NRL Memorandum Report 5099

Cosmic Ray Effects on Microelectronics
Part II: The Geomagnetic Cutoff Effects

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The earth's magnetic field modulates the energy spectra of charged particle radiation reaching a satellite from outside the magnetosphere. This report describes how a transmission function is calculated that modulates the radiation environment in the interplanetary medium to obtain the orbit-averaged radiation environment at the skin of any spacecraft in a circular orbit. It is found that the location of the electronics package within the spacecraft may affect the soft upset rate.

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COSMIC RAY EFFECTS ON MICROELECTRONICS
PART II: THE GEOMAGNETIC CUTOFF EFFECTS

1.0 Introduction

The ability of charged particle radiation to penetrate into the magnetosphere from outside is limited by the earth's magnetic field. Particles having low magnetic rigidity (i.e. momentum per unit charge) are preferentially turned back by the field, so they are unable to penetrate beyond some depth in the magnetosphere. For each point in the magnetosphere and for each direction of approach to that point, there exists a threshold value of magnetic rigidity, called the geomagnetic cutoff. Below this value, no charged particle can reach the specified point from the specified direction. Above this cutoff value, particles arrive at the specified point from the specified direction as though the magnetic field were not present at all (Lemaitre and Vallarta, 1933).

2.0 The Geomagnetic Cutoff

The geomagnetic cutoff was first computed for a perfect dipole field by Störmer (1930). This result is given below:

$$P_c = \frac{59.6}{r^2}\,[1-(1-\cos\gamma\,\cos^3\lambda)^{1/2}]^2/[\cos\gamma\,\cos\lambda]^2 \quad (1)$$

for positively charged particles, where

P_c = magnetic rigidity cutoff in GeV/ec (or GV for short),

r = radial distance from the offset dipole center in earth radii,

λ = geomagnetic latitude in offset dipole coordinates,

and,

γ = the direction from which the particle arrives with respect to local east in offset dipole coordinates.

As we can see from Störmer's equation, P_c depends strongly on the geomagnetic latitude. This means that the geomagnetic cutoff will vary drastically around the orbit of a spacecraft, especially at high inclinations.

Störmer's equation assumes the earth's field is a perfect dipole and ignores the presence of the solid earth. For these reasons, Störmer's equation does not provide accurate values of the geomagnetic cutoff.

More accurate values of the geomagnetic cutoff have been obtained by Shea and Smart (1975). These authors have used an accurate model of the earth's magnetic field and ray tracing techniques, to obtain values of the vertical geomagnetic cutoff. Their calculations take into account the

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presence of the solid earth. Shea and Smart report the values of the vertical geomagnetic cutoff at 20 km altitude on a world-wide grid of points. These results are for geomagnetically quiet conditions.

When a large solar flare occurs, it usually produces a magnetic storm at earth. These storms have a tendency to depress the geomagnetic cutoff as discussed in Adams et al. (1981), who showed that a typical suppression in cutoff could be described by:

$$P_{storm} = P_c[1.0 - 0.54 \exp(-P_c/2.9GV)] \qquad (2)$$

When the geomagnetic cutoff transmission function is being computed for the purpose of modulating solar flare spectra, eq. (2) will be used to adjust the geomagnetic cutoff values to storm-time conditions. Obviously the actual degree of supression will vary from one magnetic storm to another. The data base at present is inadequate to characterize this variation.

As can be seen from eq. (1), the geomagnetic cutoff varies with the particle's arrival direction γ. The vertical cutoff (γ = 90 degrees) is close to the average value of P_c, averaging over all directions. Figure 1 shows the results of a detailed calculation of the geomagnetic cutoff transmission averaged over all directions about a point at 20^o latitude, 0^o longitude and 400 km . The arrow indicates the value of the vertical cutoff at this location. The vertical cutoff will be used here to apply to all cosmic rays approaching a spacecraft regardless of their direction. The results of Shea and Smart (1975) are for 20 km altitude. To estimate the cutoff at higher altitudes we will extrapolate using eq. (1).

Finally, as Adams et al. (1981) have discussed, the earth casts a cosmic ray shadow on a spacecraft in earth orbit. The solid angle of the shadow cast of the solid earth is approximately,

$$\text{Omega} = 2\pi \left\{ 1- [(R_e + h)^2 - R_e^2 \;]^{1/2} / (R_e + h) \right\} , \qquad (3)$$

where R_e is the radius of the earth and h is the spacecraft altitude. This shadow is cast on one side of the spacecraft at any point on the orbit. In the results reported here, we will neglect the earth's shadow. This will lead to direction - averaged flux estimates for the radiation reaching the skin of the spacecraft that are somewhat high (never more than a factor of two, however).

3.0 Computation of The Geomagnetic Cutoff Transmission Function

The geomagnetic cutoff transmission function is obtained by averaging the geomagnetic cutoff around the spacecraft orbit so as to obtain a statement of the probability that a particle can reach the spacecraft as a function of its magnetic rigidity. The resulting transmission function is used to modulate the particle spectra found in the interplanetary medium. These modulated spectra can, in turn, be used to estimate single-event upset rates.

This procedure averages over the large variations in upset rate that are to be expected from point to point along the spacecraft's orbit. The only justification for this orbit-averaging procedure is that the mean time between upsets is normally found to be long compared to the spacecraft's orbital period. For each spacecraft design, the orbit average upset rate should be checked to see that it is no more than a one or two upsets per orbital period. If the predicted rate is higher, then the orbit averaging procedure described here is not valid and the variation in upset rate around the orbit must be considered.

By using the vertical cutoff as typical of all directions, employing eq. (1) for altitude extrapolation, and neglecting the earth's shadow, we have simplified the geomagnetic cutoff transmission calculation. All that is necessary now to obtain the orbit - averaged geomagnetic transmission to the skin of a spacecraft is to compute the spacecraft's location in small steps around the orbit and interpolate/extrapolate the cutoff value to each point. The resulting cutoffs are binned into 200 bins between 0 and 20 GeV/ec. The spacecraft must be followed for a couple of days so that its orbit is allowed to precess around the earth, sampling the worldwide pattern of geomagnetic cutoff. Finally the binned cutoffs are normalized to obtain the transmission function. This procedure is similar to the one reported by Heinrich and Spill (1979).

4.0 Computation of the Spacecraft's Position

For spacecraft in circular orbits, the geographic latitude ,θ, of the spacecraft at some time, t, is given by:

$$\theta = \cos^{-1} [\sin\theta_0 \sin(\omega t + \Psi_0)], \quad (4)$$

where θ_0 is the orbital inclination,

t is the time,

ω is the satellite angular velocity (radians/sec),

and

Ψ_0 is the angle between the spacecraft's position at t = o and the point on the equator where the spacecraft last crossed it heading into the northern hemisphere. This angle is measured about the center of the earth (i.e., the displacement from the ascending node).

The spacecraft east longitude, ϕ, is:

$$\phi = \phi_0 - \Omega t + \tan^{-1}(S_1) + \tan^{-1}(S_2) \quad (5)$$

where

$$S_1 = \frac{\cos [1/2 (\pi/2 - \theta_0)]}{\cos [1/2 (\pi/2 + \theta_0)] \tan [1/2 (\pi/2 - \omega t - \phi_0)]} \quad (6)$$

and,

$$S_2 = \frac{\sin [1/2 (\pi/2 - \theta_0)]}{\sin [1/2(\pi/2 + \theta_0)] \tan [1/2 (\pi/2 - \omega t - \phi_0)]} \quad (7)$$

The additional symbols in these equations are defined as follows:

Ω is the angular velocity of the earth (7.27×10^{-5} radians/sec)

and

ϕ_0 is the longitude of the point on the equator where the spacecraft last crossed, going into the northern hemisphere, prior to reaching its position at t = 0 (i.e. the longitude of the ascending node).

For a circular orbit, the spacecraft's angular velocity is

$$\omega = 1.24 \times 10^{-3} [R_e/(h+R_e)]^{3/2} \text{ radians/sec} \quad (8)$$

where

R_e is the earth's radius (6371 km)

and

h is the spacecraft altitude in km

Now we need to compute the quantities r, λ, and γ in eq. (1), i.e. the spacecraft's position and the particle's arrival direction in offset dipole coordinates. These quantities must also be computed for the four nearest points directly below the spacecraft on the world-wide vertical cutoff grid at 20 km. This is done using the methods of Smart and Shea (1977). With these quantities determined at the spacecraft's position and the four nearest grid points, eq. (1) is used to extrapolate the cutoff from each grid point to the spacecraft's position. These four extrapolations are weighted according to the distance between the point directly beneath the spacecraft on the 20 km altitude world grid and each grid point, then they are averaged to obtain the estimate of the vertical cutoff at the spacecraft.

Equations (4) through (8) were used to compute the cutoff at the spacecraft's position at 200 points per orbit. The computations were carried out for two days of orbits to obtain good convergence. The computer program for this calculation is given in appendix A and the geomagnetic cutoff tabulation at 20 km altitude [taken from Shea and Smart (1975)] is given in appendix B.

5.0 Comparison with Detailed Calculations

As we saw in section 2, the geomagnetic cutoff is drastically different at different points around a spacecraft's orbit. It is also different for each side of the spacecraft at the same point on the orbit. Finally the direction-averaged flux never reaches the value found in interplanetary space, even at high magnetic rigidities. This is because of the earth's shadow on the spacecraft.

Drs. D. F. Smart and M. A. Shea of Air Force Geophysical Laboratory have carried out detailed calculations of the geomagnetic cutoff at 400 km altitude for a large sampling of locations and arrival directions. Recently, we have used these results to make a precise calculation of the geomagnetic cutoff transmission function to a spacecraft in a 400 km circular orbit at several inclinations up to 50°. These results take into account the cutoff for all arrival directions and properly account for the earth's shadow. The cutoff values themselves are precise, based on a large number of ray-tracing calculations at 400 km. Figures 2 and 3 show the transmission function, averaged over all arrival directions, at two different points for a 50° inclination orbit at this altitude. Figure 2 is for 10° latitude and 120° longitude. The position is close to the highest cutoff to be found around any orbit. Figure 3 shows the transmission function at -50° latitude (southern hemisphere) and 120° longitude. This position is close to the lowest cutoff to be found around this orbit. The cutoff varies from $\simeq$ 0.4 GV to over 10 GV between these two positions. In figure 3, the transmission rises rapidly to its limiting value (limited by the earth's shadow). By contrast, in figure 2 the transmission does not reach the limiting value until nearly 100 GV. This shows how much the cutoff depends on the particle's arrival direction at low latitudes. This effect can also be seen in eq. (1).

Figure 4a shows the precise geomagnetic cutoff transmission function, averaged over all arrival directions and around a 50° inclination circular orbit at 400 km (curve a). If this function is multiplied by a particle spectrum (in particles/m^2. ster. sec. MeV/u) in the interplanetary space, one obtains the particle spectrum at the skin of the spacecraft in the same units.

We now compare this precise calculation with the approximate method described in sections 2.0, 3.0, and 4.0. Here we have neglected the change in cutoff with arrival direction, always using the vertical cutoff. We have also employed Stormer's theory to extrapolate the cutoff from precise cutoff values at 20 km. Figure 4 shows the approximate geomagnetic cutoff transmission function neglecting the earth's shadow (curve b) and the same function corrected (approximately) for the earth's shadow using eq. 3 (curve c).

Figures 5, 6, 7, 8, and 9 show the precise transmission function for a 400 km circular orbit at 40°, 30°, 20°, 10° and 0° inclination respectively. Here as in figures 1, 2, and 3, the transmission value is expressed as a solid angle (4π corresponding to a transmission factor of 1.0).

6.0 Computed Geomagnetic Cutoff Transmission Functions.

The geomagnetic cutoff transmission function has been computed, by the approximate method, for circular orbits of 30°, 40°, 50°, 60°, 70°, 80°, and 90° inclination. The results for 223 km altitude are given in figures 10. Figure 11 gives the results at 426 km, figure 12 at 741 km and figure 13 at 1111 km. In each of these figures, the lowest cutoff portion of the transmission function for the 80° and 90° inclination orbits is quite uncertain. This is because the geomagnetic cutoff near the earth's poles is unstable and poorly known. Figure 14 compares the geomagnetic cutoff transmission function to be expected during a magnetic storm, with the same function, taken from figure 13, for geomagnetically quiet times. Both functions are for a 60° inclination orbit at 1111 km. The earth's shadow has been neglected in all the calculations presented in this section.

7.0 Use of the Geomagnetic Cutoff Transmission Function.

To obtain the differential energy spectra for the various nuclei reaching the skin of a spacecraft from outside the magnetosphere, just multiply the flux in the interplanetary medium (taken from Adams et al., 1981) by the transmission function. To do this, the magnetic rigidity, P (in GeV/ec) must be computed for each particle energy, E (in MeV/u) i.e.:

$$P = \frac{A}{Z}\left[(E/1000)^2 + 1.86\times10^{-3}E\right]^{1/2} \qquad (9)$$

and then used to look up the geomagnetic cutoff transmission. Note that A is the atomic mass and Z is the particle charge (in electron charges). From eq. (9), we can see that the geomagnetic transmission at any particle energy depends on the particle's charge. If an ion is fully stripped, then $A/Z \simeq 2$, however, if the ion is only singly ionized, $A/Z = A$. Figure 15 shows the oxygen spectrum in the interplanetary medium (curve a) at the skin of a spacecraft in a 30° inclination orbit at 223 km assuming the oxygen is fully ionized (curve b) and that the anomalous component (see Adams et al., 1981) of oxygen is singly-ionized (curve c).

8.0 Conclusion

This report presents a method of computing the geomagnetic cutoff transmission function that makes it possible to compute the orbit - averaged charged particle spectra the skin of any spacecraft in a circular orbit.

The results show that these charged particle spectra depend critically on the particle's charge and the spacecraft's orbital inclination. The spectra also depend, to a lesser degree on the orbital altitude.

The geomagnetic cutoff and hence the charged particle spectra change drastically from point to point around the spacecraft orbit. At each point on the orbit, the particle spectra are different on each side of the spacecraft. Also, the flux striking one side of the spacecraft will be reduced by the cosmic ray shadow of the earth. All of these points have been neglected or averaged in the results presented here.

The points discussed above have two practical implications for upset rate predictions: 1) When the mean time between upsets is smaller than the orbital period, the observed upset rate at the low cutoff points in the orbit can be dramatically higher than predicted by this procedure, especially during a solar flare. 2) For a spacecraft that is stabilized, the observed upset rate will be dependent on the physical location of the microelectronic components within the spacecraft. In general, the lowest upset rates will be observed when the electronics are located on the side of the spacecraft that is always in the shadow of the earth. The best location will differ from mission to mission depending on the details of the orbit and spacecraft design. If the trapped radiation is the dominant cause of upsets, then the optimum location will again be different.

9. References.

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4. Shea, M. A., and Smart, D. F., Report No. AFCRL-TR-75-0185, Hanscom, AFB, Mass., 1975.

5. Smart, D. F., and Shea, M. A., 15th Intl. Cosmic Ray Conference, 11, 256-261, 1977.

6. Störmer, C., Z., Astrophys. 1, 237, 1930.

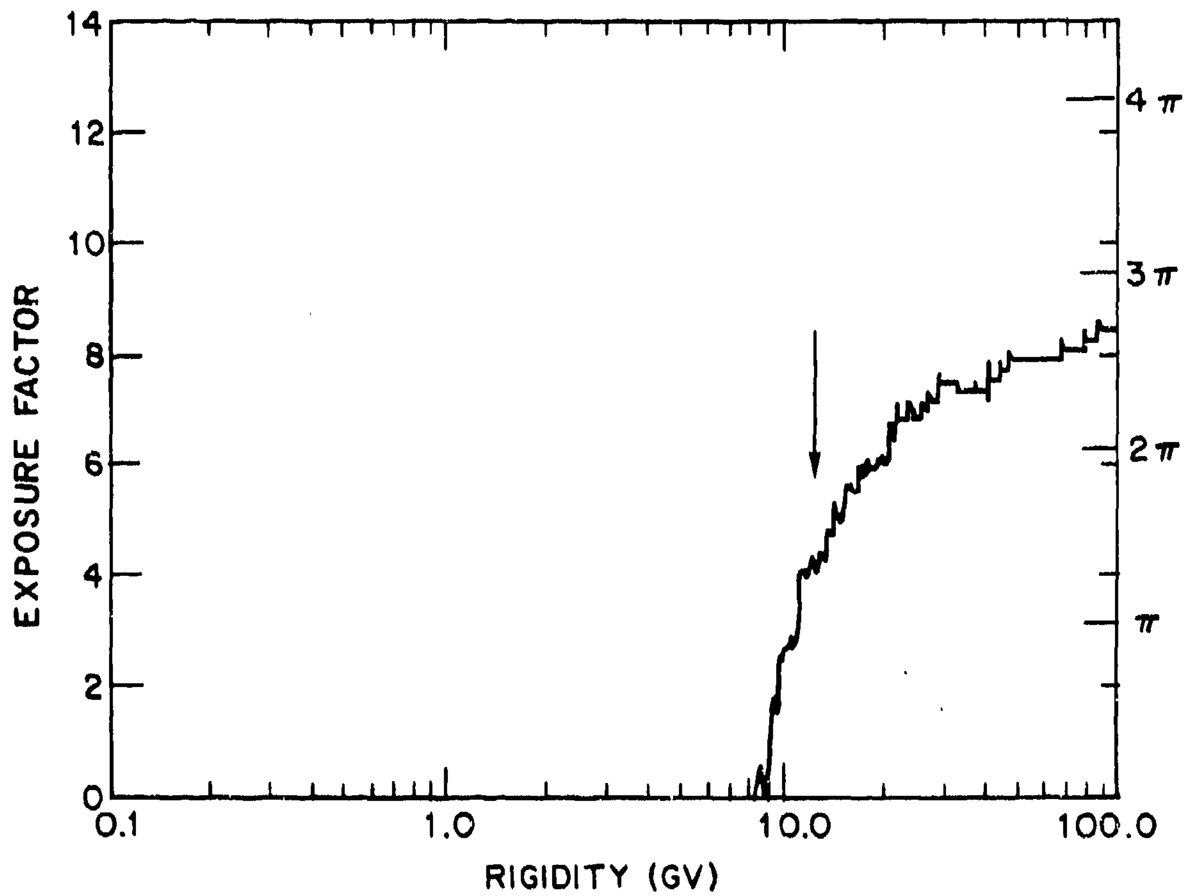

Figure 1. The precise geomagnetic cutoff transmission function, averaged over all arrival directions, for a point at 20° latitude, 0° longitude and 400 km altitude. The arrow shows the value of the the vertical geomagnetic cutoff at this location, extrapolated up from 20 km using eq. (1). This function is multiplied by the particle spectra in interplanetary space to obtain the omnidirectional spectra at this point. The exposure factor is the solid angle through which cosmic rays may arrive at this point.

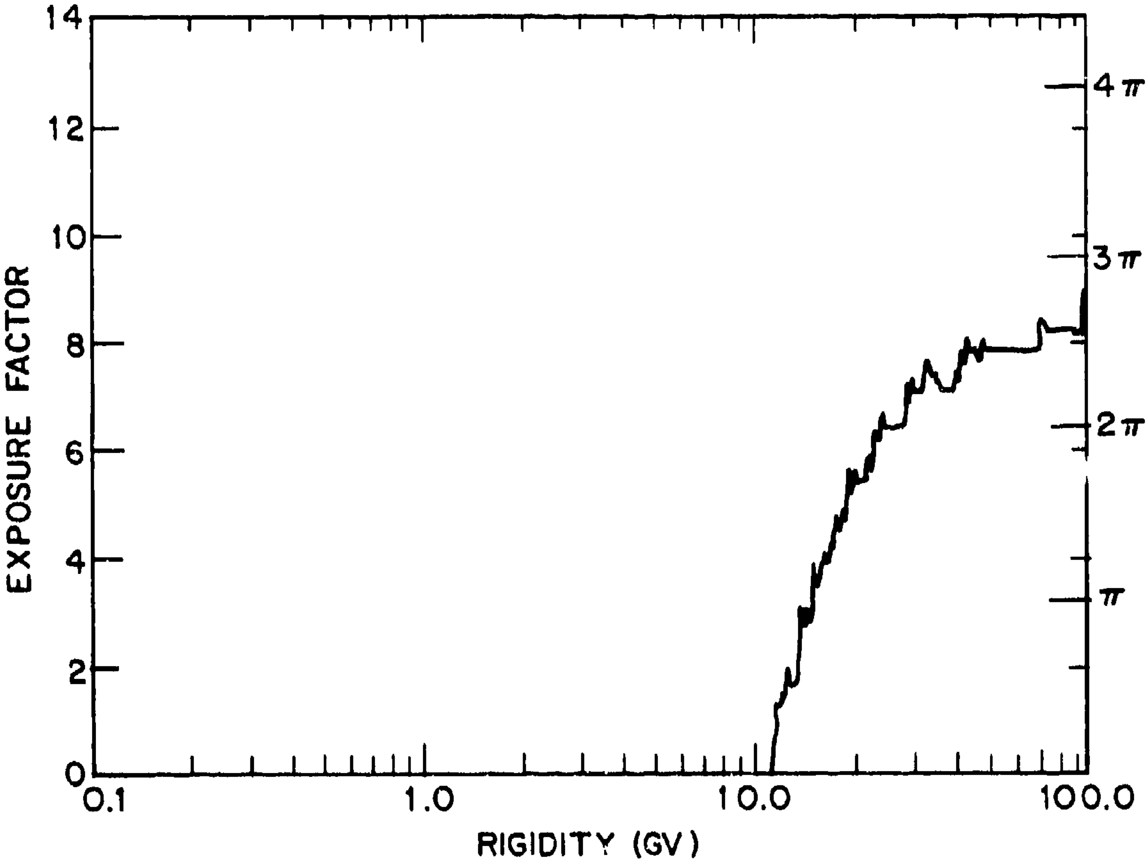

Figure 2. The precise geomagnetic cutoff transmission function at 10° latitude, 120° longitude and 400 km altitude. This is near the location of the highest cutoff experienced by any spacecraft.

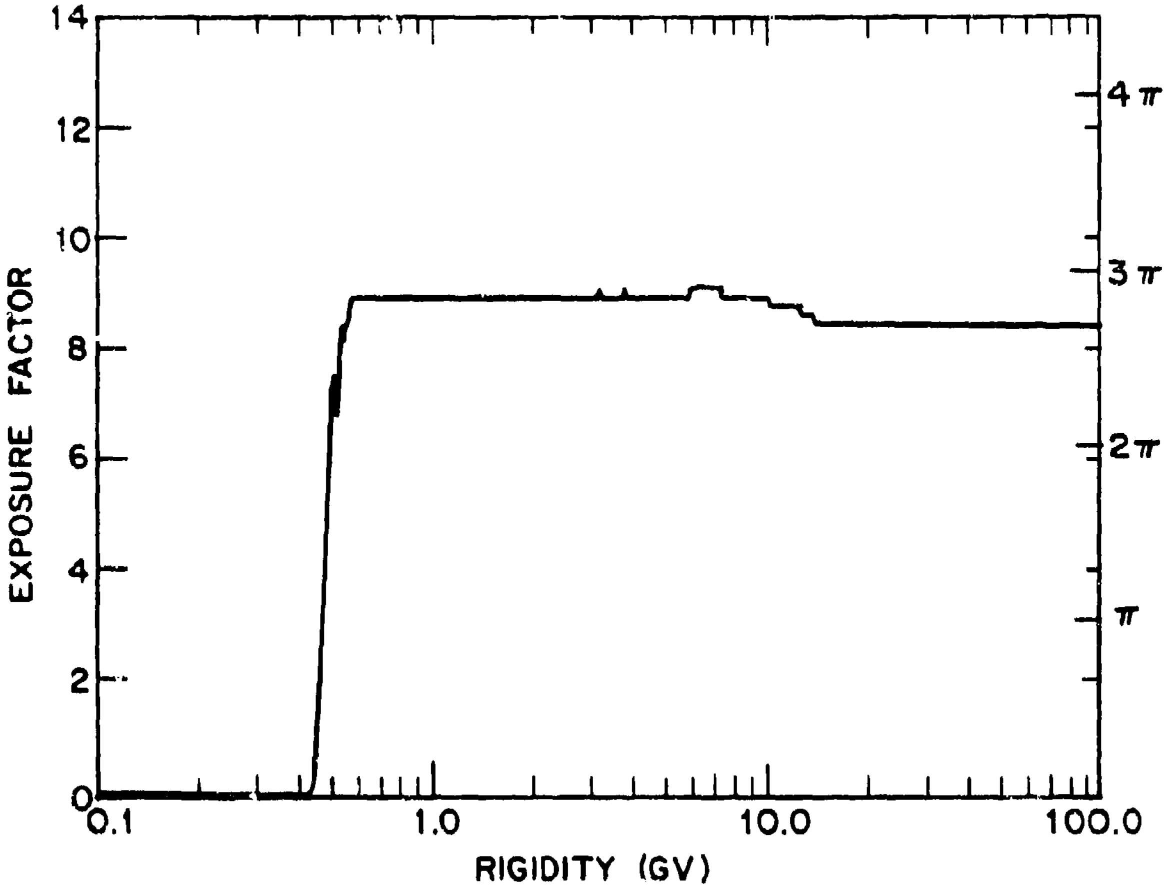

Figure 3. The precise geomagnetic cutoff transmission function at -50° latitude (in the southern hemisphere), 120° longitude and 400 km altitude. This is near the location of the lowest cutoff experienced by a spacecraft in a 50° inclination orbit.

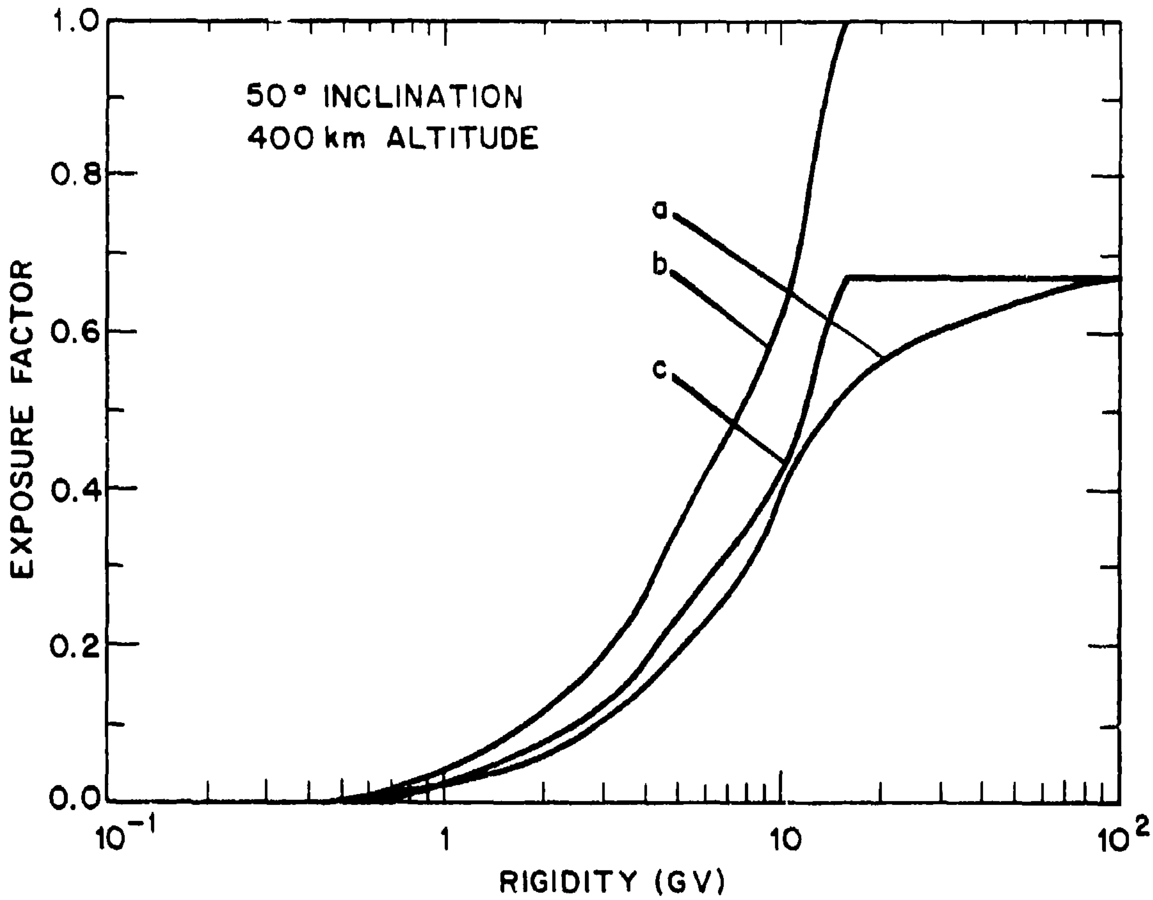

Figure 4. The geomagnetic cutoff transmission function for a spacecraft in a 50° inclination circular orbit at 400 km altitude. The cutoff has been averaged over all arrival directions and over the spacecraft's orbit. Curve (a) is a precise calculation based on a large number of ray tracing calculations; curve (b) is an approximate calculation which neglects the earth's shadow; and curve (c) is an approximate calculation which takes the earth's shadow into account in an approximate way. The vertical axis here runs from 0.0 to 1.0, corresponding to the range 0.0 to 4π, in the previous figures.

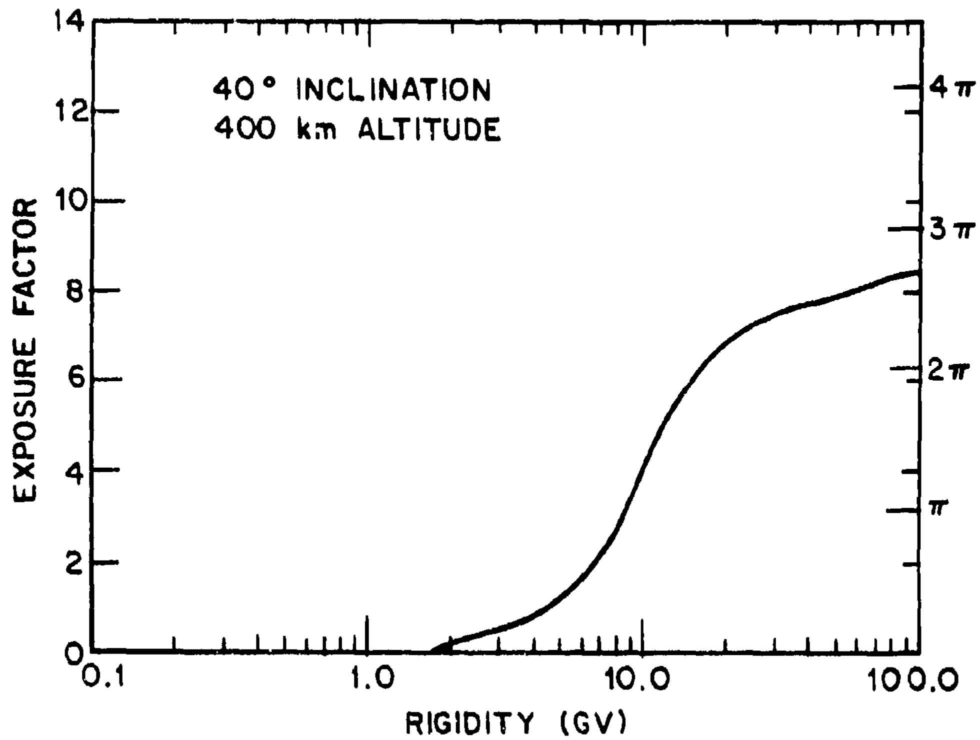

Figure 5. The precise geomagnetic cutoff transmission function for a spacecraft in a 400 km circular orbit at 40° inclination. 4π corresponds to complete transmission.

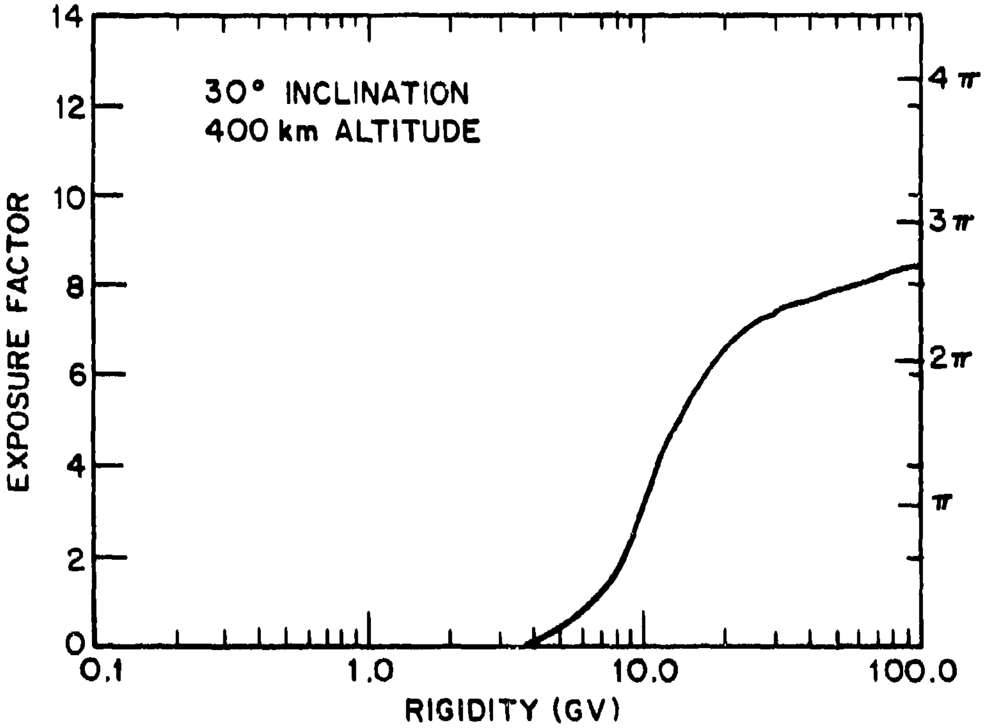

Figure 6. The same as figure 5, but for 30° inclination.

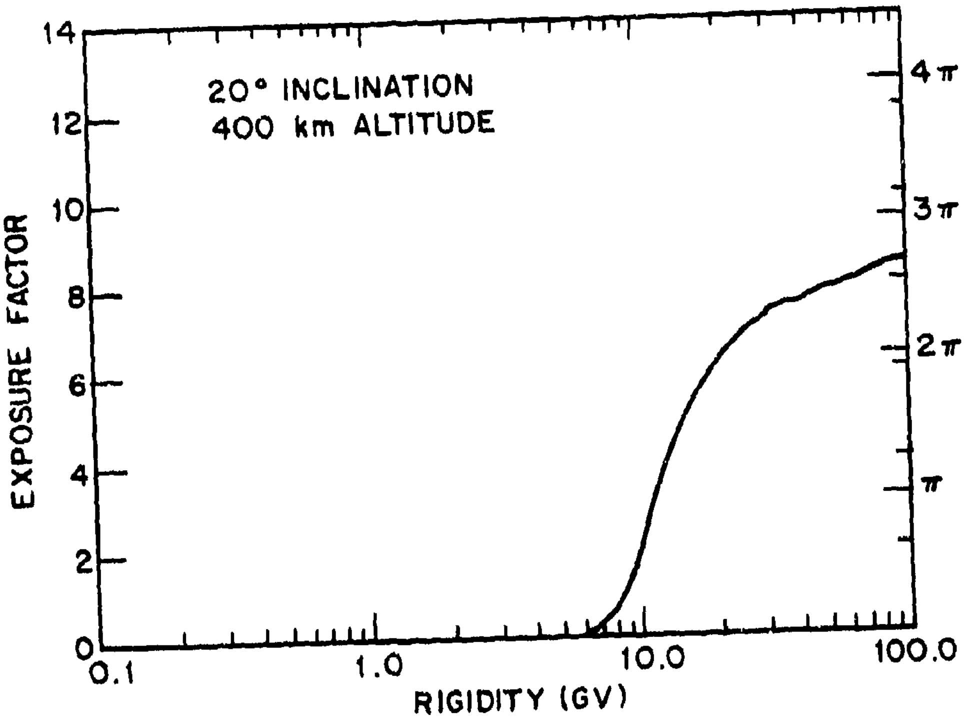

Figure 7. The same as figure 5, but for 20° inclination.

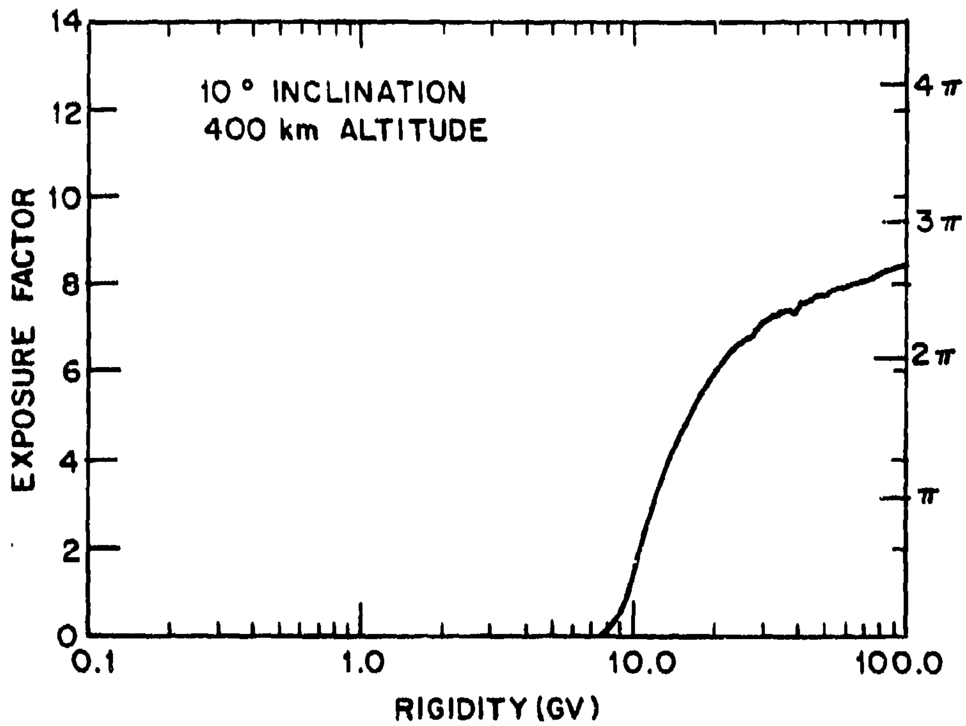

Figure 8. The same as figure 5, but for 10° inclination.

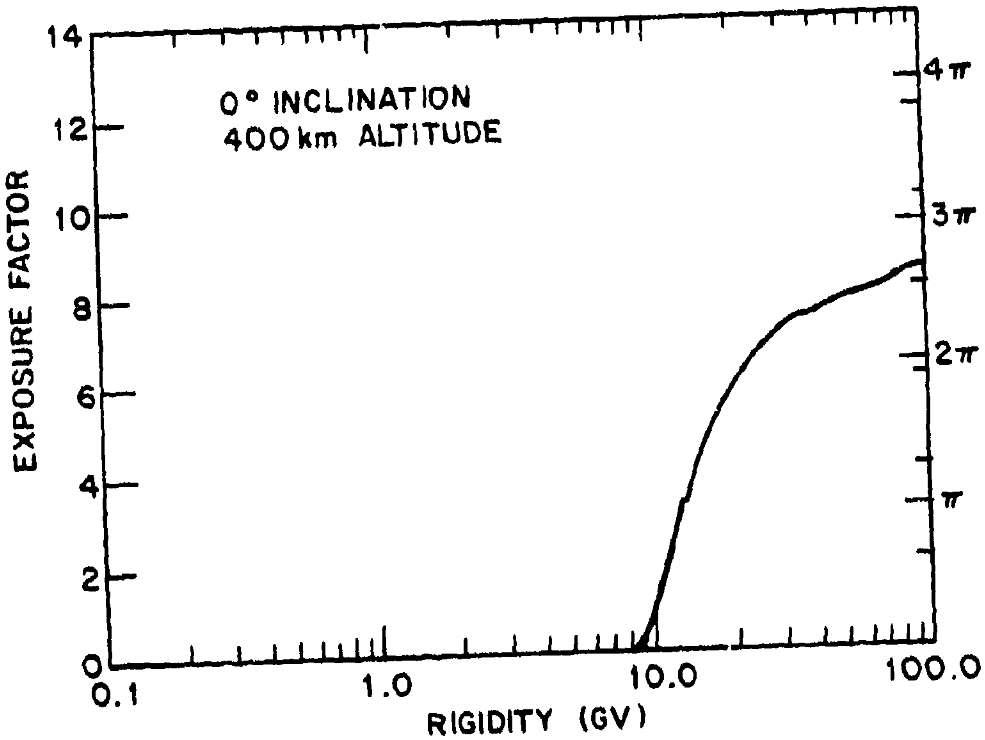

Figure 9. The same as figure 5, but for 0° inclination.

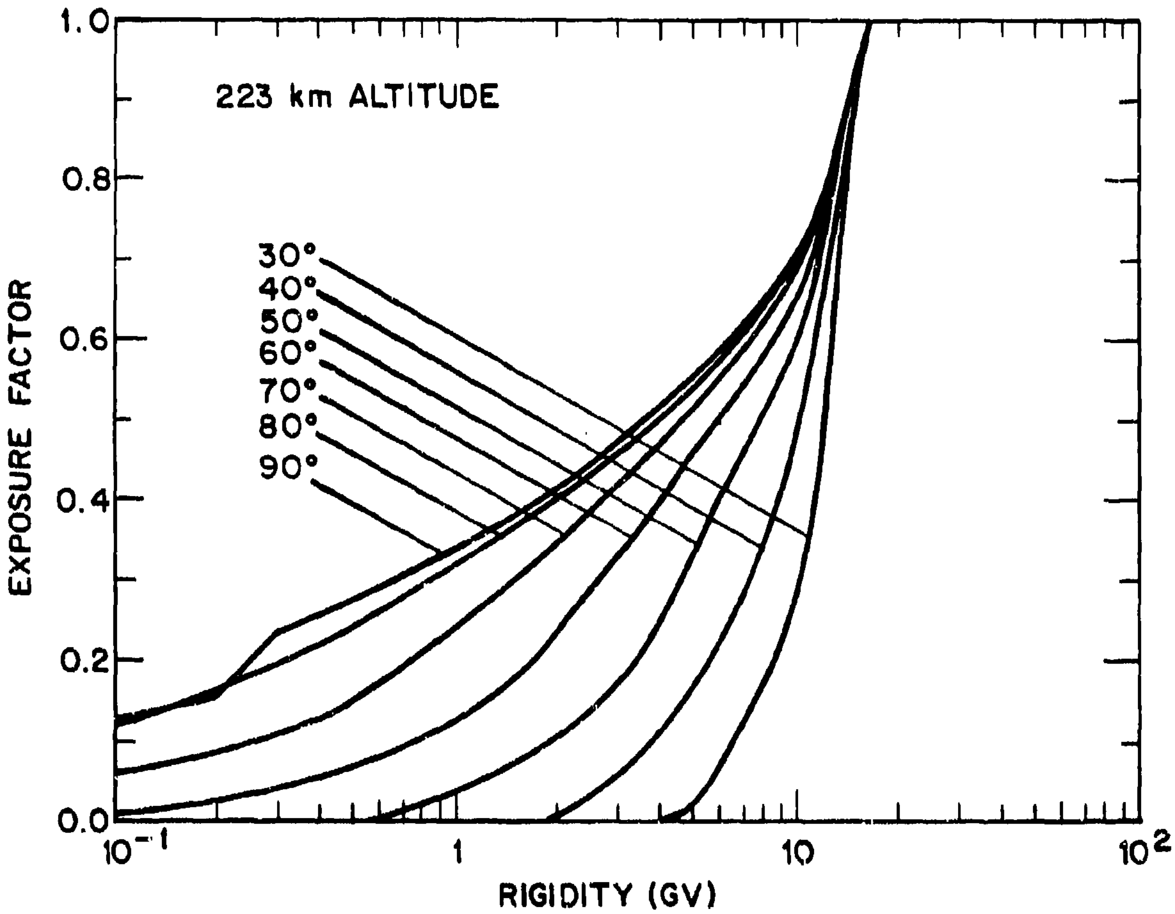

Figure 10. The approximate geomagnetic cutoff transmission function for a circular orbit at 223 km altitude. The earth's shadow has been neglected. The curves are for orbital in 'inations of 90°, 80°, 70°, 60°, 50°, 40°, and 30° as shown. To obtain the omnidirectional spectra at the skin of the spacecraft (in particles /m^2 sec. MeV/u) multiply this function by 4π and then by the spectra (in particles/m^2. ster. sec. MeV/u). The cutoff probability, plotted here is the exposure factor (in figure 1) divided by 4π.

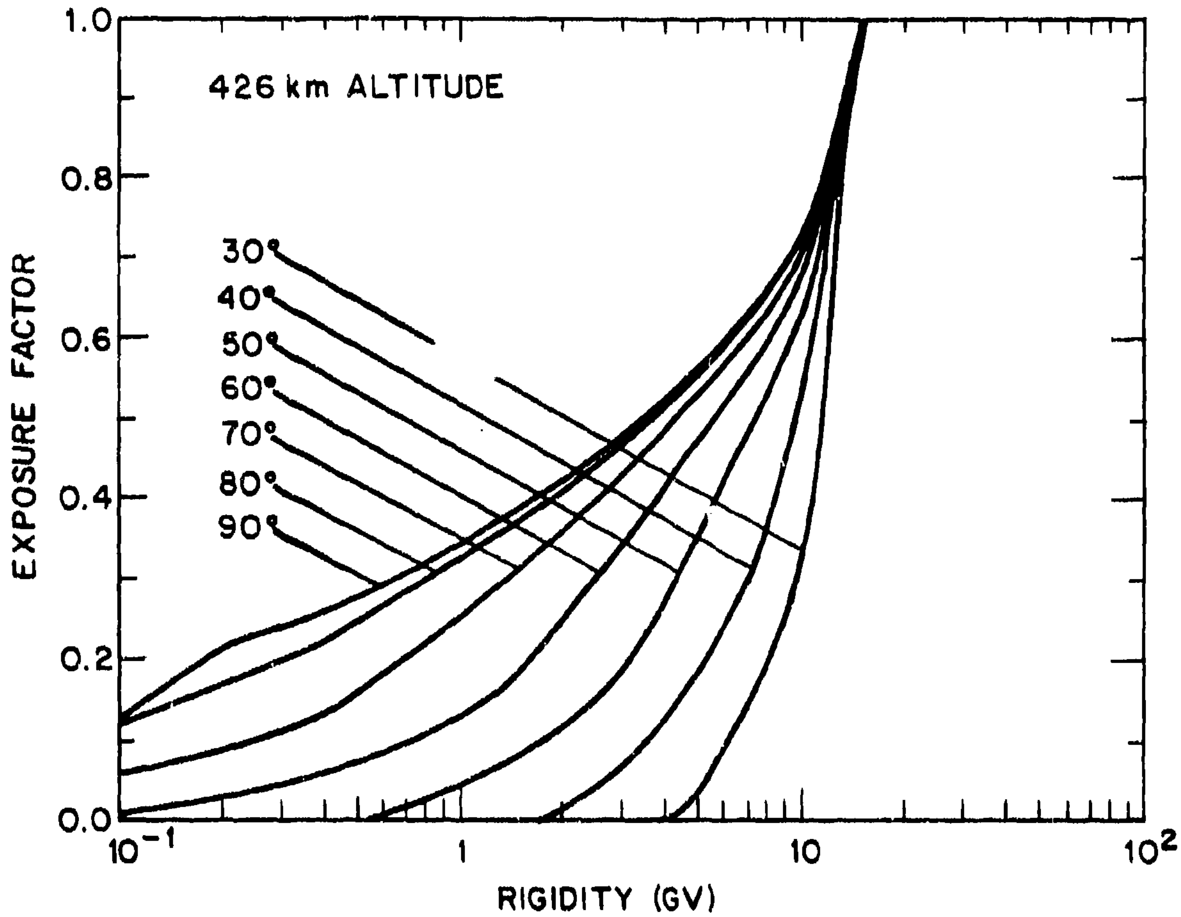

Figure 11. The same as figure 10, but for a 426 km altitude.

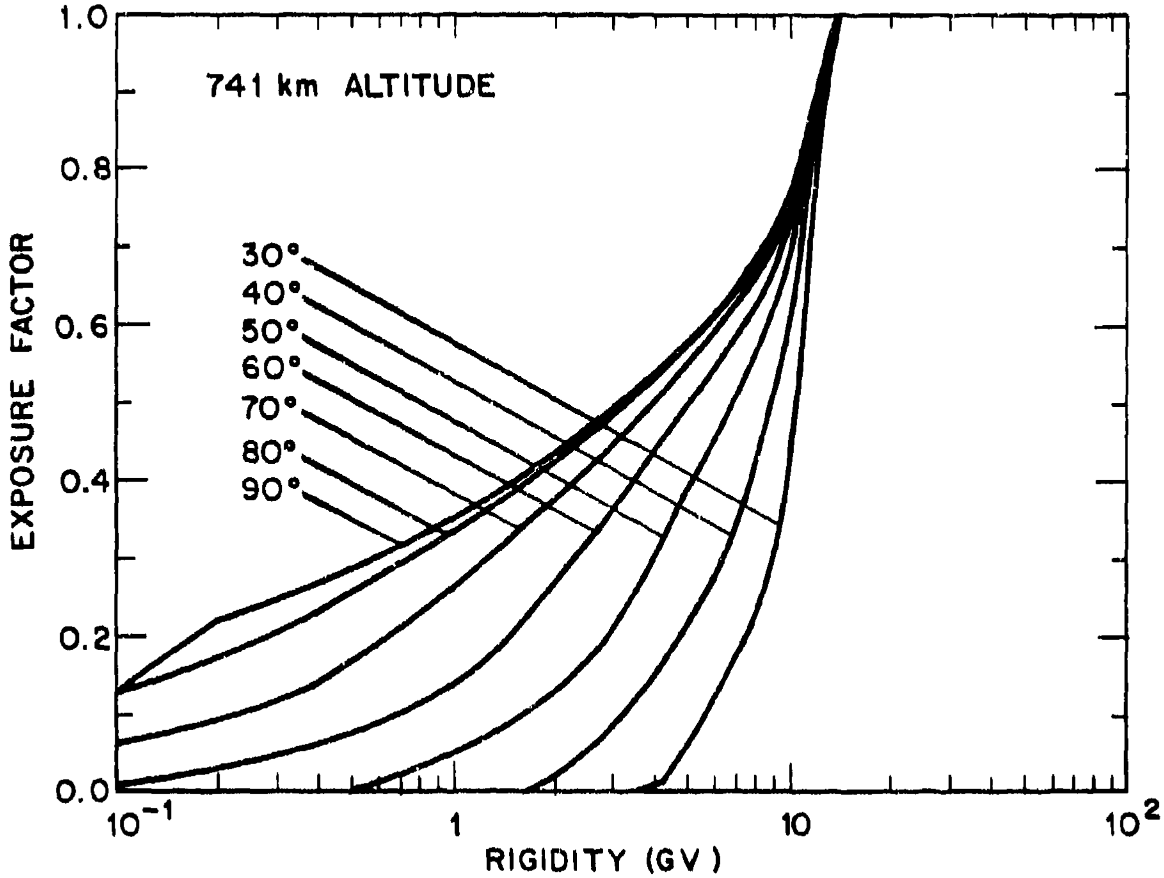

Figure 12. The same as figure 10, but for a 741 km altitude.

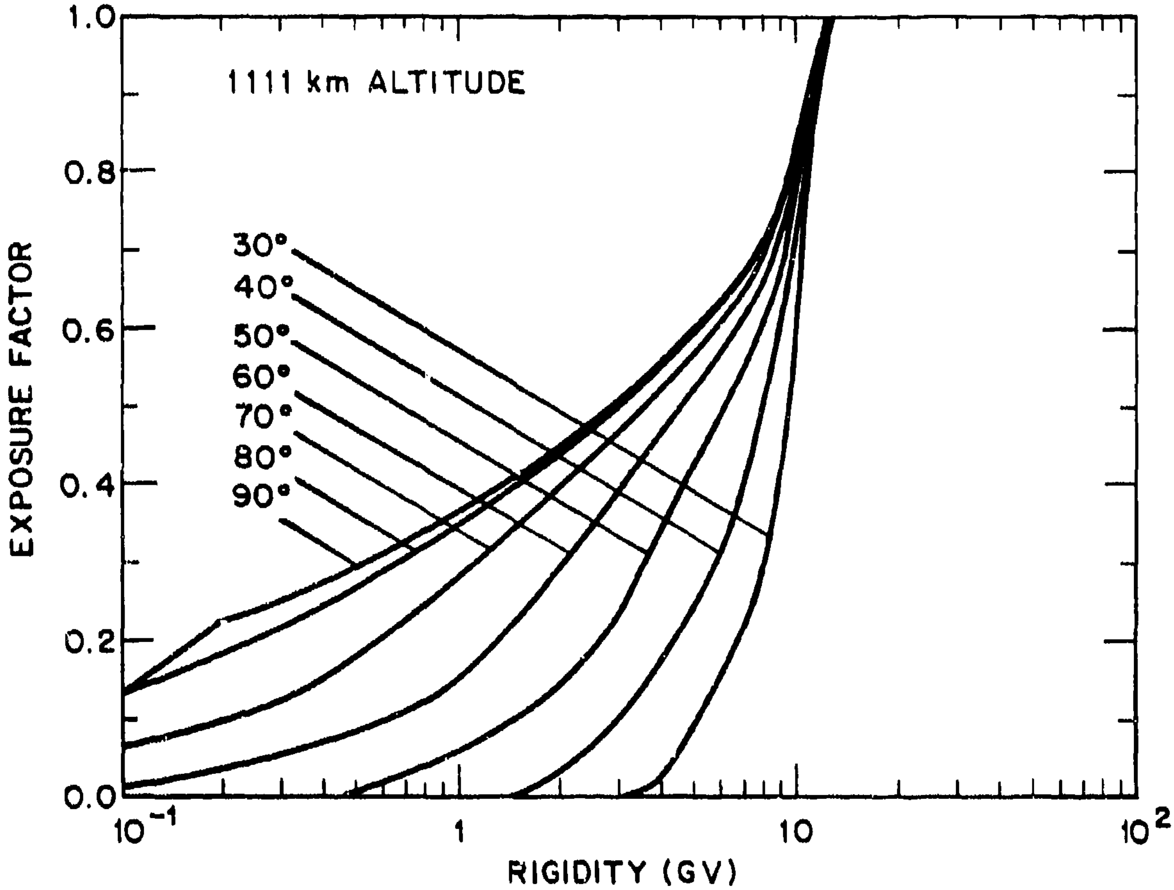

Figure 13. The same as figure 10, but for a 1111 km altitude.

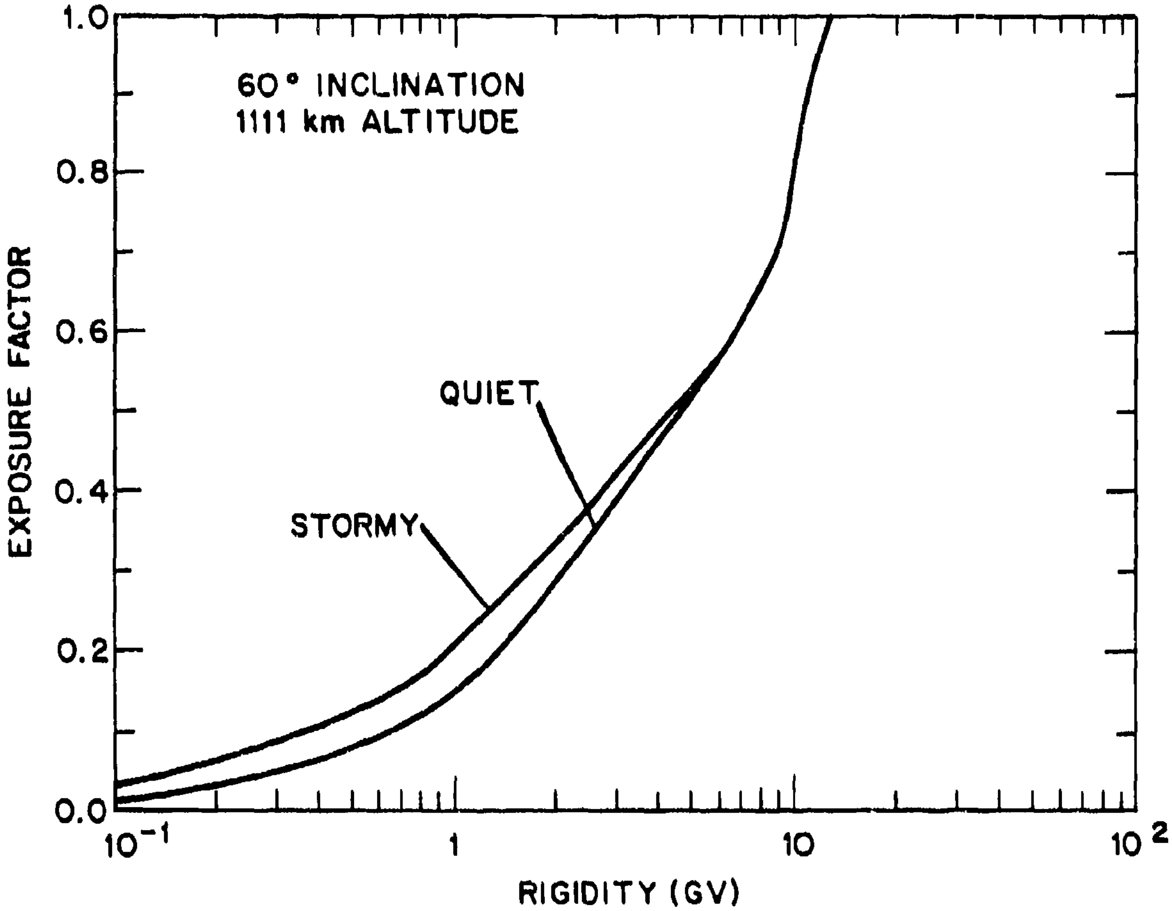

Figure 14. The effect of a magnetic storm on the geomagnetic cutoff transmission function for a 60° inclination orbit at 1111 km: The lower curve is for geomagnetically quiet times and is the same as the 60° curve in figure 13. The upper curve is for geomagnetically disturbed times such as usually exists during a solar flare particle event.

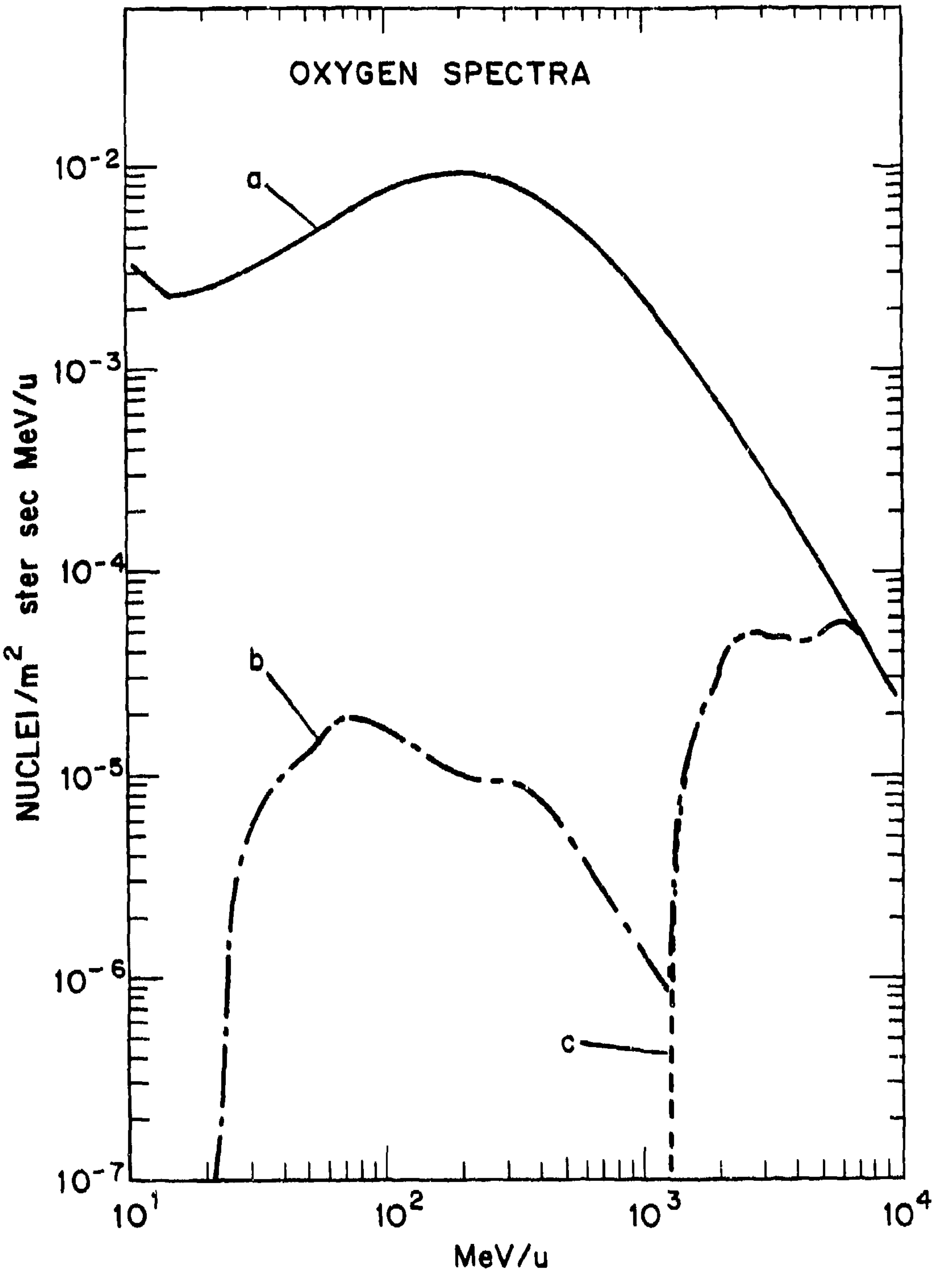

Figure 15. The oxygen spectrum at solar minimum. Curve (a) is the spectrum as seen in the interplanetary medium near earth. Curve (b) is the spectrum at the skin of a spacecraft in a 223 km orbit at 30° inclination assuming the anomalous component is fully-ionized. Curve (c) is the same as curve (b), but assuming the anomalous component is singly ionized.

Appendix A: The GEOMAG Program

The following program is written for a VAX 11/780 system. A similar version has been used on a PDP-10 computer. The program was written to find the table of world-wide vertical cutoffs in a file called CUTOFF.DAT (appendix B). The geomagnetic cutoff transmission function is tabulated and written on an output file called GTRANS.DAT.

This program interacts with the user by asking a series of questions to obtain the data needed to generate the GTRANS.DAT file. Following the program listing, there is an example of a run and a listing of the resulting GTRANS.DAT file. This example should be used to debug the program on a new computer.

The program contains provisions for specifying the longitude of the ascending mode and the displacement from the ascending mode. The values set by the program are zero in both cases. Provisions are also made for typing out the cutoff and spacecraft location at each time step and to compute the cutoff in any direction other than vertical. The function STORMER contains a common block named KARL that gives access to the coordinates of the spacecraft and the particle's arrival in offset dipole coordinates.

```
      PROGRAM GEOMAG
C
C     THIS PROGRAM CALCULATES THE 2 DAY ORBIT AVERAGE OF
C     THE GEOMAGNETIC TRANSMISSION FUNCTION FOR CIRCULAR ORBITS.
C     TO GET INTO THE PROGRAM TYPE "EXECUTE GEOMAG.FOR".  ALL INPUT
C     DATA WILL BE REQUESTED IN PROMPTS.  OUTPUT DATA TABULATED IN
C     INTERVALS OF .1 GV ARE STORED IN THE FILE, GTRANS.DAT.
C     AN INPUT FILE CALLED "CUTOFF.DAT" CONTAINS THE TABULATION
C     OF WORLDWIDE VERTICAL GEOMAGNETIC CUTOFFS AT 20KM ALITIUDE,
C     TAKEN FROM M. A. SHEA AND D. F. SMART, REPORT NO.
C     AFCRL-TR-75-0185, HANSCOM AFB, MASS., 1975
C
      DIMENSION MAT(200),CUTOFF(33,24),T(201),CF(201)
      DATA (MAT(J),J=1,200)/200*0/
C     AZ IS THE AZMUTH ANGLE OF THE PARTICLE WRT THE SPACECRAFT
C     ZE IS THE ZENITH ANGLE OF THE PARTICLE WRT THE SPACECRAFT
C     THESE ANGLES ARE BOTH IN DEGREES AND ARE DATAED IN AS ZERO
C     THEY CAN BE RESET TO ANY OTHER ARRIVAL DIRECTION
      DATA AZ/0./,ZE/0./,AZ0/0./,ZE0/0./
      OPEN(UNIT=5,READONLY,SHARED,STATUS='OLD',FILE='CUTOFF.DAT')
      OPEN(UNIT=6,FILE='GTRANS.DAT')
C     ASK FOR INPUT
C     IS THE SHADOW OF THE EARTH ON THE SPACECRAFT
C     TO BE ACCOUNTED FOR IN THIS CALCULATION?
      TYPE 411
      ACCEPT *,ISHADOW
C     IS THE MAGNETOSPHERE IN A QUIET OR STORMY?
      TYPE 412
      ACCEPT *,ISTORM
C     WHAT IS THE ORBITAL INCLINATION?
      TYPE 415
      ACCEPT *,A1
C******************************************************************
C     THE FOLLOWING REQUESTS HAVE BEEN DISABLED AND THE VALUES OF THE
C     LONGITUDE OF AND DISPLACEMENT FROM THE ASCENDING NODE
C     HAVE BEEN DATAED IN. TO ENABLE THE QUERIES, JUST REMOVE
C     THE COMMENT C'S FROM THE FIRST COLUMB.
C******************************************************************
C     WHAT IS THE LONGITUDE OF THE ASCENDING NODE?
C     TYPE 420
C     ACCEPT *,A2
C     WHAT IS THE INITIAL DISPLACEMENT OF THE ASCENDING NODE?
C     TYPE 425
C     ACCEPT *,A3
C     WHAT IS THE ORBITAL ALTITUDE?
      TYPE 430
      ACCEPT *,ALT
C     A1=ORBITAL INCLINATION (DEGREES)
C     A2=INITIAL LONGITUDE OF ASCENDING NODE (DEGREES)
C     A3=INITIAL DISPLACEMENT FROM ASCENDING NODE (DEGREES)
C     ALT=ORBITAL ALTITUDE (IN KILOMETERS)
C     SET CONSTANTS
      PI=355./113.
C     W1=THE ANGULAR VELOCITY OF THE EARTH IN RADIANS/SECOND
      W1=7.27E-5
C     W2=THE ANGULAR VELOCITY OF THE SPACECRAFT IN RADIANS/SECOND
      W2=1.24E-3*(6371.2/(6371.2+ALT))**1.5
C     CONVERT ANGLES TO RADIANS
      THO=PI*A1/180.
      PHO=PI*(A2-90.)/180.
      PSI=PI*A3/180.
```

```
C        READ IN THE TABLE OF WORLD WIDE VERTICAL
C        GEOMAGNETIC CUTOFFS AT 20KM ALTITUDE
C        THESE DATA ARE TABULATED EVERY 5 DEGREES IN LATITUDE
C        AND EVERY 15 DEGREES IN LONGITUDE
C        THEY ARE TAKEN FROM "M.A. SHEA AND D.F. SMART, REPORT NO.
C        AFCRL-TR-75-0185, HANSCOM AFB, MASS, 1975"
         DO 20 I=1,33
         II=34-I
         DO 20 J=1,24
         READ(5,405) CUTOFF(II,J)
C        THIS ACCOUNTS FOR GEOMAGNETIC CUTOFF SUPRESSION DURING
C        LARGE MAGNETIC STORMS(FOLLOWING ADAMS ET AL., 1981)
         IF(ISTORM.EQ.1) CUTOFF(II,J)=CUTOFF(II,J)*(1.-.54*EXP(
     *   -CUTOFF(II,J)/2.9))
  20     CONTINUE
C        AVERAGE THE CUTOFF AROUND THE 80 DEGREE LATITUDE LINES,
C        NORTH AND SOUTH
         CN=0.
         CS=0.
         DO 30 J=1,24
         CN=CN+CUTOFF(33,J)
  30     CS=CS+CUTOFF(1,J)
         CN=CN/24.
         CS=CS/24.
C        COMPUTE THE TOTAL NUMBER OF STEPS IN TWO DAYS IF WE MAKE
C        200 STEPS PER ORBIT
         JMAX=INT(400.*W2/W1+1.5)
C        COMPUTE THE STEP SIZE IN SECONDS
         STEP=2.*PI/W2/200.
C        COMPUTE THE VERTICAL CUTOFF AT THE SPACECRAFT
C        POSITION FOR EVERY TIME STEP
         DO 50 J=1,JMAX
         T1=FLOAT(J-1)*STEP
         R1=SIN(THO)*SIN(W2*T1+PSI)
         THP=ACOS(R1)
         ZLAT=90.-180.*THP/PI
         IF(ZLAT.GE.80..OR.ZLAT.LE.-80.) GO TO 100
C        COMPUTE THE SPACECRAFT LONGITUDE
         RP=.5*(PI/2.+THO)
         RM=.5*(PI/2.-THO)
         RF=.5*(PI/2.-W2*T1-PSI)
         IF(SIN(RF).EQ.0.).GO TO 63
         S1=SIN(RM)*COS(RF)/SIN(RP)/SIN(RF)
         S2=COS(RM)*COS(RF)/COS(RP)/SIN(RF)
         SUM=ATAN(S1)+ATAN(S2)
         PHP=PHO-W1*T1+SUM
         GO TO 65
  63     PHP=PI+PHO-W1*T1
  65     IF(PHP.GE.0..AND.PHP.LT.2.*PI) GO TO 70
         IF(PHP.LT.0.) PHP=PHP+2.*PI
         IF(PHP.GE.2.*PI) PHP=PHP-2.*PI
         GO TO 65
  70     CONTINUE
         ZLON=180.*PHP/PI
C        COMPUTE THE TABULAR POSITION OF THE VERTICAL CUTOFF
         ZI=ZLAT/5.+17.
         ZJ=ZLON/15.+1.
         ILO=INT(ZI)
         IUP=ILO+1
         JLO=INT(ZJ)
         JUP=JLO+1
```

```
          IF (JUP.EQ.25) JUP=1
C         INTERPOLATE THE VERTICAL CUTOFF TO THE EXACT LOCATION
C         OF THE SPACECRAFT USING STORMER THEORY.
          DI=ZI-FLOAT(ILO)
          DJ=ZJ-FLOAT(JLO)
          XORB=(6371.2+ALT)/6371.2
          RORD= 6391.2/6371.2
          ZLONLO=(JLO-1)*15.
          ZLONUP=ZLONLO+15.
          ZLATLO=ILO*5.-85.
          ZLATUP=ZLATLO+5.
          SC=STORMER(ZLAT,ZLON,XORB,AZ,ZE)
          SCLL=STORMER(ZLATLO,ZLONLO,RORD,AZO,ZEO)
          SCUL=STORMER(ZLATUP,ZLONLO,RORD,AZO,ZEO)
          SCLU=STORMER(ZLATLO,ZLONUP,RORD,AZO,ZEO)
          SCUU=STORMER(ZLATUP,ZLONUP,RORD,AZO,ZEO)
          Y1=SC*CUTOFF(ILO,JLO)/SCLL
         Y2= SC*CUTOFF(IUP,JLO)/SCUL
         Y3=  SC*CUTOFF(ILO,JUP)/SCLU
         Y4= SC*CUTOFF(IUP,JUP)/SCUU
          C=(1.-DI)*(1.-DJ)*Y1+(1.-DI)*DJ*Y3+DI*(1.-DJ)*Y2+DI*DJ*Y4
          GO TO 200
  100     IF(ZLAT.LE.-80.)GO TO 110
          SC=STORMER(90.,0.,XORB,AZ,ZE)
          SCX=STORMER(90.,0.,RORD,AZO,ZEO)
          C=SC*CN/SCX
          GO TO 200
  110     SC=STORMER(-90.,0.,XORB,AZ,ZE)
          SCX=STORMER(-90.,0.,RORD,AZO,ZEO)
          C=SC*CS/SCX
C         HISTOGRAM THE CUTOFFS
  200     IDEX=INT(C*10.)+1
          MAT(IDEX)=MAT(IDEX)+1
C*****************************************************************
C         TO PRINT OUT THE LONGITUDE, LATITUDE, AND CUTOFF AT EACH
C         POINT ARROUND THE SPACECRAFT'S ORBIT, JUST ENABLE THE FOLLOWING
C         STATEMENTS BY REMOVING THE COMMENT C'S.
C********************************************************************
C         TYPE 435,ZLON,ZLAT,C
   50     CONTINUE
          CMAT=0.
C         SAVE THE THRESHOLD
          JSAV=0
          DO 300 J=1,200
C         CONVER  THE HISTOGRAM TO TRANSMISSION
          CMAT=FLOAT(MAT(J))/FLOAT(JMAX)+CMAT
          IF((JSAV.EQ.0).AND.(CMAT.GT.0)) JSAV=J+1
          CF(J+1)=FLOAT(J)/10.
  300     T(J+1)=CMAT
          CF(1)=0.0
          T(1)=0.0
C         ADJUST THE HIGHEST ZERO TRANSMISSION VALUE TO BE
C         JUST AT THE CUTOFF THRESHOLD
          CF(JSAV-1)=CF(JSAV)-T(JSAV)*(CF(JSAV+1)-CF(JSAV))/
        1 (T(JSAV+1)-T(JSAV))
C         THIS IS A CORRECTION FOR THE EARTH'S SHADOW ON THE SPACECRAFT
C         ACCORDING TO SIMPLE GEOMETRICAL OPTICS.
          IF(ISHADOW.NE.1) GO TO 390
          DO 380 J=1,200
          T(J)=T(J)*(1.-0.5*(1.-((6371.2+ALT)**2.-(6371.2)**2)**.5/
        * (6371.2+ALT)))
```

```
 380    CONTINUE
 390    DO 400 J=1,200
 400    WRITE(6,410)CF(J),T(J)
 405    FORMAT(17X,F6.2)
 410    FORMAT(5X,F6.3,5X,F8.6)
 411    FORMAT(1X,'DO YOU WANT TO INCLUDE THE EFFECT OF THE SHADOW',/,
       * ' OF THE EARTH? (1 FOR YES; 0 FOR NO) ',$)
 412    FORMAT(1X,'ENTER THE MAGNETIC WEATHER CONTITION: 1 FOR STORMY;
       * 0 FOR QUIET ',$)
 415    FORMAT(1X,'ENTER ORBITAL INCLINATION IN DEGREES '$)
 420    FORMAT(1X,'ENTER LONGITUDE OF ASCENDING NODE IN DEGREES '$)
 425    FORMAT(1X,'ENTER DISPLACEMENT FROM NODE IN DEGREES '$)
 430    FORMAT(1X,'ENTER ALTITUDE IN KILOMETERS '$)
 435    FORMAT(' LONGITUDE = ',F6.2,', LATITUDE = ',F5.2,' CUTOFF = ',
       * F6.3)
        END
```

```
      FUNCTION STORMER(GCLATD,GCLOND,RGC,AZ,ZE)
      COMMON/KARL/RED,EDLAT,AZM,ZEM,GAMMA
C
C     THIS FUNCTION TRANSFORMS A GEOGRAPHIC LOCATION AND ARRIVAL
C     DIRECTION INTO OFFSET DIPOLE COORDINATES, THEN COMPUTES THE
C     STORMER CUTOFF IN GV AND RETURNS THE RESULT.  THE OFFSET DIPOLE
C     COORDINATES ARE AVAILABLE IN THE COMMON BLOCK /KARL/.
C
C
C        GCLATD IS GEOCENTRIC LATITUDE  IN DEGREES
C        GCLONG IS GEOCENTRIC LONGITUDE IN DEGREES
C        RGC    IS RADIAL DISTANCE FROM GEOCENTER IN EARTH RADII
C        AZ     IS GEOGRAPHIC AZIMUTH
C        ZE     IS GEOGRAPHIC ZENITH
C        RED    IS RADIAL DISTANCE FROM OFFSET DIPOLE POSITION IN
C                                         EARTH RADII
C     EDLAT IS THE GEOMAGNETIC LATITUDE IN OFFSET DIPOLE COORDINATES
C        AZM    IS GEOMAGNETIC AZIMUTH IN OFFSET DIPOLE COORDINATES
C        ZEM    IS GEOMAGNETIC ZENITH  IN OFFSET DIPOLE COORDINATES
C        GAMMA  IS GAMMA ANGLE MEASURED FROM MAGNETIC EAST
C
      IF(JDATA.EQ.77)   GO TO 10
        PI = ACOS(-1.0)
        RAD = 180.0/PI
        PIO2 = PI/2.0
        TWOPI = PI*2.0
     DATA ERAD,THETAD,PHID,R1KM,TH1DEG,PH1DEG/6371.2,
    1 11.4354,-290.2392,450.2586,72.8278,148.7753/
      NOPT = 0
      SQRT3 = SQRT(3.0)
C        ENTER GEOMAGNETIC DATA.      IGRF  1975
C          SEE JGR, 81, 5163, 1976
C                                          DT IS NUMBER OF YEARS SINCE 1975
      DT = 5.0
      G01 = -30186.0  +  25.6*DT
      G02 =   -1898.0  -  24.9*DT
      G11 =   -2036.0  +  10.0*DT
      G12 =    2997.0  +   0.7*DT
      H11 =    5735.0  -  10.2*DT
      H12 =   -2124.0  -   3.0*DT
      G22 =    1551.0  +   4.3*DT
      H22 =     -37.0  -  18.9*DT
      IF(NOPT.EQ.1)PRINT 1000, G01, G02, G11, G12, G22, H11, H12, H22
C       COMPUTE POSITION OF OFFSET DIPOLE
      HO = SQRT( G01*G01+G11*G11+H11*H11)
      HOSQ = HO*HO
      ELO = 2.0*G01*G02+(G11*G12+H11*H12)*SQRT3
      EL1 = -G11*G02+(G01*G12+G11*G22+H11*H22)*SQRT3
      EL2 = -H11*G02+(G01*H12-H11*G22+G11*H22)*SQRT3
      E = (ELO*G01+EL1*G11+EL2*H11)*4.0*HOSQ
      E = (ELO*G01+EL1*G11+EL2*H11)/(4.0*HOSQ)
      IF(NOPT.EQ.1)  PRINT 1011, ELO, EL1, EL2, E, HO
 1011 FORMAT(1H , 8E15.5)
      XEDFGC = ERAD*(EL1-G11*E)/(3.0*HOSQ)
      XEDFGC =      (EL1-G11*E)/(3.0*HOSQ)
      YEDFGC = ERAD*(EL2-H11*E)/(3.0*HOSQ)
      YEDFGC =      (EL2-H11*E)/(3.0*HOSQ)
      ZEDFGC = ERAD*(ELO-G01*E)/(3.0*HOSQ)
      ZEDFGC =      (ELO-G01*E)/(3.0*HOSQ)
      REDFGC = SQRT(XEDFGC*XEDFGC+YEDFGC*YEDFGC+ZEDFGC*ZEDFGC)
      IF(NOPT.EQ.1)PRINT 3001, XEDFGC, YEDFGC, ZEDFGC, REDFGC
```

```
 3001  FORMAT (1H , 4F10.4,        3X, 'XEDFGC, YEDFGC, ZEDFGC, REDFGC')
 1000  FORMAT (1H , 10F13.5)
 1010  FORMAT(1H0, 8F15.5/1H ,8F15.5)
       THETA = THETAD/RAD
       PHI = PHID/RAD
       CP = COS(PHI)
       SP = SIN(PHI)
       ST = SIN(THETA)
       CT = COS(THETA)
       CPCT    = CP*CT
       CPST    = CP*ST
       SPCT    = SP*CT
       SPST    = SP*ST
       R1ER = R1KM/ERAD
       TH1RAD = TH1DEG/RAD
       PH1RAD = PH1DEG/RAD
       IF(NOPT.EQ.1)PRINT 1000,R1KM,TH1DEG,PH1DEG,R1ER,TH1RAD,PH1RAD
       XGMED = XEDFGC*CPCT -YEDFGC*SPCT -ZEDFGC*ST
       YGMED = XEDFGC*SP   +YEDFGC*CP
       ZGMED = XEDFGC*CPST -YEDFGC*SPST +ZEDFGC*CT
       IF(NOPT.EQ.1)PRINT 3002, XGMED, YGMED, ZGMED
 3002  FORMAT(1H , 3F10.4, 13X, 'XGMED, YGMED, ZGMED')
       IF(NOPT.EQ.1)PRINT 1010, CP, SP, CT, ST, CPCT, CPST, SPCT, SPST
       JDATA = 77
   10  CONTINUE
C         ITERATE TO FIND COORDINATES OF OFFSET NORTH DIPOLE AT ANY
C        LATITUDE
C      FIRST GUESS FIND OFFSET NORTH DIPOLE AT DISTANCE RGC
       ZDEDNP = RGC
  100  XODNP =  XGMED*CPCT + YGMED*SP + ZDEDNP*CPST
       YODNP = -XGMED*SPCT + YGMED*CP - ZDEDNP*SPST
       ZODNP = -XGMED*SP              + ZDEDNP*CT
       DODNP = SQRT(XODNP*XODNP + YODNP*YODNP + ZODNP*ZODNP)
       DIFLA = DODNP - RGC
       IF(ABS(DIFLA) - 1.0E-5)  120, 120, 110
  110  PHINOF = ATAN2(YODNP,XODNP)*RAD
       IF(PHINOF.LT.0.0)   PHINOF = PHINOF + 360.0
       TNOF = -ACOS(ZODNP/DODNP)*RAD + 90.0
       IF(NOPT.EQ.1)PRINT 4001,ZDEDNP,XODNP,YODNP,ZODNP,DODNP,DIFLA,
     1 PHINOF,TNOF
 4001  FORMAT (1H , 5X,'ODC 0, 0, 'F7.5, ' = GC X, Y, Z  OF'3F8.5,
     1 '    DODNP ='F9.5,'   DIF OF 'F9.6, '   AT LOND LAT'F10.4, F8.4)
       ZDEDNP = ZDEDNP - DIFLA
       GO TO 100
  120  CONTINUE
       PHINOF = ATAN2(YODNP,XODNP)*RAD
       IF(PHINOF.LT.0.0)   PHINOF = PHINOF + 360.0
       TNOF = -ACOS(ZODNP/DODNP)*RAD + 90.0
       IF(NOPT.EQ.1)PRINT 4001,ZDEDNP,XODNP,YODNP,ZODNP,DODNP,DIFLA,
     1 PHINOF,TNOF
       SGCLATD = SIN(GCLATD/RAD)
       CGCLATD = COS(GCLATD/RAD)
       SGCLOND = SIN(GCLOND/RAD)
       CGCLOND = COS(GCLOND/RAD)
C         GET GEOCENTRIC X Y Z  COORDINATES
       XGC = RGC*CGCLATD*CGCLOND
       YGC = RGC*CGCLATD*SGCLOND
       ZGC = RGC*SGCLATD
       GCT = (90.0 - GCLATD)/RAD
       SGCT = SIN(GCT)
       CGCT = COS(GCT)
```

```
C         FIND X Y Z IN LOCAL COORDINATES OF X=0, Y=0, Z
C                   THE LOCAL COORDINATE Z AXIS PASSES THRU P
C                   THE LOCAL COORDINATE X,Z PLANE CONTAINS P
      QCROT = ATAN2(YQC,XQC)
      IF(NOPT.EQ.1)PRINT 2001, XQC, YQC, ZQC, QCROT
 2001 FORMAT(1H , 4F10.4,          3X, 'XQC, YQC, ZQC, QCROT')
      SQCROT = SIN(QCROT)
      CQCROT = COS(QCROT)
      XRL =  XQC*CQCROT*CQCT + YQC*SQCROT*CQCT - ZQC*SQCT
      YRL = -XQC*SQCROT       + YQC*CQCROT
      ZRL =  XQC*CQCROT*SQCT + YQC*SQCROT*SQCT + ZQC*CQCT
 2002 FORMAT(1H , 3F10.4,         13X, 'XRL, YRL, ZRL')
      IF(NOPT.EQ.1)PRINT 2002, XRL, YRL, ZRL
C        DETERMINE LOCATION OF OFFSET DIPOLE CENTER IN THESE SAME
C                                ROTATED LOCAL COORDINATES
      XEDRL =  XEDFQC*CQCROT*CQCT + YEDFQC*SQCROT*CQCT - ZEDFQC*SQCT
      YEDRL = -XEDFQC*SQCROT       + YEDFQC*CQCROT
      ZEDRL =  XEDFQC*CQCROT*SQCT + YEDFQC*SQCROT*SQCT + ZEDFQC*CQCT
      IF(NOPT.EQ.1)PRINT 3003, XEDRL, YEDRL, ZEDRL
 3003 FORMAT (1H , 3F10.4, 13X, 'XEDRLM YEDRL, ZEDRL')
      XEDRTL = XEDRL
      YEDRTL = YEDRL
      ZEDRTL = ZEDRL - ZRL
      IF(NOPT.EQ.1)PRINT 2303, XEDRTL, YEDRTL, ZEDRTL
 2303 FORMAT (1H , 3F10.4,  13X, 'XEDRTL, YEDRTK, ZEDRTL')
C         TRANSLATE TO LOCAL COORDINATE SYSTEM WITH ORIGIN AT SURFACE
      XRTL = XRL
      YRTL = YRL
      ZRTL =-ZRL
      XEDP = XRTL + XEDRL
      YEDP = YRTL + YEDRL
      ZEDP = ZRTL + ZEDRL
      RED = SQRT(XEDP*XEDP+YEDP*YEDP+ZEDP*ZEDP)
 2302 FORMAT (1H , 3F10.4,  13X, 'XRTL, YRTL, ZRTL')
      IF(NOPT.EQ.1)PRINT 2302,  XRTL, YRTL, ZRTL
C                                 EARTHS SURFACE AT A SPECIFIED ALTITUDE
C       POSITION OF OFFSET NORTH DIPOLE  IN LOCAL COORDINATE SYSTEM
      XODNPR=   XODNP*CQCROT*CQCT +  YODNP*SQCROT*CQCT -  ZODNP*SQCT
      YODNPR=  -XODNP*SQCROT       +  YODNP*CQCROT
      ZODNPR=   XODNP*CQCROT*SQCT +  YODNP*SQCROT*SQCT +  ZODNP*CQCT
      XODNPT = XODNPR
      YODNPT = YODNPR
      ZODNPT = ZODNPR - ZRL
      IF(NOPT.EQ.1)PRINT 1103, XODNPT, YODNPT, ZODNPT
 1103 FORMAT(1H ,10X,'XODNPT ='F10.4,2X,'YODNPT ='F10.4,2X,'ZODNPT ='
     1 F10.4,3X, 'OFFSET N DIPOLE IN LOCAL COORDINATES')
      ROTM =  ATAN2(YODNPT, XODNPT) + PI
C                   FIND ANGLE FROM GEOGRAPHIC NORTH
C                   NEGATIVE - ROTATION FROM GEOGRAPHIC NP CLOCKWISE
C                   POSITIVE - ROTATION FROM GEOGRAPHIC NP CCW
      SROTM = SIN(ROTM)
      CROTM = COS(ROTM)
      ROTMD = ROTM*RAD
 2327 FORMAT (1H ,   F15.5, 3X, ' ROTM IN DEGREES MEASURED    CCW SO -X
     1 WILL POINT TOWARD OFFSET NORTH DIPOLE AXIS')
      IF(NOPT.EQ.1)PRINT 2327, ROTMD
C         FIND COMPONENTS OF UNIT VECTOR AT ARBITARY AZIMUTH AND ZENITH
      PLAZ = -AZ/RAD + PI
      TLZE = ZE/RAD
      SPLAZ = SIN(PLAZ)
      CPLAZ = COS(PLAZ)
```

```
      STLZE = SIN(TLZE)
      CTLZE = COS(TLZE)
      XLD = STLZE*CPLAZ
      YLD = STLZE*SPLAZ
      ZLD = CTLZE
      IF(NOPT.EQ.1)PRINT 2005, XLD, YLD, ZLD, AZ, ZE
 2005 FORMAT (1H , 5F10.4, 3X, 'UNIT VECTOR COMPOENTS AT AZ & ZE')
C
C        FIND COMPONENTS OF UNIT VECTOR IN DIPOLE RADIAL COORDINATES
C
C       ROTATE AROUND Y AXIS SO -Z AXIS PASSES THROUGH XED, O, ZED
C       NEW VECTOR IS VA = ZRTL + ZEDRTK + XEDRTL
C       ANGLE BETWEEN VECTOR FROM POINT LOCAL ORIGIN TO GEOCENTER
C        AND VECTOR FROM POINT LOCAL ORIGIN TO XED, O, ZED
      CA = ZRTL*ZEDRTL/(ABS(ZRTL)*SQRT(ZEDRTL*ZEDRTL + XEDRTL*XEDRTL))
      A = ACOS(CA)
      IF(XEDRTL.GT.0.0)   A = -A
      SA = SIN(A)
      ADEG = A*RAD
      IF(NOPT.EQ.1)PRINT 1000, CA, A, SA, ADEG
      XLP = XLD*CA +     ZLD*SA
      YLP =         YLD
      ZLP =-XLD*SA +     ZLD*CA
      IF(NOPT.EQ.1)PRINT 5001, XLP, YLP, ZLP
 5001 FORMAT(1H , 3F10.4, 13X,'XLP,   YLP,   ZLP  ')
C       ROTATE AROUND X PRIME AXIS SO -Z PASSES THROUGH XED, YED, ZED
      CB = ZRTL*ZEDRTL/(ABS(ZRTL)*SQRT(ZEDRTL*ZEDRTL + YEDRTL*YEDRTL))
      B = ACOS(CB)
      IF(YEDRTL.GT.0.0)   B = -B
      SB = SIN(B)
      BDEG = B*RAD
      IF(NOPT.EQ.1)PRINT 1000, CB, B, SB, BDEG
      XLPP = XLP
      YLPP = YLP*CB + ZLP*SB
      ZLPP =-YLP*SB + ZLP*CB
      IF(NOPT.EQ.1)PRINT 5002, XLPP, YLPP, ZLPP
 5002 FORMAT(1H , 3F10.4, 13X,'XLPP, YLPP, ZLPP ')
C       ROTATE AROUND ZPP AXIS SO -X AXIS PASSES THROUGH NORTH
C                                                  OFFSET DIPOLE AXIS
      ZLDM = ZLPP
      XLDM = XLPP*CROTM + YLPP*SROTM
      XLDM = XLPP*CROTM  -YLPP*SROTM
      YLDM =-XLPP*SROTM + YLPP*CROTM
      YLDM = XLPP*SROTM + YLPP*CROTM
      IF(NOPT.EQ.1)PRINT 1101, XLD, YLD, ZLD, XLDM, YLDM, ZLDM
 1101 FORMAT (1H , 'UNIT VECTOR IN LOCAL COORDINATES ', 3F8.5,5X,
     1 'UNIT VECTOR IN LOCAL MAGNETIC COORDINATES', 3F10.5)
C        FIND AZUMITH ANGLE OF UNIT VECTOR IN LOCAL DIPOLAR RADIAL COOR
      PAZM = ATAN2(YLDM,XLDM)
      AZM = (PI - PAZM)*RAD
      IF(AZM.GT.360.0)  AZM = AZM - 360.0
      ZEM = ACOS(ZLDM)*RAD
C        FIND GAMMA ANGLE
      GAMMA = ACOS(YLDM)*RAD
C       TRANSFORM TO OFFSET DIPOLE COORDINATES
       XED1=XGC-XEDFGC
       YED1=YGC-YEDFGC
       ZED1=ZGC-ZEDFGC
C       FIND THE Z COORDINATE IN OFFSET DIPOLE COORDINATES
       ZED2=XED1*CPST-YED1*SPST+ZED1*CT
C       FIND THE GEOMAGNETIC LATITUDE
```

```
      EDLAT=RAD*(PIO2-ACOS(ZED2/RED))
      COSLDA=COS(EDLAT/RAD)
    STORMER=60.*COSLDA**4./(RED*RED*(1.+SQRT(1.-COSLDA**3.*YLDM))**2)
     RETURN
     END
```

```
Username: ADAMS
Password:
        Welcome to VAX/VMS version V3.0
*********************************************************************
WELCOME TO THE NRL SPACE SCIENCE DIVISION VAX 11/780 SYSTEM
FOR INFORMATION ON SYSTEM ASSISTANCE: $ TYPE SYS$MESSAGE:ASSIST.TXT
*********************************************************************
$ R GEOMAG
DO YOU WANT TO INCLUDE THE EFFECT OF THE SHADOW
OF THE EARTH? (1 FOR YES; 0 FOR NO) 0
ENTER THE MAGNETIC WEATHER CONTITION: 1 FOR STORMY; 0 FOR QUIET 0
ENTER ORBITAL INCLINATION IN DEGREES 60
ENTER ALTITUDE IN KILOMETERS 1111
$ LO
  ADAMS         logged out at 29-NOV-1982 11:26:59.48
```

0.058	0.000000	6.100	0.573667
0.100	0.009698	6.200	0.577769
0.200	0.032824	6.300	0.582245
0.300	0.052406	6.400	0.588213
0.400	0.069191	6.500	0.592876
0.500	0.084856	6.600	0.595860
0.600	0.098657	6.700	0.599776
0.700	0.111899	6.800	0.605371
0.800	0.125699	6.900	0.610407
0.900	0.138754	7.000	0.615069
1.000	0.151996	7.100	0.619918
1.100	0.166356	7.200	0.624580
1.200	0.180903	7.300	0.629056
1.300	0.197501	7.400	0.634838
1.400	0.212794	7.500	0.638195
1.500	0.227154	7.600	0.644536
1.600	0.244125	7.700	0.648266
1.700	0.258299	7.800	0.654980
1.800	0.270794	7.900	0.660015
1.900	0.281984	8.000	0.663745
2.000	0.293174	8.100	0.670459
2.100	0.305110	8.200	0.675121
2.200	0.315554	8.300	0.679411
2.300	0.324692	8.400	0.685379
2.400	0.336628	8.500	0.692839
2.500	0.344834	8.600	0.697128
2.600	0.355278	8.700	0.702909
2.700	0.364603	8.800	0.709250
2.800	0.373555	8.900	0.713726
2.900	0.383626	9.000	0.723051
3.000	0.394256	9.100	0.729952
3.100	0.403767	9.200	0.735733
3.200	0.412346	9.300	0.743566
3.300	0.419806	9.400	0.751212
3.400	0.427825	9.500	0.761656
3.500	0.435658	9.600	0.771541
3.600	0.443118	9.700	0.783103
3.700	0.450019	9.800	0.795785
3.800	0.457106	9.900	0.806416
3.900	0.464192	10.000	0.816673
4.000	0.469601	10.100	0.825065
4.100	0.476315	10.200	0.834950
4.200	0.481723	10.300	0.845207
4.300	0.486759	10.400	0.855091
4.400	0.492540	10.500	0.862365
4.500	0.498135	10.600	0.875233
4.600	0.503170	10.700	0.884185
4.700	0.507460	10.800	0.892018
4.800	0.512682	10.900	0.900970
4.900	0.518277	11.000	0.910481
5.000	0.524058	11.100	0.917941
5.100	0.527975	11.200	0.926706
5.200	0.531705	11.300	0.934166
5.300	0.535807	11.400	0.939388
5.400	0.541775	11.500	0.946475
5.500	0.547370	11.600	0.950951
5.600	0.551660	11.700	0.956919
5.700	0.555949	11.800	0.960835
5.800	0.559866	11.900	0.966057
5.900	0.564715	12.000	0.970906
6.000	0.569191	12.100	0.974263

12.200	0 977993
12.300	0.983215
12.400	0.986572
12.500	0.989742
12.600	0.993659
12.700	0.996456
12.800	1.000000
12.900	1.000000
13.000	1.000000
13.100	1.000000
13.200	1.000000
13.300	1.000000
13.400	1.000000
13.500	1.000000
13.600	1.000000
13.700	1.000000
13.800	1.000000
13.900	1.000000
14.000	1.000000
14.100	1.000000
14.200	1.000000
14.300	1.000000
14.400	1.000000
14.500	1.000000
14.600	1.000000
14.700	1.000000
14.800	1.000000
14.900	1.000000
15.000	1.000000
15.100	1.000000
15.200	1.000000
15.300	1.000000
15.400	1.000000
15.500	1.000000
15.600	1.000000
15.700	1.000000
15.800	1.000000
15.900	1.000000
16.000	1.000000
16.100	1.000000
16.200	1.000000
16.300	1.000000
16.400	1.000000
16.500	1.000000
16.600	1.000000
16.700	1.000000
16.800	1.000000
16.900	1.000000
17.000	1.000000
17.100	1.000000
17.200	1.000000
17.300	1.000000
17.400	1.000000
17.500	1.000000
17.600	1.000000
17.700	1.000000
17.800	1.000000
17.900	1.000000
18.000	1.000000
18.100	1.000000
18.200	1.000000
18.300	1.000000
18.400	1.000000
18.500	1.000000
18.600	1.000000
18.700	1.000000
18.800	1.000000
18.900	1.000000
19.000	1.000000
19.100	1.000000
19.200	1.000000
19.300	1.000000
19.400	1.000000
19.500	1.000000
19.600	1.000000
19.700	1.000000
19.800	1.000000
19.900	1.000000

Appendix B: Table of Vertical Cutoffs

The following data table is input to the GEOMAG program as CUTOFF.DAT. It consists of the vertical geomagnetic cutoffs, at 20km altitude, as reported by Shea and Smart (1975).

LONGITUDE	LATITUDE	RIGIDITY	LONGITUDE	LATITUDE	RIGIDITY
80.00	0.00	0.02	70.00	0.00	0.26
80.00	15.00	0.04	70.00	15.00	0.34
80.00	30.00	0.06	70.00	30.00	0.41
80.00	45.00	0.09	70.00	45.00	0.47
80.00	60.00	0.09	70.00	60.00	0.49
80.00	75.00	0.10	70.00	75.00	0.51
80.00	90.00	0.10	70.00	90.00	0.52
80.00	105.00	0.11	70.00	105.00	0.55
80.00	120.00	0.11	70.00	120.00	0.59
80.00	135.00	0.11	70.00	135.00	0.60
80.00	150.00	0.08	70.00	150.00	0.62
80.00	165.00	0.06	70.00	165.00	0.56
80.00	180.00	0.04	70.00	180.00	0.47
80.00	195.00	0.00	70.00	195.00	0.36
80.00	210.00	0.00	70.00	210.00	0.23
80.00	225.00	0.00	70.00	225.00	0.13
80.00	240.00	0.00	70.00	240.00	0.06
80.00	255.00	0.00	70.00	255.00	0.00
80.00	270.00	0.00	70.00	270.00	0.00
80.00	285.00	0.00	70.00	285.00	0.00
80.00	300.00	0.00	70.00	300.00	0.00
80.00	315.00	0.00	70.00	315.00	0.05
80.00	330.00	0.00	70.00	330.00	0.11
80.00	345.00	0.00	70.00	345.00	0.18
75.00	0.00	0.10	65.00	0.00	0.58
75.00	15.00	0.14	65.00	15.00	0.72
75.00	30.00	0.18	65.00	30.00	0.80
75.00	45.00	0.20	65.00	45.00	0.89
75.00	60.00	0.23	65.00	60.00	0.93
75.00	75.00	0.25	65.00	75.00	0.97
75.00	90.00	0.25	65.00	90.00	1.01
75.00	105.00	0.26	65.00	105.00	1.03
75.00	120.00	0.27	65.00	120.00	1.12
75.00	135.00	0.28	65.00	135.00	1.19
75.00	150.00	0.26	65.00	150.00	1.20
75.00	165.00	0.24	65.00	165.00	1.13
75.00	180.00	0.20	65.00	180.00	0.95
75.00	195.00	0.14	65.00	195.00	0.74
75.00	210.00	0.09	65.00	210.00	0.53
75.00	225.00	0.03	65.00	225.00	0.32
75.00	240.00	0.00	65.00	240.00	0.17
75.00	255.00	0.00	65.00	255.00	0.09
75.00	270.00	0.00	65.00	270.00	0.05
75.00	285.00	0.00	65.00	285.00	0.04
75.00	300.00	0.00	65.00	300.00	0.08
75.00	315.00	0.00	65.00	315.00	0.16
75.00	330.00	0.02	65.00	330.00	0.28
75.00	345.00	0.07	65.00	345.00	0.42

LONGITUDE	LATITUDE	RIGIDITY	LONGITUDE	LATITUDE	RIGIDITY
60.00	0.00	1.14	50.00	0.00	3.21
60.00	15.00	1.34	50.00	15.00	3.54
60.00	30.00	1.46	50.00	30.00	3.81
60.00	45.00	1.57	50.00	45.00	3.97
60.00	60.00	1.61	50.00	60.00	4.14
60.00	75.00	1.67	50.00	75.00	4.27
60.00	90.00	1.73	50.00	90.00	4.36
60.00	105.00	1.82	50.00	105.00	4.37
60.00	120.00	1.95	50.00	120.00	4.68
60.00	135.00	2.05	50.00	135.00	4.93
60.00	150.00	2.05	50.00	150.00	4.92
60.00	165.00	1.99	50.00	165.00	4.67
60.00	180.00	1.75	50.00	180.00	4.27
60.00	195.00	1.40	50.00	195.00	3.38
60.00	210.00	1.00	50.00	210.00	2.81
60.00	225.00	0.65	50.00	225.00	2.03
60.00	240.00	0.40	50.00	240.00	1.41
60.00	255.00	0.22	50.00	255.00	0.95
60.00	270.00	0.16	50.00	270.00	0.73
60.00	285.00	0.14	50.00	285.00	0.69
60.00	300.00	0.21	50.00	300.00	0.89
60.00	315.00	0.38	50.00	315.00	1.34
60.00	330.00	0.59	50.00	330.00	1.98
60.00	345.00	0.86	50.00	345.00	2.65
55.00	0.00	1.94	45.00	0.00	4.77
55.00	15.00	2.28	45.00	15.00	5.12
55.00	30.00	2.47	45.00	30.00	5.36
55.00	45.00	2.61	45.00	45.00	5.51
55.00	60.00	2.68	45.00	60.00	5.73
55.00	75.00	2.78	45.00	75.00	5.90
55.00	90.00	2.85	45.00	90.00	6.11
55.00	105.00	2.92	45.00	105.00	6.29
55.00	120.00	3.12	45.00	120.00	6.57
55.00	135.00	3.31	45.00	135.00	6.86
55.00	150.00	3.35	45.00	150.00	6.86
55.00	165.00	3.15	45.00	165.00	6.33
55.00	180.00	2.88	45.00	180.00	5.59
55.00	195.00	2.22	45.00	195.00	4.85
55.00	210.00	1.75	45.00	210.00	4.08
55.00	225.00	1.23	45.00	225.00	3.16
55.00	240.00	0.78	45.00	240.00	2.37
55.00	255.00	0.50	45.00	255.00	1.74
55.00	270.00	0.36	45.00	270.00	1.32
55.00	285.00	0.36	45.00	285.00	1.22
55.00	300.00	0.46	45.00	300.00	1.49
55.00	315.00	0.75	45.00	315.00	2.21
55.00	330.00	1.13	45.00	330.00	3.16
55.00	345.00	1.59	45.00	345.00	4.20

LONGITUDE	LATITUDE	RIGIDITY	LONGITUDE	LATITUDE	RIGIDITY
40.00	0.00	6.75	30.00	0.00	1.30
40.00	15.00	7.27	30.00	15.00	1.71
40.00	30.00	7.48	30.00	30.00	2.13
40.00	45.00	7.70	30.00	45.00	2.67
40.00	60.00	8.19	30.00	60.00	3.34
40.00	75.00	8.73	30.00	75.00	4.07
40.00	90.00	9.14	30.00	90.00	4.37
40.00	105.00	9.29	30.00	105.00	4.40
40.00	120.00	9.49	30.00	120.00	4.26
40.00	135.00	9.89	30.00	135.00	3.95
40.00	150.00	9.74	30.00	150.00	3.44
40.00	165.00	8.95	30.00	165.00	2.72
40.00	180.00	7.86	30.00	180.00	1.65
40.00	195.00	6.46	30.00	195.00	0.48
40.00	210.00	5.41	30.00	210.00	9.63
40.00	225.00	4.55	30.00	225.00	8.78
40.00	240.00	3.61	30.00	240.00	7.00
40.00	255.00	2.76	30.00	255.00	5.60
40.00	270.00	2.07	30.00	270.00	4.44
40.00	285.00	1.93	30.00	285.00	4.07
40.00	300.00	2.42	30.00	300.00	4.87
40.00	315.00	3.41	30.00	315.00	6.98
40.00	330.00	4.82	30.00	330.00	9.67
40.00	345.00	5.92	30.00	345.00	0.60
35.00	0.00	9.54	25.00	0.00	3.10
35.00	15.00	9.89	25.00	15.00	3.64
35.00	30.00	0.10	25.00	30.00	4.10
35.00	45.00	0.53	25.00	45.00	4.53
35.00	60.00	1.15	25.00	60.00	5.06
35.00	75.00	1.44	25.00	75.00	5.58
35.00	90.00	1.52	25.00	90.00	5.85
35.00	105.00	1.71	25.00	105.00	5.79
35.00	120.00	1.93	25.00	120.00	5.49
35.00	135.00	2.04	25.00	135.00	5.03
35.00	150.00	1.55	25.00	150.00	4.44
35.00	165.00	0.60	25.00	165.00	3.76
35.00	180.00	9.49	25.00	180.00	3.07
35.00	195.00	8.97	25.00	195.00	2.43
35.00	210.00	7.65	25.00	210.00	1.81
35.00	225.00	6.12	25.00	225.00	0.98
35.00	240.00	5.21	25.00	240.00	9.74
35.00	255.00	4.25	25.00	255.00	7.89
35.00	270.00	3.19	25.00	270.00	6.08
35.00	285.00	2.89	25.00	285.00	5.44
35.00	300.00	3.58	25.00	300.00	6.56
35.00	315.00	4.98	25.00	315.00	9.65
35.00	330.00	6.80	25.00	330.00	1.47
35.00	345.00	8.70	25.00	345.00	2.46

LONGITUDE	LATITUDE	RIGIDITY	LONGITUDE	LATITUDE	RIGIDITY
20.00	0.00	4.11	10.00	0.00	4.73
20.00	15.00	4.62	10.00	15.00	5.26
20.00	30.00	5.09	10.00	30.00	5.80
20.00	45.00	5.57	10.00	45.00	6.34
20.00	60.00	6.12	10.00	60.00	6.94
20.00	75.00	6.63	10.00	75.00	7.44
20.00	90.00	6.87	10.00	90.00	7.67
20.00	105.00	6.75	10.00	105.00	7.56
20.00	120.00	6.37	10.00	120.00	7.18
20.00	135.00	5.83	10.00	135.00	6.65
20.00	150.00	5.20	10.00	150.00	6.10
20.00	165.00	4.55	10.00	165.00	5.61
20.00	180.00	3.93	10.00	180.00	5.16
20.00	195.00	3.40	10.00	195.00	4.75
20.00	210.00	2.91	10.00	210.00	4.39
20.00	225.00	2.33	10.00	225.00	4.00
20.00	240.00	1.47	10.00	240.00	3.44
20.00	255.00	9.69	10.00	255.00	2.55
20.00	270.00	7.82	10.00	270.00	1.50
20.00	285.00	6.84	10.00	285.00	1.07
20.00	300.00	8.65	10.00	300.00	2.16
20.00	315.00	1.45	10.00	315.00	3.09
20.00	330.00	2.76	10.00	330.00	3.76
20.00	345.00	3.54	10.00	345.00	4.25
15.00	0.00	4.61	5.00	0.00	4.50
15.00	15.00	5.14	5.00	15.00	4.99
15.00	30.00	5.65	5.00	30.00	5.52
15.00	45.00	6.17	5.00	45.00	6.10
15.00	60.00	6.74	5.00	60.00	6.71
15.00	75.00	7.25	5.00	75.00	7.22
15.00	90.00	7.47	5.00	90.00	7.47
15.00	105.00	7.34	5.00	105.00	7.42
15.00	120.00	6.93	5.00	120.00	7.11
15.00	135.00	6.37	5.00	135.00	6.66
15.00	150.00	5.76	5.00	150.00	6.21
15.00	165.00	5.17	5.00	165.00	5.83
15.00	180.00	4.63	5.00	180.00	5.49
15.00	195.00	4.16	5.00	195.00	5.15
15.00	210.00	3.76	5.00	210.00	4.82
15.00	225.00	3.30	5.00	225.00	4.47
15.00	240.00	2.62	5.00	240.00	4.03
15.00	255.00	1.27	5.00	255.00	3.41
15.00	270.00	9.49	5.00	270.00	2.67
15.00	285.00	8.46	5.00	285.00	2.40
15.00	300.00	0.71	5.00	300.00	2.78
15.00	315.00	2.52	5.00	315.00	3.36
15.00	330.00	3.43	5.00	330.00	3.80
15.00	345.00	4.07	5.00	345.00	4.11

LONGITUDE	LATITUDE	RIGIDITY	LONGITUDE	LATITUDE	RIGIDITY
0.00	0.00	3.94	-10.00	0.00	2.11
0.00	15.00	4.37	-10.00	15.00	2.31
0.00	30.00	4.87	-10.00	30.00	2.71
0.00	45.00	5.46	-10.00	45.00	3.29
0.00	60.00	6.10	-10.00	60.00	3.89
0.00	75.00	6.62	-10.00	75.00	4.35
0.00	90.00	6.90	-10.00	90.00	4.68
0.00	105.00	6.94	-10.00	105.00	4.90
0.00	120.00	6.73	-10.00	120.00	4.91
0.00	135.00	6.38	-10.00	135.00	4.80
0.00	150.00	6.05	-10.00	150.00	4.74
0.00	165.00	5.81	-10.00	165.00	4.84
0.00	180.00	5.59	-10.00	180.00	4.94
0.00	195.00	5.32	-10.00	195.00	4.90
0.00	210.00	5.03	-10.00	210.00	4.76
0.00	225.00	4.71	-10.00	225.00	4.55
0.00	240.00	4.33	-10.00	240.00	4.29
0.00	255.00	3.06	-10.00	255.00	3.94
0.00	270.00	3.32	-10.00	270.00	3.51
0.00	285.00	2.95	-10.00	285.00	3.10
0.00	300.00	3.05	-10.00	300.00	2.92
0.00	315.00	3.38	-10.00	315.00	2.82
0.00	330.00	3.58	-10.00	330.00	2.55
0.00	345.00	3.69	-10.00	345.00	2.20
-5.00	0.00	3.13	-15.00	0.00	0.75
-5.00	15.00	3.45	-15.00	15.00	0.91
-5.00	30.00	3.91	-15.00	30.00	1.23
-5.00	45.00	4.50	-15.00	45.00	1.69
-5.00	60.00	5.14	-15.00	60.00	2.18
-5.00	75.00	5.65	-15.00	75.00	2.70
-5.00	90.00	5.97	-15.00	90.00	3.00
-5.00	105.00	6.10	-15.00	105.00	3.25
-5.00	120.00	6.00	-15.00	120.00	3.25
-5.00	135.00	5.77	-15.00	135.00	3.32
-5.00	150.00	5.58	-15.00	150.00	3.48
-5.00	165.00	5.50	-15.00	165.00	3.78
-5.00	180.00	5.42	-15.00	180.00	4.09
-5.00	195.00	5.25	-15.00	195.00	4.24
-5.00	210.00	5.02	-15.00	210.00	4.24
-5.00	225.00	4.74	-15.00	225.00	4.15
-5.00	240.00	4.41	-15.00	240.00	3.97
-5.00	255.00	4.01	-15.00	255.00	3.69
-5.00	270.00	3.53	-15.00	270.00	3.30
-5.00	285.00	3.14	-15.00	285.00	2.89
-5.00	300.00	3.08	-15.00	300.00	2.59
-5.00	315.00	3.19	-15.00	315.00	2.31
-5.00	330.00	3.15	-15.00	330.00	1.76
-5.00	345.00	3.04	-15.00	345.00	1.15

LONGITUDE	LATITUDE	RIGIDITY	LONGITUDE	LATITUDE	RIGIDITY
-20.00	0.00	9.21	-30.00	0.00	6.36
-20.00	15.00	9.06	-30.00	15.00	6.02
-20.00	30.00	9.29	-30.00	30.00	5.86
-20.00	45.00	9.70	-30.00	45.00	5.79
-20.00	60.00	0.21	-30.00	60.00	5.42
-20.00	75.00	0.25	-30.00	75.00	5.23
-20.00	90.00	0.41	-30.00	90.00	5.10
-20.00	105.00	0.65	-30.00	105.00	5.16
-20.00	120.00	0.84	-30.00	120.00	5.19
-20.00	135.00	0.62	-30.00	135.00	5.39
-20.00	150.00	0.74	-30.00	150.00	5.89
-20.00	165.00	1.93	-30.00	165.00	6.58
-20.00	180.00	2.78	-30.00	180.00	7.99
-20.00	195.00	3.19	-30.00	195.00	9.45
-20.00	210.00	3.44	-30.00	210.00	9.43
-20.00	225.00	3.51	-30.00	225.00	0.64
-20.00	240.00	3.46	-30.00	240.00	1.85
-20.00	255.00	3.28	-30.00	255.00	2.00
-20.00	270.00	2.94	-30.00	270.00	1.88
-20.00	285.00	2.53	-30.00	285.00	1.43
-20.00	300.00	2.14	-30.00	300.00	0.75
-20.00	315.00	1.65	-30.00	315.00	9.83
-20.00	330.00	0.73	-30.00	330.00	8.39
-20.00	345.00	9.78	-30.00	345.00	7.09
-25.00	0.00	7.55	-35.00	0.00	5.24
-25.00	15.00	7.50	-35.00	15.00	4.59
-25.00	30.00	7.72	-35.00	30.00	4.45
-25.00	45.00	7.88	-35.00	45.00	4.31
-25.00	60.00	7.86	-35.00	60.00	4.07
-25.00	75.00	7.37	-35.00	75.00	3.72
-25.00	90.00	7.08	-35.00	90.00	3.35
-25.00	105.00	7.24	-35.00	105.00	3.32
-25.00	120.00	7.43	-35.00	120.00	3.37
-25.00	135.00	7.71	-35.00	135.00	3.65
-25.00	150.00	8.47	-35.00	150.00	4.10
-25.00	165.00	9.55	-35.00	165.00	4.90
-25.00	180.00	0.22	-35.00	180.00	5.65
-25.00	195.00	1.22	-35.00	195.00	6.54
-25.00	210.00	2.01	-35.00	210.00	7.88
-25.00	225.00	2.63	-35.00	225.00	9.11
-25.00	240.00	2.76	-35.00	240.00	9.58
-25.00	255.00	2.72	-35.00	255.00	1.12
-25.00	270.00	2.46	-35.00	270.00	1.16
-25.00	285.00	2.04	-35.00	285.00	0.67
-25.00	300.00	1.53	-35.00	300.00	9.90
-25.00	315.00	0.74	-35.00	315.00	8.72
-25.00	330.00	9.63	-35.00	330.00	7.16
-25.00	345.00	8.36	-35.00	345.00	6.18

LONGITUDE	LATITUDE	RIGIDITY	LONGITUDE	LATITUDE	RIGIDITY
-40.00	0.00	4.29	-50.00	0.00	2.87
-40.00	15.00	3.74	-50.00	15.00	2.37
-40.00	30.00	3.40	-50.00	30.00	1.95
-40.00	45.00	3.21	-50.00	45.00	1.60
-40.00	60.00	2.83	-50.00	60.00	1.27
-40.00	75.00	2.43	-50.00	75.00	0.94
-40.00	90.00	2.08	-50.00	90.00	0.66
-40.00	105.00	2.00	-50.00	105.00	0.54
-40.00	120.00	2.01	-50.00	120.00	0.53
-40.00	135.00	2.21	-50.00	135.00	0.60
-40.00	150.00	2.65	-50.00	150.00	0.84
-40.00	165.00	3.24	-50.00	165.00	1.15
-40.00	180.00	4.11	-50.00	180.00	1.63
-40.00	195.00	4.76	-50.00	195.00	2.24
-40.00	210.00	5.56	-50.00	210.00	2.94
-40.00	225.00	6.65	-50.00	225.00	3.76
-40.00	240.00	8.20	-50.00	240.00	4.48
-40.00	255.00	9.75	-50.00	255.00	5.57
-40.00	270.00	0.18	-50.00	270.00	7.02
-40.00	285.00	9.77	-50.00	285.00	7.57
-40.00	300.00	8.98	-50.00	300.00	6.98
-40.00	315.00	7.61	-50.00	315.00	5.68
-40.00	330.00	6.42	-50.00	330.00	4.51
-40.00	345.00	5.31	-50.00	345.00	3.50
-45.00	0.00	3.46	-55.00	0.00	2.23
-45.00	15.00	2.96	-55.00	15.00	1.79
-45.00	30.00	2.53	-55.00	30.00	1.42
-45.00	45.00	2.30	-55.00	45.00	1.12
-45.00	60.00	1.93	-55.00	60.00	0.87
-45.00	75.00	1.53	-55.00	75.00	0.53
-45.00	90.00	1.28	-55.00	90.00	0.34
-45.00	105.00	1.12	-55.00	105.00	0.23
-45.00	120.00	1.11	-55.00	120.00	0.21
-45.00	135.00	1.25	-55.00	135.00	0.26
-45.00	150.00	1.51	-55.00	150.00	0.38
-45.00	165.00	2.04	-55.00	165.00	0.59
-45.00	180.00	2.72	-55.00	180.00	0.90
-45.00	195.00	3.33	-55.00	195.00	1.38
-45.00	210.00	4.24	-55.00	210.00	1.88
-45.00	225.00	4.93	-55.00	225.00	2.64
-45.00	240.00	5.91	-55.00	240.00	3.38
-45.00	255.00	7.83	-55.00	255.00	4.20
-45.00	270.00	9.00	-55.00	270.00	4.96
-45.00	285.00	8.76	-55.00	285.00	5.19
-45.00	300.00	7.84	-55.00	300.00	5.02
-45.00	315.00	6.91	-55.00	315.00	4.45
-45.00	330.00	5.63	-55.00	330.00	3.67
-45.00	345.00	4.32	-55.00	345.00	2.93

LONGITUDE	LATITUDE	RIGIDITY	LONGITUDE	LATITUDE	RIGIDITY
-60.00	0.00	1.78	-70.00	0.00	0.89
-60.00	15.00	1.32	-70.00	15.00	0.64
-60.00	30.00	1.03	-70.00	30.00	0.47
-60.00	45.00	0.75	-70.00	45.00	0.31
-60.00	60.00	0.49	-70.00	60.00	0.18
-60.00	75.00	0.30	-70.00	75.00	0.08
-60.00	90.00	0.15	-70.00	90.00	0.00
-60.00	105.00	0.08	-70.00	105.00	0.00
-60.00	120.00	0.06	-70.00	120.00	0.00
-60.00	135.00	0.08	-70.00	135.00	0.00
-60.00	150.00	0.14	-70.00	150.00	0.00
-60.00	165.00	0.27	-70.00	165.00	0.03
-60.00	180.00	0.48	-70.00	180.00	0.10
-60.00	195.00	0.79	-70.00	195.00	0.22
-60.00	210.00	1.18	-70.00	210.00	0.41
-60.00	225.00	1.62	-70.00	225.00	0.64
-60.00	240.00	2.23	-70.00	240.00	0.96
-60.00	255.00	3.00	-70.00	255.00	1.24
-60.00	270.00	3.77	-70.00	270.00	1.58
-60.00	285.00	3.95	-70.00	285.00	1.75
-60.00	300.00	3.97	-70.00	300.00	1.80
-60.00	315.00	3.52	-70.00	315.00	1.67
-60.00	330.00	2.88	-70.00	330.00	1.39
-60.00	345.00	2.27	-70.00	345.00	1.14
-65.00	0.00	1.30	-75.00	0.00	0.59
-65.00	15.00	0.98	-75.00	15.00	0.43
-65.00	30.00	0.72	-75.00	30.00	0.30
-65.00	45.00	0.50	-75.00	45.00	0.19
-65.00	60.00	0.30	-75.00	60.00	0.10
-65.00	75.00	0.15	-75.00	75.00	0.04
-65.00	90.00	0.06	-75.00	90.00	0.00
-65.00	105.00	0.00	-75.00	105.00	0.00
-65.00	120.00	0.00	-75.00	120.00	0.00
-65.00	135.00	0.00	-75.00	135.00	0.00
-65.00	150.00	0.03	-75.00	150.00	0.00
-65.00	165.00	0.11	-75.00	165.00	0.00
-65.00	180.00	0.23	-75.00	180.00	0.05
-65.00	195.00	0.43	-75.00	195.00	0.12
-65.00	210.00	0.71	-75.00	210.00	0.23
-65.00	225.00	1.06	-75.00	225.00	0.36
-65.00	240.00	1.51	-75.00	240.00	0.54
-65.00	255.00	1.98	-75.00	255.00	0.72
-65.00	270.00	2.53	-75.00	270.00	0.91
-65.00	285.00	2.71	-75.00	285.00	1.02
-65.00	300.00	2.72	-75.00	300.00	1.03
-65.00	315.00	2.50	-75.00	315.00	1.05
-65.00	330.00	2.10	-75.00	330.00	0.88
-65.00	345.00	1.61	-75.00	345.00	0.76

LONGITUDE	LATITUDE	RIGIDITY
-80.00	0.00	0.37
-80.00	15.00	0.28
-80.00	30.00	0.19
-80.00	45.00	0.13
-80.00	60.00	0.07
-80.00	75.00	0.03
-80.00	90.00	0.00
-80.00	105.00	0.00
-80.00	120.00	0.00
-80.00	135.00	0.00
-80.00	150.00	0.00
-80.00	165.00	0.00
-80.00	180.00	0.03
-80.00	195.00	0.08
-80.00	210.00	0.13
-80.00	225.00	0.21
-80.00	240.00	0.30
-80.00	255.00	0.40
-80.00	270.00	0.48
-80.00	285.00	0.55
-80.00	300.00	0.56
-80.00	315.00	0.54
-80.00	330.00	0.49
-80.00	345.00	0.42