| $c_j(i)$ | Concentration (particles/$cm^3$) of species j ($j = 1, \ldots, 4$) at r(i). |

Fig. 7. Input Card File Structure for Radial Particle Data.




All field formats are E10 or F10 except the AGRIDID field which is A10 and the N field which is I10.

| | |
|---|---|
| AGRIDID | Angle grid identification name. |
| N | Number of scattering angles ($N < 37$). |
| $\theta(i)$ | Scattering angle array (deg). $0 \le \theta(1) < \theta(2) < \ldots < \theta(N) \le 180^\circ$. |

**Fig. 8. Input Card File Structure for Scattering Angle Integration Grid.**

Other than the requirement that all required data be specified before a RUN card is encountered and that auxiliary data immediately follow the control card that calls for them, the program control cards may be arranged in any order.

Great care should be taken in the preparation of input data since very few checks of data consistency and setting of default values are provided. A general feature of data preparation is that, if particular data on a card are not required, they need not be specified. If none of the data on a control card is needed, that card need not be included.

## 4. EXAMPLE APPLICATION

An example application of EAPROF is made here for a plume containing $H_2O$ as the active gas species and $Al_2O_3$ as the particle species. A discussion of this plume model is made in Ref. 1. The radial gas data are shown in Fig. 9. The particle radial profile is flat with the loading value $N_p = 10^5/cm^3$. The $H_2O$ band model parameters are the NERD wideband parameters of Fig. 10 (Ref. 3) and are appropriate to a band center $\sim 3985\ cm^{-1}$ and a bandpass of $\sim 300\ cm^{-1}$. The nonresonant, self-broadening parameter is $\gamma_0 = .07394\ cm^{-1}/atm$. The efficiency for resonant self-broadening is 6.53, and the efficiency for foreign gas broadening is 1.00.

Particle scattering cross sections were computed using Mie theory, the particle size distribution of Fig. 11 and the indexes of refraction $m = 2.51 - i0.0018$, $2.51 - i0.01$ and $2.51 - i0.05$. The first listed value is the accepted value for pure $Al_2O_3$. The stuff of real plumes is not likely to be so pure. The two other values are simply arbitrary values selected to parametrically study the problem. The value $m = 2.51 - i0.01$ is used in this example. The results for the scattering cross sections are shown in Fig. 12.

Azimuthal integration was performed with a 16-point grid. The scattering angle integration grid and the manner in which it covers the weighting function $\sin\theta\, p(\theta)$ of the scattering source function integral [$p(\theta)$ is a scaled value of $d\sigma/d\Omega$] are illustrated in Fig. 13.

Calculations were made for the Lorentz line shape and the CG approximation. The number of radial/transverse zones was 10, and scattering lines of sight were also divided into 10 segments for numerical integration. The distance from the exit plane to the observation plane was taken as 3 cm, and the distance from the observation plane to the end of the plume was fixed at 15 cm. The exit plane was modeled as a flat disc with uniform temperature $T = 800$ K and emissivity $\epsilon = 0.75$.

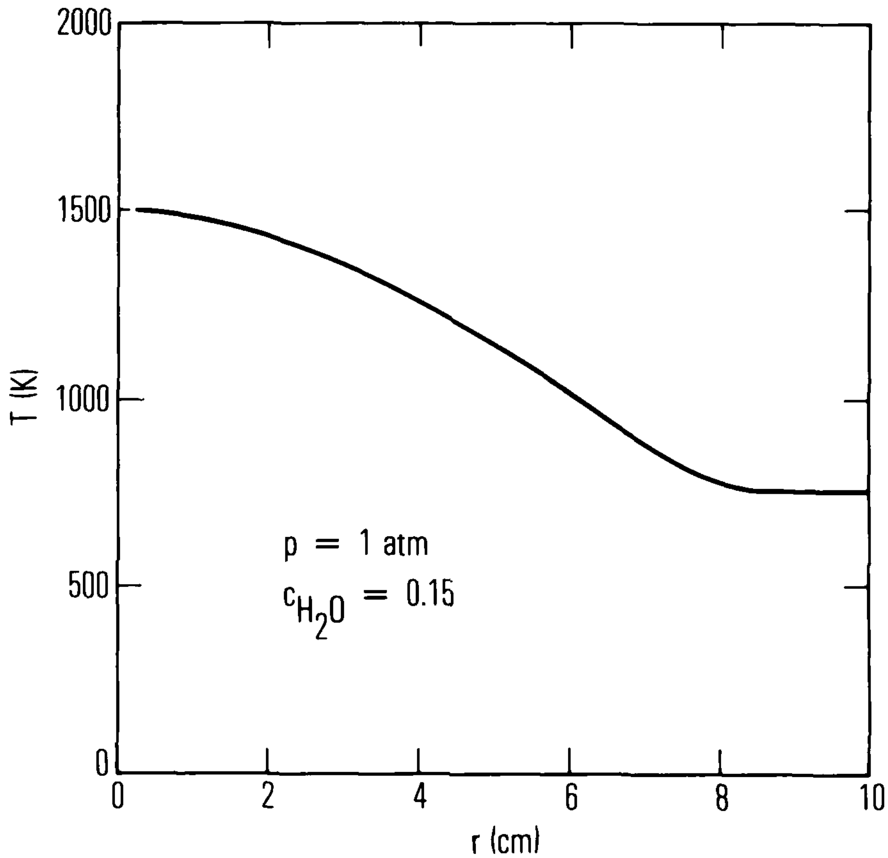



Fig. 9. Radial Gas Data.

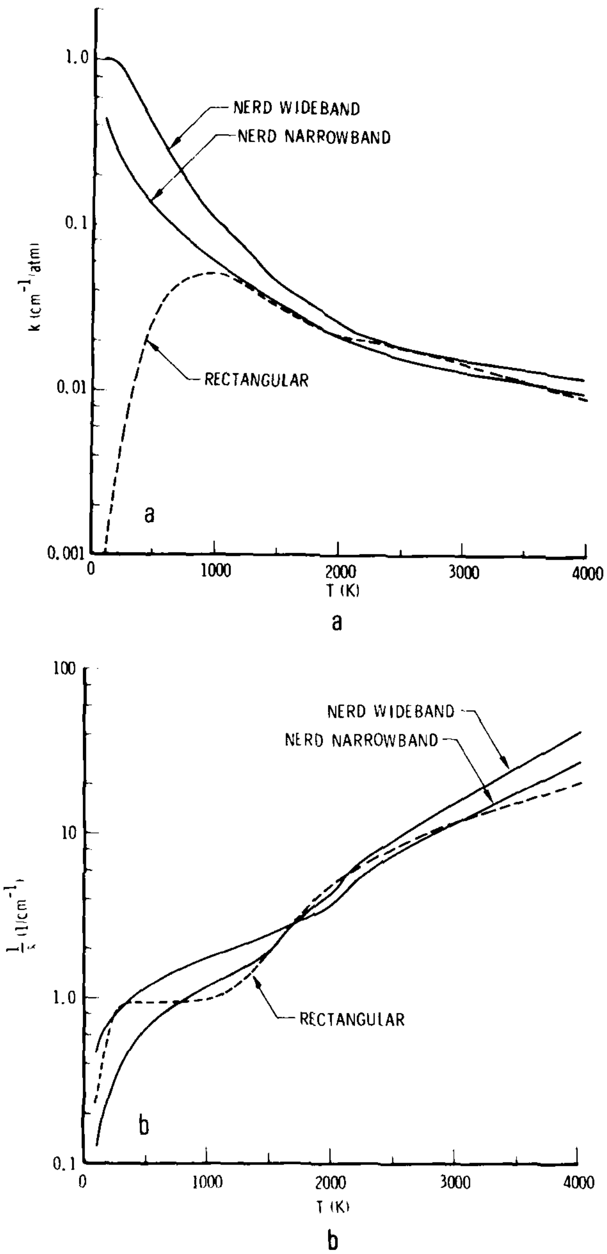



Fig. 10. $H_2O$ Band Model Parameters. a) Absorption Coefficient; b) *Line Density.*

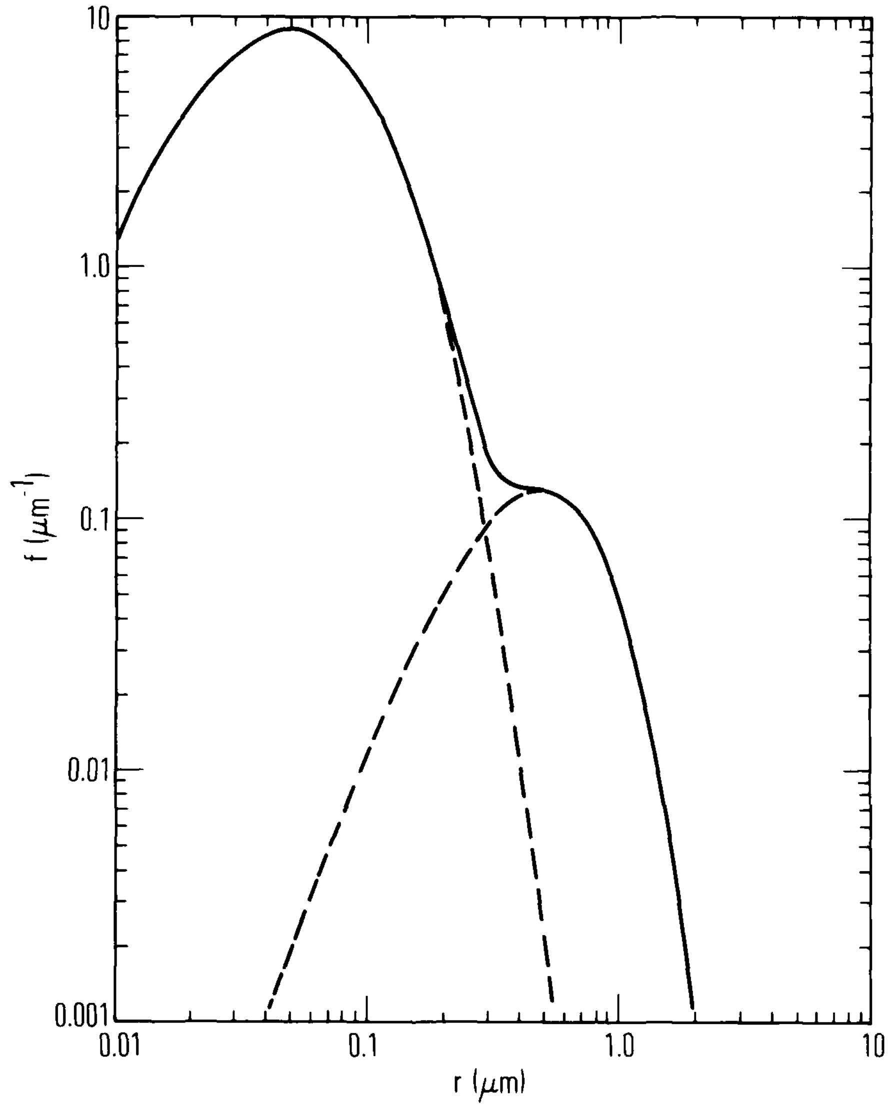



Fig. 11. $Al_2O_3$ Size Distribution.

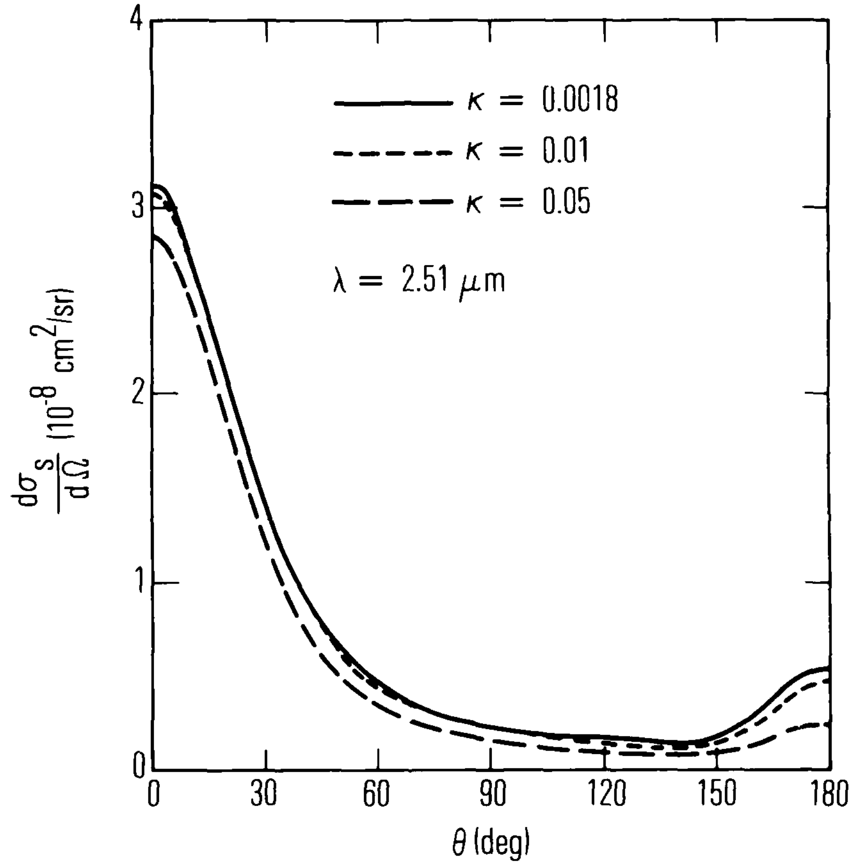



Fig. 12. Differential Scattering Cross Sections for $Al_2O_3$.

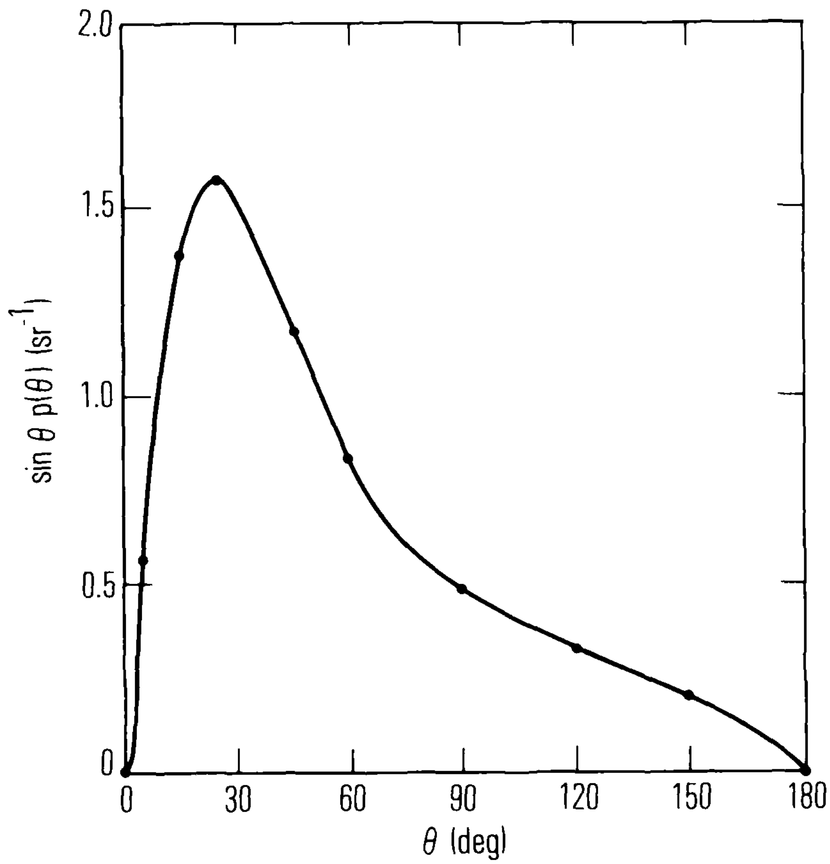



Fig. 13. Coverage of the Scattering Integral Weighting Function by the 11-Point Scattering Angle Grid.

A listing of the input data for these calculation conditions is shown in Fig. 14. The resulting output is shown in Figs. 15 and 16. Figure 16 also shows the results for computations assuming gas-only and particle only conditions. The gas-only results were obtained by changing the SFLAG value on the CALCDATA card from 1 to 0. The particle-only results were obtained by setting SFLAG back to 1 and substituting a band model parameter card deck in which the $\bar{k}$ values for all temperature were set to $\bar{k} = 10^{-40} \mathrm{cm}^{-1}/\mathrm{atm}$.

```
TITLE      EAPROF EXAMPLE RUN -- AL2O3/H2O PLUME
CALCDATA     LORENTZ        CG        10         13          1
PLMDATA           3.       15.       800.       0.75
SPECIES            1         1
GPARAM
  NEROH2OW     3985.0      300.    0.07394       6.53       1.00       10.
      100.  .4262E+00  .1242E+00
      200.  .2686E+00  .2722E+00
      300.  .1972E+00  .4058E+00
      400.  .1614E+00  .5306E+00
      500.  .1256E+00  .6658E+00
      600.  .1077E+00  .7773E+00
      700.  .8995E-01  .8926E+00
      800.  .7672E-01  .9990E+00
      900.  .6836E-01  .1096E+01
     1000.  .6000E-01  .1189E+01
     1100.  .5466E-01  .1318E+01
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     1300.  .4380E-01  .1592E+01
     1400.  .3839E-01  .1738E+01
     1500.  .3299E-01  .1893E+01
     1600.  .3057E-01  .2359E+01
     1700.  .2815E-01  .2828E+01
     1800.  .2573E-01  .3313E+01
     1900.  .2331E-01  .3822E+01
     2000.  .2089E-01  .4363E+01
     2100.  .1980E-01  .5327E+01
     2200.  .1871E-01  .6312E+01
     2300.  .1762E-01  .7323E+01
     2400.  .1653E-01  .8362E+01
     2500.  .1543E-01  .9435E+01
     2600.  .1499E-01  .1057E+02
     2700.  .1455E-01  .1169E+02
     2800.  .1411E-01  .1283E+02
     2900.  .1367E-01  .1397E+02
     3000.  .1323E-01  .1511E+02
     3100.  .1284E-01  .1665E+02
     3200.  .1246E-01  .1836E+02
     3300.  .1209E-01  .2027E+02
     3400.  .1174E-01  .2241E+02
     3500.  .1142E-01  .2479E+02
     3600.  .1107E-01  .2745E+02
     3700.  .1075E-01  .3043E+02
     3800.  .1044E-01  .3378E+02
     3900.  .1015E-01  .3753E+02
     4000.  .9861E-02  .4175E+02
SDATA
    RATES2          11        10.        H2O        CO2         CO
        0.         1.0      1500.       0.15       0.15       0.35
        1.         1.0      1475.       0.15       0.15       0.35
        2.         1.0      1435.       0.15       0.15       0.35
        3.         1.0      1365.       0.15       0.15       0.35
        4.         1.0      1280.       0.15       0.15       0.35
        5.         1.0      1165.       0.15       0.15       0.35
        6.         1.0      1035.       0.15       0.15       0.35
        7.         1.0       880.       0.15       0.15       0.35
        8.         1.0       765.       0.15       0.15       0.35
        9.         1.0       755.       0.15       0.15       0.35
       10.         1.0       750.       0.15       0.15       0.35
PPARAM
AO-K-2.5-2          21      3985.    3.20E-9    5.58E-8
        1.     3.36E-8
        5.     2.98E-8
       10.     2.75E-8
       15.     2.42E-8
       20.     2.05E-8
       30.     1.39E-8
       40.     9.14E-9
       50.     6.18E-9
       60.     4.33E-9
       70.     3.29E-9
       80.     2.59E-9
       90.     2.15E-9
      100.     1.97E-9
      110.     1.71E-9
      120.     1.62E-9
      130.     1.53E-9
      140.     1.47E-9
      150.     1.78E-9
      160.     2.62E-9
      170.     4.06E-9
      180.     4.87E-9
PDATA
  RATES2/7           2        10.      AL2O3
        0.         -1.       1.E5
       10.         -1.       1.E5
GRID                16
AL2O3-K2.5          11         0.         5.        15.        25.        35.        45.
       60.         90.       120.       150.       180.
RUN
```

Fig. 14. Input Data Listing.

```
****************************************SUMMARY LISTING OF INPUT DATA**************************

JOB TITLE                              EAPROF EXAMPLE RUN -- AL2O3/H2O PLUME
SOURCE RADIUS(CM)                       1.000E+01
LINESHAPE                                 LORENTZ
INHOMOGENEITY APPROXIMATION                    CG
NUMBER OF ZONES                                10
GAS SPECIES                                   H2O
BAND MODEL PARAMETER IDNAME              NEROH2OW
GAS DATA IDNAME                            BATES2
PARTICLE SPECIES                            AL2O3
SCATTERING PARAMETER IDNAME            AO-K-2.5-2
PARTICLE DATA IDNAME                     BATES2/7
SCATTERING GRID IDNAME                 AL2O3-K2.5
NUMBER OF SCATTERING ANGLES                    11
NUMBER OF AZIMUTHAL ANGLES                     16
NUMBER OF SIGMA-AXIS INTERVALS                 10
DISTANCE TO NOZZLE PLANE(CM)            3.000E+00
DISTANCE TO END PLANE(CM)               1.500E+01
NOZZLE TEMPERATURE(DEGK)                8.000E+02
NOZZLE EMISSIVITY                       7.500E-01
SCATTERING FLAG                                 1
```

```
******************************************E/A PROFILE RESULTS*********************************

INDEX   N(W/CM2*SR*CM-1)    N(W/CM2*SR*MICRON)    EXTINCTION    TRANSMITTANCE

  1        5.916E-05           9.395E-02          2.109E-01      7.891E-01
  2        5.730E-05           9.100E-02          2.107E-01      7.893E-01
  3        5.218E-05           8.286E-02          2.099E-01      7.901E-01
  4        4.415E-05           7.011E-02          2.082E-01      7.918E-01
  5        3.400E-05           5.400E-02          2.053E-01      7.947E-01
  6        2.311E-05           3.670E-02          2.006E-01      7.994E-01
  7        1.366E-05           2.169E-02          1.939E-01      8.061E-01
  8        7.370E-06           1.170E-02          1.829E-01      8.171E-01
  9        4.708E-06           7.476E-03          1.625E-01      8.375E-01
 10        3.454E-06           5.485E-03          1.259E-01      8.741E-01
 11        0.                  0.                 0.             1.000E+00
```

Fig. 15.    Output Listing.

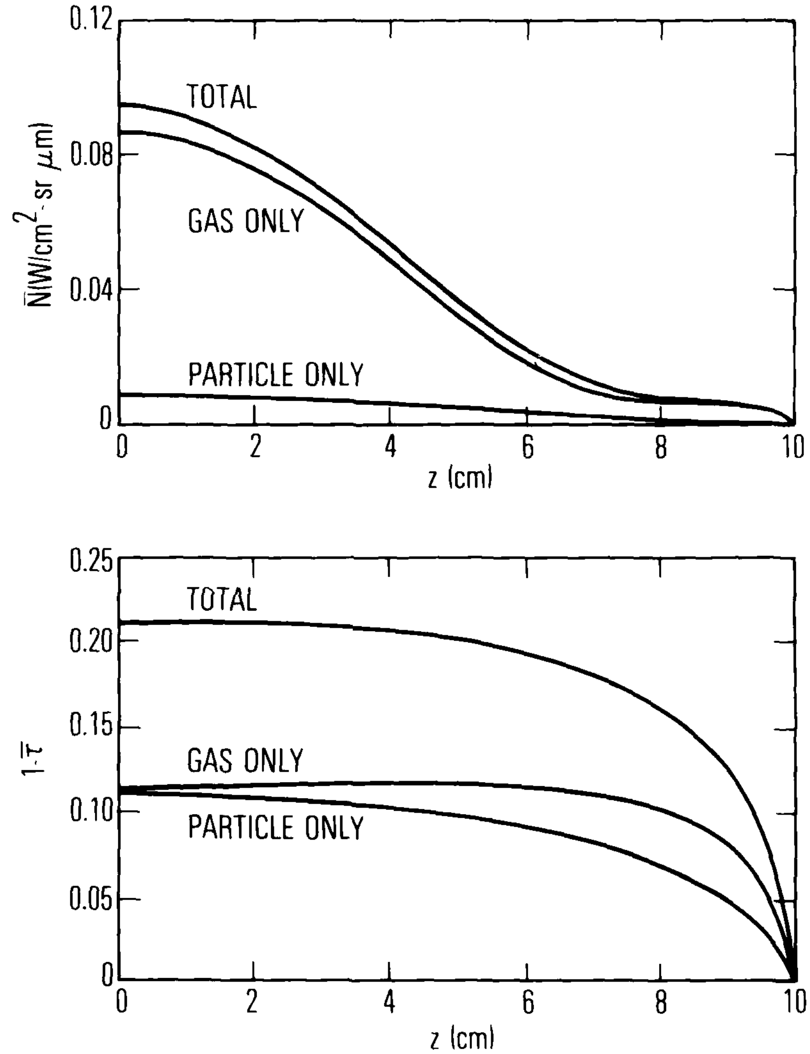


Fig. 16. Transverse Emission and Extinction Profiles.

# APPENDIX

## LISTING OF PROGRAM EAPROF

```
      PROGRAM EAPROF(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT)
C
C        COMPUTE TRANSVERSE EMISSION AND EXTINCTION PROFILES FOR AN
C        AXISYMMETRIC, AXIALLY UNIFORM, CYLINDRICAL PLUME FROM INPUT
C        RADIAL PROFILES OF GAS TEMPERATURE, PRESSURE AND CONCENTRATION
C        AND PARTICLE TEMPERATURE AND NUMBER DENSITY.  GAS AND PARTICLE
C        RADIATION ARE COUPLED BY USE OF A SINGLE-SCATTERING RADIATION
C        BAND MODEL.
C
      DIMENSION RAD(51),ABS(51)
      INTEGER SFLAG
      COMMON/OUTPT/RAD,ABS
C
C READ INPUT DATA
    1 CALL INPUT(NZONES,SFLAG)
C LOOP OVER TRANSVERSE POSITIONS
 4    DO 3 J=1,NZONES
C COMPUTE THERMAL SOURCE FUNCTION AND TRANSMITTANCE COMPONENTS
 6    CALL ZLOS(J,NLOS)
 10   CALL TRNSFR
 11   CALL INITIAL(0,NLOS)
 13   CALL QTHERM(1,SFLAG)
 15   CALL STORE
C COMPUTE SCATTERING SOURCE FUNCTION
 16   IF(SFLAG.NE.1) GO TO 2
 20   CALL INITIAL(1,NLOS)
 22   CALL QSCAT(J)
C COMPUTE LINE-OF-SIGHT RADIANCE AND EXTINCTANCE
 24 2 CALL RESTORE
 25   CALL RADNCE(SFLAG,RTN1,RTN2)
 30   RAD(J)=RTN1
 32 3 ABS(J)=RTN2
 37   RAD(NZONES+1)=0.
 37   ABS(NZONES+1)=0.
C PRINT RESULTS
 40   CALL OUTPUT
 41   GO TO 1
 42   END
```

```
      SUBROUTINE INPUT(MZONES,SFLAG)
C
C         READ, PREPARE, AND STORE ALL DATA REQUIRED FOR A
C         COMPUTATIONAL RUN OF PROGRAM EAPROF.
C
C
      DIMENSION W(7),TITLE(7),GNAME(4),PNAME(3),TYPE(10)
      DIMENSION TPARAM(40),DPARAM(40)
      DIMENSION RGX(201),PX(201),TGX(201),CGX(4,201)
      DIMENSION ANGX(181),DSX(181)
      DIMENSION RPX(201),TPX(4,201),CPX(4,201)
      DIMENSION ANG(37),PHASE(37)
      DIMENSION CX(201),TX(201)
      DIMENSION R(51),P(51),TG(51),CG(51),TP(51),CP(51)
      INTEGER   PCOL,GCOL,SFLAG
      REAL      KPARAM(40),INHOM
      COMMON/DATA1/NZONES,RADIUS,DELR,NSIGMA
      COMMON/DATA2/SHAPE,INHOM,WN
      COMMON/DATA3/TPARAM,KPARAM,DPARAM,WNG,WSTP,A1,A2,A3
      COMMON/DATA4/ANG,PHASE,NSCAT,NPHI,SIGA,SIGS
      COMMON/DATA5/P1,P2,EN,TN
      COMMON/FTCPR/R,P,TG,CG,TP,CP,NNZONE
      DATA TYPE( 1)/10HTITLE     /
      DATA TYPE( 2)/10HCALCDATA  /
      DATA TYPE( 3)/10HPLMDATA   /
      DATA TYPE( 4)/10HSPECIES   /
      DATA TYPE( 5)/10HGPARAM    /
      DATA TYPE( 6)/10HGDATA     /
      DATA TYPE( 7)/10HPPARAM    /
      DATA TYPE( 8)/10HPDATA     /
      DATA TYPE( 9)/10HGRID      /
      DATA TYPE(10)/10HRUN       /
      DATA PRINT/10H     PRINT/
C
C READ CARD TYPE AND ROUTE TO APPROPRIATE DECODING AND DATA
C READ-IN ROUTINE
    1 READ(5,100) CARD,(W(I),I=1,7)
 14   IF(EOF,5) 2,3
 20 2 STOP
 22 3 DO 4 I=1,10
 30   IF(CARD.EQ.TYPE(I)) GO TO 5
 32 4 CONTINUE
 34   WRITE(6,1000) CARD
 41   STOP
 44 5 GO TO(6,8,9,10,11,14,17,20,23,25),I
C READ TITLE
 62 6 DO 7 I=1,7
 67 7 TITLE(I)=W(I)
 71   GO TO 1
C READ CALCULATION DATA
 71 8 SHAPE=W(1)
 72   INHOM=W(2)
 74   DECODE(30,101,W(3)) NZONES,NSIGMA,SFLAG
114   MZONES=NZONES
114   NNZONE=NZONES+1
115   GO TO 1
C READ PLUME DATA
```

```
116        9 DECODE(46,102,W(1)) P1,P2,TN,EN                          INPUT
135          GO TO 1                                                   INPUT
        C READ SPECIES COLUMN DATA                                     INPUT
137       10 DECODE(20,101,W(1)) GCOL,PCOL                             INPUT
152          GO TO 1                                                   INPUT
        C READ BAND MODEL PARAMETERS                                   INPUT
154       11 READ(5,200) GPRMID,WNG,DELWN,WSTP,A1,A2,A3                INPUT
176          WN=WNG                                                    INPUT
200          DO 12 I=1,40                                              INPUT
203       12 READ(5,202) TPARAM(I),KPARAM(I),DPARAM(I)                 INPUT
223          IF(W(1).NE.PRINT) GO TO 1                                 INPUT
225          WRITE(6,300)                                              INPUT
230          WRITE(6,301) GPRMID                                       INPUT
237          WRITE(6,302) WNG                                          INPUT
246          WRITE(6,303) DELWN                                        INPUT
255          WRITE(6,304)                                              INPUT
262          WRITE(6,305) WSTP                                         INPUT
271          WRITE(6,306) A1                                           INPUT
300          WRITE(6,307) A2                                           INPUT
307          WRITE(6,308) A3                                           INPUT
316          WRITE(6,309)                                              INPUT
323          DO 13 I=1,40                                              INPUT
326       13 WRITE(6,310) I,TPARAM(I),KPARAM(I),DPARAM(I)              INPUT
350          GO TO 1                                                   INPUT
        C READ RADIAL GAS DATA                                         INPUT
358       14 READ(5,203) GDTAID,NGDTA,RADIUS,(GNAME(I),I=1,4)          INPUT
364          DO 15 I=1,NGDTA                                           INPUT
367       15 READ(5,202) RGX(I),PX(I),TGX(I),(CGX(J,I),J=1,4)          INPUT
413          PRINT1=W(1)                                               INPUT
414          IF(PRINT1.NE.PRINT) GO TO 1                               INPUT
417          WRITE(6,311)                                              INPUT
422          WRITE(6,301) GDTAID                                       INPUT
431          WRITE(6,312) RADIUS                                       INPUT
440          WRITE(6,313) NGDTA                                        INPUT
447          WRITE(6,314)                                              INPUT
454          WRITE(6,315) (GNAME(I),I=1,4)                             INPUT
463          DO 16 I=1,NGDTA                                           INPUT
466       16 WRITE(6,316) I,RGX(I),PX(I),TGX(I),(CGX(J,I),J=1,4)       INPUT
514          GO TO 1                                                   INPUT
        C READ PARTICLE SCATTERING DATA                                INPUT
515       17 READ(5,201) PPRMID,NPPRM,WNP,SIGA,SIGS                    INPUT
533          DO 18 I=1,NPPRM                                           INPUT
536       18 READ(5,202) ANGX(I),DSX(I)                                INPUT
553          IF(W(1).NE.PRINT) GO TO 1                                 INPUT
555          WRITE(6,317)                                              INPUT
561          WRITE(6,318) PPRMID                                       INPUT
570          WRITE(6,319) WNP                                          INPUT
577          WRITE(6,320) NPPRM                                        INPUT
606          WRITE(6,321) SIGA                                         INPUT
615          WRITE(6,322) SIGS                                         INPUT
624          WRITE(6,323)                                              INPUT
631          DO 19 I=1,NPPRM                                           INPUT
634       19 WRITE(6,324) I,ANGX(I),DSX(I)                             INPUT
653          GO TO 1                                                   INPUT
        C READ RADIAL PARTICLE DATA                                    INPUT
654       20 READ(5,203) PDTAID,NPDTA,RADIUS,(PNAME(I),I=1,3)          INPUT
670          DO 21 I=1,NPDTA                                           INPUT
```

```
673         READ(5,202) RPX(I),TPX(1,I),CPX(1,I),TPX(2,I),CPX(2,I),        INPUT
           X TPX(3,I),CPX(3,I)                                              INPUT
727      21 CONTINUE                                                        INPUT
731         PRINT2=W(1)                                                     INPUT
732         IF(PRINT2.NE.PRINT) GO TO 1                                     INPUT
735         WRITE(6,325)                                                    INPUT
740         WRITE(6,301) PDTAID                                             INPUT
747         WRITE(6,312) RADIUS                                             INPUT
756         WRITE(6,313) NPDTA                                              INPUT
765         WRITE(6,326) (PNAME(I),I=1,3)                                   INPUT
774         WRITE(6,327)                                                    INPUT
1001        DO 22 I=1,NPDTA                                                 INPUT
1004        WRITE(6,316) I,RPX(I),TPX(1,I),CPX(1,I),TPX(2,I),CPX(2,I),     INPUT
           X TPX(3,I),CPX(3,I)                                              INPUT
1042     22 CONTINUE                                                        INPUT
1044        GO TO 1                                                         INPUT
      C READ ANGLE INTEGRATION GRID                                         INPUT
1045     23 DECODE(10,101,W(1)) NPHI                                        INPUT
1056        READ(5,201) AGPDID,NSCAT,(ANG(I),I=1,6)                        INPUT
1071        IF(NSCAT.GT.6) READ(5,202) (ANG(I),I=7,NSCAT)                  INPUT
1106        PRINT3=W(2)                                                     INPUT
1107        IF(PRINT3.NE.PRINT) GO TO 1                                     INPUT
1112        WRITE(6,328)                                                    INPUT
1115        WRITE(6,329) AGRDID                                             INPUT
1124        WRITE(6,330) NSCAT                                              INPUT
1133        WRITE(6,331) NPHI                                               INPUT
1142        WRITE(6,332)                                                    INPUT
1147        DO 24 I=1,NSCAT                                                 INPUT
1152     24 WRITE(6,333) I,ANG(I)                                           INPUT
1166        GO TO 1                                                         INPUT
      C                                                                     INPUT
      C PREPARE DATA                                                        INPUT
1167     25 DELR=RADIUS/NZONES                                              INPUT
      C SET GAS SPECIES AND FIT RADIAL GAS DATA TO RADIAL GRID              INPUT
1172        DO 26 I=1,NGDTA                                                 INPUT
1201     26 CX(I)=CGX(GCOL,I)                                               INPUT
1203        CALL ZONEFIT(NGDTA, PX,RGX, P,R)                                INPUT
1207        CALL ZONEFIT(NGDTA, CX,RGX,CG,R)                                INPUT
1213        CALL ZONEFIT(NGDTA,TGX,RGX,TG,R)                                INPUT
1217        IF(PRINT1.NE.PRINT) GO TO 28                                    INPUT
1223        WRITE(6,334)                                                    INPUT
1226        WRITE(6,335) GNAME(GCOL)                                        INPUT
1236        WRITE(6,336)                                                    INPUT
1243        DO 27 I=1,NNZONE                                                INPUT
1246     27 WRITE(6,316) I,R(I),P(I),TG(I),CG(I)                            INPUT
      C SET PARTICLE SPECIES AND FIT RADIAL PARTICLE DATA TO RADIAL GRID    INPUT
1273     28 IF(SFLAG.NE.1) GO TO 35                                         INPUT
1275        DO 29 I=1,NPDTA                                                 INPUT
1305        TX(I)=TPX(PCOL,I)                                               INPUT
1306     29 CX(I)=CPX(PCOL,I)                                               INPUT
1310        CALL ZONEFIT(NPDTA,CX,RPX,CP,R)                                 INPUT
1314        CALL ZONEFIT(NPDTA,TX,RPX,TP,R)                                 INPUT
1320        IF(TP(1).GT.0.) GO TO 31                                        INPUT
1324        DO 30 I=1,NNZONE                                                INPUT
1331     30 TP(I)=TG(I)                                                     INPUT
1333     31 IF(PRINT2.NE.PRINT) GO TO 33                                    INPUT
1335        WRITE(6,337)                                                    INPUT
```

```
1341           WRITE(6,335) PNAME(PCOL)                                              INPUT
1351           WRITE(6,338)                                                          INPUT
1356           DO 32 I=1,NNZONE                                                      INPUT
1361        32 WRITE(6,315) I,P(I),TP(I),CP(I)                                       INPUT
      C COMPUTE PHASE FUNCTION OVER ANGLE INTEGRATION GRID                           INPUT
1403        33 IF(SFLAG.NE.1) GO TO 35                                               INPUT
1405           CALL ANGLFIT(ANGX,DSX,NPPRM)                                          INPUT
1407           IF(PRINT3.NE.PRINT) GO TO 35                                          INPUT
1413           WRITE(6,339)                                                          INPUT
1416           WRITE(6,340)                                                          INPUT
1423           DO 34 I=1,NSCAT                                                       INPUT
1426        34 WRITE(6,333) I,ANG(I),PHASE(I)                                        INPUT
      C                                                                              INPUT
      C SUMMARY DATA PRINTOUT                                                        INPUT
1445        35 WRITE(6,400)                                                          INPUT
1451           WRITE(6,401) (TITLE(I),I=1,7)                                         INPUT
1460           WRITE(6,402) RADIUS                                                   INPUT
1467           WRITE(6,403) SHAPE                                                    INPUT
1476           WRITE(6,404) INHOM                                                    INPUT
1505           WRITE(6,405) NZONES                                                   INPUT
1514           WRITE(6,406) GNAME(GCOL)                                              INPUT
1524           WRITE(6,407) GPRMID                                                   INPUT
1533           WRITE(6,408) GDTAID                                                   INPUT
1542           WRITE(6,409) PNAME(PCOL)                                              INPUT
1552           WRITE(6,410) PPRMID                                                   INPUT
1561           WRITE(6,411) PDTAID                                                   INPUT
1570           WRITE(6,412) AGRDID                                                   INPUT
1577           WRITE(6,413) NSCAT                                                    INPUT
1606           WRITE(6,414) NP4I                                                     INPUT
1615           WRITE(6,415) NSIGMA                                                   INPUT
1624           WRITE(6,416) P1                                                       INPUT
1633           WRITE(6,417) P2                                                       INPUT
1642           WRITE(6,418) TN                                                       INPUT
1651           WRITE(6,419) EN                                                       INPUT
1660           WRITE(6,420) SFLAG                                                    INPUT
1670           RETURN                                                                INPUT
      C                                                                              INPUT
       100 FORMAT(8A10)                                                              INPUT
       101 FORMAT(3I10)                                                              INPUT
       102 FORMAT(4E10.0)                                                            INPUT
       200 FORMAT(A10,8E10.0)                                                        INPUT
       201 FORMAT(A10,I10,7E10.0)                                                    INPUT
       202 FORMAT(8E10.0)                                                            INPUT
       203 FORMAT(A10,I10,E10.0,4A10)                                                INPUT
       300 FORMAT(1H1,//6X,37(1H*),*BAND MODEL PARAMETER LISTING*,37(1H*)//)         INPUT
       301 FORMAT(6X,*DATA IDNAME                         *,A10)                     INPUT
       302 FORMAT(6X,*WAVENUMBER(CM-1)                    *,1PE10.3)                 INPUT
       303 FORMAT(6X,*SPECTRAL RESOLUTION(CM-1) *,1PE10.3/)                          INPUT
       304 FORMAT(6X,*BROADENING PARAMETERS*)                                        INPUT
       305 FORMAT(10X,*STP LORENTZ HALFWIDTH(CM-1/ATM)    *,1PE10.3)                 INPUT
       306 FORMAT(10X,*SELF-BROADENING RATIO              *,1PE10.3)                 INPUT
       307 FORMAT(10X,*FOREIGN-GAS BROADENING RATIO)      *,1PE10.3)                 INPUT
       308 FORMAT(10X,*MOLECULAR WEIGHT(AMU)              *,1PE10.3//)               INPUT
       309 FORMAT(6X,*INDEX*,3X,*T(DEGK)*,4X,*K(CM-1/ATM)*,6X,*D(1/CM-1)*/)          INPUT
       310 FORMAT(I9,1P2E13.3,E16.3)                                                 INPUT
       311 FORMAT(1H1,//6X,39(1H*),*RADIAL GAS DATA LISTING*,40(1H*)//)              INPUT
       312 FORMAT(6X,*SOURCE RADIUS(CM)                   *,1PE10.3)                 INPUT
```

```
313 FORMAT(6X,*NUMBER OF RADIAL POINTS    *,I10//)                          INPUT
314 FORMAT(6X,*INDEX*,4X,*R(CM)*,7X,*P(ATM)*,5X,*T(DEGK)*,4X,6(1H*),        INPUT
   X *GAS CONCENTRATIONS(MOLE FRACTION)*,6(1H*) )                           INPUT
315 FORMAT(42X,4(2X,A10)/)                                                  INPUT
316 FORMAT(I9,1X,1P7E12.3)                                                  INPUT
317 FORMAT(1H1,//6X,32(1H*),*PARTICLE SCATTERING PARAMETER LISTING*,        INPUT
   X 33(1H*) //)                                                            INPUT
318 FORMAT(6X,*DATA IDNAME                       *,A10)                     INPUT
319 FORMAT(6X,*WAVENUMBER(CM-1)                  *,1PE10.3)                 INPUT
320 FORMAT(6X,*NUMBER OF ANGLES                  *,I10)                     INPUT
321 FORMAT(6X,*ABSORPTION CROSS SECTION(CM2)    *,1PE10.3)                  INPUT
322 FORMAT(6X,*SCATTERING CROSS SECTION(CM2)    *,1PE10.3//)                INPUT
323 FORMAT(6X,*INDEX*,4X,*ANGLE(DEG)*,4X,*DSS(CM2/SR)* /)                   INPUT
324 FORMAT(I9,1P2E15.3)                                                     INPUT
325 FORMAT(1H1,//6X,37(1H*),*RADIAL PARTICLE DATA LISTING*,37(1H*)//)       INPUT
326 FORMAT(6X,*INDEX*,4X,*R(CM)*,7X,A10,14X,A10,14X,A10)                    INPUT
327 FORMAT(2?X,3(5X,*T(DEGK)*,5X,*C(CM-3)* ) /)                            INPUT
328 FORMAT(1H1,//5X,36(1H*),*ANGLE INTEGRATION GRID LISTING*,35(1H*)/)      INPUT
329 FORMAT(6X,*DATA IDNAME                        *,A10)                    INPUT
330 FORMAT(6X,*NUMBER OF SCATTERING ANGLES    *,I10)                        INPUT
331 FORMAT(6X,*NUMBER OF AZIMUTHAL ANGLES     *,I10//)                      INPUT
332 FORMAT(6X,*INDEX*,3X,*ANGLE(DEG)* /)                                    INPUT
333 FORMAT(I9,1P2E14.3)                                                     INPUT
334 FORMAT(1H1,//6X,37(1H*),*INTERPOLATED RADIAL GAS DATA*,37(1H*)//)       INPUT
335 FORMAT(6X,*SPECIES=*,A10 //)                                            INPUT
336 FORMAT(6X,*INDEX*,4X,*R(CM)*,7X,*P(ATM)*,5X,*T(DEGK)*,3X,               INPUT
   X *C(MOLE FRAC)* /)                                                      INPUT
337 FORMAT(1H1,//6X,35(1H*),*INTERPOLATED RADIAL PARTICLE DATA*,            INPUT
   X 34(1H*) //)                                                            INPUT
338 FORMAT(6X,*INDEX*,4X,*R(CM)*,5X,*T(DEGK)*,5X,*C(CM-3)* /)               INPUT
339 FORMAT(1H1,//6X,38(1H*),*SCATTERING PHASE FUNCTION*,35(1H*) //)         INPUT
340 FORMAT(6X,*INDEX*,3X,*ANGLE(DEG)*,3X,*PHASE(SR-1)* /)                   INPUT
400 FORMAT(1H1,//6X,37(1H*),*SUMMARY LISTING OF INPUT DATA*,37(1H*)//)      INPUT
401 FORMAT(6X,*JOB TITLE                           *,7A10)                  INPUT
402 FORMAT(6X,*SOURCE RADIUS(CM)                   *,1PE10.3)               INPUT
403 FORMAT(6X,*LINESHAPE                           *,A10)                   INPUT
404 FORMAT(6X,*INHOMOGENEITY APPROXIMATION         *,A10)                   INPUT
405 FORMAT(6X,*NUMBER OF ZONES                     *,I10)                   INPUT
406 FORMAT(6X,*GAS SPECIES                         *,A10)                   INPUT
407 FORMAT(6X,*BAND MODEL PARAMETER IDNAME         *,A10)                   INPUT
408 FORMAT(6X,*GAS DATA IDNAME                     *,A10)                   INPUT
409 FORMAT(6X,*PARTICLE SPECIES                    *,A10)                   INPUT
410 FORMAT(6X,*SCATTERING PARAMETER IDNAME         *,A10)                   INPUT
411 FORMAT(6X,*PARTICLE DATA IDNAME                *,A10)                   INPUT
412 FORMAT(6X,*SCATTERING GRID IDNAME              *,A10)                   INPUT
413 FORMAT(6X,*NUMBER OF SCATTERING ANGLES         *,I10)                   INPUT
414 FORMAT(6X,*NUMBER OF AZIMUTHAL ANGLES          *,I10)                   INPUT
415 FORMAT(6X,*NUMBER OF SIGMA-AXIS INTERVALS      *,I10)                   INPUT
416 FORMAT(6X,*DISTANCE TO NOZZLE PLANE(CM)        *,1PE10.3)               INPUT
417 FORMAT(6X,*DISTANCE TO END PLANE(CM)           *,1PE10.3)               INPUT
418 FORMAT(6X,*NOZZLE TEMPERATURE(DEGK)            *,1PE10.3)               INPUT
419 FORMAT(6X,*NOZZLE EMISSIVITY                   *,1PE10.3)               INPUT
420 FORMAT(6X,*SCATTERING FLAG                     *,I10)                   INPUT
1000 FORMAT(1H1,5H*****,*INVALID DATA CARD,  CARD TYPE=*,A10)               INPUT
     END                                                                    INPUT
```

```
                SUBROUTINE ZONEFIT(N,F,XF,G,X)
          C
          C         INTERPOLATE ON THE FUNCTION F DEFINED ON THE GRID XF TO GET
          C         THE FUNCTION AT THE NZONES+1 EQUALLY SPACED GRID POINTS OF X
          C
                DIMENSION F(301),XF(301),G(51),X(51)
                COMMON/CAT81/NZONES,RADIUS,DELR,IIIII
          C
                DO 3 I=1,NZONES
                X(I)=(I-1)*DELR
    14          DO 1 J=1,N
    21          IF(X(I).LT.XF(J)) GO TO 2
    24        1 CONTINUE
    27        2 K=J-1
    31        3 G(I)=F(K)+(F(K+1)-F(K))*(X(I)-XF(K))/(XF(K+1)-XF(K))
    45          X(NZONES+1)=RADIUS
    46          G(NZONES+1)=F(N)
    51          RETURN
    51          END
```

```
              SUBROUTINE ANGLFIT(ANGT,DSS,N)
      C
      C           INTERPOLATE ON PARTICLE SCATTERING PARAMETER TABLE TO GET
      C           PHASE FUNCTION FOR ARRAY OF INTEGRATION SCATTERING ANGLES
      C
              DIMENSION ANGT(181),DSS(181),ANG(37),PHASE(37)
              COMMON/DATA4/ANG,PHASE,NSCAT,IIIII,SA,SS
      C
              DO 5 I=1,NSCAT
              AI=ANG(I)
  10          DO 1 J=1,N
  15          AJ=ANGT(J)
  16          IF(AJ.GT.AI) GO TO 2
  21        1 CONTINUE
  23          J=N
  24        2 IF(J.EQ.2) GO TO 3
  27          A1=ANGT(J-2)
  30          A2=ANGT(J-1)
  31          A3=ANGT(J)
  32          F1=DSS(J-2)
  34          F2=DSS(J-1)
  35          F3=DSS(J)
  37          GO TO 4
  37        3 A1=-ANGT(2)
  40          A2=0.
  41          A3=-A1
  42          F1=DSS(2)
  44          F2=DSS(1)
  45          F3=F1
  56        4 D=(A2-A1)*(A3-A2)*(A3-A1)
  60          A=((F1-F2)*(A3-A2)-(F2-F3)*(A2-A1))/D
  64          B=((F3-F2)*(A2-A1)**2-(F1-F2)*(A3-A2)**2)/D
  71        5 PHASE(I)=12.56637*(A*(AI-A2)**2+B*(AI-A2)+F2)/SS
 103          RETURN
 104          END
```

```
            SUBROUTINE ZLOS(J,NNLOS)
      C
      C        OBTAIN PTC VARIATION OVER THE PRIMARY LOS AT TRANSVERSE
      C        POSITION J
      C
            DIMENSION RR(51),PR(51),TGR(51),CGR(51),TPR(51),CPR(51)
            DIMENSION S(103),P(103),TG(103),CG(103),TP(103),CP(103)
            COMMON/PTCPR/RR,PR,TGR,CGR,TPR,CPR,NNZONE
            COMMON/PTCPF/S,P,TG,CG,TP,CP,NLOS
      C
            NLOS=2*(NNZONE-J) +1
  6         NNLOS=NLOS
  7         NMID=NNZONE+1-J
 10         DO 3 N=1,NLOS
 12         IF(N.LE.NMID) GO TO 1
 14         I=2*(J-1)-(NNZONE-1)+N
 17         SIGN=1.
 21         GO TO 2
 22       1 I=NNZONE+1-N
 24         SIGN=-1
 31       2 DELR=RR(2)-RR(1)
 32         Q1=(NNZONE-1)**2-(J-1)**2
 36         Q2=(I-1)**2-(J-1)**2
 41         S(N)=DELR*(SQRT(Q1)+SIGN*SQRT(Q2))
 52         P(N) = PR(I)
 54         TG(N)= TGR(I)
 57         CG(N)= CGR(I)
 62         TP(N)= TPR(I)
 70       3 CP(N)= CPR(I)
 75         RETURN
 75         END
```

```
              SUBROUTINE TRNSFR
         C
         C        TRANSFER PTC VARIATION ALONG PRIMARY LOS INTO COMMON STORAGE
         C        LOCATION FOR SCATTERING LOS
         C
              DIMENSION SP(103),PP(103),TGP(103),CGP(103),TPP(103),CPP(103)
              DIMENSION SS(103),PS(103),TGS(103),CGS(103),TPS(103),CPS(103)
              COMMON/PTCPP/SP,PP,TGP,CGP,TPP,CPP,NP
              COMMON/PTCSS/SS,PS,TGS,CGS,TPS,CPS,NS
         C
              DO 1 I=1,NP
 10           SS(I)=SP(I)
 11           PS(I)=PP(I)
 13           TGS(I)=TGP(I)
 14           CGS(I)=CGP(I)
 15           TPS(I)=TPP(I)
 16         1 CPS(I)=CPP(I)
 20           NS=NP
 22           RETURN
 22           END
```

```
          SUBROUTINE INITIAL(ISTART,N)
C
C             SET UP INITIATING ARRAY S(L,M) FOR INTEGRATION OVER A NEW
C             (ISTART=0) OR A CONTINUED(ISTART=1) LINE OF SIGHT
C
          DIMENSION START(103,13),STOP(103,13)
          COMMON/START/START,STOP
C
          IF(ISTART.EQ.1) GO TO 2
  5       DO 1 M=1,10
 15     1 START(1,M)=0.
 17       START(1,11)=1.
 20       START(1,12)=1.
 20       START(1,13)=1.
 22       RETURN
 22     2 DO 3 L=1,N
 24       DO 3 M=1,13
 33     3 START(L,M)=STOP(L,M)
 41       RETURN
 41       END
```

```
          SUBROUTINE QTHERM(LD,SFLAG)
      C
      C         COMPUTE TRANSMITTANCES AND THERMAL SOURCE FUNCTION ALONG AN
      C         ARBITRARY LINE OF SIGHT
      C
          DIMENSION S(103),P(103),TG(103),CG(103),TP(103),CP(103)
          DIMENSION START(103,13),STOP(103,13)
          DIMENSION TA(103),TB(103),TK(103),QT(103),SS(103)
          DIMENSION XXXX1(37),XXXX2(37)
          REAL      LORENTZ,INHOM,K1,K2,KE
          INTEGER   SFLAG
          COMMON/PTCSS/S,P,TG,CG,TP,CP,NLOS
          COMMON/START/START,STOP
          COMMON/DATA2/SHAPE,INHOM,WN
          COMMON/DATA4/XXXX1,XXXX2,IIII1,IIII2,SIGA,SIGS
          COMMON/QTHRM/SS,TA,TB,TK,QT,NNLOS
          DATA LORENTZ/10H   LORENTZ/
          DATA DOPPLER/10H   DOPPLER/
          DATA      DR/10H        DR/
          NNLOS=NLOS
      C
      C INITIATE LOOP OVER LOS
  5       IF(S(NLOS).LE.0.) GO TO 9
  7       SUM1=START(LD,1)
 10       SUM2=START(LD,2)
 12       SUM3=START(LD,3)
 13       SUM4=START(LD,4)
 15       SUM5=START(LD,5)
 16       SUM6=START(LD,6)
 20       SUM7=START(LD,7)
 21       WWD=START(LD, 8)
 23       WWL=START(LD, 9)
 24       W  =START(LD,10)
 26       YD1=START(LD,11)
 27       YL1=START(LD,12)
 31       Y1 =START(LD,13)
 32       S1=0.
 33       SS(1)=0.
 33       P1=P(1)
 35       TG1=TG(1)
 36       CG1=CG(1)
 40       TP1=TP(1)
 41       CP1=CP(1)
 43       CALL KDPARAM(P1,TG1,CG1,K1,D1,WL1,WD1)
 52       TA(1)=EXP(-SUM6)
 55       TB(1)=EXP(-SUM7)
 61       TK(1)=EXP(-W)
 65       QT(1)=CG1*P1*K1*Y1*PLANCK(WN,TG1)
 74       IF(SFLAG.EQ.1) QT(1)=QT(1)+SIGA*CP1*PLANCK(WN,TP1)
      C CONTINUE LOOP OVER LOS
105       DO 8 L=2,NLOS
111       S2=S(L)
112       SS(L)=S2
112       P2=P(L)
114       TG2=TG(L)
115       CG2=CG(L)
117       TP2=TP(L)
```

```
120          CP2=CP(L)
122          CALL KDPARAM(P2,TG2,CG2,K2,D2,WL2,WD2)
133          DS =(S2-S1)/2.
      C COMPUTE BAND MODEL GAS TRANSMITTANCE
136          X1=CG1*P1
140          X2=CG2*P2
142          SUM1=SUM1+(X1+X2)*DS
145          U=SUM1
145          X1=X1*K1
147          X2=X2*K2
150          SUM2=SUM2+(X1+X2)*DS
153          KE=SUM2/SUM1
154          X3=X1/D1
156          X4=X2/D2
160          SUM3=SUM3+(X3+X4)*DS
163          DEL=1./D2
164          DELE=SUM3/SUM2
166          Q=DELE/DEL
167          IF(SHAPE.EQ.LORENTZ) GO TO 2
173          X3=2.12893*X1*WD1*D1
176          X4=2.12893*X2*WD2*D2
201          SUM4=SUM4+(X3+X4)*DS
205          BED=SUM4/SUM2
206          XD=U*KE/BED
210          BD=X4/X2
212          RD=BD/BED
214          IF(INHOM.EQ.DR) GO TO 1
216          YD2=YCGD(XD,RD)
220          WWD=BED*G(XD)
224          GO TO 2
226        1 YD2=YMLD(XD,RD,Q)
231          WWD=WWD+(X1*YD1+X2*YD2)*DS
240        2 IF(SHAPE.NE.DOPPLER) GO TO 3
242          Y2 =YD2
243          W=WWD
245          GO TO 7
246        3 X3=6.283185*X1*WL1*D1
251          X4=6.283185*X2*WL2*D2
254          SUM5=SUM5+(X3+X4)*DS
260          BEL=SUM5/SUM2
261          XL=U*KE/BEL
263          BL=X4/X2
265          RL=BL/BEL
267          IF(INHOM.EQ.DR) GO TO 4
271          YL2=YCGL(XL,RL)
273          WWL=BEL*F(XL)
277          GO TO 5
301        4 YL2=YDRL(XL,RL,Q)
304          WWL=WWL+(X1*YL1+X2*YL2)*DS
313        5 IF(SHAPE.NE.LORENTZ) GO TO 6
315          Y2 =YL2
316          W= WWL
320          GO TO 7
321        6 WW =U*KE
323          W=WMIX(WWD,WWL,WW)
326          Y2=YMIX(WWD,WWL,WW,W,YD2,YL2)
335        7 TK(L)=EXP(-W)
```

```
      C COMPUTE PARTICLE TRANSMITTANCES                                   QTHERM   116
342         A1=CP1*SIGA                                                   QTHERM   117
344         A2=CP2*SIGA                                                   QTHERM   118
345         SUM6=SUM6+(A1+A2)*DS                                          QTHERM   119
351         TA(L)=EXP(-SUM6)                                              QTHERM   120
355         B1=CP1*SIGS                                                   QTHERM   121
357         B2=CP2*SIGS                                                   QTHERM   122
360         SUM7=SUM7+(B1+B2)*DS                                          QTHERM   123
364         T3(L)=EXP(-SUM7)                                              QTHERM   124
      C COMPUTE THERMAL SOURCE FUNCTION                                   QTHERM   125
370         QT(L)=X2*Y2*PLANCK(WN,TG2)                                    QTHERM   126
376         IF(SFLAG.EQ.1) QT(L)=QT(L)+A2*PLANCK(WN,TP2)                  QTHERM   127
      C SET UP ENDING ARRAY, STEP VARIABLES, AND CONTINUE LOOP OVER LOS   QTHERM   128
406         STOP(L, 1)=SUM1                                               QTHERM   129
410         STOP(L, 2)=SUM2                                               QTHERM   130
412         STOP(L, 3)=SUM3                                               QTHERM   131
413         STOP(L, 4)=SUM4                                               QTHERM   132
415         STOP(L, 5)=SUM5                                               QTHERM   133
416         STOP(L, 6)=SUM6                                               QTHERM   134
420         STOP(L, 7)=SUM7                                               QTHERM   135
421         STOP(L, 8)=WWD                                                QTHERM   136
423         STOP(L, 9)=WWL                                                QTHERM   137
424         STOP(L,10)=W                                                  QTHERM   138
426         STOP(L,11)=YD2                                                QTHERM   139
427         STOP(L,12)=YL2                                                QTHERM   140
431         STOP(L,13)=Y2                                                 QTHERM   141
432         S1=S2                                                         QTHERM   142
433         P1=P2                                                         QTHERM   143
435         CG1=CG2                                                       QTHERM   144
436         K1=K2                                                         QTHERM   145
440         D1=D2                                                         QTHERM   146
441         WD1=WD2                                                       QTHERM   147
443         WL1=WL2                                                       QTHERM   148
444         CP1=CP2                                                       QTHERM   149
446         YD1=YD2                                                       QTHERM   150
447         YL1=YL2                                                       QTHERM   151
453       8 CONTINUE                                                      QTHERM   152
455         RETURN                                                        QTHERM   153
      C TRANSFER PATH ARRAY FOR A ZERO LENGTH PATH                        QTHERM   154
456       9 DO 10 L=1,NLOS                                                QTHERM   155
463      10 SS(L)=0.                                                      QTHERM   156
465         RETURN                                                        QTHERM   157
465         END                                                           QTHERM   158
```

```
            SUBROUTINE STORE
      C
      C         STORE AND RESTORE TRANSMITTANCES AND THERMAL SOURCE
      C         FUNCTION ALONG PRIMARY LINE OF SIGHT
      C
            DIMENSION S(103),TA(103),TB(103),TK(103),QT(103)
            DIMENSION SS(103),TTA(103),TTB(103),TTK(103),QQT(103)
            COMMON/OTHRM/S,TA,TB,TK,QT,N
      C
            NN=N
   3        DO 1 I=1,N
  11        SS(I)=S(I)
  12        TTA(I)=TA(I)
  14        TTB(I)=TB(I)
  15        TTK(I)=TK(I)
  16      1 QQT(I)=QT(I)
  17        RETURN
  20        ENTRY RESTORE
  25        N=NN
  27        DO 2 I=1,N
  35        S(I)=SS(I)
  36        TA(I)=TTA(I)
  40        TB(I)=TTB(I)
  41        TK(I)=TTK(I)
  42      2 QT(I)=QQT(I)
  43        RETURN
  44        END
```

```
              SUBROUTINE OSCAT(JZ)                                              QSCAT
        C                                                                       QSCAT
        C         COMPUTE SCATTERING SOURCE FUNCTION ALONG PRIMARY LINE         QSCAT
        C         OF SIGHT                                                      QSCAT
        C                                                                       QSCAT
              DIMENSION S(103),TP(103),CP(103),QS(103)                          QSCAT
              DIMENSION PHASE(37),ANG(37)                                       QSCAT
              DIMENSION XXXX1(103),XXXX2(103),XXXX3(103),XXXX9(103,13)          QSCAT
              DIMENSION START(103,13)                                           QSCAT
              COMMON/PTCPP/S,XXXX1,XXXX2,XXXX3,TP,CP,NLOS                       QSCAT
              COMMON/DATA2/XXXX4,XXXX5,WN                                       QSCAT
              COMMON/DATA4/ANG,PHASE,NS,NA,XXXX6,SIGS                           QSCAT
              COMMON/DATA5/XXXX7,XXXX8,EN,TN                                    QSCAT
              COMMON/START/START,XXXX9                                          QSCAT
              COMMON/QSCAT/QS                                                   QSCAT
        C                                                                       QSCAT
        C LOOP OVER PRIMARY LOS                                                 QSCAT
              DO 4 N=1,NLOS                                                     QSCAT
        C INTEGRATE OVER SOLID ANGLE                                            QSCAT
              CALL SLOS(S(N),JZ,0.,0.,IDUMMY)                                   QSCAT
   10         CALL QTHERM(N,1)                                                  QSCAT
   12         CALL RADNCE(C,RAD,DUMMY)                                          QSCAT
   15         F1=6.283185*PHASE(1)*RAD                                          QSCAT
   17         SUMA=0.                                                           QSCAT
   20         DAA=6.283185/NA                                                   QSCAT
   22         AS2=ANG(2)/57.2957795                                             QSCAT
   25         DO 1 J=1,NA                                                       QSCAT
   27         AA=(J-1)*DAA                                                      QSCAT
   32         CALL SLOS(S(N),JZ,AS2,AA,IFLAG)                                   QSCAT
   37         CALL QTHERM(N,1)                                                  QSCAT
   41         CALL RADNCE(C,RAD,ABS)                                            QSCAT
   44         IF(IFLAG.EQ.1) RAD=RAD+(1.-ABS)*EN*PLANCK(WN,TN)                  QSCAT
   56       1 SUMA=SUMA+RAD                                                     QSCAT
   63         F2=SUMA*PHASE(2)*DAA                                              QSCAT
   65         P1=F1*(1.-COS(AS2))                                               QSCAT
   71         P2=(F2-F1)/AS2**2                                                 QSCAT
   74         P3=2.*AS2*SIN(AS2)                                                QSCAT
  100         P4=(AS2**2-2.)*COS(AS2)+2.                                        QSCAT
  105         SUMS=P1+P2*(P3-P4)                                                QSCAT
  111         F2=F2*SIN(AS2)                                                    QSCAT
  115         DO 3 I=3,NS                                                       QSCAT
  120         F1=F2                                                             QSCAT
  121         AS1=AS2                                                           QSCAT
  122         AS2=ANG(I)/57.2957795                                             QSCAT
  124         DAS=(AS2-AS1)/2.                                                  QSCAT
  126         SUMA=0.                                                           QSCAT
  127         DO 2 J=1,NA                                                       QSCAT
  131         AA=(J-1)*DAA                                                      QSCAT
  134         CALL SLOS(S(N),JZ,AS2,AA,IFLAG)                                   QSCAT
  141         CALL QTHERM(N,1)                                                  QSCAT
  143         CALL RADNCE(C,RAD,ABS)                                            QSCAT
  146         IF(IFLAG.EQ.1) RAD=RAD+(1.-ABS)*EN*PLANCK(WN,TN)                  QSCAT
  160       2 SUMA=SUMA+RAD                                                     QSCAT
  165         F2=SUMA*PHASE(I)*DAA*SIN(AS2)                                     QSCAT
  172       3 SUMS=SUMS+(F1+F2)*DAS                                             QSCAT
  200         TK=EXP(-START(N,10))                                              QSCAT
  205       4 QS(N)=(SIGS*CP(N)/12.56637)*SUMS/TK                               QSCAT
```

```
215       RETURN                                                      QSCAT     59
215       END                                                         QSCAT     60
```

```
      SUBROUTINE SLOS(S0,J,THETA,PHI,IFLAG)
C
C         COMPUTE PTC VARIATION OVER A SCATTERING LOS
C
      DIMENSION RR(51),PR(51),TGR(51),CGR(51),TPR(51),CPR(51)
      DIMENSION S(103),P(103),TG(103),CG(103),TP(103),CP(103)
      COMMON/PTCRR/RR,PR,TGR,CGR,TPR,CPR,NNZONE
      COMMON/PTCSS/S,P,TG,CG,TP,CP,NL
      COMMON/DATA1/NZONES,RADIUS,DELR,NSIGMA
      COMMON/DATA5/P1,P2,XXXX1,XXXX2
C
C
      AS=THETA
  7   AA=PHI
 11   SINS=SIN(AS)
 12   COSS=COS(AS)
 14   SINA=SIN(AA)
 16   COSA=COS(AA)
 24   IFLAG=0
 24   D=(J-1)*DELR
 30   SM=2.*SQRT(RADIUS**2-D**2)
 41   X0=S0-SM/2.
 43   Y0=D
 44   IFLAG=0
C
C COMPUTE LENGTH OF LOS AND SET FLAG IF IT INTERSECTS NOZZLE PLANE
 45   IF(ABS(SINS).LE.0.0001) GO TO 3
 51   IF(ABS(COSA).LE.0.0001) GO TO 3
 54   IF(COSA.LT.0.) GO TO 1
 55   PPF=P1
 56   IFLAG=1
 57   GO TO 2
 60 1 PPP=P2
 62 2 SIGMA=ABS(PPF/(SINS*COSA))
 65   RE=SQRT((X0+SIGMA*COSS)**2+(Y0+SIGMA*SINS*SINA)**2)
 75   IF(RE.GT.1.001*RADIUS) GO TO 3
105   SMAX=SIGMA
106   GO TO 4
106 3 IFLAG=0
107   A=1.-(SINS*COSA)**2
111   B=2.*(X0*COSS+Y0*SINS*SINA)
117   C=RADIUS**2-(XC**2+Y0**2)
123   ARG=B**2+4.*A*C
126   IF(ARG.LE.0.) ARG=0.
131   SMAX=(SQRT(ARG)-B)/(2.*A)
142 4 IF(SMAX.LE.0.) RETURN
C
C COMPUTE PTC VARIATION
145   NL=NSIGMA+1
147   DS=SMAX/NSIGMA
151   DO 5 L=1,NL
153   S(L)=(L-1)*DS
156   X=X0+S(L)*COSS
160   Y=Y0+S(L)*SINS*SINA
164   R=SQRT(X**2+Y**2)
170   I0=1.+R/DELR
173   IF(I0.EQ.NNZONE) I0=I0-1
```

```
203          R0=(I0-1)*DELR                                                    SLOS      59
207          DR=(R-R0)/DELR                                                    SLOS      60
211          P(L) = PR(I0)+( PR(I0+1)- PR(I0))*DR                              SLOS      61
214          TG(L)=TGR(I0)+(TGR(I0+1)-TGR(I0))*DR                              SLOS      62
220          CG(L)=CGR(I0)+(CGR(I0+1)-CGR(I0))*DR                              SLOS      63
224          TP(L)=TPR(I0)+(TPR(I0+1)-TPR(I0))*DR                              SLOS      64
231        5 CP(L)=CPR(I0)+(CPR(I0+1)-CPR(I0))*DR                              SLOS      65
240          RETURN                                                            SLOS      66
241          END                                                               SLOS      67
```

```
          SUBROUTINE RADNCE(SFLAG,RAD,ABS)
C
C             COMPUTE LINE OF SIGHT INTEGRAL OVER SOURCE FUNCTIONS
C
          DIMENSION S(103),TA(103),TB(103),TK(103),QT(183),QS(183)
          COMMON/OTHPM/S,TA,TB,TK,QT,NLOS
          COMMON/QSCAT/QS
          INTEGER SFLAG
C
          SUM=0.
  6       DO 1 L=2,NLOS
 17       DS=S(L)-S(L-1)
 21       P1=TA(L-1)*TK(L-1)
 23       P2=TA(L)*TK(L)
 25       S1=QT(L-1)
 26       S2=QT(L)
 30       IF(SFLAG.NE.1) GO TO 1
 32       P1=P1*TB(L-1)
 33       P2=P2*TB(L)
 34       S1=S1+QS(L-1)
 36       S2=S2+QS(L)
 37     1 SUM=SUM+(P1*S1+P2*S2)*DS
 47       RAD=SUM/2.
 50       ABS=1.-F2
 52       RETURN
 53       END
```

```
            SUBROUTINE OUTPUT
      C
      C         PRINT TRANSVERSE E/A PROFILES
      C
            DIMENSION RAD(51),ABS(51)
            COMMON/OUTPT/RAD,ABS
            COMMON/DATA1/NZONES,XXXX1,XXXX2,IIIII
            COMMON/DATA2/XXXX3,XXXX4,WN
            NN=NZONES+1
      C
  3         WRITE(6,100)
  7         WRITE(6,101)
 13         DO 1 J=1,NN
 16         RAD1=RAD(J)
 17         RAD2=0.0001*RAD1*WN**2
 21         ABS1=ABS(J)
 23         TRNS=1.-ABS1
 25       1 WRITE(6,102) J,RAD1,RAD2,ABS1,TRNS
 45         RETURN
      C
        100 FORMAT(1H1,//6X,42(1H*),*E/A PROFILE RESULTS*,42(1H*) //)
        101 FORMAT(6X,*INDEX*,3X,*N(W/CM2*,9H*SR*CM-1),3X,*N(W/CM2*,
           * 11H*SR*MICRON),3X,*EXTINCTION*,3X,*TRANSMITTANCE* /)
        102 FORMAT(I9,1PE18.3,E20.3,E17.3,E14.3)
 45         END
```

```
      FUNCTION PLANCK(WN,T)                                           PLANCK   2
C                                                                     PLANCK   3
C         COMPUTE THE PLANCK RADIATION FUNCTION(W/CM2*SR*CM-1)  FOR   PLANCK   4
C         WAVENUMBER WN(CM-1) AND TEMPERATURE T(DEGK)                 PLANCK   5
C                                                                     PLANCK   6
      PLANCK=1.191E-12*WN**3/(EXP(1.4388*WN/T)-1.)                    PLANCK   7
14    RETURN                                                          PLANCK   8
15    END                                                             PLANCK   9
```

```
          SUBROUTINE KDPARAM(P,T,C,K,D,WL,WD)
    C
    C         COMPUTE THE BAND MODEL PARAMETERS
    C              K=ABSORPTION COEFFICIENT(CM-1/ATM)
    C              C=EFFECTIVE LINE DENSITY(LINES/CM-1)
    C              WL=HWHM LORENTZ LINE WIDTH(CM-1)
    C              WD=HWHM DOPPLER LINE WIDTH(CM-1)
    C         FROM INPUT P(ATM), T(DEGK), AND C(MOLE FRACTION) DATA.
    C
          DIMENSION TPARAM(40),DPARAM(40)
          REAL      KPARAM(40),K
          COMMON/DATA3/TPARAM,KPARAM,DPARAM,WN,WSTP,A1,A2,A3
    C
    C TEST FOR T OUTSIDE INTERPOLATION RANGE
          TE=100.
12        IF(T.LE. 100.) GO TO 1
14        TE=4000.
15        IF(T.GE.4000.) GO TO 1
17        TE=T
    C
    C INTERPOLATE FOR K AND D
20      1 N=TE/100.
22        IF(N.EQ.40) N=39
25        DELT=(TE-TPARAM(N))/100.
30        K=KPARAM(N) +DELT*(KPARAM(N+1)-KPARAM(N))
34        D=DPARAM(N) +DELT*(DPARAM(N+1)-DPARAM(N))
    C
    C COMPUTE LINE WIDTHS
41        SRT=SQRT(273./TE)
44        WL=P*WSTP*(C*A1*SRT**2+C*SRT+(1.-C)*A2*SRT)
60        WD=3.56817E-7*WN*SQRT(TE/A3)
66        RETURN
67        END
```

```
                FUNCTION YCGL(X,R)                                            YCGL       2
      C                                                                       YCGL       3
      C             EQUIVALENT WIDTH DERIVATIVE FUNCTION FOR A BAND OF LORENTZ YCGL       4
      C             LINES WITH AN EXPONENTIAL-TAILED INVERSE LINE STRENGTH    YCGL       5
      C             DISTRIBUTION AND FOR THE CURTIS-GODSON APPROXIMATION      YCGL       6
      C                                                                       YCGL       7
                YCGL=1.                                                       YCGL       8
     5          IF (X.EQ.0.) RETURN                                           YCGL       9
     7          Z=3.1415927*X                                                 YCGL      10
    10          XX=SQRT(1.+2.*Z)                                              YCGL      11
    15          YCGL=(2.-R)/XX+(R-1.)*(XX-1.)/Z                               YCGL      12
    26          RETURN                                                        YCGL      13
    26          END                                                           YCGL      14
```

```
      FUNCTION YDRL(X,R,Q)
C
C         COMPUTE Y(X,R,Q) IN THE DERIVATIVE APPROXIMATION BY
C         INTEGRATION OF Y(X,R,1) OBTAINED FOR A STATISTICAL ARRAY
C         OF LORENTZ LINES WITH AN EXPONENTIAL-TAILED INVERSE LINE
C         STRENGTH DISTRIBUTION AND THE LINDQUIST-SIMMONS APPROXIMATION
C
      DATA F/0.10/
      Z=3.141592654*X
      YDRL=YLSL(Z,R)
      IF(Q.LE.1.) RETURN
      YDRL=YDRL/Q
      IF(Z.GT.0.01) GO TO 1
      YDRL=YDRL+(Q-1.)*(1.-2.*Z/((1.+R)*(1.+Q)))/Q
      RETURN
    1 SUM=Q*(1.-0.02/((1.+R)*(1.+Q)))*(.01)**(1./Q)
      IFLAG=0
      U1=0.01
    2 U2=(SQRT(1.+8.*U1*(1.+2.*U1)/F)-1.)/4.
      IF(U2.LT.Z) GO TO 3
      U2=Z
      IFLAG=1
    3 B=2./(U2-U1)
      A=1.-U2*B
      UU1=(-A+0.57735027)/B
      UU2=(-A-0.57735027)/B
      QQ=(1./Q)-1.
      P1=YLSL(UU1,R)*UU1**QQ
      P2=YLSL(UU2,R)*UU2**QQ
      SUM=SUM+(P1+P2)/B
      IF(IFLAG.EQ.1) GO TO 4
      U1=U2
      GO TO 2
    4 YDRL=YDRL+(Q-1.)*SUM/(Q*Q*X**(1./Q))
      RETURN
      END
```

```
              FUNCTION YLSL(X,R)                                           YLSL     2
         C                                                                 YLSL     3
         C        EQUIVALENT WIDTH DERIVATIVE FUNCTION FOR A BAND OF LORENTZ YLSL     4
         C        LINES WITH AN EXPONENTIAL-TAILED INVERSE LINE STRENGTH   YLSL     5
         C        DISTRIBUTION AND FOR THE LINDQUIST-SIMMONS APPROXIMATION YLSL     6
         C                                                                 YLSL     7
              XX=SQRT(1.+2.*X)                                             YLSL     8
   10         YLSL=(2.*R*(1.+X)+(1.+R**2)*XX)/(XX*(R+XX)**2)               YLSL     9
   22         RETURN                                                       YLSL    10
   22         END                                                          YLSL    11
```

```
      FUNCTION YCGD(X,R)                                                YCGD   2
C                                                                       YCGD   3
C         EQUIVALENT WIDTH DERIVATIVE FUNCTION FOR A BAND OF DOPPLER    YCGD   4
C         LINES WITH AN EXPONENTIAL-TAILED INVERSE LINE STRENGTH        YCGD   5
C         DISTRIBUTION AND FOR THE CURTIS-GODSON APPROXIMATION          YCGD   6
C                                                                       YCGD   7
      YCGD=1.                                                           YCGD   8
 5    IF(X.EQ.0.) RETURN                                                YCGD   9
 7    Z=3.1415927*X                                                     YCGD  10
10    YCGD=(2.-R)*YLSD(Z,1.)+(R-1.)*G(Z)/Z                              YCGD  11
26    RETURN                                                            YCGD  12
27    END                                                               YCGD  13
```

```
          FUNCTION YMLD(X,R,Q)
    C
    C         EQUIVALENT WIDTH DERIVATIVE FUNCTION FOR A BAND OF DOPPLER
    C         LINES WITH AN EXPONENTIAL-TAILED INVERSE LINE STRENGTH
    C         DISTRIBUTION AND FOR THE MEAN-LINE DERIVATIVE APPROXIMATION
    C
          YMLD=1.
  6       IF(Q.EQ.0.) RETURN
 10       IF(X.EQ.0.) RETURN
 13       Z=3.1415927*X/Q
 15       YMLD=YLSD(Z,R)
 20       RETURN
 20       END
```

```
      FUNCTION YLSD(X,R)                                                YLSD
C                                                                       YLSD
C         EQUIVALENT WIDTH DERIVATIVE FUNCTION FOR A BAND OF DOPPLER    YLSD
C         LINES WITH AN EXPONENTIAL-TAILED INVERSE LINE STRENGTH        YLSD
C         DISTRIBUTION AND FOR THE LINDQUIST-SIMMONS APPROXIMATION      YLSD
C                                                                       YLSD
C                                                                       YLSD
C TABULAR INTERPOLATION DATA                                            YLSD
      DIMENSION XX(22),WW(8),YY(22,8),S(3)                              YLSD
      DATA(XX(I),I=1,22)/ 1.0E-2, 2.0E-2, 5.0E-2, 1.0E-1, 2.0E-1,       YLSD
     X     5.0E-1, 1.0E-0, 2.0E-0, 5.0E-0, 1.0E+1, 2.0E+1, 5.0E+1,      YLSD
     X     1.0E+2, 2.0E+2, 5.0E+2, 1.0E+3, 2.0E+3, 5.0E+3, 1.0E+4,      YLSD
     X     2.0E+4, 5.0E+4, 1.0E+5/                                      YLSD
      DATA(WW(J),J=1,3)  / 0.3333333333, 0.5000000000, 0.5555555556 /   YLSD
      DATA(WW(J),J=4,6)  / 0.6000000000, 0.6666666667, 0.7500000000 /   YLSD
      DATA(WW(J),J=7,8)  / 0.8333333333, 1.0000000000               /   YLSD
      DATA(YY(K),K=  1, 22)/ .99114E+0, .98243E+0, .95723E+0, .91503E+0, YLSD
     X .84868E+0, .69248E+0, .53069E+0, .36239E+0, .18622E+0, .10301E+0, YLSD
     X .54426E-1, .22544E-1, .11408E-1, .57394E-2, .23038E-2, .11533E-2, YLSD
     X .57700E-3, .23088E-3, .11546E-3, .57731E-4, .23093E-4, .11547E-4/ YLSD
      DATA(YY(K),K= 23, 44)/ .99299E+0, .98608E+0, .96603E+0, .93460E+0, YLSD
     X .87828E+0, .74750E+0, .60490E+0, .44564E+0, .25945E+0, .15883E+0, YLSD
     X .92598E-1, .43173E-1, .23642E-1, .12759E-1, .55565E-2, .29368E-2, YLSD
     X .15432E-2, .65458E-3, .34067E-3, .17676E-3, .73960E-4, .39163E-4/ YLSD
      DATA(YY(K),K= 45, 66)/ .99380E+0, .98770E+0, .96995E+0, .94207E+0, YLSD
     X .89190E+0, .77433E+0, .64392E+0, .49455E+0, .31182E+0, .20643E+0, YLSD
     X .13195E+0, .70728E-1, .43542E-1, .26649E-1, .13871E-1, .84594E-2, YLSD
     X .51628E-2, .26937E-2, .16503E-2, .10132E-2, .53344E-3, .32916E-3/ YLSD
      DATA(YY(K),K= 67, 88)/ .99450E+0, .98907E+0, .97329E+0, .94846E+0, YLSD
     X .90367E+0, .79799E+0, .67937E+0, .54100E+0, .36533E+0, .25986E+0, YLSD
     X .18053E+0, .10995E+0, .75384E-1, .51787E-1, .31709E-1, .21992E-1, YLSD
     X .15322E-1, .95640E-2, .67263E-2, .47468E-2, .30083E-2, .21370E-2/ YLSD
      DATA(YY(K),K= 89,110)/ .99556E+0, .99119E+0, .97844E+0, .95836E+0, YLSD
     X .92200E+0, .83553E+0, .73706E+0, .61957E+0, .46432E+0, .35450E+0, YLSD
     X .28411E+0, .20490E+0, .16102E+0, .12735E+0, .94277E-1, .75569E-1, YLSD
     X .60853E-1, .45971E-1, .37322E-1, .30380E-1, .23224E-1, .18996E-1/ YLSD
      DATA(YY(K),K=111,132)/ .99686E+0, .99377E+0, .98474E+0, .97050E+0, YLSD
     X .94464E+0, .88273E+0, .81132E+0, .72444E+0, .60548E+0, .52441E+0, YLSD
     X .45506E+0, .38046E+0, .33469E+0, .29611E+0, .25358E+0, .22568E+0, YLSD
     X .20319E+0, .17650E+0, .15906E+0, .14358E+0, .12570E+0, .11393E+0/ YLSD
      DATA(YY(K),K=133,154)/ .99805E+0, .99613E+0, .99053E+0, .98158E+0, YLSD
     X .96560E+0, .92592E+0, .88198E+0, .82669E+0, .74932E+0, .69430E+0, YLSD
     X .64664E+0, .59211E+0, .55672E+0, .52535E+0, .48873E+0, .45396E+0, YLSD
     X .44126E+0, .41390E+0, .39491E+0, .37718E+0, .35546E+0, .34018E+0/ YLSD
      DATA(YY(K),K=155,176)/ .10000E+1, .10000E+1, .10000E+1, .10000E+1, YLSD
     X .10000E+1, .10000E+1, .10000E+1, .10000E+1, .10000E+1, .10000E+1, YLSD
     X .10000E+1, .10000E+1, .10000E+1, .10000E+1, .10000E+1, .10000E+1, YLSD
     X .10000E+1, .10000E+1, .10000E+1, .10000E+1, .10000E+1, .10000E+1/ YLSD
C                                                                       YLSD
C TABULAR INTERPOLATION FUNCTIONS                                       YLSD
      AA(Y1,Y2,Y3,X1,X2,X3)=(ALOG(Y3/Y2)/ALOG(X3/X2)-ALOG(Y2/Y1)/ALOG(X2 YLSD
     X/X1))/ALOG(X3/X1)                                                 YLSD
      BB(Y2,Y3,X2,X3,A)=ALOG(Y3/Y2)/ALOG(X3/X2)-A*ALOG(X3/X2)           YLSD
C                                                                       YLSD
C                                                                       YLSD
      Z=X                                                               YLSD
C SMALL X APPROXIMATION                                                 YLSD
```

```
  72          IF(Z.GT.0.01) GO TO 1
  76          YLSD=1.-Z/SQRT(1.+R**2)+Z**2/SQRT(1.+2.*R**2)             YLSD
 117          RETURN                                                    YLSD
        C LARGE X APPROXIMATION                                         YLSD
 117        1 IF(Z.LE.10000.) GO TO 2                                   YLSD
 122          YLSD=0.                                                   YLSD
 123          RETURN                                                    YLSD
        C SMALL R APPROXIMATION                                         YLSD
 123        2 IF(R.GE.0.5) GO TO 3                                      YLSD
 126          YLSD=1./SQRT((1.+Z)*(1.-7*(R**2-1.)))                     YLSD
 137          RETURN                                                    YLSD
        C LARGE R APPROXIMATION                                         YLSD
 140        3 IF(R.LE.10000.) GO TO 4                                   YLSD
 143          YLSD=1.                                                   YLSD
 144          RETURN                                                    YLSD
 145        4 CONTINUE                                                  YLSD
        C                                                               YLSD
        C TABULAR INTERPOLATION FOR INTERMEDIATE X AND R                YLSD
 145          DO 5 I=1,27                                               YLSD
 153          IF(Z.LE.XX(I)) GO TO 6                                    YLSD
 155        5 CONTINUE                                                  YLSD
 157        6 N=I-1                                                     YLSD
 161          IF(N.LE.1) N=2                                            YLSD
 164          W=R/(1.+R)                                                YLSD
 167          DO 7 J=1,8                                                YLSD
 174          IF(W.LE.WW(J)) GO TO 8                                    YLSD
 176        7 CONTINUE                                                  YLSD
 200        8 M=J-1                                                     YLSD
 202          IF(M.LE.1) M=2                                            YLSD
 205          DO 9 K=1,3                                                YLSD
 207          L=N-2+K                                                   YLSD
 211          A=AA(YY(L,M-1),YY(L,M),YY(L,M+1),WW(M-1),WW(M),WW(M+1))   YLSD
 226          B=BB(YY(L,M),YY(L,M+1),WW(M),WW(M+1),A)                   YLSD
 242          C=ALOG(YY(L,M))                                           YLSD
 251        9 S(K)=EXP(A*ALOG(W/WW(M))**2+B*ALOG(W/WW(M))+C)            YLSD
 270          A=AA(S(1),S(2),S(3),XX(N-1),XX(N),XX(N+1))                YLSD
 302          B=BB(S(2),S(3),XX(N),XX(N+1),A)                           YLSD
 313          C=ALOG(S(2))                                              YLSD
 316          YLSD=EXP(A*ALOG(Z/XX(N))**2+B*ALOG(Z/XX(N))+C)            YLSD
 332          RETURN                                                    YLSD
 332          END                                                       YLSD
```

```
            FUNCTION YMIX(WD,WL,WW,WV,YD,YL)
      C
      C         COMPUTE DERIVATIVE FUNCTION Y FOR A VOIGT LINE BY A
      C         COMBINATION OF DERIVATIVE FUNCTIONS AND EQUIVALENT
      C         WIDTHS FOR PURE LORENTZ AND DOPPLER LINE SHAPES
      C         ACCORDING TO THE NASA HANDBOOK APPROXIMATION.
      C
            YMIX=1.
 11         IF(WV.EQ.0.) RETURN
 15         RL=(WL/WW)**2
 16         RD=(WD/WW)**2
 17         RV=(WV/WW)**2
 21         Y=1./(1.-RL)**2+1./(1.-RD)**2-1.
 30         DL=(SQRT(Y)*(1.-RL))**3
 35         DD=(SQRT(Y)*(1.-RD))**3
 50         A=(WL/WV)/DL
 52         B=(WD/WV)/DD
 54         C=(WW/WV)*(RV-(RL/DL+RD/DD))
 61         YMIX=A*YL+B*YD+C
 65         RETURN
 65         END
```

```
      FUNCTION F(X)
C
C         CURVE OF GROWTH FUNCTION FOR A BAND OF LORENTZ LINES
C         WITH AN EXPONENTIAL-TAILED INVERSE LINE STRENGTH
C         DISTRIBUTION.
C
      F=0.3183099*(SQRT(1.+6.283185*X)-1.)
11    RETURN
11    END
```

```
          FUNCTION G(X)
      C
      C        CURVE OF GROWTH FUNCTION FOR A BAND OF DOPPLER LINES
      C        WITH AN EXPONENTIAL-TAILED INVERSE LINE STRENGTH
      C        DISTRIBUTION
      C
      C
      C TABULAR INTERPOLATION DATA
          DIMENSION XX(21),GG(21)
          DATA(XX(I),I=1,21) / 1.0E-1, 2.0E-1, 4.0E-1, 6.0E-1, 8.0E-1,
         X      1.0E-0, 2.0E-0, 4.0E-0, 6.0E-0, 8.0E-0, 1.0E+1, 2.0E+1,
         X      4.0E+1, 6.0E+1, 8.0E+1, 1.0E+2, 2.0E+2, 4.0E+2, 6.0E+2,
         X      8.0E+2, 1.0E+3/
          DATA(GG(I),I=1,21) /    .9664 5E-1, .18722E-0, .35325E-0, .51289E-0,
         X .63940E-0, .76515E-0, .12814E+1, .20057E+1, .25279E+1, .29414E+1,
         X .32857E+1, .44796E+1, .58466E+1, .67192E+1, .73687E+1, .78891E+1,
         X .95938E+1, .11423E+2, .12548E+2, .13369E+2, .14019E+2/
      C
      C TABULAR INTERPOLATION FUNCTIONS
          AA(Y1,Y2,Y3,X1,X2,X3)=(ALOG(Y3/Y2)/ALOG(X3/X2)-ALOG(Y2/Y1)/ALOG(X2
         X/X1))/ALOG(X3/X1)
          BB(Y2,Y3,X2,X3,A)=ALOG(Y3/Y2)/ALOG(X3/X2)-A*ALOG(X3/X2)
      C
      C
      C SERIES SOLUTION FOR SMALL X
          Z=3.1415927*X
67        IF(Z.GT.0.1) GO TO 1
73        G1=1.000000+0.192450*Z**2+0.089443*Z**4
77        G2=0.353553*Z+0.125000*Z**3+0.06801*Z**5
106       G=Z*(G1-G2)/3.1415927
112       RETURN
      C
      C ASYMPTOTIC EXPANSION SOLUTION FOR LARGE X
112     1 IF(Z.LT.1000.) GO TO 2
115       G=0.23945*ALOG(Z)**1.5*(1.+1.2337/ALOG(Z)**2+1.0654/ALOG(Z)**4)
131       RETURN
      C
      C TABULAR INTERPOLATION FOR INTERMEDIATE X
131     2 DO 3 I=1,21
137       IF(Z.LE.XX(I)) GO TO 4
141     3 CONTINUE
143     4 N=I-1
145       IF(N.LE.1) N=2
150       A=AA(GG(N-1),GG(N),GG(N+1),XX(N-1),XX(N),XX(N+1))
162       B=BB(GG(N),GG(N+1),XX(N),XX(N+1),A)
173       C=ALOG(GG(N))
176       G=0.318310*EXP(A*ALOG(Z/XX(N))**2+B*ALOG(Z/XX(N))+C)
213       RETURN
213       END
```

```
            FUNCTION WMIX(WD,WL,WW)
      C
      C         COMPUTE EQUIVALENT WIDTH W FOR A VOIGT LINE BY A
      C         COMBINATION OF EQUIVALENT WIDTHS FOR PURE LORENTZ
      C         AND DOPPLER LINES ACCORDING TO THE NASA HANDBOOK
      C         APPROXIMATION.
      C
            WMIX=0.
   5        IF(WW.EQ.0.) RETURN
  10        Y=1./(1.-(WL/WW)**2)**2+1./(1.-(WD/WW)**2)**2-1.
  15        WMIX=WW*SQRT(1.-1./SQRT(Y))
  31        RETURN
  32        END
```

END
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