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THE PLASMA DATA FROM THE PIONEER-10 AND -11 PLASMA ANALYZER EXPERIMENT

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SECTION 1. INTRODUCTION

All the Pioneer-10 and -11 Plasma Analyzer Experiment data that were processed as of 10 September, 1983, have been collected onto two tapes, one for each spacecraft. This document provides the information necessary to use these tapes.

Section 2 describes the data, the processing they have undergone, and the resulting expected accuracy. The coordinate systems used in these tapes are explained in Section 2.3.1.

Section 3 gives information about the tapes, such as record size or tape density. A sample program to list items from the data records is included.

These tapes are available from the NSSDC. Microfiche plots of all parameters versus time have also been deposited with the NSSDC.

In case of questions about the tapes or the data records, contact:

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SECTION 2. THE DATA

The NASA/Ames plasma analyzers on Pioneer-10 and -11 have been described by Wolfe, et al., J. G. R. 79, 3489, 1974 and McKibben et al., Space Sci. Inst, 3, 219, 1977. Only the proton component of the solar wind has been successfully measured beyond about 1.5 AU, so the electron or helium components will not be discussed further.

2.1 The Time Intervals Covered by the Data

Because of the very large computer time devoured by the least-squares processing program, for many years after launch, only one sample per hour was processed. Collection time of a sample in the most common data mode is about 5 minutes. After 1978, the data tracking rate for the spacecraft was fairly low, so all samples obtained from 1978 on have been processed. Some intervals of particular interest before 1978 have also been fully processed. All data processed by the least-squares program as of 10 September, 1983, are included in these data sets.

2.1.1 Different Formats for the Date

For convenience all dates will be represented in one of two forms. The first is denoted by YYMMDD, a 6 digit integer of which the first two are the year - 1900, the next two are the month number, 1-12, and the last two are the day-of-month, 1-31. For example, 14 February, 1976 is 760214.

The second form is denoted by YYDDD and is somteimes called the "Julian Day." The first two digits are the year - 1900; the last three are the day-of-year, 1-365. Thus 14 February, 1976 is 76045.

2.1.2 Pioneer-10

Pioneer-10 was launched on 24 April, 1972, and encountered Jupiter in December, 1973. The trajectory is shown in Figure 2-1. The plasma data cover the interval from launch until 25 June, 1983 or 72109-83176. There are occasional data gaps of a month or less.

2.1.3 Pioneer-11

Pioneer-11 was launched on 6 April, 1973, encountering Jupiter in December, 1974 and Saturn in September, 1979. The trajectory is shown in Figure 2-1. The instrument was non-operational between April 1975 and December, 1977. A change in the bit rate in December, 1981 has caused processing problems which were not resolved as of September, 1983. The plasma data are for 21 April, 1973 - 12 April, 1975 and for 1 December 1977 - 6 December 1981, or 73111-75012 and 77335-81340. There are occasional data gaps of a month or less.

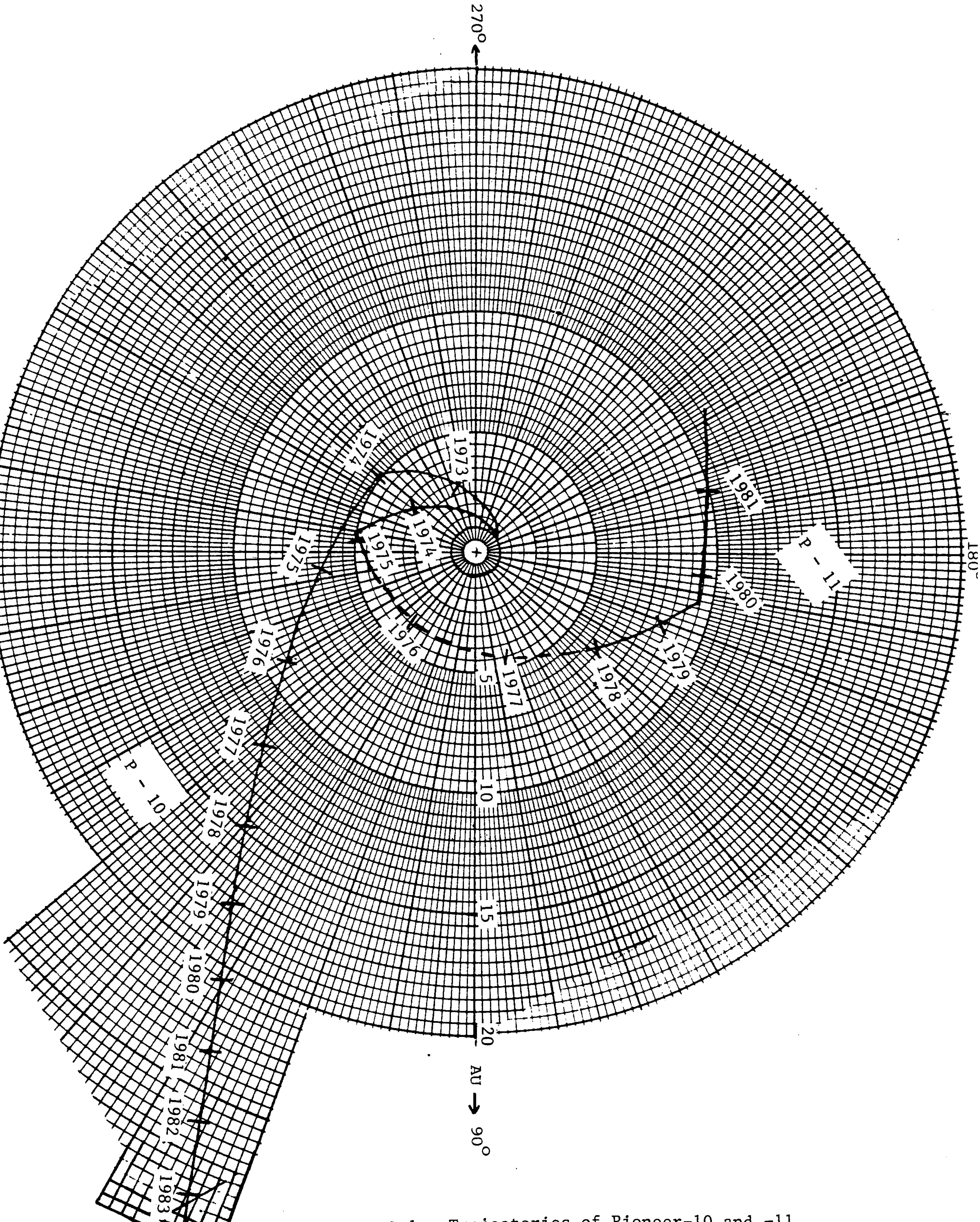

Figure 2-1. Trajectories of Pioneer-10 and -11

2.2 The Least-Square Processing

The raw data are fed into a computer program which fits them to a convecting isotropic Maxwellian distribution for protons. The output from this program are five parameters, the uncertainties associated with each parameter, and the "chi-square" of the fit. The five parameters are the proton bulk speed with respect to the spacecraft, temperature, density, and two angles oriented with respect to the spacecraft which give the direction of the bulk flow. The significance of the uncertainties is not entirely clear, since they are often negative. The "chi-square" ranges from 0. to over 1000., and very small values as well as very large values are obviously bad fits.

The algorithms in this program have been modified several times since inception of the program, especially to improve the ability to fit at low temperatures. No significant systematic differences were found in comparing parameters resulting from running identical input data with different versions of the program.

2.3 Additional Processing

The least-square parameters were collected into a single data set, sorted into chronological order, with duplicates removed. The bulk speed and instrument angles were corrected for the spacecraft velocity, and converted to the "inertial" coordinate system (SES) defined in Section 2.3.1.2, using the spacecraft attitude angles described in Section 2.3.3. Trajectory data were added from the trajectory tapes described in Section 2.3.2, linearly interpolated to the sample time. Solar equatorial coordinates were also computed, as defined in Section 2.3.1.3.

The resulting parameters were plotted against time, and obvious bad fits were flagged as described in Section 2.4. The final data set comprises File 1 of each data tape.

Two additional data sets for each spacecraft were generated from the full "summary" data set, one containing hourly averages and one containing daily averages. They are described in Section 2.5. These data sets are contained in Files 2 and 3 of each tape.

2.3.1 Coordinate Systems

Three coordinate systems are used on the data tape. They are defined below.

2.3.1.1 The Heliocentric Ecliptic Coordinates (HEC)

The HEC have their origin at the Sun. The X-axis points to the Vernal Equinox, the Z-axis to the North Ecliptic Pole, and the Y-axis forms a right-handed system. The X-Y plane is the ecliptic. All of the trajectory parameters are in this system.

2.3.1.2 The Pioneer Ecliptic System (PES)

The PES is centered at the spacecraft with the Z-axis pointing to the North Ecliptic Pole, the X-axis away from the Sun, and the Y-axis completes a right-handed system. The X-Y plane is parallel to the ecliptic. The bulk velocity is given in this system, as shown in Figure 2-2. The PES involves both a translation from the HEC and a rotation about the Z-axis.

2.3.1.3 The Solar Equatorial System (SES)

The SES system is centered on the Sun and is based on a tilt of the solar equator from the ecliptic of $7^{o}15'$. The Z-axis is the solar rotation axis. The X-axis, from which longitude is measured, is the ascending node of the solar equator on the ecliptic, which is taken to be $74^{o}22' + 84'T$ from the Vernal Equinox, where T is the epoch in centuries from 1900.

2.3.2 Trajectory Data

The trajectory data on these tapes were obtained from Trajectory Tapes containing smoothed, predicted orbit data. These data are therefore not identical to those obtained every 10 days or so in the process of determining spacecraft attitude, and a systematic variation in the bulk flow azimuth, described below, is probably due to this discrepancy. The Trajectory Tapes usually contain one record per day, with more frequent records during encounters. 16 items were selected from each record to create a trajectory data file for each spacecraft. Interpolation in this file provided the trajectory elements in each plasma data record. The trajectory file is supplied on each tape as File 4.

2.3.3 Attitude Data

The spacecraft attitude, necessary to correct the instrumental bulk velocity to an inertial system, was obtained from printouts of cone and clock angles supplied every 10 days or so, whenever commands to the spacecraft resulted in a determination of position and attitude. The cone and clock angles and the clock angle correction term relate the spacecraft-fixed rotating coordinate system to the PES system, and are described briefly in Section 4.4.

The table of cone and clock angles is supplied in File 5 on each tape. Linear interpolation in this table to the sample times provided the attitudes for correcting the instrumental velocities.

2.4 <u>Uncertainty of the Measurements</u>

The expected accuracy of the measurements is derived mostly from the internal consistency of the measurements, and partly from the formal uncertainties produced by the least-squares program. Comparison of

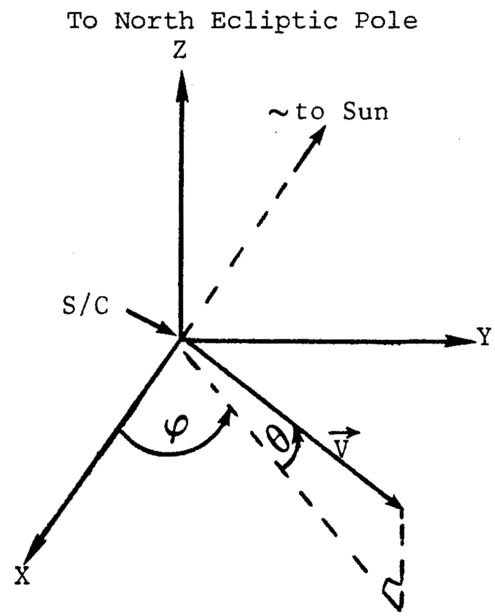

Figure 2-2. The SES System

parameters derived from different versions of the least-squares program operating on the same input data shows agreement to better than 0.5% in the speed, 12% in density, and 20% in temperature. Comparison of the flight data to the fitted Maxwellian distribution shows that about 10% of the data base contains forced fits for distributions that are substantially non-Maxwellian, anisotropic, or contain a strong He^{++} component. Extremely large formal errors usually correspond to questionable fits.

The absolute accuracy of the fitted parameters is difficult to obtain, but comparisons of Pioneer plasma data with data from IMP 6, 7, and 8 have not found significant systematic differences.

2.4.1 Bulk Speed

The bulk flow speed is the most accurately determined of the parameters, with respect to the spacecraft. Uncertainty in the attitude, however, leads to additional uncertainty in the bulk speed after subtraction of the spacecraft velocity. The final uncertainty is about $\pm$ 20 km/sec.

For some samples of low density, the least-squares program gets trapped in a set of parameters with velocities above 930 km/s. These are very easy to recognize in the plots, and are flagged with a value of 100 (see Section 2.4.6).

2.4.2 Density

The density is estimated to be relatively accurate to 12%, from internal consistency. For extremely low densities, such as have been encountered since 1982, the number of particles collected in a sample may be so low that no fit is possible. This lower cutoff is about 0.005/cc.

2.4.3 Temperature

This parameter is the one most sensitive to the fitting algorithms. The internal consistency is about $\pm$ 4000°K for temperatures below 15,000 K, about 15% for temperatures between 25,000 K and 100,000 K, and increases to an uncertainty of 50% or more for values over 10^6 K.

2.4.4 Angle of Flow

The angles of flow depend critically on the spacecraft attitude. Most of the time, this is quite well determined, to 0.3° or so. About 10% of the time, however, especially when the spacecraft is being precessed, the attitude may be uncertain by 30° or more. On the average, angles should be good to $\pm$ 0.7°, after the correction noted below.

A systematic error in the aximuthal angle has been found, with a period of one year and an amplitude very approximately equal to 1 AU subtended at the spacecraft. This may be due to inconsistencies between the actual spacecraft positions used in attitude determination, and the smoothed trajectories used to subtract the spacecraft velocity. A rough correction is to subtract

$$0^{\circ}.3 + [2^{\circ}.537 - 0^{\circ}.129\,(y - 1972.0)] * \cos\left(2\pi * \frac{d}{365}\right) \qquad \text{(Pioneer-10)}$$

from the azimuthal angle in the data record. Here y is the date, as year plus decimal fraction of a year, and d is the day of year.

2.4.5 Formal Uncertainties

The formal uncertainties of the least-squares program do not correspond very well to the true goodness of fit, as judged by a visual comparison of the flight data with the derived Maxwellian. Occasionally, the uncertainties are even negative. Consequently, only fits with extremely large (or negative) uncertainties are flagged as questionable.

The same is true of the "chi-square" of the fit. Fits with values over 1000 are flagged as bad, and flagged as questionable for chi-square between 200-1000.

2.4.6 Quality Flags

Each fit has been assigned a quality. A quality of 0 is a good fit, a quality of 10 or 20 is a questionable fit, and a quality of 100 is a bad fit.

A value of 100 is assigned if the velocity is greater than 1000 km/s, if the temperature is greater than 2×10^6 K, or if the density is greater than 100/cc at 1 AU (decreasing to 5/cc at 10 AU, etc.). A chi-square value over 1000. is considered a bad fit. Finally, on visually scanning the data plotted against time, individual fits may be considered spurious and assigned a quality of 100 by hand-editing.

From the visual scans, individual fits are also marked as of questionable quality and assigned a value of 10 or 20 (worse) by hand editing.

This quality value is stored in the data record and can be used as a flag to omit records when using the data set.

2.5 Averaged Data Sets

Two data sets have been generated from the full "summary" data set for each spacecraft, with bad records omitted, and questionable records given half weight. The first of these contains hourly averages, and the second contains daily averages. These averaged data sets have a format similar to that of the full set. The differences are described below.

- The time of each record in seconds-of-day is replaced by hour (0 to 23) for the hourly averages, and by 0 for the daily averages.
- The five formal parameter uncertainties are replaced by the root-mean-square dispersion of the parameter values. Chi-square is replaced by the number of records in the average.
- Four quantities are calculated and averaged: the proton flux NV, thermal pressure NkT, convective pressure Nm_pV^2 and kinetic energy flux, $1/2\ Nm_pV^3$. They fill the three blank items and the quality value in the full set.
- The processing date in the averages is that when the average was generated, compared to the least-squares processing date in the full set.

SECTION 3. THE TAPES

The following section describes the tapes and the Job Control Language necessary to read them.

3.1 The Contents of Each Tape

There is one tape for Pioneer-10 and one for Pioneer-11 . Each tape contains 5 files and was written in binary on an IBM 360 in 32-bit words. The files contain

1) the full summary "data set",
2) the hourly averages,
3) the daily averages,
4) the trajectory data, and
5) the attitude data.

3.2 Job Control Language (JCL)

The actual JCL used will depend on the particular installation conventions, but the following parameters will probably appear.

- The tapes are no-label: LABEL=(,NL)

- The tape density is 1600 bpi: DEN=3

- The record format is variable block, spanned; this is the preferred format for a unformatted FORTRAN READ: RECFM=VSB

- The logical record size and block size depend on the type of data, and are given below as LRECL and BLKSIZE:

  For files 1-3, LRECL=144,BLKSIZE=14404
  For file 4, LRECL=68,BLKSIZE=13604
  For file 5, LRECL=24,BLKSIZE=12004

As an example, the data definition statement suitable for reading the full data set on an IBM 360 might be;

```
//FT10F001    DD    UNIT=1600,DISP=SHR,LABEL=(1,NL),VOL=SER=123456,

//                  DCB=(DEN=3,RECFM=VSB,LRECL=144,BLKSIZE=14404)
```

3.3 Sample Program

A FORTRAN program follows that will read the hourly averages data set and write out some parameters within a desired time interval.

```
      DIMENSION REC(35)
      COMMON /CREC/ JYDD, JYMD, JHR, TEMP, VEL, AZ, EL, DEN, RMS(6), ORBIT(16),
     +  FLUX, PRES, PCONV, ENERGY, KPROC
      EQUIVALENCE (REC(1), JYDD)
      DATA IU/6/, AU/1.497E8/
C
C..READ IN DESIRED START, STOP DATES AS YYMMDD.
      READ (5,1001) ISTART, ISTOP
 1001 FORMAT (I6, I7)
      WRITE (IU, 1003)
C
C..READ DATA RECORDS FROM FT10F001.  TEST FOR DESIRED INTERVAL
   20 READ (10, END=100) REC
      IF (JYMD. LT. ISTART) GO TO 20
      IF (JYMD. GT. ISTOP) GO TO 100
C..RECORD IS IN DESIRED INTERVAL
      R = ORBIT(1) / AU
      WRITE (IU, 1004) JYMD, JHR, VEL, DEN, TEMP, R
 1003 FORMAT ('1 YYMMDD  HR    VEL    DEN      TEMP   R(AU)'//)
 1004 FORMAT (I8, I4, F8.1, F8.3, F9.0, F7.2)
      GO TO 20
C
C..END OF LISTING
  100 STOP
      END
```

SECTION 4. RECORD CONTENTS

The contents of each of the five files is described below. Each item is a 32-bit word, with standard nomenclature to indicate fixed or floating point. Coordinate systems are described in Section 2.3.1.

4.1 The Full "Summary" Data Record (File 1)

WORD	VARIABLE		DESCRIPTION
1	JYDD		Julian date of record, YYDDD
2	JYMD		Date of record in form YYMMDD
3	NSEC		Time of record in seconds of day, at spacecraft at start of data
4	TEMP		Proton bulk temperature (K)
5	VEL		Average bulk flow speed (km/s)
6	AZIM		Azimuthal angle of flow, φ, in PES system (degrees)
7	ELEV		Elevation angle of flow, θ, in PES system (degrees)
8	DEN		Proton density (#/cc)
9	DT		Uncertainty in temperature
10	DV		Uncertainty in velocity
11	DANG1		Uncertainty in azimuth, in rotating instrument coordinates
12	DANG2		Undertainty in elevation, in rotating instrument coordinates
13	DN		Uncertainty in density
14	CHISQ		Chi-square of fit
15-30	ORBIT(16)		14 trajectory parameters and 2 SES coords. All angles are in degrees, distances are in km, and velocities are km/s. Coordinate system is HEC except as indicated.
15		(1)	Distance of spacecraft from Sun
16		(2)	Longitude of spacecraft
17		(3)	Latitude of spacecraft
18-20		(4-6)	X,Y,Z coordinates of spacecraft
21-23		(7-9)	X,Y,Z components of spacecraft velocity
24		(10)	Speed of spacecraft
25		(11)	Distance of Earth from Sun
26		(12)	Latitude of Earth
27		(13)	Longitude of Earth
28		(14)	Distance between spacecraft and Earth
29		(15)	Solar equatorial latitude of spacecraft in SES system

30		(16)	Solar equatorial longitude of spacecraft in SES system
31-33	SPARE(3)		Three blank words
34	BADREC		Record quality. 0. is good, 10.-20. is doubtful, 100. is bad fit
35	JPROC		Julian date of the least-square processing

4.2 The Hourly and Daily Averages Records (Files 2, 3)

WORD	VARIABLE		DESCRIPTION
1	JYDD		Julian date of record, YYDDD
2	JYMD		Date of record in form YYMMDD
3	NHR		Hour of record, 0-23. (0 for daily averages)
4	TEMP		Average proton temperature (K)
5	VEL		Average bulk flow speed (km/s)
6	AZIM		Average azimuthal angle of flow (degrees, PES system)
7	ELEV		Average elevation angle of flow (degrees, PES system)
8	DEN		Average density (#/cc)
9-13	RMS(5)		Root-mean-square dispersion of preceding 5 parameters
14	AREC		Number of records in average (questionable records counted as 1/2)
15-30	ORBIT(16)		Average trajectory parameters
15		(1)	Distance of spacecraft from Sun (km)
16-17		(2-3)	Longitude and latitude of spacecraft in HEC system (degrees)
18-20		(4-6)	X, Y, Z coordinates of spacecraft in HEC system (km)
21-23		(7-9)	X, Y, Z components of spacecraft velocity (km/s)
24		(10)	Speed of spacecraft (km/s)
25-27		(11-13)	Distance, latitude, longitude of Earth
28		(14)	Distance of spacecraft from Earth (km)
29-30		(15-16)	Solar equatorial latitude and longitude of spacecraft in SES (degrees)
31	FLUX		Average proton flux, $\langle NV \rangle$, (#/cm^2-s)
32	PRES		Average thermal pressure, $\langle NkT \rangle$, (dynes/cm^2)
33	PCONV		Average convective pressure, $\langle Nm_pV^2 \rangle$, (dynes/cm^2)
34	ERG		Average kinetic energy flux, $\langle 1/2Nm_pV^3 \rangle$, (ergs/cm^2-s)
35	KPROC		Julian date on which data set was produced.

4.3 The Trajectory Record (File 4)

All coordinates are in the HEC system, expressed in km, or degrees

WORD	VARIABLE	DESCRIPTION
1	JYMD	Date of record as YYMMDD.
2	MSEC	Time of record in msec at spacecraft
3-5	XYZ(3)	X, Y, Z coordinates of spacecraft
6-8	XYZDOT(3)	X, Y, Z components of spacecraft velocity (km/s)
9	R	Distance of spacecraft from Sun
10	V	Speed of spacecraft (km/s)
11	RE	Distance of Earth from Sun
12-13	ANGL(2)	Latitude and longitude of spacecraft
14-15	EANGL(2)	Latitude and longitude of Earth
16	REP	Distance of spacecraft from Earth

4.4 The Attitude Record (File 5)

The cone and clock angle coordinate system has its Z-axis along the spacecraft spin axis, which points roughly toward Earth, the X-axis is the projection in the spin plane of the South Ecliptic pole and Y forms a right-handed system. The cone angle is the polar angle of the Sun measured from the Z-axis. The clock angle is the meridian roll angle of the Sun, measured counterclockwise from the Y-axis.

WORD	VARIABLE	DESCRIPTION
1	JYDD	Julian date of record, YYDDD
2	NSEC	The GMT time of record, in seconds of day
3	CONE	Cone angle of Sun
4	CLOCK	Clock angle of Sun
5	CLOCKC	Roll angle at Sun pulse

APPENDIX

A set of five tapes containing these data sets is available at NASA/Ames, through the Plasma Experiment personnel. These tapes differ from the NSSDC format. Each Ames tape contains one of the five data sets, with Pioneer-11 data stacked after Pioneer-10 data, in the same file. Furthermore, all variables in all data sets are expressed in floating point (REAL*4).

The data is blocked on these tapes, with blocksizes as given below. All the Pioneer-10 data is written first, with the last Pioneer-10 block zero-filled. The Pioneer-11 data begins in the next block, and again the last block is zero-filled. (The choice of blocksize for the orbit and attitude tapes was 8 bytes too small, so that on these tapes each full block is followed by a block containing the last two data words). A FORTRAN 77 program is attached which reads these tapes and rewrites them in the NSSDC format.

All the tapes are no-label with 32-bit words. The density is 1600 bpi, and the record format is VBS. There is one file on a tape. Logical record length = blocksize - 4.

Tape 90645D contains the attitude data. Blocksize = 9000 bytes.
Tape 90646B contains the trajectory data. Blocksize = 9600 bytes.
Tape 90647D contains the full data set. Blocksize = 14010 bytes.
Tape 90648D contains hourly averages. Blocksize = 14010 bytes.
Tape 90649D contains daily averages. Blocksize = 14010 bytes.

```
**** TSO FOREGROUND HARDCOPY ****
DSNAME=XRSEK.PIONEER.CNTL                                    (DAYJCL   )

//XRSEKPRD JOB (SB001,BF2,05),PIONEER.TAPE.READ,TIME=(01,00),CLASS=A
//*COPY AMES PIONEER DATA TAPE TO LOCAL TAPES
//*PROGRAM IS WRITTEN IN IBM VSFORTRAN (FORTRAN 77)
//  EXEC  FORTRANV
//FORT.SYSIN  DD  *
      PROGRAM PIONRD
C..READS AMES CDC-IBM PIONEER DATA TAPE AND REWRITES IT FOR GSFC.
C..PIONEER-10 DATA IS OUTPUT ON UNIT 10, PIONEER-11 DATA ON UNIT 11.
C..NR IS # WORDS PER RECORD; NB IS BLOCKING FACTOR.
C..FOR NR = 35,16,5, USE NB = 100,150,450 (DATA,ORBIT,ATTITUDE).
      PARAMETER (NR=35, NB=100)
      DIMENSION REC(35),NREC(10:11),BLOCK(NR,NB)
      EQUIVALENCE (REC(1),IYDD),(REC(2),IYMD),(REC(3),NSEC),
     .  (REC(35),KPROC)
      DATA NREC,NERR/3*0/, IU/10/
C
   20 READ(15,END=100,ERR=90) BLOCK
      DO 50 I = 1,NB
         IF(BLOCK(1,I) .NE. 0.) THEN
            DO 40 J = 1,NR
   40       REC(J) = BLOCK(J,I)
            NREC(IU) = NREC(IU) + 1
            IYDD = REC(1)
            IYMD = REC(2)
C..OMIT NEXT TWO LINES FOR ORBIT OR ATTITUDE DATA FILES.
            NSEC = REC(3)
            KPROC = REC(35)
            WRITE(IU) (REC(M),M=1,NR)
         ELSE
            IU = 11
            GO TO 20
         END IF
   50 CONTINUE
      GO TO 20
C
   90 NERR = NERR + 1
      GO TO 20
C
  100 WRITE(6,1002) NREC,NERR
 1002 FORMAT(////I15,' RECORDS OF PIONEER-10 DATA'/
     1  I15,' RECORDS OF PIONEER-11 DATA'/
     2  I15,' TAPE-READ ERRORS'//)
      STOP
      END
/*
//  EXEC  LOADER,REGION=600K,PARM='SIZE=600K'
//SYSLIB DD DSN=SYS1.VFORTLIB,DISP=SHR
//SYSLIN DD DSN=&LOADSET
//*FT10 AND FT11 ARE OUTPUT TAPES; FT15 IS THE AMES INPUT TAPE
//FT10F001 DD UNIT=6250,DSN=PIONER10,LABEL=(1,NL),VOL=SER=SEK001,
//            DCB=(DEN=1,RECFM=VSB,LRECL=144,BLKSIZE=14404),DISP=NEW
//FT11F001 DD UNIT=6250,DSN=PIONER11,LABEL=(1,NL),VOL=SER=SEK002,
//            DCB=(DEN=3,RECFM=VSB,LRECL=144,BLKSIZE=14404),DISP=NEW
//FT15F001 DD UNIT=6250,DSN=PIODATA,LABEL=(1,NL),VOL=SER=SEK003,
//            DCB=(DEN=3,RECFM=VSB,LRECL=14006,BLKSIZE=14010),DISP=OLD
//*FOR ORBIT(OR ATTITUDE) TAPE, LRECL=9596(8996),BLKSIZE=9600(9000)
```