X-621-70-71
PREPRINT

NASA TM X-63879

EXPLORER 32 ELECTROSTATIC PROBE DATA ANALYSIS: TESTING THE RESULTS FOR ACCURACY

E. J. GREGG

MARCH 1970

GODDARD SPACE FLIGHT CENTER
GREENBELT, MARYLAND

X-621-70-71

EXPLORER 32 ELECTROSTATIC PROBE DATA ANALYSIS: TESTING THE RESULTS FOR ACCURACY

E. J. Gregg

March 1970

GODDARD SPACE FLIGHT CENTER
Greenbelt, Maryland

PRECEDING PAGE BLANK NOT FILMED.

EXPLORER 32 ELECTROSTATIC PROBE DATA ANALYSIS: TESTING THE RESULTS FOR ACCURACY

E. J. Gregg

ABSTRACT

Computer analysis of electrostatic probe data from approximately 10,000 passes has been completed. From a selection of data corresponding to a wide range of electron temperature and density, a detailed comparison was made with hand and computer methods. The accuracy of the initial analysis was better than 10% in most of the passes. Errors exceeding this value were found to be caused by the following: (1) curves taken in the wake of the satellite were not always excluded from the analysis. (2) The curves with limited ions reference were sometimes analyzed improperly by the program. (3) The program sometimes failed to select the proper detector range for the most accurate analysis of electron temperatures.

PRECEDING PAGE BLANK NOT FILMED.

CONTENTS

ILLUSTRATIONS

EXPLORER 32 ELECTROSTATIC PROBE DATA ANALYSIS: TESTING THE RESULTS FOR ACCURACY

INTRODUCTION

The Explorer 32 cylindrical electrostatic probe measures the electron temperature and density in the vicinity of the spacecraft. Production computer analysis has been completed for over a million and a half temperature and density measurements taken by this experiment.

To test the accuracy of the temperature analysis a selected group of data was hand and computer analyzed. Over four hundred temperature curves from low, medium and high temperature ranges were chosen to be analyzed by these more detailed methods. This report describes the results of that study.

ELECTRON TEMPERATURE PROBE EXPERIMENT

The electrostatic probe experiment is composed of two cylindrical collectors mounted 135 degrees apart at the equator of the spacecraft. While the spacecraft is operating, a sawtooth voltage (Va) is applied between the collector and the spacecraft shell causing the current to the collector to vary. The current is a function of the applied voltage and of the surrounding plasma. The current, in the microampere range, is collected and converted to a voltage suitage for telemetry.

The experiment employed four linear current ranges and two sawtooth amplitudes in sequence to provide the current and voltage resolution needed to encompass the range of temperature and density experienced in flight. The electronic system and data sequence are shown in Figure 1. The voltage sweep period was 330 milliseconds. The current range was sequenced at 5 second intervals, thus 15 volt-ampere curves were obtained in each of the four current ranges. The amplitude of Va was changed on alternate current sequences to provide additional voltage resolution of the curves.

Figure 2 shows the nature of the raw telemetry data in a complete sequence for the high Va. The figure also illustrates the effects of the satellite wake on the curves. The wake curves are labelled (ω) in the figure. In these curves, the electron and ion currents are greatly reduced in amplitude, and are characteristically distorted.

Figure 3 illustrates a single volt-ampere characteristic taken on high Va with a current range which resolves the entire characteristic. To the right of

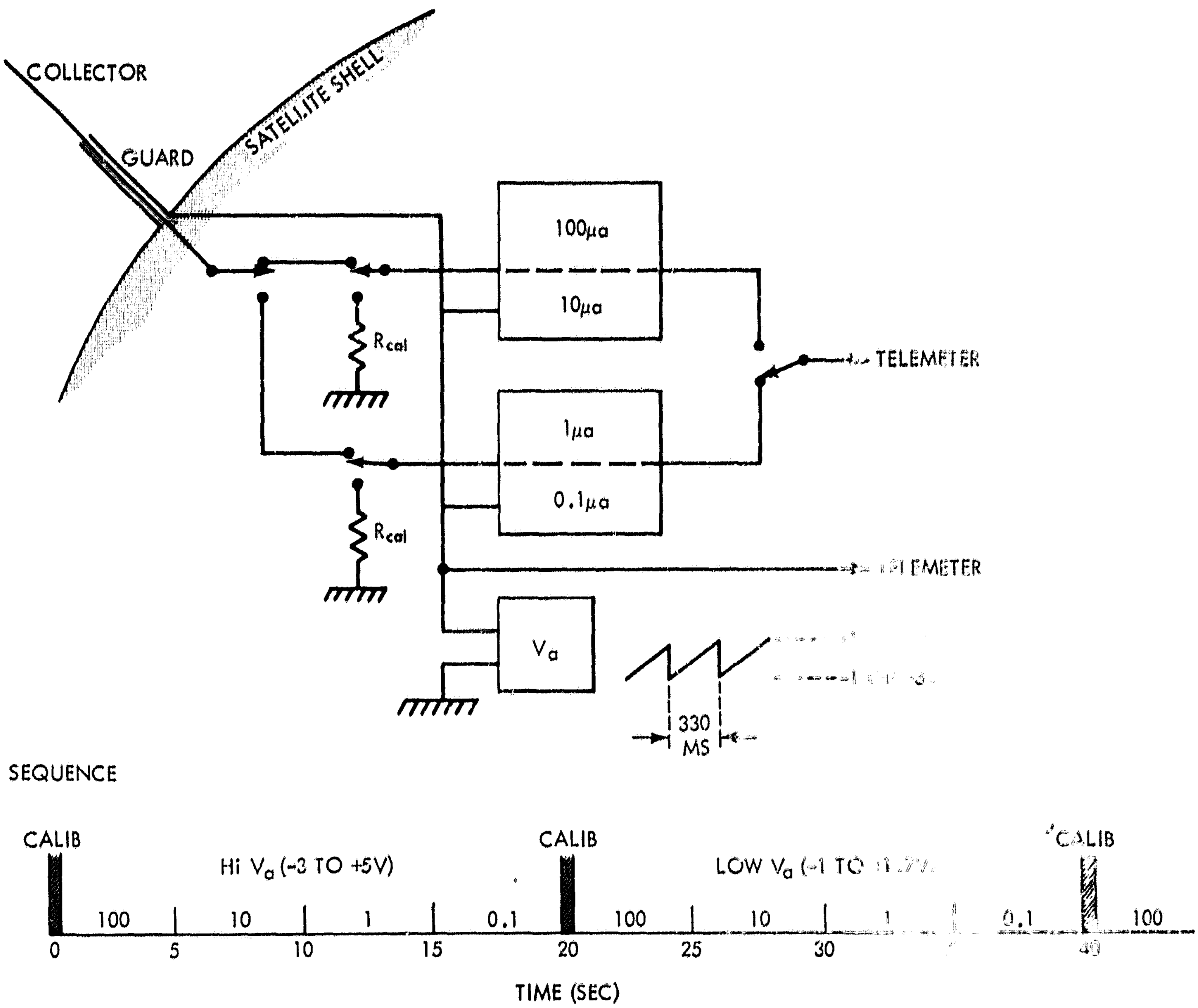

Figure 1. Timing sequence and electrical arrangement of probe system number 2. Probe 1 system was identical except that the current sensitivities were greater (50, 5, 0.5, 0.05 μa, respectively).

the plasma potential, is the electron saturation region, which is employed in determining density. To the left of plasma potential is the electron retardation region employed to derive electron temperature.

Figure 4 represents raw telemetry data points on high Va (150 millivoltage sampling interval) showing a full sequence of retarding region electron currents. The figure also shows the physical characteristics of the wake curves in relation to non-wake curves. This clearly shows how the wake curves are distorted.

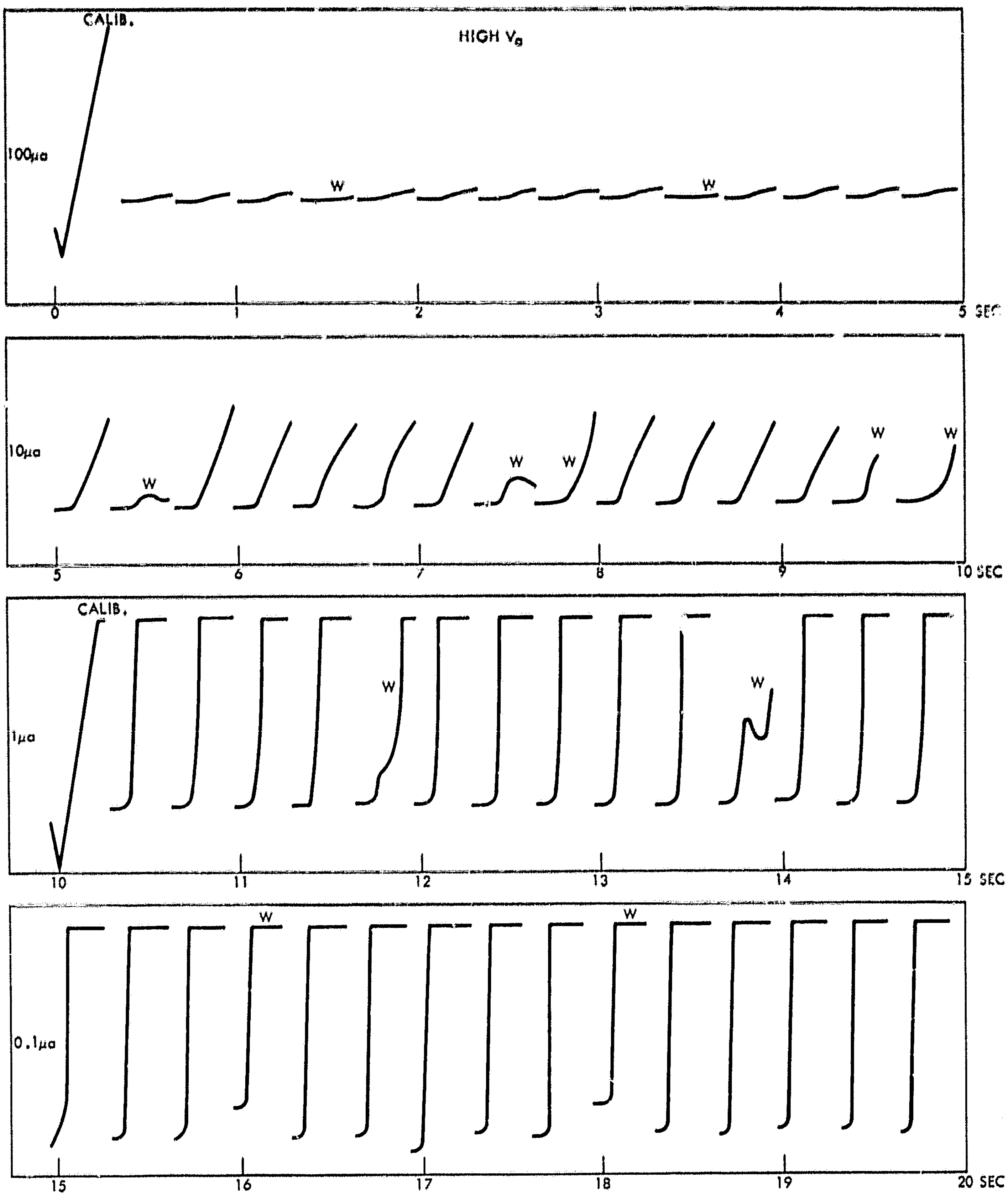

Figure 2. High Va sequence from probe 2. Approximately 15 volt-ampere curves are taken on each current range. The current range has a sequence interval of 5-seconds.

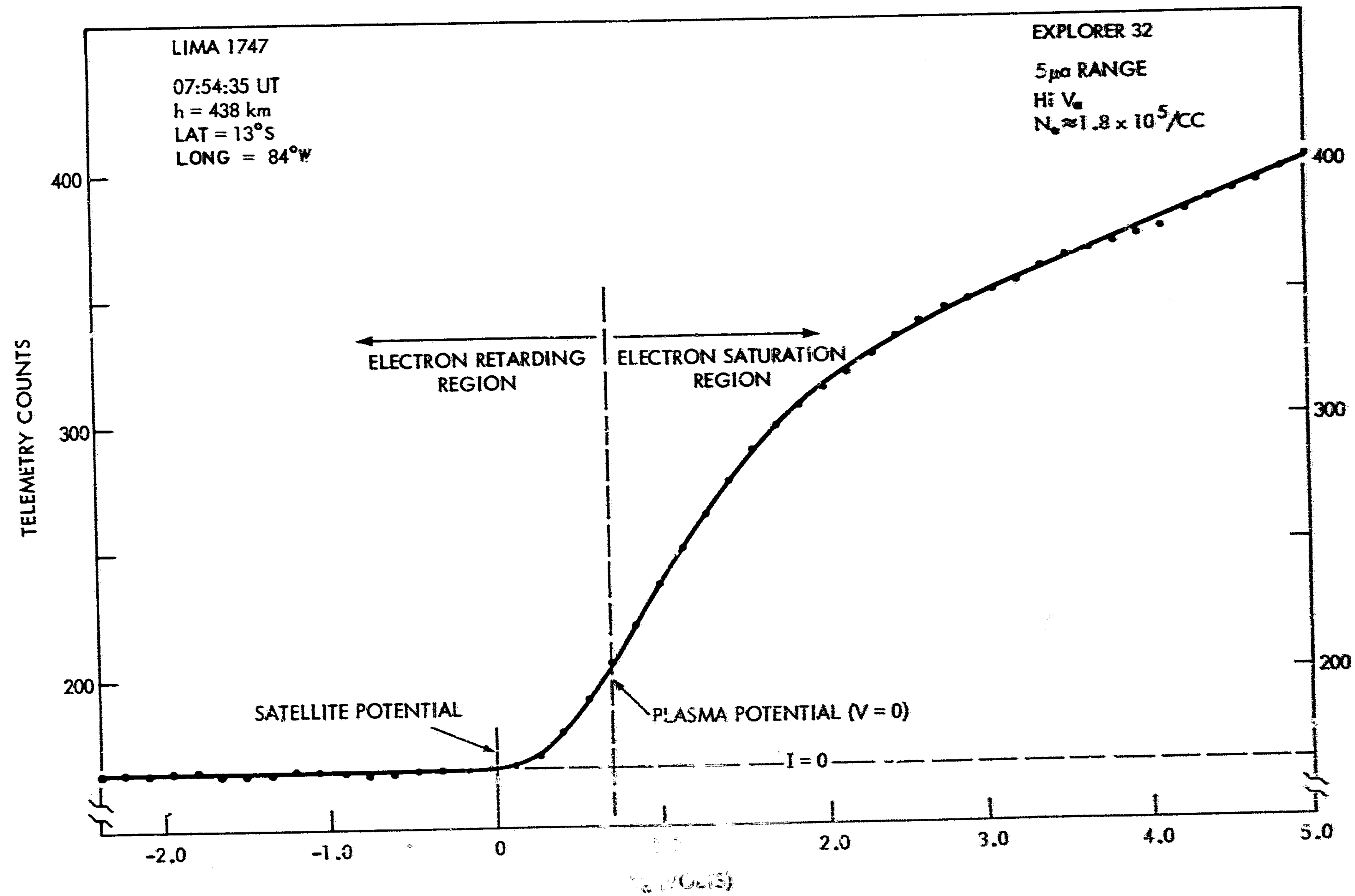

Figure 3. Illustration of volt-ampere characteristics showing the retarding and saturation region on a typical pass. The points are the telemetered counts, and the line is a free-hand fit to the points.

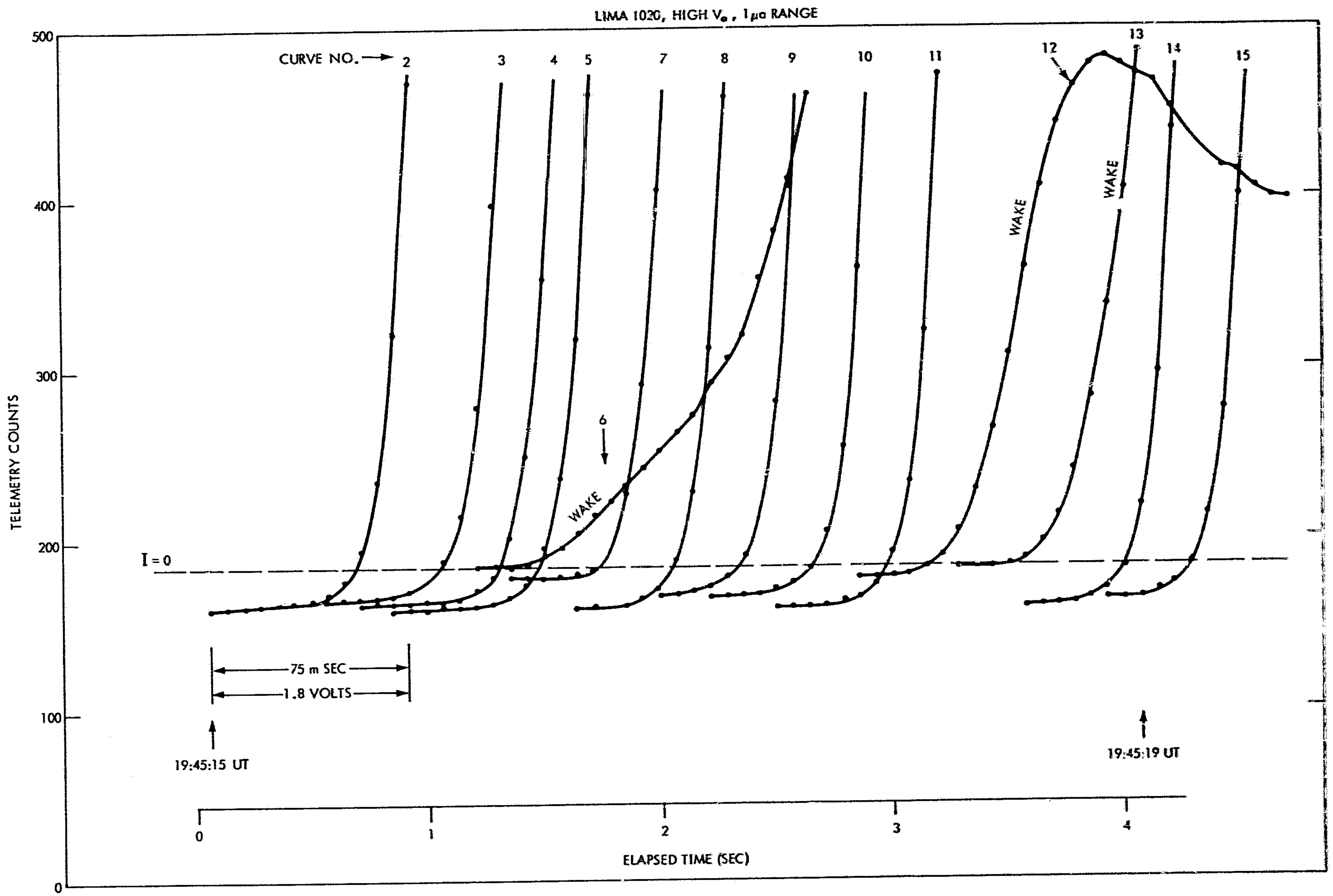

Figure 4. A good example of raw telemetry data points on high Va (150 mv sampling interval) showing a full sequence of retarding region electron currents. This sequence of curves were recorded in a 5-second interval, but are overlapped in time on the plot to compress them onto a single figure. Curves 6, 12 and 13 are distorted by wake effects in both the ion and electron current regions. The other curves are very similar in shape and the temperature derived from each would agree well.

METHOD OF ANALYSIS

The electron saturation current I_e is given by

$$I_e = \frac{AN_e\, e}{\pi} \left(2\, eV/M_e\right)^{1/2}, \qquad \frac{eV}{kT_e} >> 1 \tag{1}$$

where

A = probe area

N_e = electron concentration

I_e = electron temperature

e = electron charge

V = potential of the probe relative to the plasma

M_e = electron mass

This equation is employed in the region $1 < V < 2$ volts to derive N_e.

The electron current in the retardation region is given by

$$I_e = AN_e\, e\left(kT_e/2\pi M_e\right)^{1/2} \exp\left(eV/kT_e\right) \tag{2}$$

where

k = Boltzmann constant

T_e = electron temperature

I_e = electron current

This relationship is employed to derive T_e.

THE PRODUCTION ANALYSIS PROGRAM

In production analysis we combined the experiment data tape, the orbit-aspect data tape and the analysis program to obtain measurements of temperature and density combined with coordinate information.

Because errors in the individual values of temperature can occur owing to wake distortions of the curves, and perhaps poor resolution of the retarding region, we average the values of temperature from each sequence of 15 curves. Individual outlying temperatures are rejected until the standard deviation is less than 5% of the mean values or until half of the individual values of temperature have been rejected, whichever occurs first. Usually, at least 80% of the temperature values are retained. This averaging procedure provides one value of temperature in each 20 second period from each probe.

The outputs from the program consist of (1) a tape that is used later to produce microfilm plots of the raw data, (2) punched data cards for each value of averaged temperature and density (3) summary listings of the temperature and density measurements and (4) a printout describing any problems encountered in the analysis.

The data cards are sorted and edited, then listed with coordinate information on a tape which we call a master tape. The master tape includes all recognizable bad data, such as erroneous altitude and time readings. After the tape has been properly edited, it is used as input to an SC-4020 plotter which produced tabulation plots such as shown in Figures 5, 6 and 7. Plots of the corresponding altitude and local time of the orbit are shown in Figures 8 and 9, respectively. Figure 5 through 9 give a complete grouping of data for a period of four days. Similar plots were made for the entire 10 months of data received.

ERROR ANALYSIS

Since the development of the production program employed for Explorer 32, a more accurate temperature analysis program has been developed. This newer method has been employed on a selected set of Explorer 32 data to evaluate any short-comings of the earlier analysis. Data selected for this study were taken from various latitudes, longitudes and from three temperature ranges; high, medium and low. The high temperature is in the range of 5000°K or above which occurs at high altitude with densities of about 10^4/cc. The medium temperature is in the range of 1500°K to 4000°K at altitudes of approximately 300 km to 700 km with density ranges of 4×10^4/cc to 7×10^5/cc. The third selection of temperature is in the range of 1000°K to 1500°K which occurs at low altitude with higher density $N_e > 10^5$/cc. Applied voltage (high or low) and current detector sensitivity were also factors used to determine the data selection.

These temperature curves were taken from microfilm files and punched on cards in groups. After completing the punching, the cards were computer analyzed using the newer program. Then values that were derived from these two programs were compared. Table 1 lists the results of twenty-two sets that were compared in this manner. Also, shown is the percentage error.

STA DAN	PASS	GEOG. LAT	LONG	ALT. (KM)	DATE YRMODA	GMT HRMNSS	T(E) KEL.	N(E) NO./CC	B	L	DIP LAT	DIP	GEOMAG LAT	LONG	L.T HRS	ZEN ANG	A.PI	F	SAT POT	C D
ROS	682	18	-79	1977	660719	131844	0	8.1E 03	0.19	1.88	32	51	29	-11	7.9	58	4	98	-0.98	21A
ROS	682	17	-79	2006	660719	131936	0	9.2E 03	0.18	1.77	30	49	28	-10	8.0	57	4	98	-1.13	22A
ROS	682	17	-79	2010	660719	131939	0	7.3E 03	0.18	1.76	30	49	28	-10	8.0	57	4	98	-0.93	21A
ROS	682	15	-78	2043	660719	131955	0	8.9E 03	0.17	1.73	29	48	27	-9	8.0	57	4	98	-1.15	22A
ROS	682	15	-78	2043	660719	131955	0	8.5E 03	0.17	1.73	29	48	27	-9	8.0	57	4	98	-0.98	21A
LIM	682	2	-73	2331	660719	132541	0	1.1E 04	0.13	1.50	14	29	13	-3	8.5	55	4	98	-1.10	2A
LIM	682	2	-73	2334	660719	132548	5280	0.0	0.13	1.50	15	29	13	-3	8.5	55	4	98	0.0	2A
LIM	682	1	-73	2345	660719	132600	0	9.4E 03	0.12	1.50	15	28	12	-3	8.5	55	4	98	-1.00	1A
LIM	682	1	-73	2348	660719	132605	5250	0.0	0.12	1.49	15	28	12	-3	8.5	55	4	98	0.0	1A
LIM	682	1	-73	2348	660719	132605	5320	0.0	0.12	1.49	15	28	12	-3	8.5	55	4	98	0.0	2A
LIM	682	0	-73	2359	660719	132620	0	1.1E 04	0.12	1.49	14	27	12	-3	8.5	55	4	98	-1.08	2A
LIM	682	0	-72	2361	660719	132622	4830	0.0	0.12	1.49	14	27	12	-3	8.5	55	4	98	0.0	1A
LIM	682	0	-72	2362	660719	132625	5130	0.0	0.12	1.49	14	26	12	-3	8.5	55	4	98	0.0	2A
LIM	682	0	-72	2370	660719	132635	0	9.9E 03	0.12	1.48	14	26	12	-3	8.5	55	4	98	-1.07	1A
LIM	682	0	-72	2373	660719	132640	5490	0.0	0.12	1.48	13	26	11	-3	8.5	55	4	98	0.0	1A
LIM	682	0	-72	2376	660719	132644	4740	0.0	0.12	1.48	13	25	11	-3	8.5	55	4	98	0.0	2A
LIM	682	0	-72	2385	660719	132657	4880	0.0	0.12	1.48	13	24	10	-2	8.6	55	4	98	0.0	1A
LIM	682	0	-72	2386	660719	132659	0	1.1E 04	0.12	1.48	13	24	10	-2	8.6	55	4	98	-0.98	2A
LIM	682	0	-72	2389	660719	132704	5530	0.0	0.12	1.48	13	24	10	-2	8.6	55	4	98	0.0	2A
LIM	682	-1	-72	2394	660719	132711	0	9.4E 03	0.12	1.47	12	24	10	-2	8.6	55	4	98	-1.01	1A
LIM	682	-1	-72	2397	660719	132716	5160	0.0	0.12	1.47	12	23	10	-2	8.6	55	4	98	0.0	1A
LIM	682	-1	-72	2403	660719	132723	4880	0.0	0.12	1.47	12	23	9	-2	8.6	55	4	98	0.0	2A
LIM	682	-1	-72	2409	660719	132733	4960	0.0	0.12	1.47	12	22	9	-2	8.6	55	4	98	0.0	1A
LIM	682	-2	-71	2412	660719	132738	0	1.2E 04	0.12	1.47	11	22	9	-2	8.6	55	4	98	-1.24	2A
LIM	682	-2	-71	2416	660719	132743	5110	0.0	0.12	1.47	11	22	9	-2	8.6	55	4	98	0.0	2A
LIM	682	-2	-71	2418	660719	132747	0	9.7E 03	0.11	1.47	11	21	9	-2	8.6	55	4	98	-0.90	1A
LIM	682	-2	-71	2421	660719	132752	5270	0.0	0.11	1.47	11	21	8	-2	8.6	55		98	0.0	1A
LIM	682	-3	-71	2428	660719	132802	5050	0.0	0.11	1.46	10	20	8	-1	8.6	55	[illegible]	98	0.0	2A
LIM	682	-3	-71	2433	660719	132810	4850	0.0	0.11	1.46	10	20	8	-1	8.7	55	[illegible]	98	0.0	1A
LIM	682	-3	-71	2438	660719	132817	0	1.1E 04	0.11	1.46	10	19	7	-1	8.7	[illegible]		98	-1.[illegible]	2A
LIM	682	-3	-71	2441	660719	132822	5110	0.0	0.11	1.46	10	19	[illegible]	1	8.[illegible]	5[illegible]	[illegible]	9[illegible]	0.0	2[illegible]
LIM	682	-3	-71	2442	660719	132824	0	9.3E 03	0.11	1.46	10	19	[illegible]	-1	8.7	[illegible]	4	[illegible]	-0.92	1A
LIM	682	-3	-71	2445	660719	132829	5380	0.0	0.11	1.46	10	[illegible]	7	-1	[illegible]	[illegible]	[illegible]	98	0.0	[illegible]
LIM	682	-4	-71	2453	660719	132841	4890	0.0	0.11	1.46	9	[illegible]	7	-1	[illegible]	[illegible]			0.[illegible]	2A
LIM	682	-4	-71	2457	660719	132847	4170	0.0	0.11	1.46	9	17	6	-1	8.[illegible]			[illegible]	[illegible]	1A
LIM	682	-5	-70	2462	660719	132856	0	1.1E 04	0.11	1.45	9	17	6	-1	8.7	56			[illegible]	2A
LIM	682	-5	-70	2465	660719	132901	0	9.4E 03	0.11	1.45	8	1[illegible]	6	-1	[illegible]	[illegible]	[illegible]	[illegible]	-0.94	1A
LIM	682	-5	-70	2465	660719	132901	5520	0.0	0.11	1.45	8	16	[illegible]		[illegible]	[illegible]	[illegible]	98	[illegible]	2A
LIM	682	-5	-70	2468	660719	132906	5270	0.0	0.11	1.45	8	16	[illegible]		[illegible]			[illegible]	[illegible]	1A
LIM	682	-10	-68	2554	660719	133141	0	1.1E 04	0.10	1.45	3	6		[illegible]	8.[illegible]	[illegible]			-1.2[illegible]	2A
LIM	682	-11	-68	2557	660719	133146	5310	0.0	0.10	1.45	3	5	0	1	8.8	5[illegible]		[illegible]	0.0	2A
LIM	682	-11	-68	2564	660719	133201	0	8.0E 03	0.10	1.45	-2	-4	0	[illegible]	8.9	56	[illegible]	[illegible]	-0.82	1A
LIM	682	-11	-68	2566	660719	133206	5580	0.0	0.10	1.45	-2	-4	0	1	8.9	56	[illegible]	[illegible]	0.0	2A
LIM	682	-11	-68	2567	660719	133208	5460	0.0	0.10	1.45	-2	-4	0	1	8.9	56	4	[illegible]	0.0	1A
LIM	682	-12	-68	2573	660719	133220	0	1.1E 04	0.10	1.45	-2	-3	0	1	8.9	56	4	98	-1.2[illegible]	2A
LIM	682	-12	-68	2575	660719	133224	4860	0.0	0.10	1.45	-1	-3	-1	1	8.9	56	4	98	0.0	1A
LIM	682	-12	-68	2576	660719	133225	5740	0.0	0.10	1.45	-1	-3	-1	1	9.0	57	4	98	0.0	2A
LIM	682	-13	-67	2585	660719	133245	5150	0.0	0.10	1.45	-1	-1	-1	1	9.0	57	4	98	0.0	2A
LIM	682	-13	-67	2591	660719	133259	0	1.0E 04	0.10	1.45	0	0	-2	1	9.0	57	[illegible]	[illegible]	[illegible]	2A
LIM	682	-13	-67	2594	660719	133304	5320	0.0	0.10	1.45	0	0	-2	2	9.0	[illegible]	[illegible]	[illegible]	[illegible]	2A

Figure 5. Tabulation format of Explorer 32 data.

Figure 10 shows the temperature error as a function of temperature and density. The errors are usually less then 10%. It is clear, that the error is not closely related to the values of temperature and density in the range of density examined.

Figure 11 shows the same temperature errors plotted against temperature alone. The temperature errors greater than 10% were further analyzed to determine the causes of these unacceptable errors.

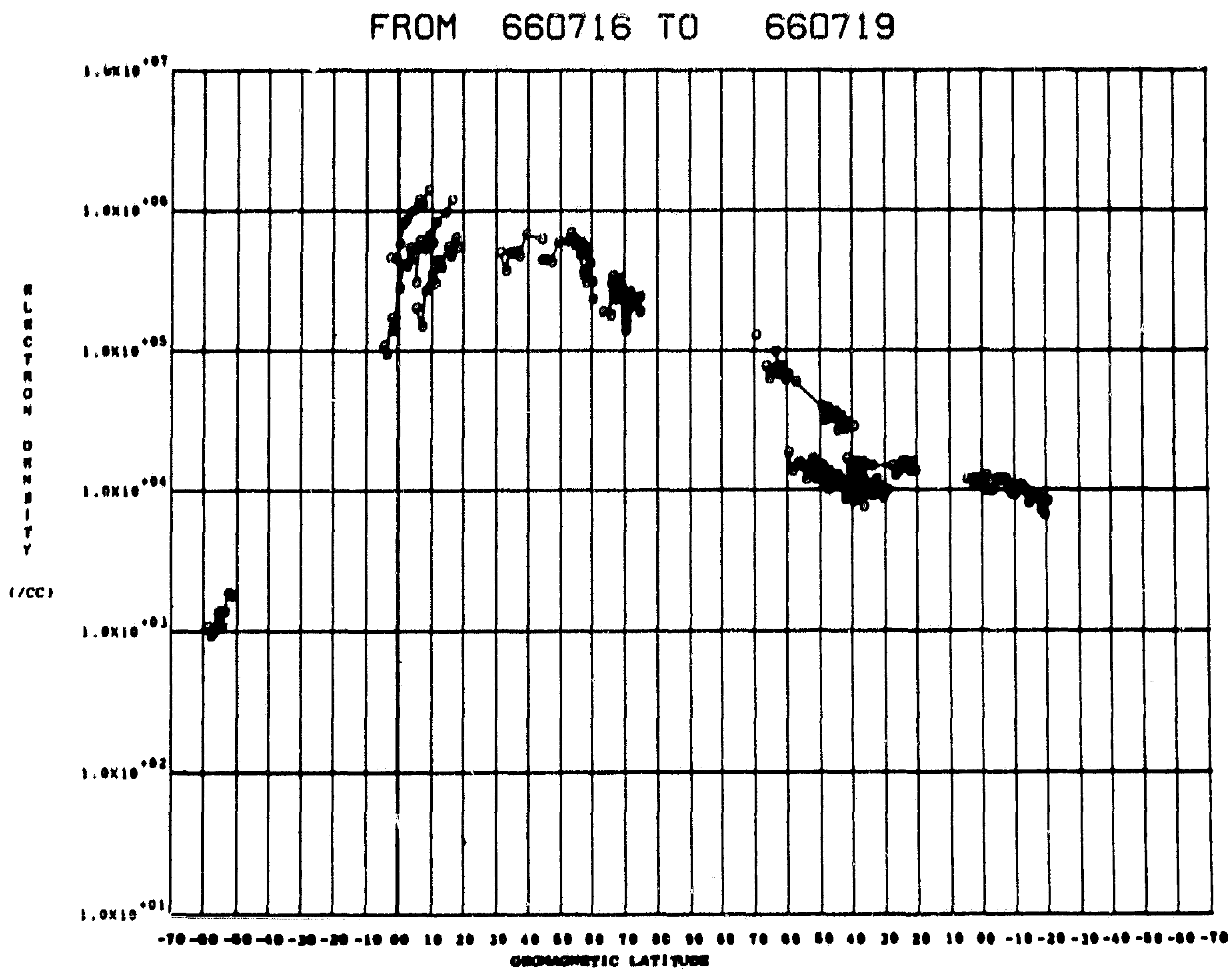

Figure 6. A sample of Explorer 32 latitudinal density plots over a period of four days. Density points can be picked and analyzed for accuracy.

SOURCES OF ERROR

As suggested earlier, several factors influence the accuracy of the analysis for T_e. Wake distortion of the curves causes the temperature information to be lost, and this error is not always eliminated in the averaging and rejection process discussed earlier. In addition, the program sometimes erroneously selects an improper current range and must work with lower resolution of the retarding region. This also reduces the measurement accuracy. It appears that the rejection of wake curves and the selection of current range permits errors as great as 15% to occur.

In addition, when large variation of temperature occurs within a sequence of curves, the analysis program is limited in its ability to select the accurate group

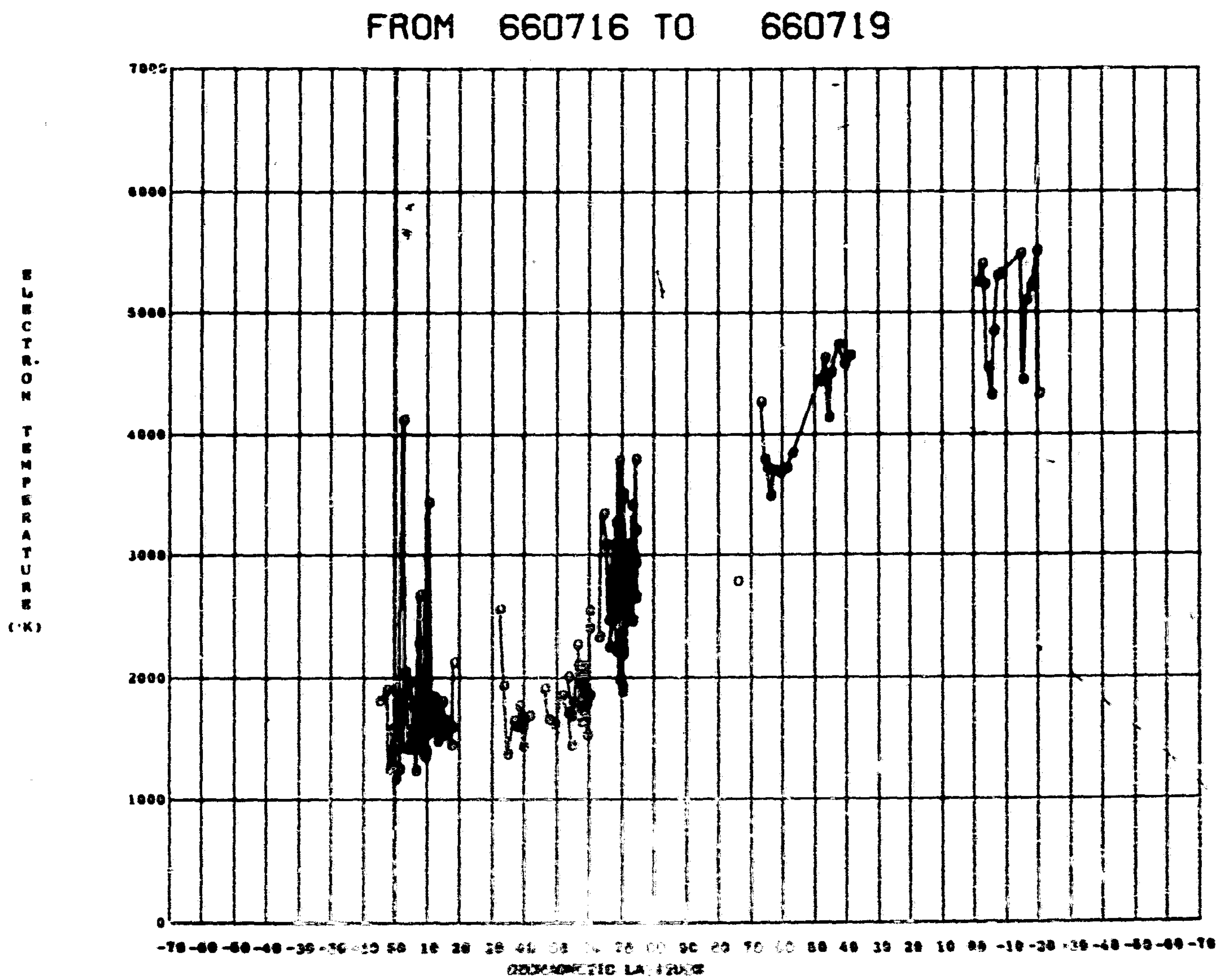

Figure 7. Latitudinal temperature plots from data taken over a period of four days. This type of plot provides the necessary data format for identifying possible errors in electron density and temperature.

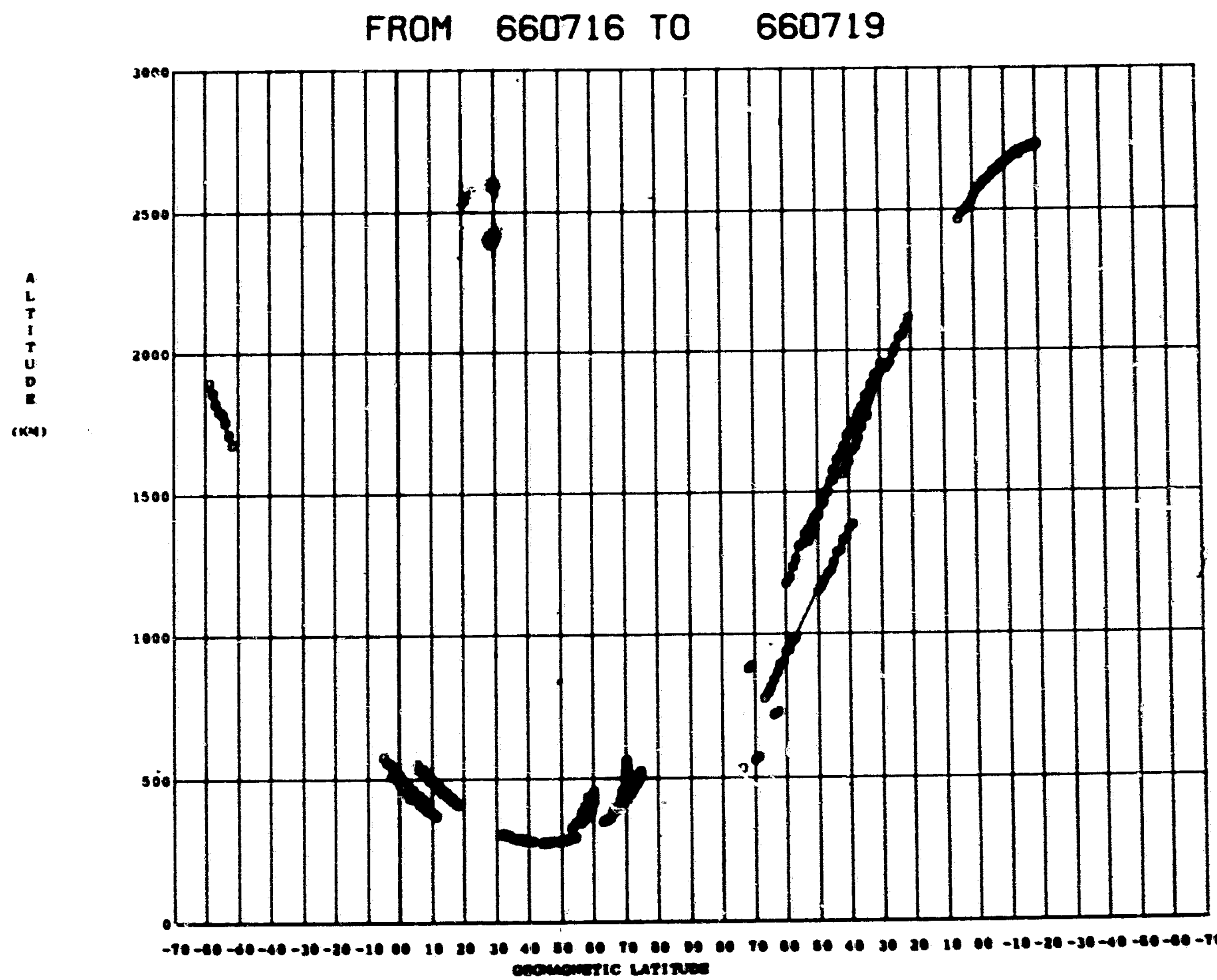

Figure 8. Explorer 32 altitude plots over the same period as Figures 6 and 7. This figure provides necessary data for locating points of temperature and density values to be examined for accuracy.

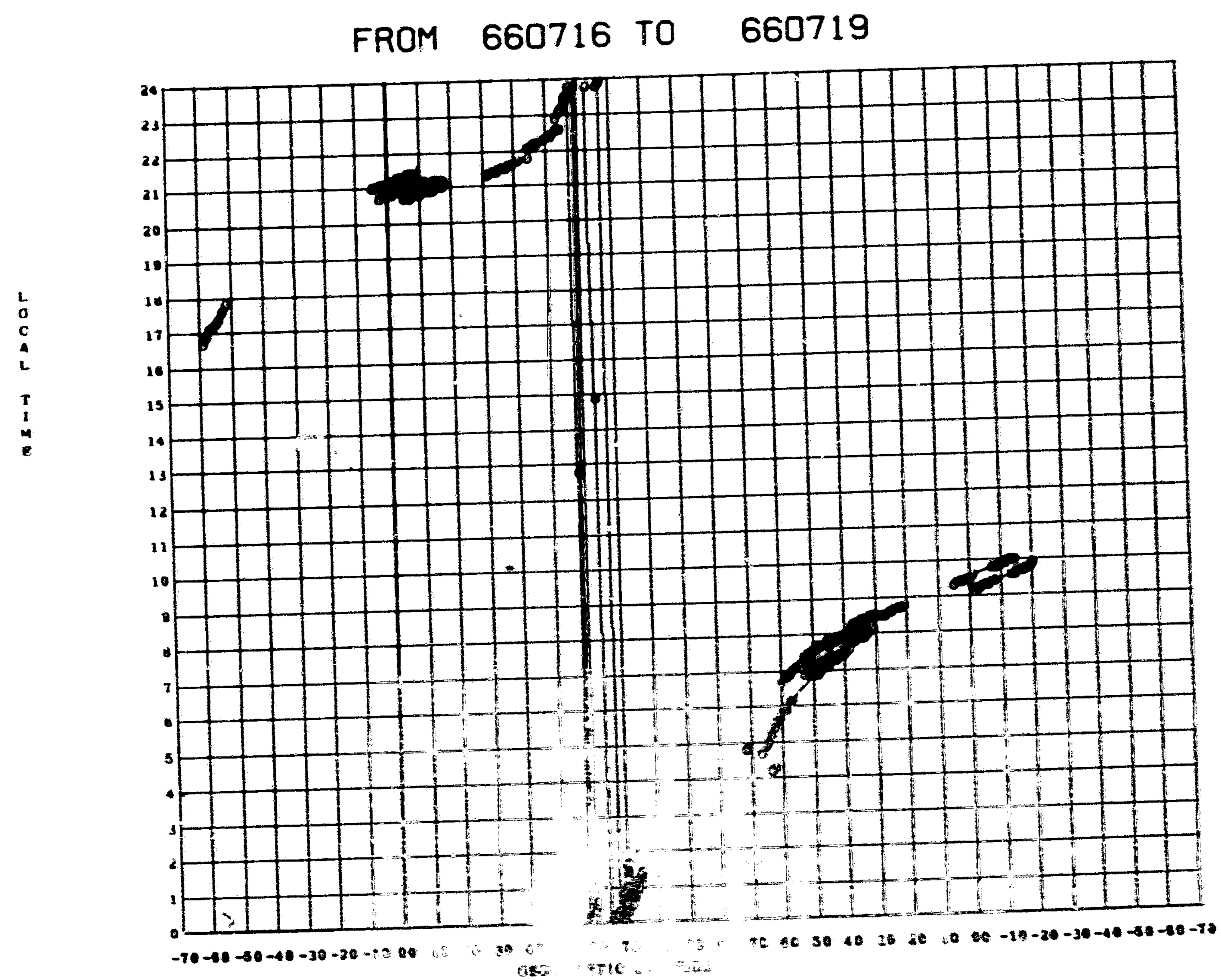

Figure 9. Local time plots corresponding to data in Figures 6 and 7.

Table 1

Temperature Comparison

Curve No.	Group No.	Sta.	Pass	Det.	New T_e	Old T_e	% Err.	N_e	Probe	Alt. km
1	Group 3	SKA	3209	1	6692	6930	-3.55	4.0E04	1	1529
2	Group 7	SNT	3222	1	5631	6370	-13.12	1.8E04	1	2241
3	Group 14	NFL	3319	1	6840	6470	5.86	6.0E04	1	1912
4	Group 7	NFL	3319	1	8757	7390	15.61	1.8E04	1	1981
5	Group 9	QUI	60	1	3974	3630	8.65	6.3E04	1	329
6	Group 10	QUI	60	5	3526	3250	7.82	6.3E04	1	565
7	Group 19	QUI	60	1	3844	3690	4	6.3E04	2	581
8	Group 20	QUI	60	5	3782	3360	11.15	6.3E04	2	565
9	Group 7	WNK	72	6	3248	3130	3.6	5.9E05	1	328
10	Group 19	WNK	72	6	3430	3220	6.12	5.9E05	1	370
11	Group 17	WNK	72	1	3602	3290	8.66	5.8E05	2	363
12	Group 11	JOB	2224	3	2318	2320	-0.08	1.7E06	1	405
13	Group 12	JOB	2224	2	2185	2230	-2.05	1.7E06	1	403
14	Group 13	JOB	2224	7	2349	2330	.8	1.7E06	1	395
15	Group 14	JOB	2224	6	1911	1720	10.02	1.7E06	1	392
16	Group 5	JOB	2224	2	2635	2640	-0.18	6.0E05	1	472
17	Group 6	JOB	2224	6	2437	2330	4.39	7.6E05	1	459
18	Group 26	QUI	1673	5	1416	1300	8.2	2.7E05	2	369
19	Group 30	QUI	1673	5	1512	1370	9.38	2.4E05	2	336
20	Group 5	LIM	1599	1	1352	1400	-3.55	5.3E04	1	545
21	Group 6	LIM	1599	1	1238	1090	11.95	5.3E04	1	532
22	Group 2	QUI	1673	5	1136	1160	-2.11	1.8E05	1	379

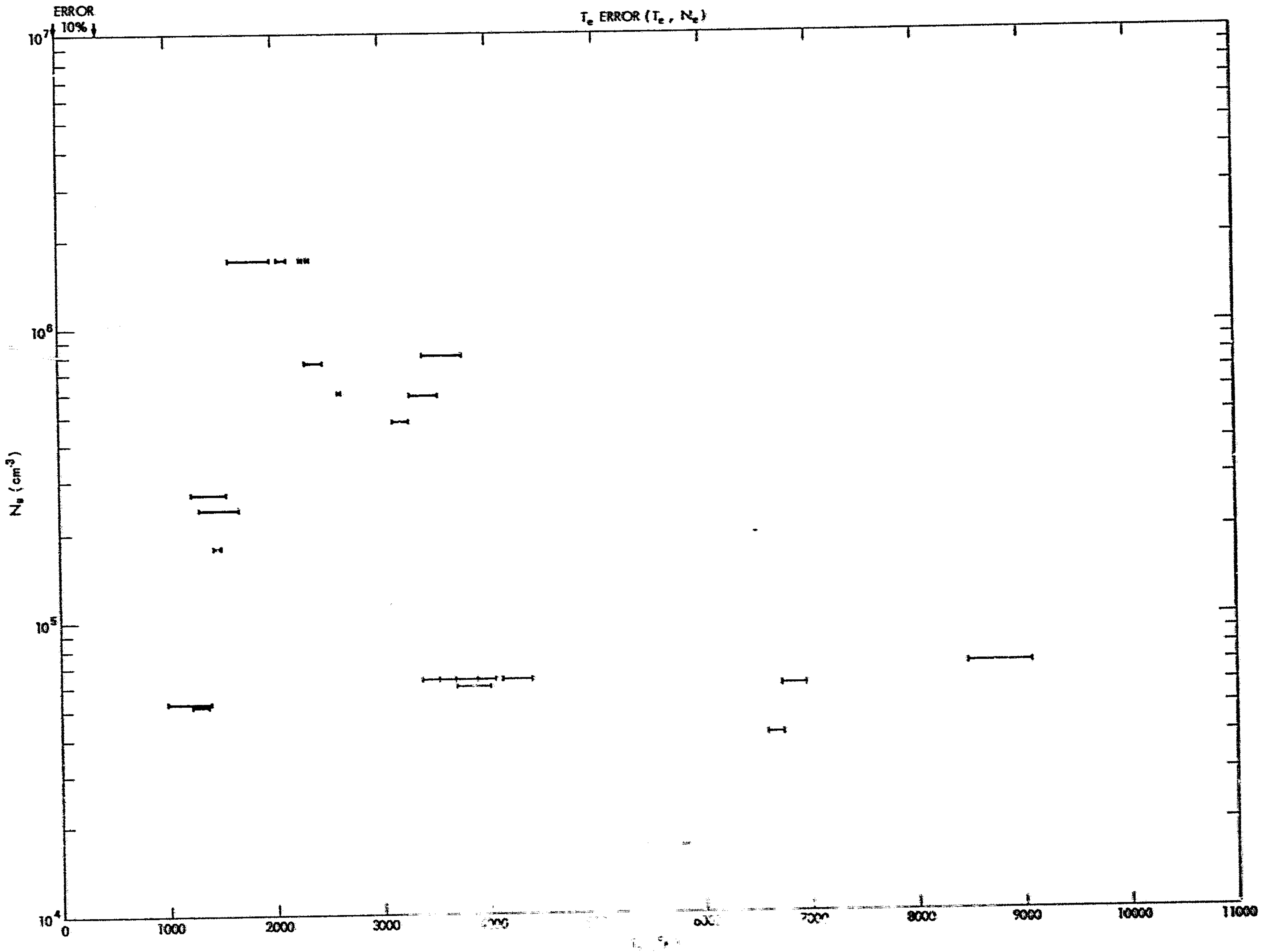

Figure 10. Bar grap[illegible] [illegible]mperature [illegible] temperature and density.

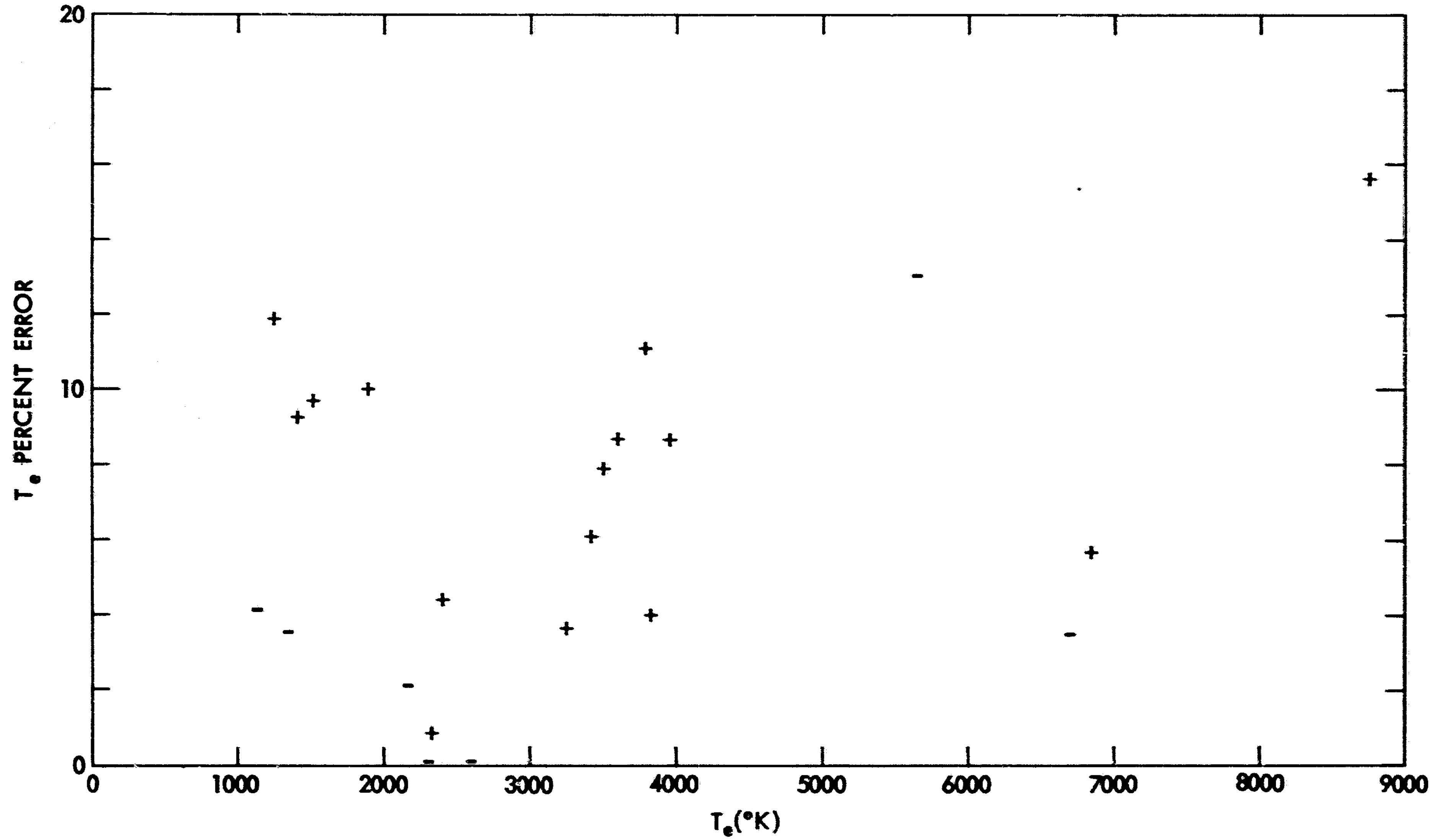

Figure 11. Temperature percentage error as a function of temperature. The temperature errors greater than 10% were further analyzed. Positive errors indicate that the production program gave temperatures too high.

temperature. The average temperature may not be very meaningful in this situation.

SUMMARY

Temperatures derived from the cylindrical electrostatic probe Explorer 32 program show an accuracy within 10% when compared with a more accurate analysis method. Based on this study corrections are being made to improve the accuracy of the production data.

ACKNOWLEDGMENT

I am very grateful to Mr. L. H. Brace for his supervision in preparing this report. I also thank Mr. R. F. Theis and Mr. L. P. Rudolph for the use of their programs which made the data available for analysis.