APPENDIX 1. LISTINGS OF THE MAIN PROGRAM AND SUBROUTINES IN THE MAIN DECK

This appendix contains listings of the main program and those subroutines that have only one version (with the exception of subroutine RAYPLT, which has a do-nothing version for users lacking a plotter to plot ray paths). Thus, the routines which form the contents of this appendix will be used in all ray path calculations.

Additionally, this appendix contains the main input parameter form for ray tracing and the input parameter forms for plotting. These forms are very useful when using the program because they indicate the input parameters needed for ray path calculations

The contents of this appendix are arranged as follows:

INPUT PARAMETER FORM
FOR THREE-DIMENSIONAL RAY PATHS

Name_____ Project No._____ Date_____

Ionospheric ID (3 characters) _____

Title (75 characters) _____

Models:	Electron density	_____	
	Perturbation	_____	
	Magnetic field	_____	
	Ordinary	_____	(W1 = + 1.)
	Extraordinary	_____	(W1 = - 1.)
	Collision frequency	_____	
Transmitter:	Height	_____	km, nautical miles, feet (W3)
	Latitude	_____	rad, deg, km (W4)
	Longitude	_____	rad, deg, km (W5)
	Frequency, initial	_____	MHz (W7)
	final	_____	(W8)
	step	_____	(W9)
	Azimuth angle, initial	_____	rad, deg clockwise of north (W11)
	final	_____	(W12)
	step	_____	(W13)
	Elevation angle, initial	_____	rad, deg (W15)
	final	_____	(W16)
	step	_____	(W17)
Receiver:	Height	_____	km, nautical miles, feet (W20)
Penetrating rays:	Wanted	_____	(W21 = 0.)
	Not wanted	_____	(W21 = 1.)
Maximum number of hops		_____	(W22)
Maximum number of steps per hop		_____	(W23)
Maximum allowable error per step		_____	(W42)

Additional calculations:

= 1. to integrate
= 2. to integrate and print

Phase path	_____	(W57)
Absorption	_____	(W58)
Doppler shift	_____	(W59)
Path length	_____	(W60)
Other	_____	
	_____	
	_____	

Printout: Every _____ steps of the ray trace (W71)

Punched cards (raysets): _____ (W72 = 1.)

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      PROGRAM NITIAL                                                    NITI001
C          SETS THE INITIAL CONDITIONS FOR EACH RAY AND CALLS TRACE     NITI002
      DIMENSION MFLD(2)                                                 NITI003
      COMMON /CONST/ PI,PIT2,PID2,DEGS,RAD,K,C,LOGTEN                   NITI004
      COMMON /FLG/ NTYP,NEWWR,NEWWP,PENET,LINES,IHOP,HPUNCH             NITI005
      COMMON /RIN/ MODRIN(3),COLL,FIELD,SPACE,N2,N2I,PNP(10),POLAR,     NITI006
     1             LPOLAR,SGN                                           NITI007
      COMMON /RK/ N,STEP,MODE,E1MAX,E1MIN,E2MAX,E2MIN,FACT,RSTART       NITI008
      COMMON /XX/ MODX(2),X,PXPR,PXPTH,PXPPH,PXPT,HMAX                  NITI009
      COMMON /YY/ MODY,Y(16) /ZZ/ MODZ,Z(4)                             NITI010
      COMMON R(20),T,STP,DRDT(20) /WW/ ID(10),W0,W(400)                 NITI011
      EQUIVALENCE (RAY,W(1)),(EARTHR,W(2)),(XMTRH,W(3)),(TLAT,W(4)),    NITI012
     1 (TLON,W(5)),(F,W(6)),(FBEG,W(7)),(FEND,W(8)),(FSTEP,W(9)),       NITI013
     2 (AZ1,W(10)),(AZBEG,W(11)),(AZEND,W(12)),(AZSTEP,W(13)),          NITI014
     3 (BETA,W(14)),(ELBEG,W(15)),(ELEND,W(16)),(ELSTEP,W(17)),         NITI015
     4 (ONLY,W(21)),(HOP,W(22)),(MAXSTP,W(23)),(PLAT,W(24)),(PLON,W(25))NITI016
     5,(INTYP,W(41)),(MAXERR,W(42)),(ERATIO,W(43)),(STEP1,W(44)),       NITI017
     6 (STPMAX,W(45)),(STPMIN,W(46)),(FACTR,W(47)),(SKIP,W(71)),        NITI018
     7 (RAYSET,W(72)),(PLT,W(81)),(PERT,W(150))                         NITI019
      LOGICAL SPACE,NEWWR,NEWWP,PENET                                   NITI020
      REAL N2,N2I,LOGTEN,K,MAXSTP,INTYP,MAXERR,MU                       NITI021
      COMPLEX PNP,POLAR,LPOLAR                                          NITI022
      NDATE=IDATE(0)                                                    NITI025
      SECOND=KLOCK(0)*.001                                              NITI026
      KOLL=4H  NO                                                       NITI027
      IF (COLL.NE.0.) KOLL=4HWITH                                       NITI028
C********** CONSTANTS                                                   NITI029
      PI=3.1415926536                                                   NITI030
      PIT2=2.*PI                                                        NITI031
      PID2=PI/2.                                                        NITI032
      DEGS=180./PI                                                      NITI033
      RAD=PI/180.                                                       NITI034
      C=2.997925E5                                                      NITI035
      K=2.81785E-15*C**2/PI                                             NITI036
      LOGTEN=ALOG(10.)                                                  NITI037
C********** INITIALIZE SOME VARIABLES IN THE W ARRAY                    NITI038
      DO 5 NW=1,400                                                     NITI039
    5 W(NW)=0.                                                          NITI040
      PLON=0.                                                           NITI041
      PLAT=PID2                                                         NITI042
      EARTHR=6370.                                                      NITI043
      INTYP=3.                                                          NITI044
      MAXERR=1.E-4                                                      NITI045
      ERATIO=50.                                                        NITI046
      STEP1=1.                                                          NITI047
      STPMAX=100.                                                       NITI048
      STPMIN=1.E-8                                                      NITI049
      FACTR=0.5                                                         NITI050
      MAXSTP=1000.                                                      NITI051
      HOP=1.                                                            NITI052
C********** READ W ARRAY AND PRINT NON-ZERO VALUES                      NITI053
   10 CALL READ W                                                       NITI054
      F=BETA=AZ1=0.                                                     NITI055
      IF (SKIP.EQ.0.) SKIP=MAXSTP                                       NITI056
   12 RAY=SIGN(1.,RAY)                                                  NITI057
      NTYP=2.+FIELD*RAY                                                 NITI058
      GO TO (13,14,15), NTYP                                            NITI059
   13 MFLD(1)=8HEXTRAORD                                                NITI060
      MFLD(2)=5HINARY                                                   NITI061
      GO TO 16                                                          NITI062
   14 MFLD(1)=8HNO FIELD                                                NITI063
      MFLD(2)=1H                                                        NITI064
      GO TO 16                                                          NITI065
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   15 MFLD(1)=8HORDINARY                                                  NITI066
      MFLD(2)=8H                                                          NITI067
   16 MODSAV=MODX(2)                                                      NITI068
      IF (PERT.EQ.0.) MODX(2)=6H                                          NITI069
      IF (RAYSET.NE.0.) PUNCH 2000, ID,MODX(1),(W(NW),NW=101,107),        NITI070
     1 MODX(2),(W(NW),NW=151,157),MODY,(W(NW),NW=201,207),                NITI071
     2 MODZ,(W(NW),NW=251,257)                                            NITI072
 2000 FORMAT (10A8,4(/A8,2X,7E10.3))                                      NITI073
      PRINT 1000, ID,NDATE,MODX,MODY,MODZ,MODRIN,MFLD,KOLL                NITI074
 1000 FORMAT (1H1,10A8,25X,A8/4(1X,A8),24X,3A8,1X,A8,A5,1X,A4,            NITI075
     1 11H COLLISIONS/)                                                   NITI076
      PRINT 1050                                                          NITI077
 1050 FORMAT (85H INITIAL VALUES FOR THE W ARRAY -- ALL ANGLES IN RADIANS NITI078
     1S, ONLY NONZERO VALUES PRINTED/)                                    NITI079
      DO 17 NW=1,400                                                      NITI080
      IF (W(NW).NE.0.) PRINT 1700, NW,W(NW)                               NITI081
 1700 FORMAT (I4,E19.11)                                                  NITI082
   17 CONTINUE                                                            NITI083
C********* LET SUBROUTINES PRINTR AND RAYPLT KNOW THERE IS A NEW W ARRAY  NITI084
      NEWWP=.TRUE.                                                        NITI085
      NEWWR=.TRUE.                                                        NITI086
C********* INITIALIZE PARAMETERS FOR INTEGRATION SUBROUTINE RKAM          NITI087
      N=6                                                                 NITI088
      DO 20 NR=7,20                                                       NITI089
      IF (W(50+NR).NE.0.) N=N+1                                           NITI090
   20 CONTINUE                                                            NITI091
      MODE=INTYP                                                          NITI092
      STEP=STEP1                                                          NITI093
      E1MAX=MAXERR                                                        NITI094
      E1MIN=MAXERR/ERATIO                                                 NITI095
      E2MAX=STPMAX                                                        NITI096
      E2MIN=STPMIN                                                        NITI097
      FACT=FACTR                                                          NITI098
C********* DETERMINE TRANSMITTER LOCATION IN COMPUTATIONAL COORDINATE     NITI099
C********* SYSTEM (GEOMAGNETIC COORDINATES IF DIPOLE FIELD IS USED)       NITI100
      R0=EARTHR+XMTRH                                                     NITI101
      SP=SIN (PLAT)                                                       NITI102
      CP=SIN (PID2-PLAT)                                                  NITI103
      SDPH=SIN (TLON-PLON)                                                NITI104
      CDPH=SIN (PID2-(TLON-PLON))                                         NITI105
      SL=SIN (TLAT)                                                       NITI106
      CL=SIN (PID2-TLAT)                                                  NITI107
      ALPHA=ATAN2(-SDPH*CP,-CDPH*CP*SL+SP*CL)                             NITI108
      TH0=ACOS (CDPH*CP*CL+SP*SL)                                         NITI109
      PH0=ATAN2(SDPH*CL,CDPH*SP*CL-CP*SL)                                 NITI110
C********* LOOP ON FREQUENCY, AZIMUTH ANGLE, AND ELEVATION ANGLE          NITI111
      NFREQ=1                                                             NITI112
      IF (FSTEP.NE.0.) NFREQ=(FEND-FBEG)/FSTEP+1.5                        NITI113
      NAZ=1                                                               NITI114
      IF (AZSTEP.NE.0.) NAZ=(AZEND-AZBEG)/AZSTEP+1.5                      NITI115
      NBETA=1                                                             NITI116
      IF (ELSTEP.NE.0.) NBETA=(ELEND-ELBEG)/ELSTEP+1.5                    NITI117
      DO 50 NF=1,NFREQ                                                    NITI118
      F=FBEG+(NF-1)*FSTEP                                                 NITI119
      DO 45 J=1,NAZ                                                       NITI120
      AZ1=AZBEG+(J-1)*AZSTEP                                              NITI121
      AZA=AZ1*DEGS                                                        NITI122
      GAMMA=PI-AZ1+ALPHA                                                  NITI123
      SGAMMA=SIN (GAMMA)                                                  NITI124
      CGAMMA=SIN (PID2-GAMMA)                                             NITI125
      DO 40 I=1,NBETA                                                     NITI126
      BETA=ELBEG+(I-1)*ELSTEP                                             NITI127
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      EL=BETA*DEGS                                                      NITI128
      CBETA=SIN (PID2-BETA)                                             NITI129
      R(1)=R0                                                           NITI130
      R(2)=TH0                                                          NITI131
      R(3)=PH0                                                          NITI132
      R(4)=SIN (BETA)                                                   NITI133
      R(5)=CBETA*CGAMMA                                                 NITI134
      R(6)=CBETA*SGAMMA                                                 NITI135
      T=0.                                                              NITI136
      RSTART=1.                                                         NITI137
C     SGN=1.  (NEED FOR RAY TRACING IN COMPLEX SPACE.)                  NITI138
C********* ALLOW IONOSPHERIC MODEL SUBROUTINES TO READ AND PRINT DATA   NITI139
      CALL RINDEX                                                       NITI140
      IF (I.NE.1.AND.NPAGE.LT.3.AND.LINES.LE.17) GO TO 25               NITI141
      NPAGE=LINES=0                                                     NITI142
      PRINT 1000, ID,NDATE,MODX,MODY,MODZ,MODRIN,MFLD,KOLL              NITI143
      PRINT 2400, F,AZA                                                 NITI144
 2400 FORMAT (18X,11HFREQUENCY =,F12.6,37H MHZ, AZIMUTH ANGLE OF TRANSMINITI145
     1SSION =,F12.6,4H DEG)                                             NITI146
   25 NPAGE=NPAGE+1                                                     NITI147
      PRINT 2500, EL                                                    NITI148
 2500 FORMAT (/31X,33HELEVATION ANGLE OF TRANSMISSION =,F12.6,4H DEG/)  NITI149
      IF (N2.GT.0.) GO TO 30                                            NITI150
      CALL ELECTX                                                       NITI151
      FN=SIGN (SQRT (ABS (X))*F,X)                                      NITI152
      PRINT 2900, FN                                                    NITI153
 2900 FORMAT (58HOTRANSMITTER IN EVANESCENT REGION, TRANSMISSION IMPOSSINITI154
     1BLE/20H0PLASMA FREQUENCY = ,E17.10)                               NITI155
      GO TO 44                                                          NITI156
   30 MU=SQRT (N2/(R(4)**2+R(5)**2+R(6)**2))                            NITI157
      DO 34 NN=4,6                                                      NITI158
   34 R(NN)=R(NN)*MU                                                    NITI159
      DO 35 NN=7,N                                                      NITI160
   35 R(NN)=0.                                                          NITI161
      CALL TRACE                                                        NITI162
      OSEC=SECOND                                                       NITI163
      SECOND=KLOCK(0)*.001                                              NITI164
      DIFF=SECOND-OSEC                                                  NITI165
      PRINT 3500, DIFF                                                  NITI166
 3500 FORMAT (36X,26HTHIS RAY CALCULATION TOOK ,F8.3,4H SEC)            NITI167
      IF (PENET.AND.ONLY.NE.0..AND.IHOP.EQ.1) GO TO 44                  NITI168
   40 CONTINUE                                                          NITI169
   44 IF (PLT.NE.0.) CALL ENDPLT                                        NITI170
   45 CONTINUE                                                          NITI171
      IF(PENET.AND.ONLY.NE.0..AND.IHOP.EQ.1.AND.NAZ.EQ.1.AND.NBETA.EQ.1)NITI172
     1 GO TO 55                                                         NITI173
   50 CONTINUE                                                          NITI174
   55 IF (RAYSET.NE.0.) PUNCH 5000                                      NITI175
 5000 FORMAT (78X,1H-)                                                  NITI176
      MODX(2)=MODSAV                                                    NITI177
      GO TO 10                                                          NITI178
         END                                                            NITI179-
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      SUBROUTINE READ W                                                  READ001
C                          READS W ARRAY                               READ002
C       A 1 IN THE FOLLOWING COLUMNS WILL MAKE THE DESCRIBED CONVERSIONSREAD003
COL 18   DEGREES TO RADIANS                                            READ004
COL 19   GREAT CIRCLE DISTANCE IN KM TO RADIANS                        READ005
COL 20   NAUTICAL MILES TO KM                                          READ006
COL 21   FEET TO KM                                                    READ007
C                                                                      READ008
      COMMON /CONST/ PI,PIT2,PID2,DEGS,RAD,DUM(3)                      READ009
      COMMON /WW/ ID(10),W0,W(400)                                     READ010
      EQUIVALENCE (EARTHR,W(2))                                        READ011
      INTEGER DEG,FEET                                                 READ012
      READ 1000, ID                                                    READ013
 1000 FORMAT (10A8)                                                    READ014
      IF (EOF,60) 3,4                                                  READ015
    3 CALL EXIT                                                        READ016
    4 READ 1100, NW,W(NW),DEG,KM,NM,FEET                               READ017
 1100 FORMAT (I3,E14.7,5I1)                                            READ018
      IF (NW.EQ.0) GO TO 10                                            READ019
      IF (NW.GT.0.AND.NW.LE.400) GO TO 5                               READ020
      PRINT 4000, NW                                                   READ021
 4000 FORMAT(15H1THE SUBSCRIPT ,I3,77H ON THE W-ARRAY INPUT IS OUT OF BOREAD022
     1UNDS.  ALLOWABLE VALUES ARE 1 THROUGH 400. )                     READ023
      CALL EXIT                                                        READ024
    5 IF (DEG.NE.0.) W(NW)=W(NW)*RAD                                   READ025
      IF (KM.NE.0) W(NW)=W(NW)/EARTHR                                  READ026
      IF (NM.NE.0) W(NW)=W(NW)*1.852                                   READ027
      IF (FEET.NE.0) W(NW)=W(NW)*3.048006096E-4                        READ028
      GO TO 4                                                          READ029
   10 RETURN                                                           READ030
      END                                                              READ031-
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      SUBROUTINE TRACE                                                 TRAC001
C          CALCULATES THE RAY PATH                                      TRAC002
      DIMENSION ROLD(20),DROLD(20)                                     TRAC003
      COMMON /RK/ N,STEP,MODE,E1MAX,E1MIN,E2MAX,E2MIN,FACT,RSTART      TRAC004
      COMMON /FLG/ NTYP,NEWWR,NEWWP,PENET,LINES,IHOP,HPUNCH            TRAC005
      COMMON /TRAC/ GROUND,PERIGE,THERE,MINDIS,NEWRAY,SMT              TRAC006
      COMMON /RIN/ MODRIN(3),COLL,FIELD,SPACE,N2,PNP(10),POLAR,LPOLAR  TRAC007
      COMMON /XX/ MODX(2),X,PXPR,PXPTH,PXPPH,PXPT,HMAX                 TRAC008
      COMMON R(20),T,STP,DRDT(20) /WW/ ID(10),W0,W(400)                TRAC009
      LOGICAL SPACE,HOME,WASNT,UNDRGD,GROUND,PERIGE,THERE,MINDIS,NEWWR, TRAC010
     1        NEWWP,PENET,NEWRAY,WAS                                    TRAC011
      REAL MAXSTP                                                      TRAC012
      COMPLEX N2,PNP,POLAR,LPOLAR                                      TRAC013
      EQUIVALENCE (EARTHR,W(2)),(RCVRH,W(20)),(HOP,W(22)),(MAXSTP,W(23))TRAC014
     1,(SKIP,W(71)),(RAYSET,W(72)),(PLT,W(81))                         TRAC015
      NHOP=HOP                                                         TRAC016
      MAX=MAXSTP                                                       TRAC017
      NSKIP=SKIP                                                       TRAC018
      RSTART=1.                                                        TRAC019
      CALL HAMLTN                                                      TRAC020
      HOME=DRDT(1)*(R(1)-EARTHR-RCVRH).GE.0.                           TRAC021
C********* IHOP=0 TELLS PRINTR TO PRINT HEADING AND PUNCH A TRANSMITTER TRAC022
C********* RAYSET AND TELLS RAYPLT TO START A NEW RAY                  TRAC023
      IHOP=0                                                           TRAC024
      CALL PRINTR (8HXMTR    ,0.)                                      TRAC025
      IF (PLT.NE.0.) CALL RAYPLT                                       TRAC026
      HTMAX=0.                                                         TRAC027
      NEWRAY=.TRUE.                                                    TRAC028
      THERE=R(1)-EARTHR.EQ.RCVRH                                       TRAC029
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C********* LOOP ON NUMBER OF HOPS                                          TRAC030
   10 IHOP=IHOP+1                                                         TRAC031
      IF (IHOP.GT.NHOP) RETURN                                            TRAC032
      PENET=.FALSE.                                                       TRAC033
      APHT=RCVRH                                                          TRAC034
C********* LOOP ON MAXIMUM NUMBER OF STEPS PER HOP                        TRAC035
      DO 79 J=1,MAX                                                       TRAC036
      H=R(1)-EARTHR                                                       TRAC037
      IF (ABS(H-RCVRH).GT.ABS(APHT-RCVRH)) APHT=H                         TRAC038
      HTMAX=AMAX1(H,HTMAX)                                                TRAC039
      IF (.NOT.SPACE) GO TO 12                                            TRAC040
      CALL REACH                                                          TRAC041
      RSTART=1.                                                           TRAC042
      H=R(1)-EARTHR                                                       TRAC043
      IF (ABS(H-RCVRH).GT.ABS(APHT-RCVRH)) APHT=H                         TRAC044
      HTMAX=AMAX1(H,HTMAX)                                                TRAC045
      IF (.NOT.SPACE) GO TO 12                                            TRAC046
      IF (PERIGE) CALL PRINTR (8HPERIGEE ,0.)                             TRAC047
      IF (THERE) GO TO 51                                                 TRAC048
      IF (MINDIS) GO TO 40                                                TRAC049
      IF (GROUND) GO TO 60                                                TRAC050
      IF (PLT.NE.0.) CALL RAYPLT                                          TRAC051
      IF (PERIGE) GO TO 79                                                TRAC052
   12 DO 13 L=1,N                                                         TRAC053
      ROLD(L)=R(L)                                                        TRAC054
   13 DROLD(L)=DRDT(L)                                                    TRAC055
      TOLD=T                                                              TRAC056
      WAS=THERE                                                           TRAC057
      CALL RKAM                                                           TRAC058
      H=R(1)-EARTHR                                                       TRAC059
      THERE=.FALSE.                                                       TRAC060
      WASNT=.NOT.HOME                                                     TRAC061
      HOME=DRDT(1)*(H-RCVRH).GE.0.                                        TRAC062
      TMP=(DRDT(1)-DROLD(1))*(T-TOLD)                                     TRAC063
      SMT=0.                                                              TRAC064
      IF (TMP.NE.0.) SMT=0.5*(R(1)-ROLD(1)+0.5*TMP)**2/ABS(TMP)           TRAC065
      IF (((H-RCVRH)*(ROLD(1)-EARTHR-RCVRH).LT.0..AND..NOT.WAS).OR.       TRAC066
     1 (WAS.AND.DRDT(1)*DROLD(1).LT.0..AND.HOME)) GO TO 50                TRAC067
      IF (HOME.AND.WASNT) GO TO 30                                        TRAC068
      IF (H.LT.0..OR.DRDT(1).GT.0..AND.DROLD(1).LT.0..AND.SMT.GT.H)       TRAC069
     1 GO TO 20                                                           TRAC070
      IF (DROLD(1).LT.0..AND.DRDT(1).GT.0.) CALL PRINTR(8HPERIGEE ,0.)    TRAC071
      IF (DROLD(1).GT.0..AND.DRDT(1).LT.0.) CALL PRINTR(8HAPOGEE  ,0.)    TRAC072
      IF (DROLD(2)*DRDT(2).LT.0.) CALL PRINTR(8HMAX LAT ,0.)              TRAC073
      IF (DROLD(3)*DRDT(3).LT.0.) CALL PRINTR(8HMAX LONG,0.)              TRAC074
      DO 14 I=4,6                                                         TRAC075
      IF (ROLD(I)*R(I).LT.0.) CALL PRINTR(8HWAVE REV,0.)                  TRAC076
   14 CONTINUE                                                            TRAC077
      GO TO 75                                                            TRAC078
C********* RAY WENT UNDERGROUND                                           TRAC079
   20 CALL BACK UP(0.)                                                    TRAC080
      GO TO 60                                                            TRAC081
C********* RAY MAY HAVE MADE A CLOSEST APPROACH                           TRAC082
   30 CALL GRAZE(RCVRH)                                                   TRAC083
      IF (THERE) GO TO 51                                                 TRAC084
   40 DRDT(1)=0.                                                          TRAC085
      HPUNCH=R(1)-EARTHR                                                  TRAC086
      CALL PRINTR(8HMIN DIST,RAYSET)                                      TRAC087
      IF (PLT.NE.0.) CALL RAYPLT                                          TRAC088
      IF (IHOP.GE.NHOP) RETURN                                            TRAC089
      IHOP=IHOP+1                                                         TRAC090
      CALL PRINTR (8HMIN DIST,RAYSET)                                     TRAC091
      GO TO 89                                                            TRAC092
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C********* RAY CROSSED RECEIVER HEIGHT                                    TRAC093
   50 CALL BACK UP(RCVRH)                                                 TRAC094
      THERE=.TRUE.                                                        TRAC095
   51 R(1)=EARTHR+RCVRH                                                   TRAC096
      HTMAX=AMAX1(RCVRH,HTMAX)                                            TRAC097
      HPUNCH=APHT                                                         TRAC098
      CALL PRINTR(8HRCVR    ,RAYSET)                                      TRAC099
      IF (PLT.NE.0.) CALL RAYPLT                                          TRAC100
      IF (RCVRH.NE.0.) GO TO 89                                           TRAC101
      IF (IHOP.GE.NHOP) RETURN                                            TRAC102
      IHOP=IHOP+1                                                         TRAC103
      APHT=RCVRH                                                          TRAC104
C********* GROUND REFLECT                                                TRAC105
   60 R(1)=EARTHR                                                         TRAC106
      IF (ABS(RCVRH).GT.ABS(APHT-RCVRH)) APHT=0.                          TRAC107
      R(4)=ABS (R(4))                                                     TRAC108
      DRDT(1)=ABS (DRDT(1))                                               TRAC109
      RSTART=1.                                                           TRAC110
      HPUNCH=HTMAX                                                        TRAC111
      CALL PRINTR(8HGRND REF,RAYSET)                                      TRAC112
      HTMAX=0.                                                            TRAC113
      IF (RCVRH.NE.0.) GO TO 65                                           TRAC114
      THERE=.TRUE.                                                        TRAC115
      HPUNCH=APHT                                                         TRAC116
      CALL PRINTR (8HRCVR    ,RAYSET)                                     TRAC117
      GO TO 89                                                            TRAC118
   65 H=0.                                                                TRAC119
      THERE=.FALSE.                                                       TRAC120
C*********                                                               TRAC121
   75 IF (PLT.NE.0.) CALL RAYPLT                                          TRAC122
      IF (H.GT.HMAX.AND.H.GT.RCVRH.AND.DRDT(1).GT.0.) GO TO 90            TRAC123
      IF (MOD(J,NSKIP).EQ.0) CALL PRINTR(8H        ,0.)                   TRAC124
   79 CONTINUE                                                            TRAC125
C********* EXCEEDED MAXIMUM NUMBER OF STEPS                              TRAC126
      HPUNCH=H                                                            TRAC127
      CALL PRINTR(8HSTEP MAX,RAYSET)                                      TRAC128
      RETURN                                                              TRAC129
C*********                                                               TRAC130
   89 HOME=.TRUE.                                                         TRAC131
      GO TO 10                                                            TRAC132
C********* RAY PENETRATED                                                TRAC133
   90 PENET=.TRUE.                                                        TRAC134
      HPUNCH=H                                                            TRAC135
      CALL PRINTR(8HPENETRAT,RAYSET)                                      TRAC136
      RETURN                                                              TRAC137
         END                                                              TRAC138
```

```
      SUBROUTINE BACK UP(HS)                                              BACK001
      COMMON /RK/ N,STEP,MODE,E1MAX,E1MIN,E2MAX,E2MIN,FACT,RSTART         BACK002
      COMMON /TRAC/ GROUND,PERIGE,THERE,MINDIS,NEWRAY,SMT                 BACK003
      COMMON R(20),T,STP,DRDT(20) /WW/ ID(10),W0,W(400)                   BACK004
      EQUIVALENCE (EARTHR,W(2)),(INTYP,W(41)),(STEP1,W(44))               BACK005
      REAL INTYP                                                          BACK006
      LOGICAL GROUND,PERIGE,THERE,MINDIS,NEWRAY,HOME                      BACK007
C********* DIAGNOSTIC PRINTOUT                                           BACK008
C        CALL PRINTR (8HBACK UP0,0.)                                      BACK009
C********* GOING AWAY FROM THE HEIGHT HS                                 BACK010
      HOME=DRDT(1)*(R(1)-EARTHR-HS).GE.0.                                 BACK011
      IF (HS.GT.0..AND..NOT.HOME.OR.HS.EQ.0..AND.DRDT(1).GT.0.) GO TO 30  BACK012
```

```
C********* FIND NEAREST INTERSECTION OF RAY WITH THE HEIGHT HS          BACK013
      DO 10 I=1,10                                                     BACK014
      STEP=-(R(1)-EARTHR-HS)/DRDT(1)                                   BACK015
      STEP=SIGN(AMIN1(ABS(STP),ABS(STEP)),STEP)                        BACK016
      IF (ABS(R(1)-EARTHR-HS).LT..5E-4.AND.ABS(STEP).LT.1.) GO TO 60   BACK017
C********* DIAGNOSTIC PRINTOUT                                        BACK018
C        CALL PRINTR(8HBACK UP1,0.)                                     BACK019
      MODE=1                                                           BACK020
      RSTART=1.                                                        BACK021
      CALL RKAM                                                        BACK022
   10 RSTART=1.                                                        BACK023
C                                                                      BACK024
C********* FIND NEAREST CLOSEST APPROACH OF RAY TO THE HEIGHT HS       BACK025
      ENTRY GRAZE                                                      BACK026
      THERE=.FALSE.                                                    BACK027
C********* DIAGNOSTIC PRINTOUT                                        BACK028
C        CALL PRINTR (8HGRAZE 0 ,0.)                                    BACK029
      IF (SMT.GT.ABS(R(1)-EARTHR-HS)) GO TO 30                         BACK030
      DO 20 I=1,10                                                     BACK031
      STEP=-R(4)/DRDT(4)                                               BACK032
      STEP=SIGN(AMIN1(ABS(STP),ABS(STEP)),STEP)                        BACK033
      IF (ABS(R(4)).LE.1.E-6.AND.ABS(STEP).LT.1.) GO TO 60             BACK034
C********* DIAGNOSTIC PRINTOUT                                        BACK035
C        CALL PRINTR (8HGRAZE 1 ,0.)                                    BACK036
      MODE=1                                                           BACK037
      RSTART=1.                                                        BACK038
      CALL RKAM                                                        BACK039
      RSTART=1.                                                        BACK040
      IF (DRDT(4)*(R(1)-EARTHR-HS).LT.0.) GO TO 30                     BACK041
      IF(R(5).EQ.0..AND.R(6).EQ.0.) GO TO 60                           BACK042
   20 CONTINUE                                                         BACK043
C********* IF A CLOSEST APPROACH COULD NOT BE FOUND IN 10 STEPS, IT    BACK044
C********* PROBABLY MEANS THAT THE RAY INTERSECTS THE HEIGHT HS        BACK045
   30 CONTINUE                                                         BACK046
C********* DIAGNOSTIC PRINTOUT                                        BACK047
C        CALL PRINTR (8HBACK UP2,0.)                                    BACK048
      MODE=1                                                           BACK049
C********* ESTIMATE DISTANCE TO NEAREST INTERSECTION OF RAY WITH HEIGHT BACK050
C********* HS BEHIND THE PRESENT RAY POINT                             BACK051
      STEP=(-R(4)-SQRT(R(4)**2-2.*(R(1)-EARTHR-HS)*DRDT(4)))/DRDT(4)   BACK052
      RSTART=1.                                                        BACK053
      CALL RKAM                                                        BACK054
      RSTART=1.                                                        BACK055
C********* FIND NEAREST INTERSECTION OF RAY WITH HEIGHT HS             BACK056
      DO 40 I=1,10                                                     BACK057
      STEP=-(R(1)-EARTHR-HS)/DRDT(1)                                   BACK058
      STEP=SIGN(AMIN1(ABS(STP),ABS(STEP)),STEP)                        BACK059
      IF (ABS(R(1)-EARTHR-HS).LT..5E-4.AND.ABS(STEP).LT.1.) GO TO 60   BACK060
C********* DIAGNOSTIC PRINTOUT                                        BACK061
C        CALL PRINTR (8HBACK UP3,0.)                                    BACK062
      MODE=1                                                           BACK063
      RSTART=1.                                                        BACK064
      CALL RKAM                                                        BACK065
   40 RSTART=1.                                                        BACK066
   50 THERE=.TRUE.                                                     BACK067
C********* RESET STANDARD MODE AND INTEGRATION TYPE                    BACK068
   60 MODE=INTYP                                                       BACK069
      STEP=STEP1                                                       BACK070
      RETURN                                                           BACK071
         END                                                           BACK072-
```

```
      SUBROUTINE REACH                                                  REAC001
C          CALCULATES THE STRAIGHT LINE RAY PATH BETWEEN THE EARTH      REAC002
C          AND THE IONOSPHERE OR BETWEEN IONOSPHERIC LAYERS             REAC003
      COMMON /RK/ N,STEP,MODE,E1MAX,E1MIN,E2MAX,E2MIN,FACT,RSTART       REAC004
      COMMON /TRAC/ GROUND,PERIGE,THERE,MINDIS,NEWRAY,SMT               REAC005
      COMMON /COORD/ S                                                  REAC006
      COMMON /RIN/ MODRIN(3),COLL,FIELD,SPACE,N2,N2I,PNP(10),POLAR,     REAC007
     1             LPOLAR                                             REAC008
      COMMON /XX/ MODX(2),X,PXPR,PXPTH,PXPPH,PXPT,HMAX                  REAC009
      COMMON R(20),T,STP,DRDT(20) /WW/ ID(10),W0,W(400)                 REAC010
      EQUIVALENCE (EARTHR,W(2)),(XMTRH,W(3)),(RCVRH,W(20))              REAC011
      LOGICAL CROSS,CROSSG,CROSSR,SPACE,GROUND,PERIGE,THERE,MINDIS,     REAC012
     1        NEWRAY,RSPACE                                             REAC013
      REAL N2,N2I                                                       REAC 14
      COMPLEX PNP,POLAR,LPOLAR                                          REAC 15
      DATA (NSTEP=500)                                                  REAC 16
      CALL HAMLTN                                                       REAC 17
      H=R(1)-EARTHR                                                     REAC 18
      IF (.NOT.NEWRAY.AND..NOT.RSPACE) CALL PRINTR(8HEXIT ION,0.)       REAC 19
      NEWRAY=.FALSE.                                                    REAC 20
      V=SQRT(R(4)**2+R(5)**2+R(6)**2)                                   REAC 21
C********* NORMALIZE THE WAVE NORMAL DIRECTION TO ONE                   REAC 22
      R(4)=R(4)/V                                                       REAC 23
      R(5)=R(5)/V                                                       REAC 24
      R(6)=R(6)/V                                                       REAC 25
C********* NEGATIVE OF DISTANCE ALONG RAY TO CLOSEST APPROACH TO CENTER REAC 26
C********* OF EARTH                                                     REAC 27
      UP=R(1)*R(4)                                                      REAC 28
      RADG=EARTHR**2-R(1)**2*(R(5)**2+R(6)**2)                          REAC 29
      DISTG=SQRT (AMAX1(0.,RADG))                                       REAC 30
C********* DISTANCE ALONG RAY TO FIRST INTERSECTION WITH OR CLOSEST     REAC 31
C********* APPROACH TO THE EARTH                                        REAC 32
      SG=-UP-DISTG                                                      REAC 33
C********* CROSSG IS TRUE IF THE RAY WILL INTERSECT OR TOUCH THE EARTH  REAC 34
      CROSSG=UP.LT.0..AND.RADG.GE.0.                                    REAC 35
      RADR=(EARTHR+RCVRH)**2-R(1)**2*(R(5)**2+R(6)**2)                  REAC 36
      DISTR=SQRT (AMAX1(0.,RADR))                                       REAC 37
C********* DISTANCE ALONG RAY TO THE FIRST INTERSECTION WITH OR CLOSEST REAC 38
C********* APPROACH TO THE RECEIVER HEIGHT                              REAC 39
      SR=DISTR-UP                                                       REAC 40
      IF (UP.LT.0..AND.DISTR.LT.-UP.AND.R(1).NE.EARTHR+RCVRH) SR=-DISTR REAC 41
     1 -UP                                                              REAC 42
C********* CROSSR IS TRUE IF THE RAY WILL INTERSECT WITH OR MAKE A      REAC 43
C********* CLOSEST APPROACH TO THE RECEIVER HEIGHT                      REAC 44
      CROSSR=R(4).LT.0..OR.R(1).LT.(EARTHR+RCVRH)                       REAC 45
      CROSS=CROSSG.OR.CROSSR                                            REAC 46
C********* MAXIMUM DISTANCE IN WHICH TO LOOK FOR THE IONOSPHERE         REAC 47
      S1=AMIN1(SR,SG)                                                   REAC 48
      IF(.NOT.CROSSG) S1=SR                                             REAC 49
      IF (UP.GE.0.) GO TO 15                                            REAC 50
      CROSS=.TRUE.                                                      REAC 51
C********* IF RAY IS GOING DOWN, S1 IS AT MOST THE DISTANCE TO A PERIGEEREAC 52
      S1=AMIN1(S1,-UP)                                                  REAC 53
C********* CONVERT THE POSITION AND DIRECTION OF THE RAY TO CARTESIAN   REAC 54
C********* COORDINATES                                                  REAC 55
   15 CALL POL CAR                                                      REAC 56
      SSTEP=100.                                                        REAC 57
      S=SSTEP                                                           REAC 58
      DO 20 I=1,NSTEP                                                   REAC 59
      IF ((S-SSTEP).GT.S1.AND.CROSS) GO TO 25                           REAC 60
C********* CONVERT POSITION AND DIRECTION TO SPHERICAL POLAR COORDINATESREAC 61
C********* AT A DISTANCE S ALONG THE RAY                                REAC 62
      CALL CAR POL                                                      REAC 63
      CALL ELECTX                                                       REAC 64
C********* FREE SPACE                                                   REAC 65
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      IF (X.EQ.0.) GO TO 20                                                REAC 66
      CALL RINDEX                                                          REAC 67
C********* EFFECTIVELY FREE SPACE                                          REAC 68
      IF (SPACE) GO TO 20                                                  REAC 69
      IF (SSTEP.LT.0.5E-4) GO TO 25                                        REAC 70
C********* RAY IN THE IONOSPHERE.  STEP BACK OUT                          REAC 71
      S=S-SSTEP                                                            REAC 72
C********* DECREASE STEP SIZE                                             REAC 73
      SSTEP=SSTEP/10.                                                      REAC 74
   20 S=S+SSTEP                                                            REAC 75
      PRINT 2000, NSTEP                                                    REAC 76
 2000 FORMAT (9H EXCEEDED,I5,26H STEPS IN SUBROUTINE REACH)                REAC 77
      CALL EXIT                                                            REAC 78
   25 IF(CROSS) S=AMIN1(S,S1)                                              REAC 79
C********* CONVERT POSITION AND DIRECTION TO SPHERICAL POLAR COORDINATESREAC 80
C********* AT A DISTANCE S ALONG THE RAY                                  REAC 81
      CALL CAR POL                                                         REAC 82
C********* AVOID THE RAY BEING SLIGHTLY UNDERGROUND                       REAC 83
      R(1)=AMAX1(R(1),EARTHR)                                              REAC 84
C********* ONE STEP INTEGRATION                                           REAC 85
      IF (N.LT.7) GO TO 31                                                 REAC 86
      DO 30 NN=7,N                                                         REAC 87
   30 R(NN)=P(NN)+S*DROT(NN)                                               REAC 88
   31 T=T+S                                                               REAC 89
      CALL RINDEX                                                          REAC 90
C********* AT A PERIGEE                                                   REAC 91
      PERIGE=S.EQ.(-UP)                                                    REAC 92
C********* CORRECT MINOR ERRORS                                           REAC 93
      IF (PERIGE) R(4)=0.                                                  REAC 94
C********* KEEP CONSISTENCY AFTER CORRECTING MINOR ERRORS                 REAC 95
      DROT(1)=R(4)                                                         REAC 96
C********* ON THE GROUND                                                  REAC 97
      GROUND=S.EQ.SG.AND.CROSSG                                            REAC 98
C********* AT THE RECEIVER HEIGHT                                         REAC 99
      THERE=S.EQ.SR.AND.CROSSR.AND..NOT.PERIGE                             REAC100
C********* AT A CLOSEST APPROACH TO THE RECEIVER HEIGHT                   REAC101
      MINDIS=PERIGE.AND.S.EQ.SR.AND.CROSSR                                 REAC102
      RSPACE=SPACE                                                         REAC103
      V=SQRT(N2/(R(4)**2+R(5)**2+R(6)**2))                                 REAC104
C********* RENORMALIZE THE WAVE NORMAL DIRECTION TO = SQRT(REAL(N**2))     REAC105
      R(4)=R(4)*V                                                          REAC106
      R(5)=R(5)*V                                                          REAC107
      R(6)=R(6)*V                                                          REAC108
      RSTART=1.                                                            REAC109
      IF (.NOT.SPACE) CALL PRINTR (8HENTR ION,0.)                          REAC110
      RETURN                                                               REAC111
         END                                                               REAC112-
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      SUBROUTINE POL CAR                                                   POLC001
      DIMENSION XO(6),X(6),RO(4)                                           POLC002
      COMMON R(6) /COORD/ S                                                POLC003
      COMMON /CONST/ PI,PIT2,PID2,DUM(5)                                   POLC004
C                                                                          POLC005
C          CONVERTS SPHERICAL COORDINATES TO CARTESIAN                      POLC006
      IF (R(5).EQ.0..AND.R(6).EQ.0.) GO TO 1                               POLC007
      VERT=0.                                                              POLC008
      SINA=SIN(R(2))                                                       POLC009
      COSA=SIN(PID2-R(2))                                                  POLC010
      SINP=SIN(R(3))                                                       POLC011
      COSP=SIN(PID2-R(3))                                                  POLC012
      XO(1)=R(1)*SINA*COSP                                                 POLC013
      XO(2)=R(1)*SINA*SINP                                                 POLC014
      XO(3)=R(1)*COSA                                                      POLC015
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      X(4)=R(4)*SINA*COSP+R(5)*COSA*COSP-R(6)*SINP                        POLC016
      X(5)=R(4)*SINA*SINP+R(5)*COSA*SINP+R(6)*COSP                       POLC017
      X(6)=R(4)*COSA-R(5)*SINA                                           POLC018
      RETURN                                                             POLC019
C           VERTICAL INCIDENCE                                           POLC020
    1 VERT=1.                                                            POLC021
      RO(1)=R(1)                                                         POLC022
      RO(2)=R(2)                                                         POLC023
      RO(3)=R(3)                                                         POLC024
      RO(4)=SIGN (1.,R(4))                                               POLC025
      RETURN                                                             POLC026
C                                                                        POLC027
C           STEPS THE RAY A DISTANCE S, AND THEN                         POLC028
C           CONVERTS CARTESIAN COORDINATES TO SPHERICAL COORDINATES       POLC029
      ENTRY CAR POL                                                      POLC030
      IF (VERT.NE.0.) GO TO 2                                            POLC031
      X(1)=XO(1)+S*X(4)                                                  POLC032
      X(2)=XO(2)+S*X(5)                                                  POLC033
      X(3)=XO(3)+S*X(6)                                                  POLC034
      TEMP=SQRT(X(1)**2+X(2)**2)                                         POLC035
      R(1)=SQRT(X(1)**2+X(2)**2+X(3)**2)                                 POLC036
      R(2)=ATAN2(TEMP,X(3))                                              POLC037
      R(3)=ATAN2(X(2),X(1))                                              POLC038
      R(4)=(X(1)*X(4)+X(2)*X(5)+X(3)*X(6))/R(1)                          POLC039
      R(5)=(X(3)*(X(1)*X(4)+X(2)*X(5))-(X(1)**2+X(2)**2)*X(6))/          POLC040
     1 (R(1)*TEMP)                                                       POLC041
      R(6)=(X(1)*X(5)-X(2)*X(4))/TEMP                                    POLC042
      RETURN                                                             POLC043
C           VERTICAL INCIDENCE                                           POLC044
    2 R(1)=RO(1)+RO(4)*S                                                 POLC045
      R(2)=RO(2)                                                         POLC046
      R(3)=RO(3)                                                         POLC047
      R(4)=RO(4)                                                         POLC048
      R(5)=0.                                                            POLC049
      R(6)=0.                                                            POLC050
      RETURN                                                             POLC051
         END                                                             POLC 52-


      SUBROUTINE PRINTR(NWHY,CARD)                                       PRIN001
C           PRINTS OUTPUT AND PUNCHES RAYSETS WHEN REQUESTED             PRIN002
      DIMENSION G(3,3),G1(3,3),TYPE(3),HEADR1(20),HEADR2(20),UNITS(20),  PRIN003
     1          HEAD1(20),HEAD2(20),UNIT(20),RPRINT(20),NPR(20)          PRIN004
      COMMON /CONST/ PI,PIT2,PID2,DEGS,RAD,DUM(3)                        PRIN005
      COMMON /FLG/ NTYP,NEWWR,NEWWP,PENET,LINES,IHOP,HPUNCH              PRIN006
      COMMON /RIN/ MODRIN(3),COLL,FIELD,SPACE,N2,N2I,PNP(10),POLAR(2),   PRIN007
     1             LPOLAR(2)                                           PRIN008
      COMMON R(20),T /WW/ ID(10),WO,W(400)                               PRIN009
      EQUIVALENCE (THETA,R(2)),(PHI,R(3))                                PRIN010
      EQUIVALENCE (EARTHR,W(2)),(XMTRH,W(3)),(TLAT,W(4)),(TLON,W(5)),    PRIN011
     1 (F,W(6)),(AZ1,W(10)),(BETA,W(14)),(RCVRH,W(20)),(HOP,W(22)),      PRIN012
     2 (PLAT,W(24)),(PLON,W(25)),(RAYSET,W(72))                          PRIN013
      LOGICAL SPACE,NEWWR,NEWWP,PENET                                    PRIN014
      REAL N2,N2I,LPOLAR                                                 PRIN015
      COMPLEX PNP                                                        PRIN016
      DATA (TYPE=1HX,1HN,1HO)                                            PRIN017
     2,(HEADR1(7)=6H  PHAS),(HEADR2(7)=6HE PATH),(UNITS(7)=6H    KM ),   PRIN018
     3 (HEADR1(8)=6H  ABSO),(HEADR2(8)=6HRPTION),(UNITS(8)=6H    DB ),   PRIN019
     4 (HEADR1(9)=6H   DOP),(HEADR2(9)=6HPLER  ),(UNITS(9)=6H  C/S ),    PRIN020
     5 (HEADR1(10)=5H PATH ),(HEADR2(10)=6HLENGTH),(UNITS(10)=6H   KM )  PRIN023
      CALL RINDEX                                                        PRIN024
      IF (.NOT.NEWWP) GO TO 10                                           PRIN025
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C********* NEW W ARRAY -- REINITIALIZE                                      PRIN026
      NEWWP=.FALSE.                                                         PRIN027
      SPL=SIN (PLON-TLON)                                                   PRIN028
      CPL=SIN (PID2-(PLON-TLON))                                            PRIN029
      SP=SIN (PLAT)                                                         PRIN030
      CP=SIN (PID2-PLAT)                                                    PRIN031
      SL=SIN (TLAT)                                                         PRIN032
      CL=SIN (PID2-TLAT)                                                    PRIN033
C********* MATRIX TO ROTATE COORDINATES                                     PRIN034
      G(1,1)=CPL*SP*CL-CP*SL                                                PRIN035
      G(1,2)=SPL*SP                                                         PRIN036
      G(1,3)=-SL*SP*CPL-CL*CP                                               PRIN037
      G(2,1)=-SPL*CL                                                        PRIN038
      G(2,2)=CPL                                                            PRIN039
      G(2,3)=SL*SPL                                                         PRIN040
      G(3,1)=CL*CP*CPL+SP*SL                                                PRIN041
      G(3,2)=CP*SPL                                                         PRIN042
      G(3,3)=-SL*CP*CPL+SP*CL                                               PRIN043
      DENM=G(1,1)*G(2,2)*G(3,3)+G(1,2)*G(3,1)*G(2,3)+G(2,1)*G(3,2)*G(1,3PRIN044
     1)-G(2,2)*G(3,1)*G(1,3)-G(1,2)*G(2,1)*G(3,3)-G(1,1)*G(3,2)*G(2,3)  PRIN045
C********* THE MATRIX G1 IS THE INVERSE OF THE MATRIX G                     PRIN046
      G1(1,1)=(G(2,2)*G(3,3)-G(3,2)*G(2,3))/DENM                            PRIN047
      G1(1,2)=(G(3,2)*G(1,3)-G(1,2)*G(3,3))/DENM                            PRIN048
      G1(1,3)=(G(1,2)*G(2,3)-G(2,2)*G(1,3))/DENM                            PRIN049
      G1(2,1)=(G(3,1)*G(2,3)-G(2,1)*G(3,3))/DENM                            PRIN050
      G1(2,2)=(G(1,1)*G(3,3)-G(3,1)*G(1,3))/DENM                            PRIN051
      G1(2,3)=(G(2,1)*G(1,3)-G(1,1)*G(2,3))/DENM                            PRIN052
      G1(3,1)=(G(2,1)*G(3,2)-G(3,1)*G(2,2))/DENM                            PRIN053
      G1(3,2)=(G(3,1)*G(1,2)-G(1,1)*G(3,2))/DENM                            PRIN054
      G1(3,3)=(G(1,1)*G(2,2)-G(2,1)*G(1,2))/DENM                            PRIN055
      R0=EARTHR+XMTRH                                                       PRIN056
C********* CARTESIAN COORDINATES OF TRANSMITTER                             PRIN057
      XR=R0*G(1,1)                                                          PRIN058
      YR=R0*G(2,1)                                                          PRIN059
      ZR=R0*G(3,1)                                                          PRIN060
      CTHR=G(3,1)                                                           PRIN061
      STHR=SIN (ACOS (CTHR))                                                PRIN062
      PHIR=ATAN2(YR,XR)                                                     PRIN063
      ALPH=ATAN2(G(3,2),G(3,3))                                             PRIN064
C*********                                                                  PRIN065
      NR=6                                                                  PRIN066
      NP=0                                                                  PRIN067
      DO 7 NN=7,20                                                          PRIN068
      IF (W(NN+50).EQ.0.) GO TO 7                                           PRIN069
C********* DEPENDENT VARIABLE NUMBER NN IS BEING INTEGRATED                 PRIN070
C********* NR IS THE NUMBER OF DEPENDENT VARIABLES BEING INTEGRATED         PRIN071
      NR=NR+1                                                               PRIN072
      IF (W(NN+50).NE.2.) GO TO 7                                           PRIN073
C********* DEPENDENT VARIABLE NUMBER NN IS BEING INTEGRATED AND PRINTED.    PRIN074
C********* NP IS THE NUMBER OF DEPENDENT VARIABLES BEING INTEGRATED AND     PRIN075
C********* PRINTED                                                          PRIN076
      NP=NP+1                                                               PRIN077
C********* SAVE THE INDEX OF THE DEPENDENT VARIABLE TO PRINT                PRIN078
      NPR(NP)=NR                                                            PRIN079
      HEAD1(NP)=HEADR1(NN)                                                  PRIN080
      HEAD2(NP)=HEADR2(NN)                                                  PRIN081
      UNIT(NP)=UNITS(NN)                                                    PRIN082
    7 CONTINUE                                                              PRIN083
      NP1=MIN0(NP,3)                                                        PRIN084
      PDEV=ABSORB=DOPP=0.                                                   PRIN085
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C********* PRINT COLUMN HEADINGS AT THE BEGINNING OF EACH RAY                PRIN086
   10 IF (IHOP.NE.0) GO TO 12                                                 PRIN087
      PRINT 1100, (HEAD1(NN),HEAD2(NN),NN=1,NP1)                              PRIN088
 1100 FORMAT (44X,7HAZIMUTH/43X,9HDEVIATION,8X,9HELEVATION/                   PRIN089
     1 19X,16HHEIGHT      RANGE,1X,2(5X,12HXMTR   LOCAL),5X,26HPOLARIZATIPRIN090
     2ON     GROUP PATH,5A6,A5)                                              PRIN091
      PRINT 1150, (JNIT(NN),NN=1,NP1)                                         PRIN092
 1150 FORMAT (13X,2(8X,2HKM),2X,2(6X,3HDEG,5X,3HDEG),6X,12HREAL     IMAG,PRIN093
     1 7X,2HKM,4X,3(4X,A6,2X))                                               PRIN094
      IF (RAYSET.EQ.0.) GO TO 12                                              PRIN095
C********* PUNCH A TRANSMITTER RAYSET                                        PRIN096
      TLOND=TLON*DEGS                                                         PRIN097
      IF (TLOND.LT.0.) TLOND=TLOND+360.                                       PRIN098
      TLATD=TLAT*DEGS                                                         PRIN099
      IF (TLATD.LT.0.) TLATD=TLATD+360.                                       PRIN100
      AZ=AZ1*DEGS                                                             PRIN101
      EL=BETA*DEGS                                                            PRIN102
      NHOP=HOP                                                                PRIN103
      PUNCH 1200, ID(1),TYPE(NTYP),XMTRH,TLATD,TLOND,RCVRH,F,AZ,EL,POLARPRIN104
     1,NHOP,1HT                                                               PRIN105
 1200 FORMAT (A3,A1,4PF9.0,3P2F6.0,4P2F9.0,5P2F10.0,5X,2P2F5.0,I1,A1)         PRIN106
C*********                                                                   PRIN107
   12 V=0.                                                                    PRIN108
      IF (N2.NE.0.) V=(R(4)**2+R(5)**2+R(6)**2)/N2-1.                         PRIN109
      H=R(1)-EARTHR                                                           PRIN110
      STH=SIN (THETA)                                                         PRIN111
      CTH=SIN (PID2-THETA)                                                    PRIN112
C********* CARTESIAN COORDINATES OF RAY POINT, ORIGIN AT TRANSMITTER         PRIN113
      XP=R(1)*STH*SIN (PID2-PHI)-XR                                           PRIN114
      YP=R(1)*STH*SIN (PHI)-YR                                                PRIN115
      ZP=R(1)*CTH-ZR                                                          PRIN116
C********* CARTESIAN COORDINATES OF RAY POINT, ORIGIN AT TRANSMITTER ANDPRIN117
C********* ROTATED                                                           PRIN118
      EPS=XP*G1(1,1)+YP*G1(1,2)+ZP*G1(1,3)                                    PRIN119
      ETA=XP*G1(2,1)+YP*G1(2,2)+ZP*G1(2,3)                                    PRIN120
      ZETA=XP*G1(3,1)+YP*G1(3,2)+ZP*G1(3,3)                                   PRIN121
      RCE2=ETA**2+ZETA**2                                                     PRIN122
      RCE=SQRT (RCE2)                                                         PRIN123
C********* GROUND RANGE                                                      PRIN124
      RANGE=EARTHR*ATAN2(RCE,EARTHR+EPS)                                      PRIN125
C********* ANGLE OF WAVE NORMAL WITH LOCAL HORIZONTAL                        PRIN126
      ELL=ATAN2(R(4),SQRT (R(5)**2+R(6)**2))*DEGS                             PRIN127
C********* STRAIGHT LINE DISTANCE FROM TRANSMITTER TO RAY POINT              PRIN128
      SR=SQRT (RCE2+EPS**2)                                                   PRIN129
      IF (NP.LT.1) GO TO 16                                                   PRIN130
      DO 15 I=1,NP                                                            PRIN131
      NN=NPR(I)                                                               PRIN132
   15 RPRINT(I)=R(NN)                                                         PRIN133
   16 IF (SR.GE.1.E-6) GO TO 20                                               PRIN134
C********* TOO CLOSE TO TRANSMITTER TO CALCULATE DIRECTION FROM              PRIN135
C********* TRANSMITTER                                                       PRIN136
      PRINT 1500, V,NWHY,H,RANGE,ELL,POLAR,T,(RPRINT(NN),NN=1,NP1)           PRIN137
 1500 FORMAT (1X,E6.0,1X,A8,F10.4,F11.4,26X,F8.3,F9.3,F8.3,4F12.4)           PRIN138
      GO TO 40                                                                PRIN139
C********* ELEVATION ANGLE OF RAY POINT FROM TRANSMITTER                     PRIN140
   20 EL=ATAN2(EPS,RCE)*DEGS                                                  PRIN141
      IF (RCE.GE.1.E-6) GO TO 30                                              PRIN142
C********* NEARLY DIRECTLY ABOVE OR BELOW TRANSMITTER. CAN NOT CALCULATEPRIN143
C********* AZIMUTH DIRECTION FROM TRANSMITTER ACCURATELY                      PRIN144
      PRINT 2500, V,NWHY,H,RANGE,EL,ELL,POLAR,T,(RPRINT(NN),NN=1,NP1)         PRIN145
 2500 FORMAT (1X,E6.0,1X,A8,F10.4,F11.4,17X,F9.3,F8.3,F9.3,F8.3,             PRIN146
     1 4F12.4)                                                               PRIN147
      GO TO 40                                                                PRIN148
```

```
C********* AZIMUTH ANGLE OF RAY POINT FROM TRANSMITTER                      PRIN149
   30 ANGA=ATAN2(ETA,ZETA)                                                  PRIN150
      AZDEV=180.-AMOD(540.-(AZ1-ANGA)*DEGS,360.)                            PRIN151
      IF (R(5).NE.0..OR.R(6).NE.0.) GO TO 34                                PRIN152
C********* WAVE NORMAL IS VERTICAL, SO AZIMUTH DIRECTION CANNOT BE          PRIN153
C********* CALCULATED                                                       PRIN154
      PRINT 3000, V,NWHY,H,RANGE,AZDEV,EL,ELL,POLAR,T,(RPRINT(NN),NN=1,     PRIN155
     1 NP1)                                                                 PRIN156
 3000 FORMAT (1X,E6.0,1X,A8,F10.4,F11.4,F9.3,8X,F9.3,F8.3,F9.3,F8.3,        PRIN157
     1 4F12.4)                                                              PRIN158
      GO TO 40                                                              PRIN159
   34 ANA=ANGA-ALPH                                                         PRIN160
      SANA=SIN (ANA)                                                        PRIN161
      SPHI=SANA*STHR/STH                                                    PRIN162
      CPHI=-SIN (PID2-ANA)*SIN (PID2-(PHI-PHIR))+SANA*SIN (PHI-PHIR)        PRIN163
     1 *CTHR                                                                PRIN164
      AZA=180.-AMOD (540.-(ATAN2(SPHI,CPHI)-ATAN2(R(6),R(5)))*DEGS,360.)    PRIN165
      PRINT 3500, V,NWHY,H,RANGE,AZDEV,AZA,EL,ELL,POLAR,T,(RPRINT(NN),NNPRIN166
     1 =1,NP1)                                                              PRIN167
 3500 FORMAT (1X,E6.0,1X,A8,F10.4,F11.4,2(F9.3,F8.3),F9.3,F8.3,             PRIN168
     1 4F12.4)                                                              PRIN169
C*********                                                                  PRIN170
   40 LINES=LINES+1                                                         PRIN171
      IF (NP.LE.3) GO TO 45                                                 PRIN172
C********* ADDITIONAL LINE TO PRINT REMAINING DEPENDENT INTEGRATION         PRIN173
C********* VARIABLES                                                        PRIN174
      PRINT 4000, (RPRINT(NN),NN=4,NP)                                      PRIN175
 4000 FORMAT (99X,3F12.4)                                                   PRIN176
      LINES=LINES+1                                                         PRIN177
   45 IF (CARD.EQ.0.) RETURN                                                PRIN178
C                                                                           PRIN179
C********* PUNCH A RAYSET                                                   PRIN180
      IF (AZDEV.LT.-90.) AZDEV=AZDEV+360.                                   PRIN181
      IF (AZA.LT.-90.) AZA=AZA+360.                                         PRIN182
      TDEV=T-SR                                                             PRIN183
      NR=6                                                                  PRIN184
      IF (W(57).EQ.0.) GO TO 47                                             PRIN185
C********* PHASE PATH                                                       PRIN186
      NR=NR+1                                                               PRIN187
      PDEV=R(NR)-SR                                                         PRIN188
   47 IF (W(58).EQ.0.) GO TO 48                                             PRIN189
C********* ABSORPTION                                                       PRIN190
      NR=NR+1                                                               PRIN191
      ABSORB=R(NR)                                                          PRIN192
C********* DOPPLER SHIFT                                                    PRIN193
   48 IF (W(59).NE.0.) DOPP=R(NR+1)                                         PRIN194
      PUNCH 4500, HPUNCH,RANGE,AZDEV,AZA,ELL,SR,TDEV,PDEV,ABSORB,DOPP,      PRIN195
     1 POLAR,IHOP,NWHY                                                      PRIN196
 4500 FORMAT (4P2F9.0,3P3F6.0,3PF8.0,3P4F6.0,2P2F5.0,I1,A1)                 PRIN197
      RETURN                                                                PRIN198
         END                                                                PRIN199-
```

INPUT PARAMETER FORM FOR PLOTTING THE PROJECTION OF THE RAY PATH ON A VERTICAL PLANE

Coordinates of the left edge of the graph:

Latitude = _____ rad / deg / km north (W83)

Longitude = _____ rad / deg / km east (W84)

Coordinates of the right edge of the graph:

Latitude = _____ rad / deg / km north (W85)

Longitude = _____ rad / deg / km east (W86)

Height above the ground of the bottom of the graph = _____ km (W88)

Distance between tic marks = _____ rad / deg / km (W87)

(W81 = 1.)

INPUT PARAMETER FORM FOR PLOTTING THE PROJECTION OF THE RAY PATH ON THE GROUND

Coordinates of the left edge of the graph:

Latitude = _____ rad / deg / km north (W83)

Longitude = _____ rad / deg / km east (W84)

Coordinates of the right edge of the graph:

Latitude = _____ rad / deg / km north (W85)

Longitude = _____ rad / deg / km east (W86)

Factor to expand lateral deviation scale by = _____ (W82)

Distance between tic marks on range scale = _____ rad / deg / km (W87)

(W81 = 2.)

```
      SUBROUTINE RAYPLT                                                 YPLT001
C        REPLACES SUBROUTINES RAYPLT,PLOT, AND LABPLT IF PLOTS ARE      YPLT002
C        NOT WANTED OR IF A PLOTTER IS NOT AVAILABLE                    YPLT003
      COMMON /WW/ ID(10),W0,W(400)                                      YPLT004
      EQUIVALENCE (PLT,W(81))                                           YPLT005
      PLT=0.                                                            YPLT006
      ENTRY ENDPLT                                                      YPLT007
      RETURN                                                            YPLT008
         END                                                            YPLT  9-
```

```
      SUBROUTINE RAYPLT                                                 RAYP001
C        W(81)=1. PLOTS PROJECTION OF RAYPATH ON VERTICAL PLANE         RAYP002
C              =2. PLOTS PROJECTION OF RAYPATH ON GROUND                RAYP003
      COMMON /PLT/ XL,XR,YB,YT,RESET                                    RAYP004
      COMMON /CONST/ PI,PIT2,PID2,DUM(5)                                RAYP005
      COMMON /FLG/ NTYP,NEWWR,NEWWP,PENET,LINES,IHOP,HPUNCH             RAYP006
      COMMON R(6) /WW/ ID(10),W0,W(400)                                 RAYP007
      EQUIVALENCE (TH,R(2)),(PH,R(3))                                   RAYP008
      EQUIVALENCE (EARTHR,W(2)),(PLAT,W(24)),(PLON,W(25)),(PLT,W(81)),  RAYP009
     1 (FACTR,W(82)),(LLAT,W(83)),(LLON,W(84)),(RLAT,W(85)),(RLON,W(86))RAYP010
     2,(TIC,W(87)),(HB,W(88))                                           RAYP011
      REAL LLAT,LLON,LTIC                                               RAYP012
      LOGICAL NEWWR,NEWWP,PENET                                         RAYP013
      IF (.NOT.NEWWR) GO TO 5                                           RAYP014
C                                                                       RAYP015
C           NEW W ARRAY -- REINITIALIZE                                 RAYP016
      NEWWR=.FALSE.                                                     RAYP017
      RESET=1.                                                          RAYP018
CONVERT COORDINATES OF VERTICAL PLANE FROM GEOGRAPHIC TO GEOMAGNETIC    RAYP019
      SW=SIN (PLAT)                                                     RAYP020
      CW=SIN (PID2-PLAT)                                                RAYP021
      SLM=SIN (LLAT)                                                    RAYP022
      CLM=SIN (PID2-LLAT)                                               RAYP023
      SRM=SIN (RLAT)                                                    RAYP024
      CRM=SIN (PID2-RLAT)                                               RAYP025
      CDPHI=SIN (PID2-(LLON-PLON))                                      RAYP026
      PHL=ATAN2(SIN (LLON-PLON)*CLM,CDPHI*SW*CLM-CW*SLM)                RAYP027
      CTHL=CDPHI*CW*CLM+SW*SLM                                          RAYP028
      STHL=SIN (ACOS (CTHL))                                            RAYP029
      CDPHI=SIN (PID2-(RLON-PLON))                                      RAYP030
      PHR=ATAN2(SIN (RLON-PLON)*CRM,CDPHI*SW*CRM-CW*SRM)                RAYP031
      CTHR=CDPHI*CW*CRM+SW*SRM                                          RAYP032
      STHR=SIN (ACOS (CTHR))                                            RAYP033
      CLR=CTHL*CTHR+STHL*STHR*SIN (PID2-(PHL-PHR))                      RAYP034
      SLR=SQRT (1.-CLR**2)                                              RAYP035
      IF (PLT.EQ.2.) GO TO 3                                            RAYP036
      FACTR=1.                                                          RAYP037
      R0=EARTHR+HB                                                      RAYP038
      ALPHA=.5*ACOS (CLR)                                               RAYP039
      XR=R0*SIN (ALPHA)                                                 RAYP040
      XL=-XR                                                            RAYP041
      YB=R0*SIN (PID2-ALPHA)                                            RAYP042
      YT=YB+2.*XR                                                       RAYP043
      GO TO 5                                                           RAYP044
    3 IF (FACTR.EQ.0.) FACTR=1.                                         RAYP045
      ALPH1=ATAN2(STHR*SIN (PHR-PHL),(CTHR-CTHL*CLR)/STHL)              RAYP046
      XL=0.                                                             RAYP047
      XR=EARTHR*ACOS (CLR)                                              RAYP048
      YT=0.5*XR/FACTR                                                   RAYP049
      YB=-YT                                                            RAYP050
```

```
C                                                                       RAYP051
    5 STH=SIN (TH)                                                      RAYP052
      CTH=SIN (PID2-TH)                                                 RAYP053
      CR=CTHR*CTH+STHR*STH*SIN (PID2-(PHR-PH))                          RAYP054
      CL=CTHL*CTH+STHL*STH*SIN (PID2-(PHL-PH))                          RAYP055
      CEA=ATAN2(CR-CL*CLR,CL*SLR)                                       RAYP056
      NEW=1                                                             RAYP057
      IF (IHOP.NE.0) NEW=0                                              RAYP058
      IF (PLT.EQ.2.) GO TO 10                                           RAYP059
      CALL PLOT (R(1)*SIN(CEA-ALPHA),R(1)*SIN(PID2-(CEA-ALPHA)),NEW)    RAYP060
      RETURN                                                            RAYP061
   10 SL=SQRT (1.-CL**2)                                                RAYP062
      TMP1=STH*SIN (PH-PHL)                                             RAYP063
      TMP2=(CTH-CTHL*CL)/STHL                                           RAYP064
      ALPH2=0.                                                          RAYP065
      IF (TMP1.NE.0..OR.TMP2.NE.0.) ALPH2=ATAN2(TMP1,TMP2)              RAYP066
      CALL PLOT (EARTHR*CEA,EARTHR*ASIN(SL*SIN (ALPH1-ALPH2)),NEW)      RAYP067
      RETURN                                                            RAYP068
C                                                                       RAYP069
C          DRAW AXES AND CALL FOR LABELING AND TERMINATION OF THIS PLOT RAYP070
      ENTRY ENDPLT                                                      RAYP071
      TICKX=0.01*(YT-YB)                                                RAYP072
      IF (PLT.EQ.2.) GO TO 25                                           RAYP073
      R1=EARTHR-TICKX                                                   RAYP074
      X=XL                                                              RAYP075
      Y=YB                                                              RAYP076
      CALL PLOT (X,Y,1)                                                 RAYP077
      NTIC=2                                                            RAYP078
      IF (TIC.NE.0.) NTIC=NTIC+2.*ALPHA/TIC                             RAYP079
      NLINE=MAX0 (1,100/NTIC)                                           RAYP080
      DO 20 I=1,NTIC                                                    RAYP081
      ANG=-ALPHA+(I-1)*TIC                                              RAYP082
      CALL PLOT (R1*SIN (ANG),R1*SIN (PID2-ANG),0)                      RAYP083
      CALL PLOT (X,Y,0)                                                 RAYP084
      DO 20 J=1,NLINE                                                   RAYP085
      ANG=ANG+TIC/NLINE                                                 RAYP086
      X=EARTHR*SIN (ANG)                                                RAYP087
      Y=EARTHR*SIN (PID2-ANG)                                           RAYP088
   20 CALL PLOT (X,Y,0)                                                 RAYP089
      CALL PLOT (XR,YB,0)                                               RAYP090
      GO TO 50                                                          RAYP091
   25 DTIC=TIC*EARTHR                                                   RAYP092
      LTIC=DTIC/FACTR                                                   RAYP093
      TICY=XL+0.01*(XR-XL)                                              RAYP094
      NTIC=YT/LTIC                                                      RAYP095
      TIC1=-LTIC*NTIC                                                   RAYP096
      CALL PLOT (XL,YB,1)                                               RAYP097
      NTIC=2*NTIC+1                                                     RAYP098
      DO 30 I=1,NTIC                                                    RAYP099
      Y=TIC1+(I-1)*LTIC                                                 RAYP100
      CALL PLOT (XL,Y,0)                                                RAYP101
      CALL PLOT (TICY,Y,0)                                              RAYP102
   30 CALL PLOT (XL,Y,0)                                                RAYP103
      CALL PLOT (XL,YT,0)                                               RAYP104
      CALL PLOT (XL,0.,1)                                               RAYP105
      NTIC=(XR-XL)/DTIC                                                 RAYP106
      DO 40 I=1,NTIC                                                    RAYP107
      X=I*DTIC                                                          RAYP108
      CALL PLOT (X,0.,0)                                                RAYP109
      CALL PLOT (X,TICKX,0)                                             RAYP110
   40 CALL PLOT (X,0.,0)                                                RAYP111
      CALL PLOT (XR,0.,0)                                               RAYP112
   50 CALL LABPLT                                                       RAYP113
      CALL PLTEND                                                       RAYP114
      RETURN                                                            RAYP115
         END                                                            RAYP116-
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      SUBROUTINE PLOT (X,Y,NEW)                                          PLOT001
      COMMON /PLT/ XMIN0,XMAX0,YMIN0,YMAX0,RESET                         PLOT002
      COMMON /DD/ INT,IOR,IT,IS,IC,ICC,IX,IY                             PLOT003
      DATA (INITAL=1),(MINX=0),(MINY=0),(MAXX=1023),(MAXY=1023),         PLOT004
     1 (MINX0=23),(MINY0=23),(MAXX0=1023),(MAXY0=1023)                   PLOT005
C                                                                        PLOT006
C           INITIALIZE LIBRARY PLOTTING ROUTINES                         PLOT007
      IF (INITAL.EQ.0) GO TO 1                                           PLOT008
      INITAL=0                                                           PLOT009
      CALL DDINIT (1,1H )                                                PLOT010
C                                                                        PLOT011
C           COMPUTE SCALE FACTORS                                        PLOT012
    1 IF (RESET.EQ.0.) GO TO 5                                           PLOT013
      RESET=0.                                                           PLOT014
      XSCALE=(MAXX0-MINX0)/(XMAX0-XMIN0)                                 PLOT015
      YSCALE=(MAXY0-MINY0)/(YMAX0-YMIN0)                                 PLOT016
      XMIN=XMIN0-(MINX0-MINX)/XSCALE                                     PLOT017
      YMIN=YMIN0-(MINY0-MINY)/YSCALE                                     PLOT018
      XMAX=XMAX0+(MAXX-MAXX0)/XSCALE                                     PLOT019
      YMAX=YMAX0+(MAXY-MAXY0)/YSCALE                                     PLOT020
C                                                                        PLOT021
C           START A NEW LINE                                             PLOT022
    5 IF (NEW.EQ.0) GO TO 10                                             PLOT023
      IX=MINX0+(X-XMIN0)*XSCALE                                          PLOT024
      IY=MINY0+(Y-YMIN0)*YSCALE                                          PLOT025
      IF (IX.GE.MINX.AND.IX.LE.MAXX.AND.IY.GE.MINY.AND.IY.LE.MAXY)       PLOT026
     1 CALL DDBP                                                         PLOT027
      GO TO 50                                                           PLOT028
C                                                                        PLOT029
C           HORIZONTAL DISPLACEMENT                                      PLOT030
   10 XS=X-XOLD                                                          PLOT031
      YS=Y-YOLD                                                          PLOT032
      IF (XS) 11,12,16                                                   PLOT033
C           NEGATIVE                                                     PLOT034
   11 X1=XMAX                                                            PLOT035
      X2=XMIN                                                            PLOT036
      GO TO 20                                                           PLOT037
C           ZERO                                                         PLOT038
   12 IF (YS) 13,50,14                                                   PLOT039
   13 S1=(YMAX-YOLD)/YS                                                  PLOT040
      S2=(YMIN-YOLD)/YS                                                  PLOT041
      GO TO 40                                                           PLOT042
   14 S1=(YMIN-YOLD)/YS                                                  PLOT043
      S2=(YMAX-YOLD)/YS                                                  PLOT044
      GO TO 40                                                           PLOT045
C           POSITIVE                                                     PLOT046
   16 X1=XMIN                                                            PLOT047
      X2=XMAX                                                            PLOT048
C                                                                        PLOT049
C           VERTICAL DISPLACEMENT                                        PLOT050
   20 IF (YS) 21,22,26                                                   PLOT051
C           NEGATIVE                                                     PLOT052
   21 Y1=YMAX                                                            PLOT053
      Y2=YMIN                                                            PLOT054
      GO TO 30                                                           PLOT055
C           ZERO                                                         PLOT056
   22 S1=(X1-XOLD)/XS                                                    PLOT057
      S2=(X2-XOLD)/XS                                                    PLOT058
      GO TO 40                                                           PLOT059
C           POSITIVE                                                     PLOT060
   26 Y1=YMIN                                                            PLOT061
      Y2=YMAX                                                            PLOT062
C                                                                        PLOT063
   30 S1=AMAX1((X1-XOLD)/XS,(Y1-YOLD)/YS)                                PLOT064
      S2=AMIN1((X2-XOLD)/XS,(Y2-YOLD)/YS)                                PLOT065
```

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C                                                                       PLOT066
C          PLOT LINE -- CHECKING FOR BORDER CROSSINGS                   PLOT067
   40 S=SQRT(XS**2+YS**2)                                               PLOT068
      IF (S2.LT.0..OR.S*S1-S.GT.0.) GO TO 50                            PLOT069
      IF (S1.LT.0.) GO TO 42                                            PLOT070
C          PREVIOUS POINT OFF GRAPH                                     PLOT071
      IX=MINX0+(XOLD+XS*S1-XMIN0)*XSCALE+0.5                            PLOT072
      IY=MINY0+(YOLD+YS*S1-YMIN0)*YSCALE+0.5                            PLOT073
      CALL DDBP                                                         PLOT074
   42 IF (S*S2-S.GT.0.) GO TO 44                                        PLOT075
C          CURRENT POINT OFF GRAPH                                      PLOT076
      IX=MINX0+(XOLD+XS*S2-XMIN0)*XSCALE+0.5                            PLOT077
      IY=MINY0+(YOLD+YS*S2-YMIN0)*YSCALE+0.5                            PLOT078
      CALL DDVC                                                         PLOT079
      GO TO 50                                                          PLOT080
C          CURRENT POINT ON GRAPH                                       PLOT081
   44 IX=MINX0+(X-XMIN0)*XSCALE+0.5                                     PLOT082
      IY=MINY0+(Y-YMIN0)*YSCALE+0.5                                     PLOT083
      CALL DDVC                                                         PLOT084
C                                                                       PLOT085
C          EXIT ROUTINE                                                 PLOT086
   50 XOLD=X                                                            PLOT087
      YOLD=Y                                                            PLOT088
      RETURN                                                            PLOT089
C                                                                       PLOT090
C          TERMINATE THE CURRENT PLOT                                   PLOT091
      ENTRY PLTEND                                                      PLOT092
      CALL DDFR                                                         PLOT093
      RETURN                                                            PLOT094
         END                                                            PLOT 95-
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```
      SUBROUTINE LABPLT                                                 LABP001
C          LABEL THE CURRENT PLOT                                       LABP002
      DIMENSION LABEL(9),TYPE(3)                                        LABP003
      COMMON /DD/ INT,IOR,IT,IS,IC,ICC,IX,IY                            LABP004
      COMMON /CONST/ PI,PIT2,PID2,DEGS,DUM(4)                           LABP005
      COMMON /FLG/ NTYP,NEWWR,NEWWP,PENET,LINES,IHOP,HPUNCH             LABP006
      COMMON /WW/ ID(10),W0,W(400)                                      LABP007
      EQUIVALENCE (EARTHR,W(2)),(F,W(6)),(AZ1,W(10)),(PLT,W(81)),       LABP008
     1 (FACTR,W(82)),(TIC,W(87))                                        LABP009
      LOGICAL NEWWR,NEWWP,PENET                                         LABP010
      REAL LTIC                                                         LABP011
      DATA (TYPE=8HEXTRAORD,8HNO FIELD,8HORDINARY)                      LABP012
      IOR=IT=0                                                          LABP013
      IS=2                                                              LABP014
      IX=0      $  IY=1023  $  CALL DDTAB  $  CALL DDTEXT (7,ID)        LABP015
      NDATE=IDATE(0)                                                    LABP016
      CALL DDTEXT (1,NDATE)                                             LABP017
      AZA=AZ1*DEGS                                                      LABP018
      DTIC=TIC*EARTHR                                                   LABP019
      ENCODE (72,1000,LABEL)  F,AZA,TYPE(NTYP),DTIC                     LABP020
 1000 FORMAT (3HF =,F7.3,6H, AZ =,F7.2,2H, ,A8,2H, ,F7.2,24H KM BETWEEN LABP021
     1TICK MARKS≠.)                                                     LABP022
      IX=0      $  IY=991   $  CALL DDTAB  $  CALL DDTEXT (9,LABEL)     LABP023
      IF (PLT.EQ.1.) RETURN                                             LABP024
      LTIC=DTIC/FACTR                                                   LABP025
      ENCODE (32,2000,LABEL)  LTIC                                      LABP026
 2000 FORMAT (F7.2,24H KM BETWEEN TICK MARKS≠.)                         LABP027
      IOR=1                                                             LABP028
      IX=0      $  IY=0     $  CALL DDTAB  $  CALL DDTEXT (4,LABEL)     LABP029
      IOR=0                                                             LABP030
      RETURN                                                            LABP031
         END                                                            LABP 32-
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      SUBROUTINE RKAM                                                    RKAM001
C        NUMERICAL INTEGRATION OF DIFFERENTIAL EQUATIONS                 RKAM002
      COMMON /RK/ NN,SPACE,MODE,E1MAX,E1MIN,E2MAX,E2MIN,FACT,RSTART      RKAM003
      COMMON Y(20),T,STEP,DYDT(20)                                       RKAM004
      DIMENSION DELY(4,20),BET(4),XV(5),FV(4,20),YU(5,20)                RKAM005
      TYPE DOUBLE YU                                                     RKAM006
      IF (RSTART.EQ.0.) GO TO 1000                                       RKAM007
      LL=MM=1                                                            RKAM008
      IF (MODE.EQ.1) MM=4                                                RKAM009
      ALPHA=T                                                            RKAM010
      EPM=0.0                                                            RKAM011
      BET(1)=BET(2)=0.5                                                  RKAM012
      BET(3)=1.0                                                         RKAM013
      BET(4)=0.0                                                         RKAM014
      STEP=SPACE                                                         RKAM015
      R=19.0/270.0                                                       RKAM016
      XV(MM)=T                                                           RKAM017
      IF (E1MIN.LE.0.) E1MIN=E1MAX/55.                                   RKAM018
      IF (FACT.LE.0.) FACT=0.5                                           RKAM019
      CALL HAMLTN                                                        RKAM020
      DO 320 I=1,NN                                                      RKAM021
      FV(MM,I)=DYDT(I)                                                   RKAM022
  320 YU(MM,I)=Y(I)                                                      RKAM023
      RSTART=0.                                                          RKAM024
      GO TO 1001                                                         RKAM025
 1000 IF (MODE.NE.1) GO TO 2000                                          RKAM026
C                                                                        RKAM027
C           RUNGE-KUTTA                                                  RKAM028
 1001 DO 1034 K=1,4                                                      RKAM029
      DO 1350 I=1,NN                                                     RKAM030
      DELY(K,I)=STEP*FV(MM,I)                                            RKAM031
      Z=YU(MM,I)                                                         RKAM032
 1350 Y(I)=Z+BET(K)*DELY(K,I)                                            RKAM033
      T=BET(K)*STEP+XV(MM)                                               RKAM034
      CALL HAMLTN                                                        RKAM035
      DO 1034 I=1,NN                                                     RKAM036
 1034 FV(MM,I)=DYDT(I)                                                   RKAM037
      DO 1039 I=1,NN                                                     RKAM038
      DEL=(DELY(1,I)+2.0*DELY(2,I)+2.0*DELY(3,I)+DELY(4,I))/6.0          RKAM039
 1039 YU(MM+1,I)=YU(MM,I)+DEL                                            RKAM040
      MM=MM+1                                                            RKAM041
      XV(MM)=XV(MM-1)+STEP                                               RKAM042
      DO 1400 I=1,NN                                                     RKAM043
 1400 Y(I)=YU(MM,I)                                                      RKAM044
      T=XV(MM)                                                           RKAM045
      CALL HAMLTN                                                        RKAM046
      IF (MODE.EQ.1) GO TO 42                                            RKAM047
      DO 150 I=1,NN                                                      RKAM048
  150 FV(MM,I)=DYDT(I)                                                   RKAM049
      IF (MM.LE.3) GO TO 1001                                            RKAM050
C                                                                        RKAM051
C           ADAMS-MOULTON                                                RKAM052
 2000 DO 2048 I=1,NN                                                     RKAM053
      DEL=STEP*(55.*FV(4,I)-59.*FV(3,I)+37.*FV(2,I)-9.*FV(1,I))/24.      RKAM054
      Y(I)=YU(4,I)+DEL                                                   RKAM055
 2048 DELY(1,I)=Y(I)                                                     RKAM056
      T=XV(4)+STEP                                                       RKAM057
      CALL HAMLTN                                                        RKAM058
      XV(5)=T                                                            RKAM059
      DO 2051 I=1,NN                                                     RKAM060
      DEL=STEP*(9.*DYDT(I)+19.*FV(4,I)-5.*FV(3,I)+FV(2,I))/24.           RKAM061
      YU(5,I)=YU(4,I)+DEL                                                RKAM062
 2051 Y(I)=YU(5,I)                                                       RKAM063
      CALL HAMLTN                                                        RKAM064
      IF (MODE.LE.2) GO TO 42                                            RKAM065
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C                                                                       RKAM066
C           ERROR ANALYSIS                                              RKAM067
      SSE=0.0                                                           RKAM068
      DO 3033 I=1,NN                                                    RKAM069
      EPSIL=R*ABS(Y(I)-DELY(1,I))                                       RKAM070
      IF (MODE.EQ.3.AND.Y(I).NE.0.) EPSIL=EPSIL/ABS(Y(I))               RKAM071
      IF (SSE.LT.EPSIL) SSE=EPSIL                                       RKAM072
 3033 CONTINUE                                                          RKAM073
      IF (E1MAX.GT.SSE) GO TO 3035                                      RKAM074
      IF (ABS(STEP).LE.E2MIN) GO TO 42                                  RKAM075
      LL=MM=1                                                           RKAM076
      STEP=STEP*FACT                                                    RKAM077
      GO TO 1001                                                        RKAM078
 3035 IF (LL.LE.1.OR.SSE.GE.E1MIN.OR.E2MAX.LE.ABS(STEP)) GO TO 42       RKAM079
      LL=2                                                              RKAM080
      MM=3                                                              RKAM081
      XV(2)=XV(3)                                                       RKAM082
      XV(3)=XV(5)                                                       RKAM083
      DO 5363 I=1,NN                                                    RKAM084
      FV(2,I)=FV(3,I)                                                   RKAM085
      FV(3,I)=DYDT(I)                                                   RKAM086
      YU(2,I)=YU(3,I)                                                   RKAM087
 5363 YU(3,I)=YU(5,I)                                                   RKAM088
      STEP=2.0*STEP                                                     RKAM089
      GO TO 1001                                                        RKAM090
C                                                                       RKAM091
C           EXIT ROUTINE                                                RKAM092
   42 LL=2                                                              RKAM093
      MM=4                                                              RKAM094
      DO 12 K=1,3                                                       RKAM095
      XV(K)=XV(K+1)                                                     RKAM096
      DO 12 I=1,NN                                                      RKAM097
      FV(K,I)=FV(K+1,I)                                                 RKAM098
   12 YU(K,I)=YU(K+1,I)                                                 RKAM099
      XV(4)=XV(5)                                                       RKAM100
      DO 52 I=1,NN                                                      RKAM101
      FV(4,I)=DYDT(I)                                                   RKAM102
   52 YU(4,I)=YU(5,I)                                                   RKAM103
      IF (MODE.LE.2) RETURN                                             RKAM104
      E=ABS(XV(4)-ALPHA)                                                RKAM105
      IF (E.LE.EPM) GO TO 2000                                          RKAM106
      EPM=E                                                             RKAM107
      RETURN                                                            RKAM108
         END                                                            RKAM109-
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      SUBROUTINE HAMLTN                                                 HAML001
C********* CALCULATES HAMILTONS EQUATIONS FOR RAY TRACING               HAML002
      COMMON /CONST/ PI,PIT2,PID2,DEGS,RAD,K,C,LOGTEN                   HAML003
      COMMON /RIN/ MODRIN(3),COLL,FIELD,SPACE,KAY2,KAY2I,               HAML004
     1              H,HI,PHPT,PHPTI,PHPR,PHPRI,PHPTH,PHPTHI,PHPPH,PHPPHIHAML005
     2, PHPOM,PHPOMI,PHPKR,PHPKRI,PHPKTH,PHPKTI, PHPKPH,PHPKPI          HAML006
     3 ,KPHPK,KPHPKI,POLAR,POLARI,LPOLAR,LPOLRI                         HAML007
      COMMON R(20),T,STP,DRDT(20) /WW/ ID(10),W0,W(400)                 HAML008
      EQUIVALENCE (TH,R(2)),(PH,R(3)),(KR,R(4)),(KTH,R(5)),(KPH,R(6)),  HAML009
     1 (DTHDT,DRDT(2)),(DPHDT,DRDT(3)),(DKRDT,DRDT(4)),(DKTHDT,DRDT(5)),HAML010
     2 (DKPHDT,DRDT(6)),(F,W(6))                                        HAML011
      REAL KR,KTH,KPH,KPHPK,KPHPKI,LPOLAR,LPOLRI,LOGTEN,K,KAY2,KAY2I    HAML012
      OM=PIT2*1.E6*F                                                    HAML013
      STH=SIN(TH)                                                       HAML014
      CTH=SIN(PID2-TH)                                                  HAML015
      RSTH=R(1)*STH                                                     HAML016
      RCTH=R(1)*CTH                                                     HAML017
      CALL RINDEX                                                       HAML018
      DRDT=-PHPKR/(PHPOM*C)                                             HAML019
      DTHDT=-PHPKTH/(PHPOM*R(1)*C)                                      HAML020
      DPHDT=-PHPKPH/(PHPOM*RSTH*C)                                      HAML021
      DKRDT=PHPR/(PHPOM*C)+KTH*DTHDT+KPH*STH*DPHDT                      HAML022
      DKTHDT=(PHPTH/(PHPOM*C)-KTH*DRDT+KPH*RCTH*DPHDT)/R(1)             HAML023
      DKPHDT=(PHPPH/(PHPOM*C)-KPH*STH*DRDT-KPH*RCTH*DTHDT)/RSTH         HAML024
      NR=6                                                              HAML025
C********* PHASE PATH                                                  HAML026
      IF (W(57).EQ.0.) GO TO 10                                         HAML027
      NR=NR+1                                                           HAML028
      DRDT(NR)=-     KPHPK/PHPOM/OM                                     HAML029
C********* ABSORPTION                                                  HAML030
   10 IF (W(58).EQ.0.) GO TO 15                                         HAML031
      NR=NR+1                                                           HAML032
      DRDT(NR)= 10./LOGTEN*KPHPK*KAY2I/(KR*KR+KTH*KTH+KPH*KPH)/PHPOM/C HAML033
C********* DOPPLER SHIFT                                               HAML034
   15 IF (W(59).EQ.0.) GO TO 20                                         HAML035
      NR=NR+1                                                           HAML036
      DRDT(NR)=-PHPT/PHPOM/C/PIT2                                       HAML037
C********* GEOMETRICAL PATH LENGTH                                     HAML038
   20 IF (W(60).EQ.0.) GO TO 25                                         HAML039
      NR=NR+1                                                           HAML040
      DRDT(NR)=-SQRT(PHPKR**2+PHPKTH**2+PHPKPH**2)/PHPOM   /C           HAML041
C********* OTHER CALCULATIONS                                          HAML042
   25 CONTINUE                                                          HAML043
      RETURN                                                            HAML044
         END                                                            HAML045-
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