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INTERIM FLIGHT REPORT NO. 2
INTERPLANETARY MONITORING PLATFORM
IMP III — EXPLORER XXVIII

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GODDARD SPACE FLIGHT CENTER

GREENBELT, MARYLAND

INTERIM FLIGHT REPORT NO. 2

INTERPLANETARY MONITORING PLATFORM

IMP III — EXPLORER XXVIII

By

Frank A. Carr

July 1966

Goddard Space Flight Center
Greenbelt, Maryland

ABSTRACT

The third of the series of IMP Spacecraft, launched 29 May 1965, continues to operate providing abundant scientific data on the earth's magnetosphere, the transition region and interplanetary space.

The (first) INTERIM FLIGHT REPORT (Reference 1), described the launch, orbit, spacecraft attitude, and spacecraft performance based on the first six months of operation; this report presents additional information concerning the first year of operation.

As the spacecraft fulfilled the mission objective of a one-year lifetime, it had completed 62-1/2 orbits and some 10,000 hours of data (including overlapping coverage) had been recorded.

Operation of the primary spacecraft systems—telemetry, power and data handling, continue to be excellent. Experiment status continues unchanged: specifically, six of the nine are working properly, one partially, and two solar plasma experiments not providing any data.

The spacecraft continues to operate, in its fourteenth month after launch as of this writing. Future operation will be discussed in the final flight report to be issued at the termination of the mission.

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INTERIM FLIGHT REPORT NO. 2

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IMP III — EXPLORER XXVIII

By

Frank A. Carr
IMP Project Office

INTRODUCTION

The third IMP Spacecraft was launched on 29 May 1965 from Cape Kennedy, Florida, into a highly elliptical orbit.

The Delta-31 launch vehicle (standard Delta with X-258 third stage) injected the spacecraft into an orbit (Table 1) with an apogee height of 260,777 km (~41 Re), a period of 140 hours and an inclination of 33.9 degrees. The apogee-earth-sun angle was 236° and increasing (approaching the sub-solar point), the spin axis-sun angle was about 30° and the spin-rate about 23.7 RPM.

ATTITUDE & SPIN RATE

The position of the spin-axis on the celestial sphere is determined by an optical aspect-system consisting of sun and earth sensors. The initial coordinates are compared to nominals in Table 2.

The difference between the initial (actual) position and the nominal is 20-1/2 degrees and represents the "tip-off" incurred during the launch phase. Tip-off is used here to denote the total angular displacement of the spin axis from the nominal (and presumed actual), injection velocity vector.

The initial spin axis-sun angle was about 31 degrees, measured from the Rb Magnetometer (Figure 1). This was about 17° beyond nominal and 10° beyond

Table 1

IMP III — Explorer XXVIII Orbit Data.

Date	Nominal (1)	5/29/65	7/20/65	8/19/65	9/28/65	12/25/65	1/17/66	2/15/66	3/22/66	4/21/66
Days After Launch	—	0	52	82	122	210	233	262	297	327
Apogee Height KM. N.M	 204,813 110,599	 260,777 140,820	 257,784 139,203	 256,996 138,779	 253,021 136,631	 245,108 132,358	 244,465 132,011	 242,000 130,680	 238,308 128,686	 236,937 127,946
Perigee Height KM. N.M.	 189.1 102.1	 205.2 110.8	 3286.9 1775	 4038.9 2181	 7849.5 4239	 15,918 8,596	 17,686 9,550	 18,278 9,870	 21,112 11,400	 24,435 13,195
Period Minutes Days & Hrs.	 5959.0 $4^d 3^h 19^m$	 8398.6 $5^d 19^h 58.6^m$	 8402.7 $5^d 20^h 2.7^m$	 8401 $5^d 20^h 1^m$	 8393.4 $5^d 19^h 53.4^m$	 8400.6 $5^d 20^h 0.6^m$	 8452.4 $5^d 20^h 52.4^m$	 8366.2 $5^d 19^h 26.2^m$	 8326.8 $5^d 18^h 46.8^m$	 8416.5 $5^d 20^h 16.5^m$
Inclination (Deg)	33.01	33.87	37.4	40.7	47.1	46.2	45.9	49.1	52.5	51.5
Eccentricity	0.940	0.952	0.929	0.924	0.896	0.837	0.825	0.819	0.798	0.775
Date Computed	—	8/11/65	10/65	11/13/65	12/7/65	2/ /66	3/ /66	4/7/66	5/14/66	6/6/66
Source	DELTA 31 DTO	RWMAP 1	RWMAP 2	RWMAP 3	RWMAP 4	RWMAP 6	RWMAP 7	RWMAP 8	RWMAP 9	RWMAP 10

(1) Nominal orbit shown was computed by Douglas Aircraft Co.; Delta project (GSFC) estimated nominal apogee to be 120,000 N.M.

(2) Orbit lifetime estimated to be about 1086 days (~3 years).

Table 2

IMP III Spin Axis Coordinates.

	Right Ascension	Declination
Actual-Initial	+64.87°	-10.9°
Nominal-Initial	+82.2°	-23.0°
Launch Plus 3 Months	+65.5	-10.7
Launch Plus 6 Months	+70.8	-10.1
Launch Plus 1 Year	+71.7	-14.2

the 40° limit imposed as a launch window restraint. The discrepancy resulted from the tip-off mentioned above.

The most important effect of a 30° spin axis-sun angle versus 40° is a 10% reduction of solar paddle power output. Consequently, the power available was marginal during the first two orbits although operation was sustained. Later in the mission, as the one-year mark was approached and the sun angle returned to 30°, a number of under-voltage turn-offs were experienced since, by that time, an additional decrease of solar paddle power output had been incurred due to radiation degradation.

For the first 19 orbits the spin-axis was very stable with no coning detectable. Beginning about September 15, 1965 (T + 109 days) a slight coning motion began. A maximum full cone angle of about 3° was reached on October 5, 1965 (T + 129 days). The cone angle then diminished reaching zero on January 12, 1966 (orbit 40) and thereafter. It is thought that this anomaly is associated with radiation pressure torques acting on the spinning spacecraft.

The spin rate (Figure 1) changes from 23.7 RPM initially to a minimum of 18.25 RPM by T + 90 days to a maximum of 27.4 RPM by T + 270 days to 22.4 RPM at T + 1 year. The variation of spin rate is due to the effect of solar radiation pressure acting on the solar paddles; the spin rate decreases when the sun shines from above the spacecraft equator and increases when the sun is below the spacecraft equator.

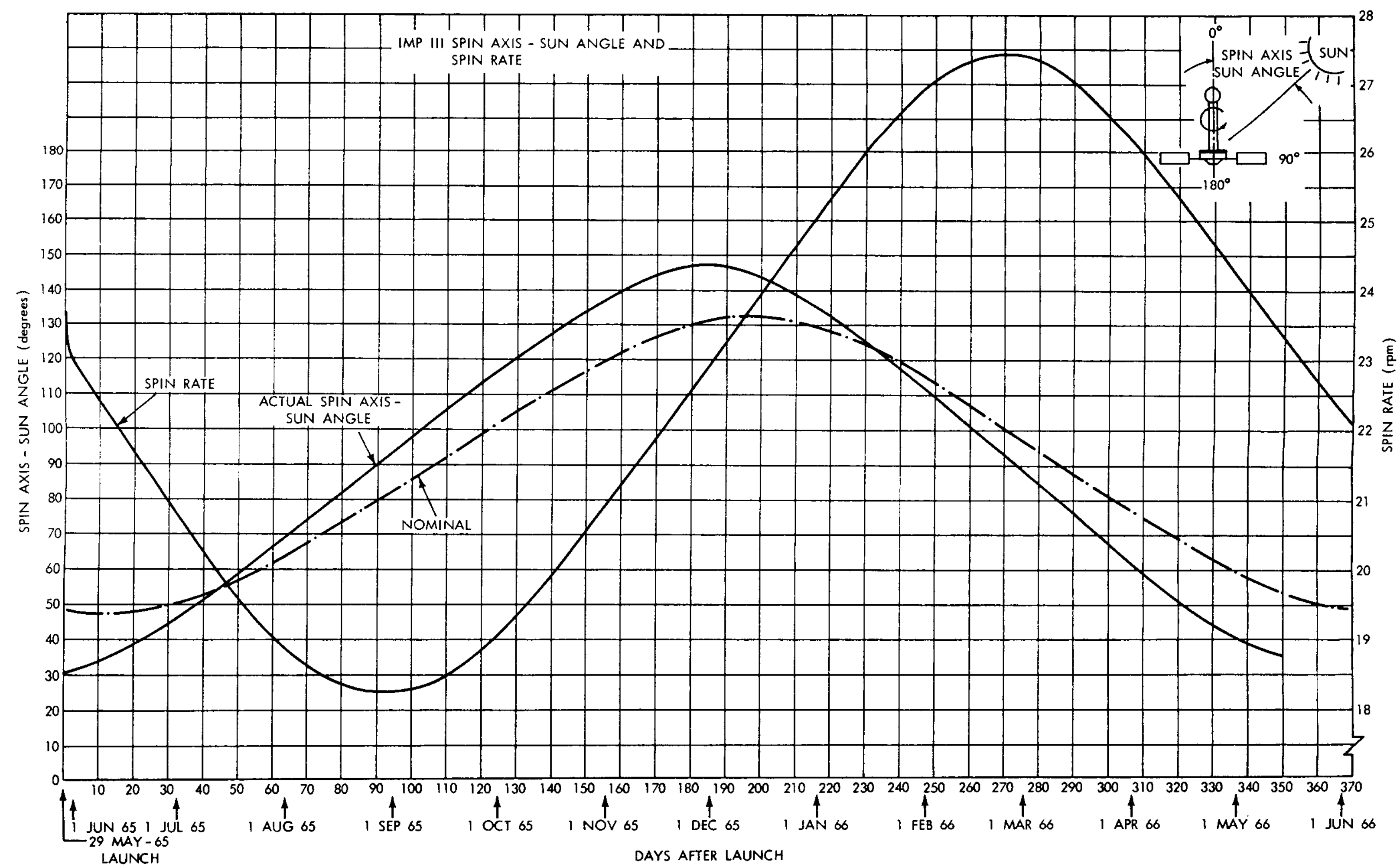

Figure 1—Spin Axis-Sun Angle and Spin Rate.

PERFORMANCE PARAMETER IN-FLIGHT DATA

Power System Data

The solar array output current and spacecraft load current are shown in Figure 2.

Two of the three solar array curves of Figure 2 represent the minimum and maximum output during a spin period; the third curve shows the average of a few hours worth of data.

As the satellite rolls thru one spin period the solar array current varies between the min & max limits shown in Figure 2. Pulsing of the battery occurs because the total projected area of the four solar paddles relative to the sun varies as the satellite spins. If the spin-axis-sun angle is near 30°, 90° or 150° then the average projected area is at a minimum and at certain roll positions, the illuminated paddle area is insufficient to produce enough power to operate the spacecraft. At this instant, the battery must supply the deficiency. A few degrees later in the revolution, the area will increase providing the necessary power for the spacecraft plus an excess amount, a portion of which the battery accepts. Consequently, alternate discharging and charging of the battery occurs.

It has been demonstrated in ground tests that under certain conditions pulsing of the battery can cause a net discharge even though the average paddle current exceeds the spacecraft requirements. The operation of IMP III beginning at T + 339 days gives further evidence of this effect. At that time, the first of a series of under-voltage turn-offs occurred. The basic cause for these shutdowns was low power from the solar array due to an unfavorable incident sun angle (30°). However, a few turn-offs occurred when the average solar array current exceeded the spacecraft current requirement.

In all a total of 34 undervoltage turn-offs[1] occurred during the first year of operation: the first was due to the transversal of the earth's shadow near apogee on April 7, 1966 (T + 313 days), the remainder due to low power from the solar array as explained above. These resulted in the loss of about 100 hours of data.

The "bump" in the spacecraft current (PP4) curve occurring at T + 355 to T + 374 days is due to the fact that the battery was being discharged at this time

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[1] See Appendix A for dates and times of turn-offs.

causing the operating voltage to be reduced to about 15 volts instead of the normal 18.3 v. Since the spacecraft load acts as a constant power device, the current required increases.

The solar array power as a function of incident sun angle is shown in Figure 3. The predicted power excluding radiation damage is shown for comparison. Both curves are computed on the basis of an operating voltage of 18.3 volts.

A comparison of the average current from the solar array shows that about 16% degradation occurred during the first year in orbit.

The telemetered data of the +12v and +50v Prime Converter outputs and the +7v Multi Converter output indicated that these voltages were within specified tolerances throughout the first year.

The two-step voltage regulator which prevents over charging of the battery has worked flawlessly and represents a major improvement in the IMP spacecraft power system design (Ref. 1). Based on available data, it appears that this technique has been 100% successful in preventing battery over-charging and the associated internal pressure build ups, leaks, etc. Furthermore, the continued satisfactory performance of the IMP III battery after one year in orbit is a first for an IMP battery and is directly attributable to this device.

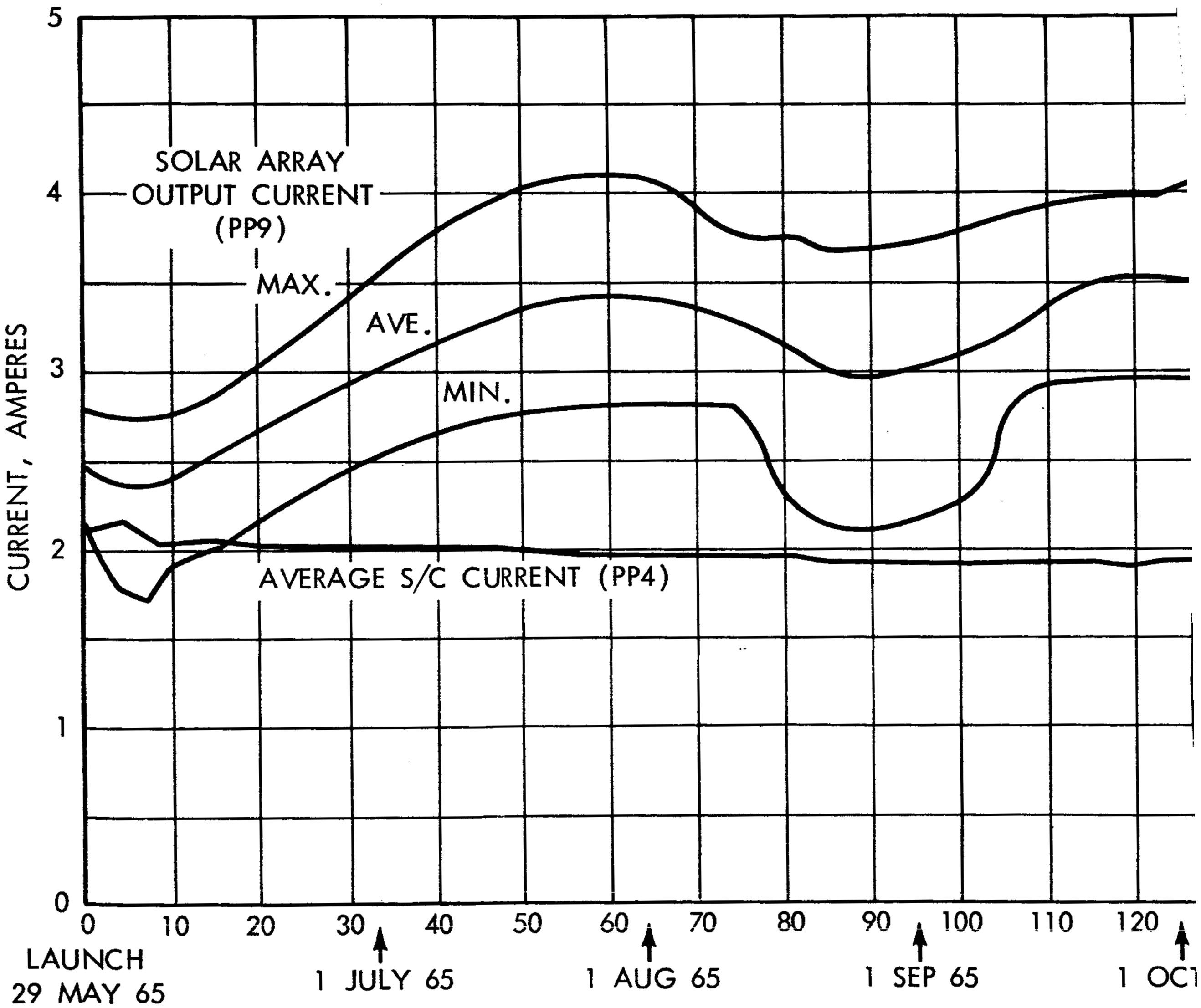
The operation of the Undervoltage system has been flawless. The recycle time—a nominal three hours for IMP III instead of the previous 8 hours, has been very consistant varying but a few minutes at most. Since the backup clock was set for four hours and no recycle periods of four hours duration have been recorded, it is concluded that the primary recycle clock (3 hour) has operated correctly and has re-activated the spacecraft after each of the 34 turn-offs.

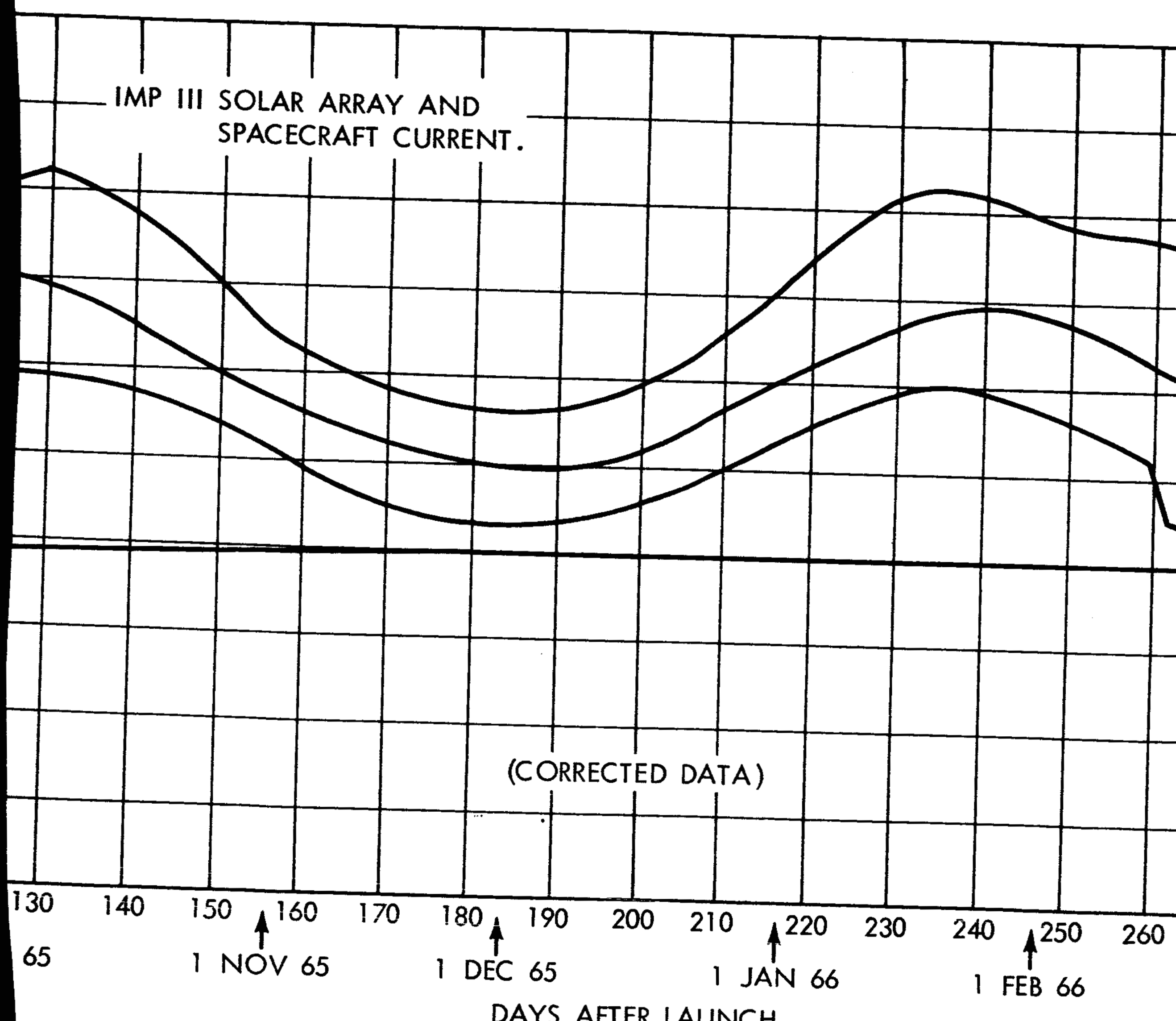
Temperature Data

The temperature of the Prime Converter, Battery, Transmitter and a Solar Paddle as a function of time are shown in Figure 4. In general, the passive thermal design performed satisfactorily, maintaining the temperature of platform mounted items within the +5° to +50°C range throughout the year. Experiments and other low power items probably did not exceed +40°C.

Comparisons of actual temperatures versus predictions as a function of spin axis-sun angle are shown in Figures 5 thru 8.

The temperature of the battery exceeded predictions for the third time in as many flights. The IMP III thermal design was modified to keep the battery


SOLAR ARRAY
OUTPUT CURRENT
(PP9)
MAX.
AVE.
MIN.
AVERAGE S/C CURRENT (PP4)
CURRENT, AMPERES
5
4
3
2
1
0
0
10
20
30
40
50
60
70
80
90
100
110
120
LAUNCH
29 MAY 65
1 JULY 65
1 AUG 65
1 SEP 65
1 OCT


IMP III SOLAR ARRAY AND SPACECRAFT CURRENT.
(CORRECTED DATA)
130
140
150
160
170
180
190
200
210
220
230
240
250
260
65
1 NOV 65
1 DEC 65
1 JAN 66
1 FEB 66
DAYS AFTER LAUNCH

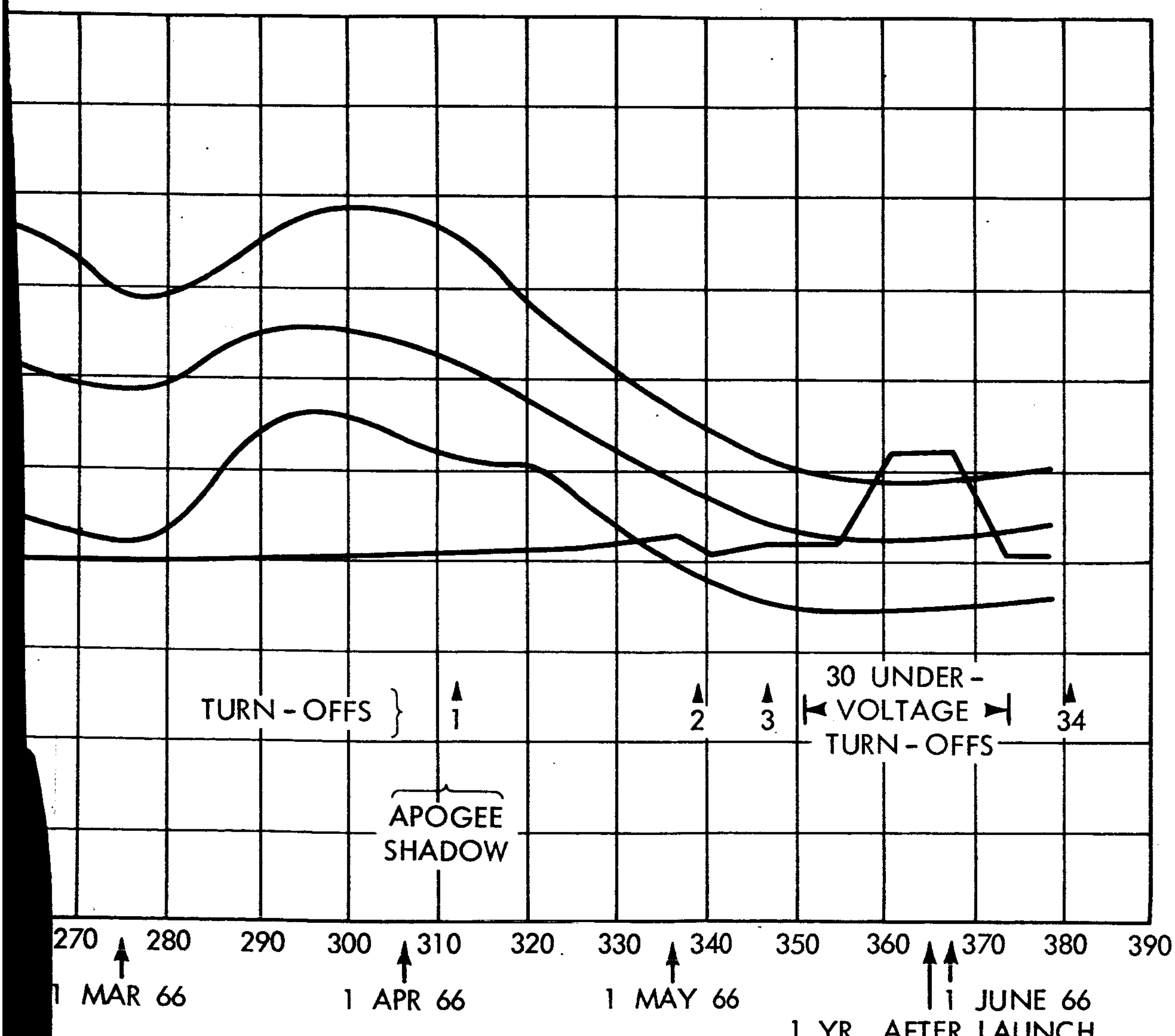


Figure 2—Solar Array and Spacecraft Current.

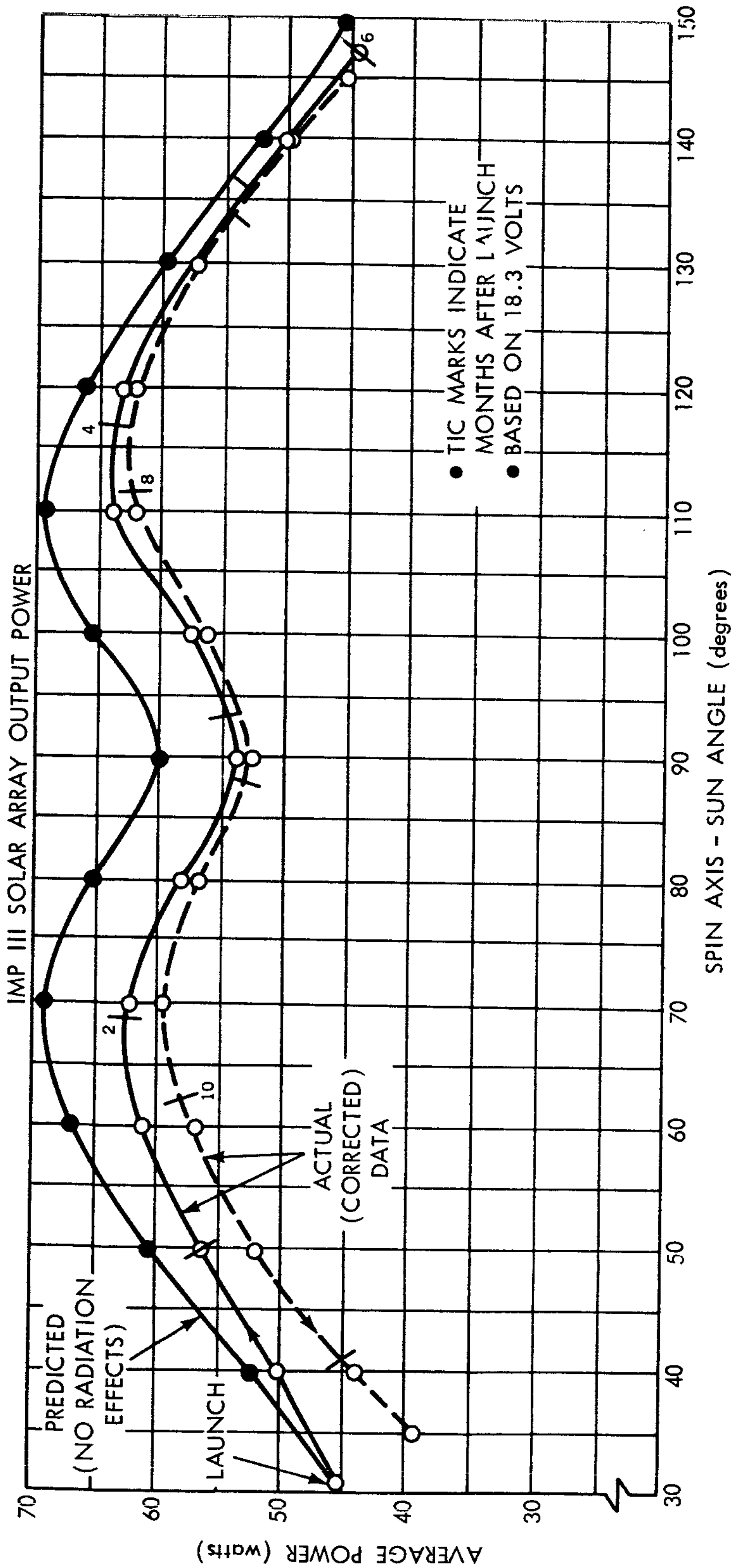


Figure 3—Solar Array Output Power.

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cooler than previous IMP's and, in fact, about an 8°C reduction (at the maximum temperature) was accomplished. This was only about half of the reduction which was desired. Consequently, the battery was exposed to temperatures at or above +35°C for some 85 days and to temperatures at or above +40°C for about 40 days. However, no degradation of the Battery has been observed to date.

The Battery, Prime Converter & Transmitter (Figures 5-7) all show a tendency toward higher temperatures at identical sun angles but at later times in the mission. For example, a spin axis-sun angle of 40° was experienced on day 22 and on day 337. The temperature of the battery on these days was 19°C and 27°C respectively; the temperature of the Prime Converter, +43°C and +51.5°C respectively and the temperature of the Transmitter, +16°C and +22.5°C respectively. The solar paddle temperature was -29.5°C on both days.

The cause of this warming trend is thought to be associated with an increase in the absorptivity of the white paint coatings. The degradation appears to occur rather rapidly following launch and tending to level off later in the mission. Ground tests have shown that the absorptivity of the white paint may increase by as much as a factor of two (Reference 2).

APOGEE SHADOW

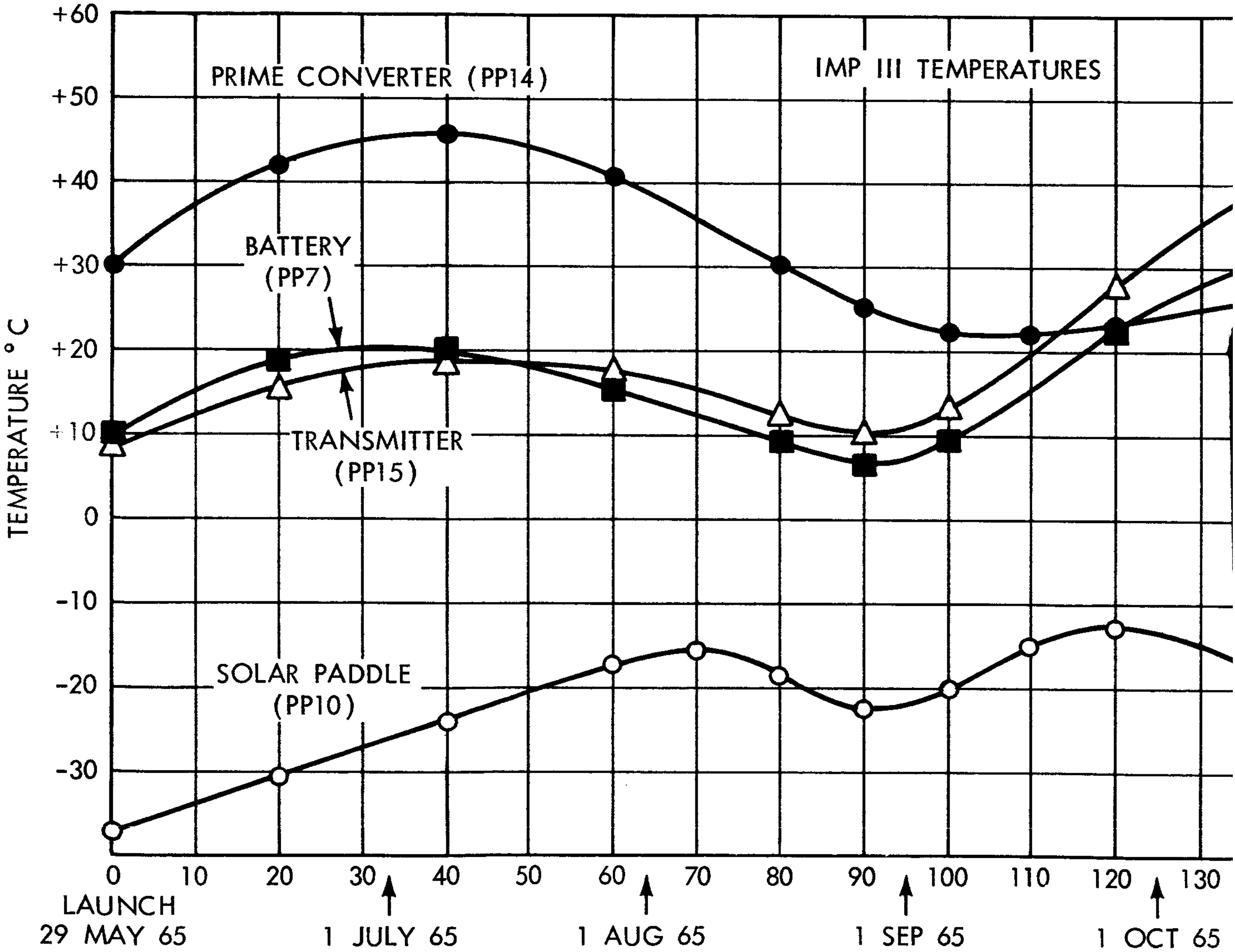
The spacecraft began to enter the shadow of the earth on 7 April 1966 during orbit 54 inbound at a range of about 200,000 km. The predicted shadow duration for this date was 5-1/2 hours.

The spacecraft data indicates that the actual shade time was a maximum of 4-3/4 hours of which much, if not all, was only a partial eclipse (penumbra region).

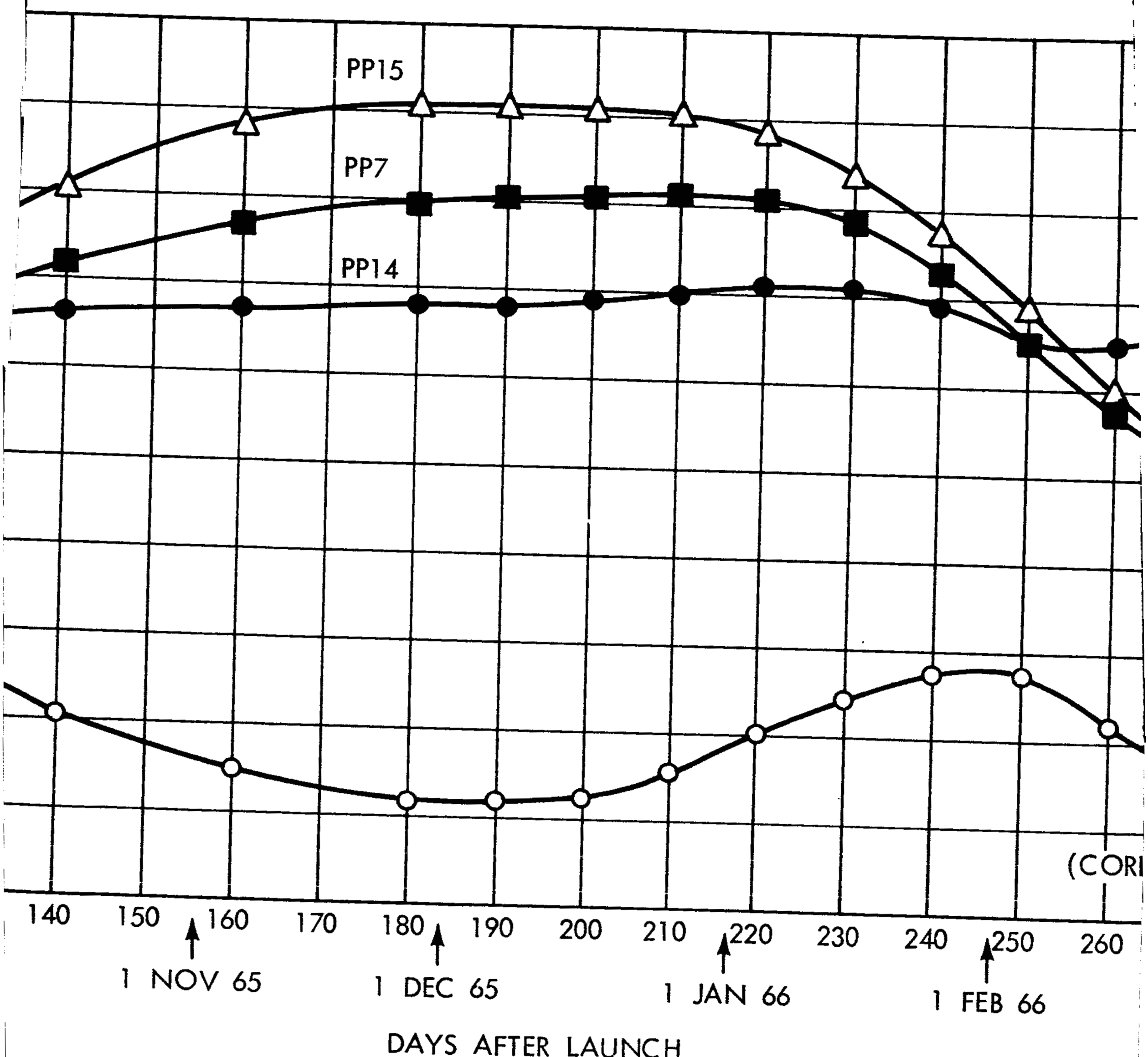
The spacecraft entered the penumbra at 0840 hrs.[(1)] after which the temperature of components (Figure 9) and solar array output current began to decrease. The spacecraft turned off due to battery depletion at 1029 hrs. At this time the illumination was ≤ 0.1 solar constant and the battery had delivered 2.8 ampere-hours. At 1325 hrs, the spacecraft resumed operation after a 2^h54^m recycle period and the data showed it to be in full sunlight at that time.

Although the battery has a nominal capacity of 5 ampere-hours, it only delivered 2.8 A H entering the shadow. The reason for this is probably due to

(1) All times noted here are UT on 4/7/66.



IMP III TEMPERATURES
PRIME CONVERTER (PP14)
BATTERY (PP7)
TRANSMITTER (PP15)
SOLAR PADDLE (PP10)
TEMPERATURE °C
+60
+50
+40
+30
+20
+10
0
-10
-20
-30
0
10
20
30
40
50
60
70
80
90
100
110
120
130
LAUNCH
29 MAY 65
1 JULY 65
1 AUG 65
1 SEP 65
1 OCT 65


PP15
PP7
PP14
(CORI
140 150 160 170 180 190 200 210 220 230 240 250 260
1 NOV 65
1 DEC 65
1 JAN 66
1 FEB 66
DAYS AFTER LAUNCH

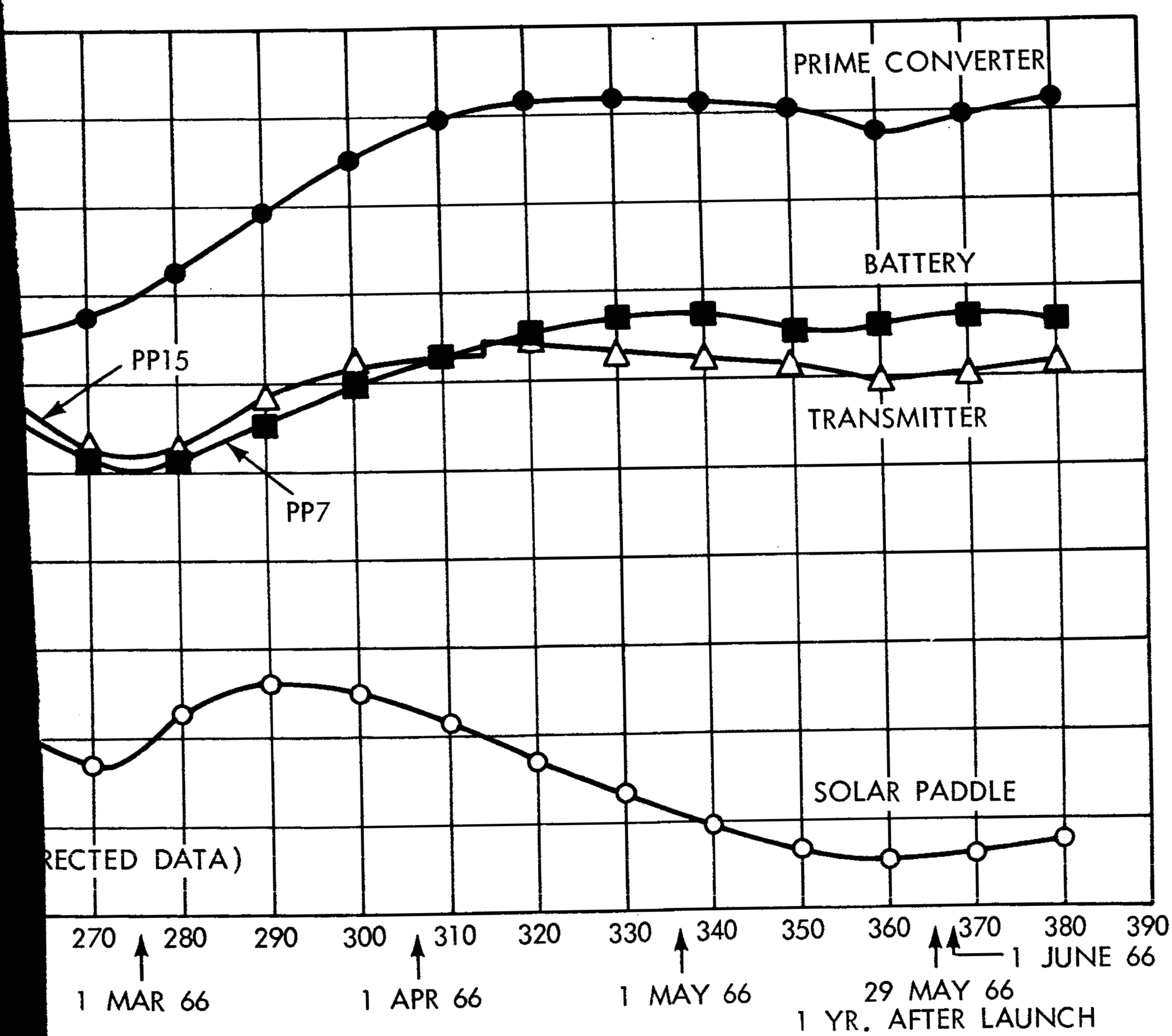


Figure 4—Temperatures.

11-3

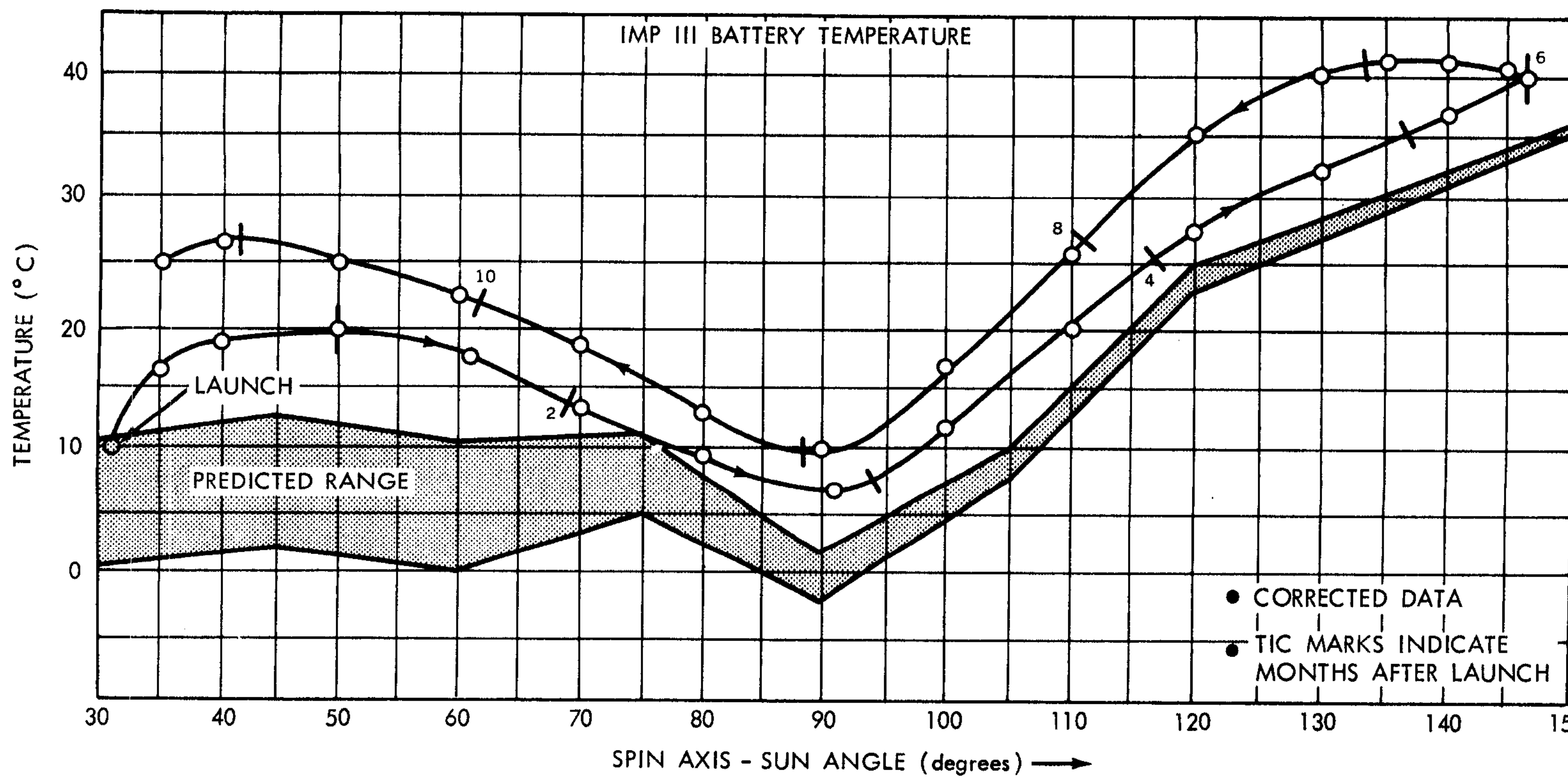


Figure 5—Battery Temperature.

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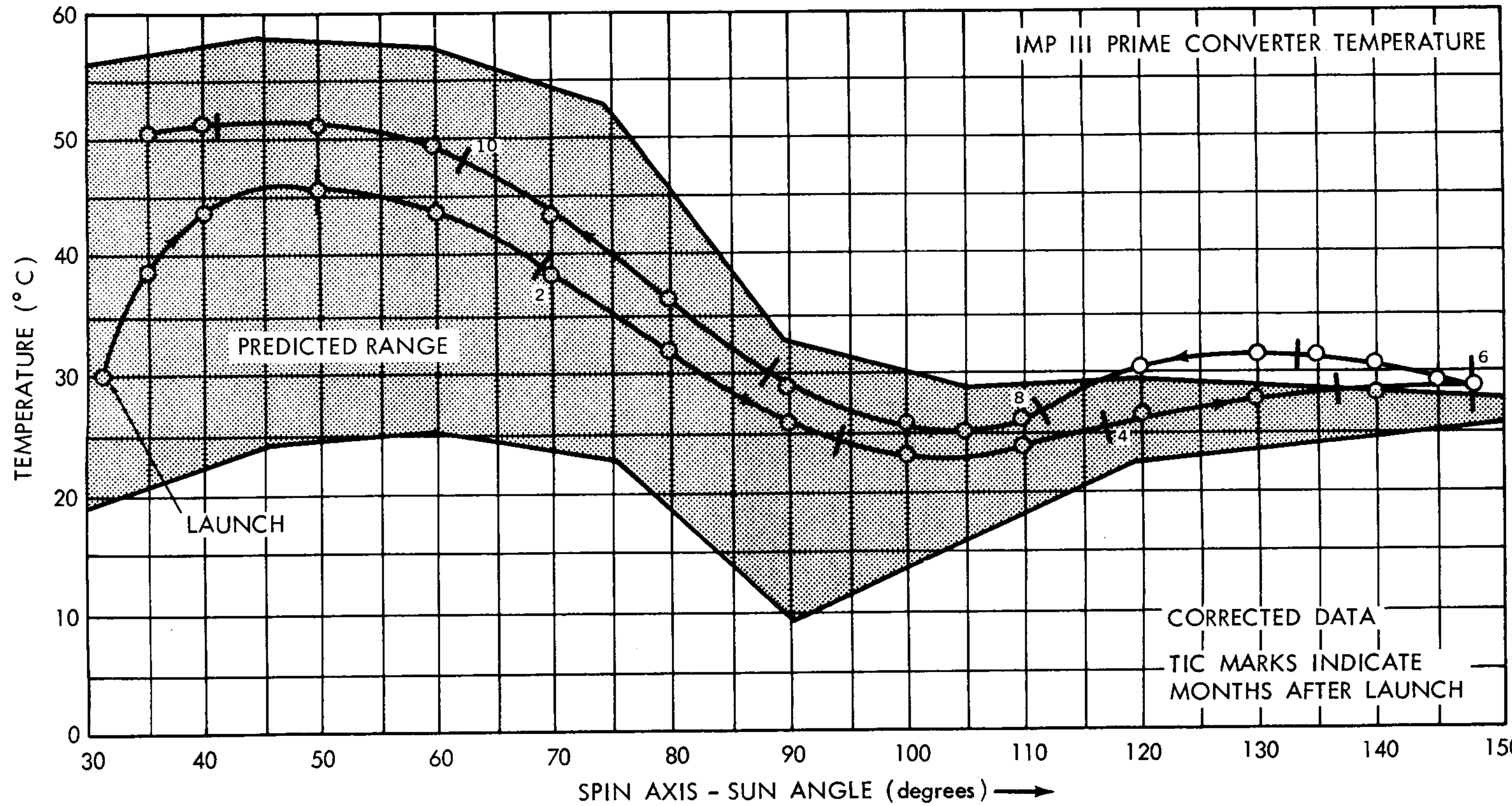

Figure 6—Prime Converter Temperature.

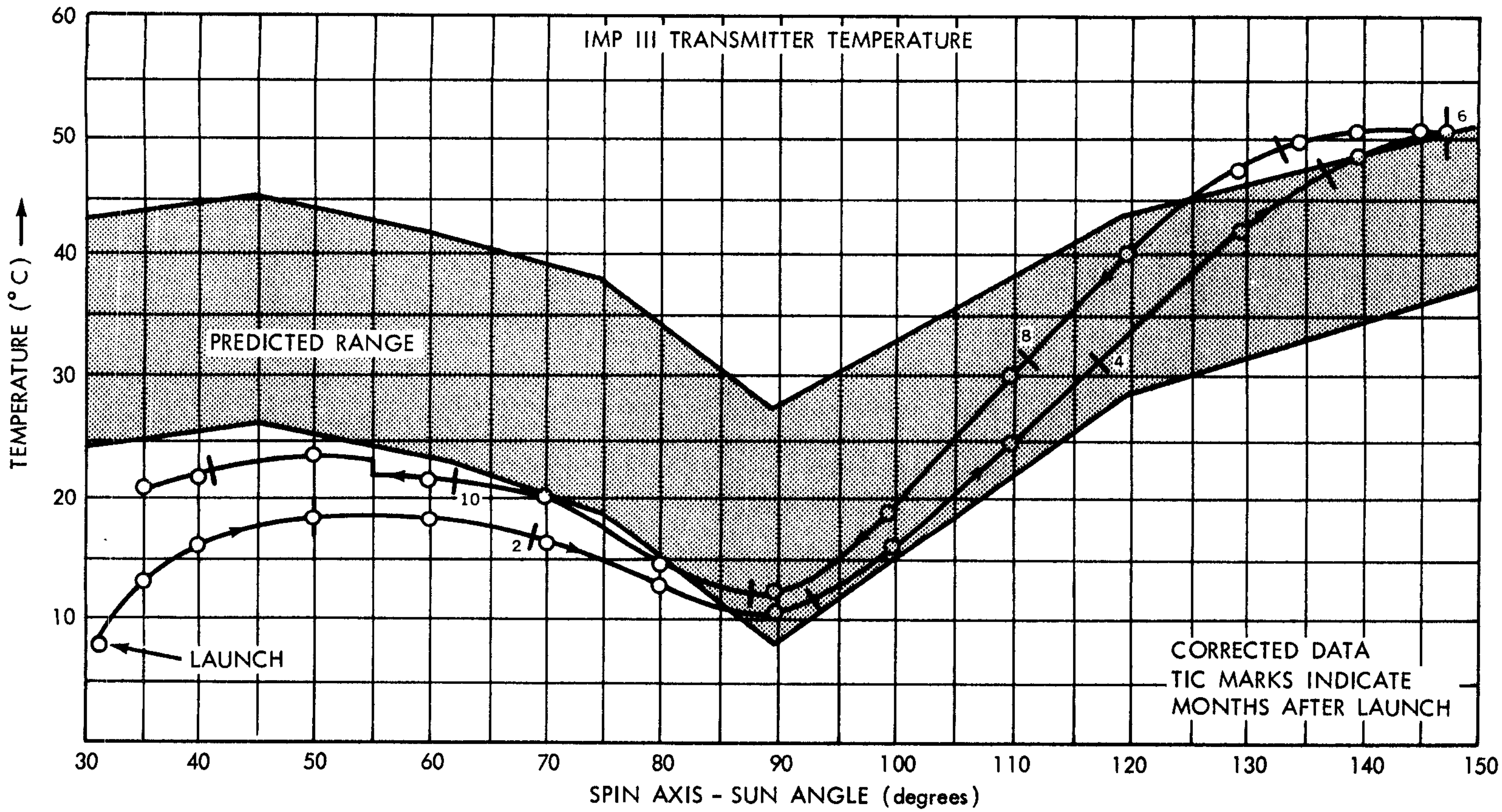

Figure 7—Transmitter Temperature.

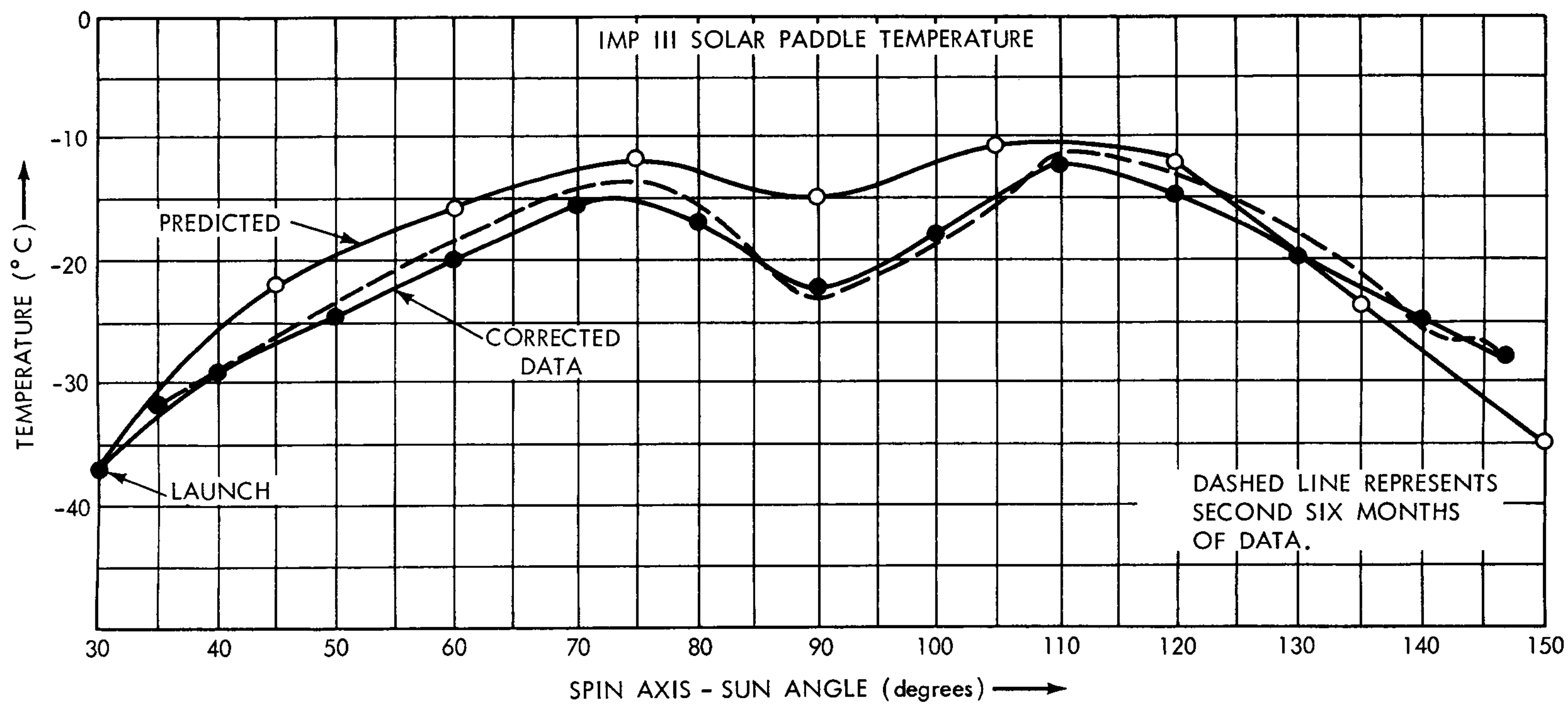

Figure 8—Solar Paddle Temperature.

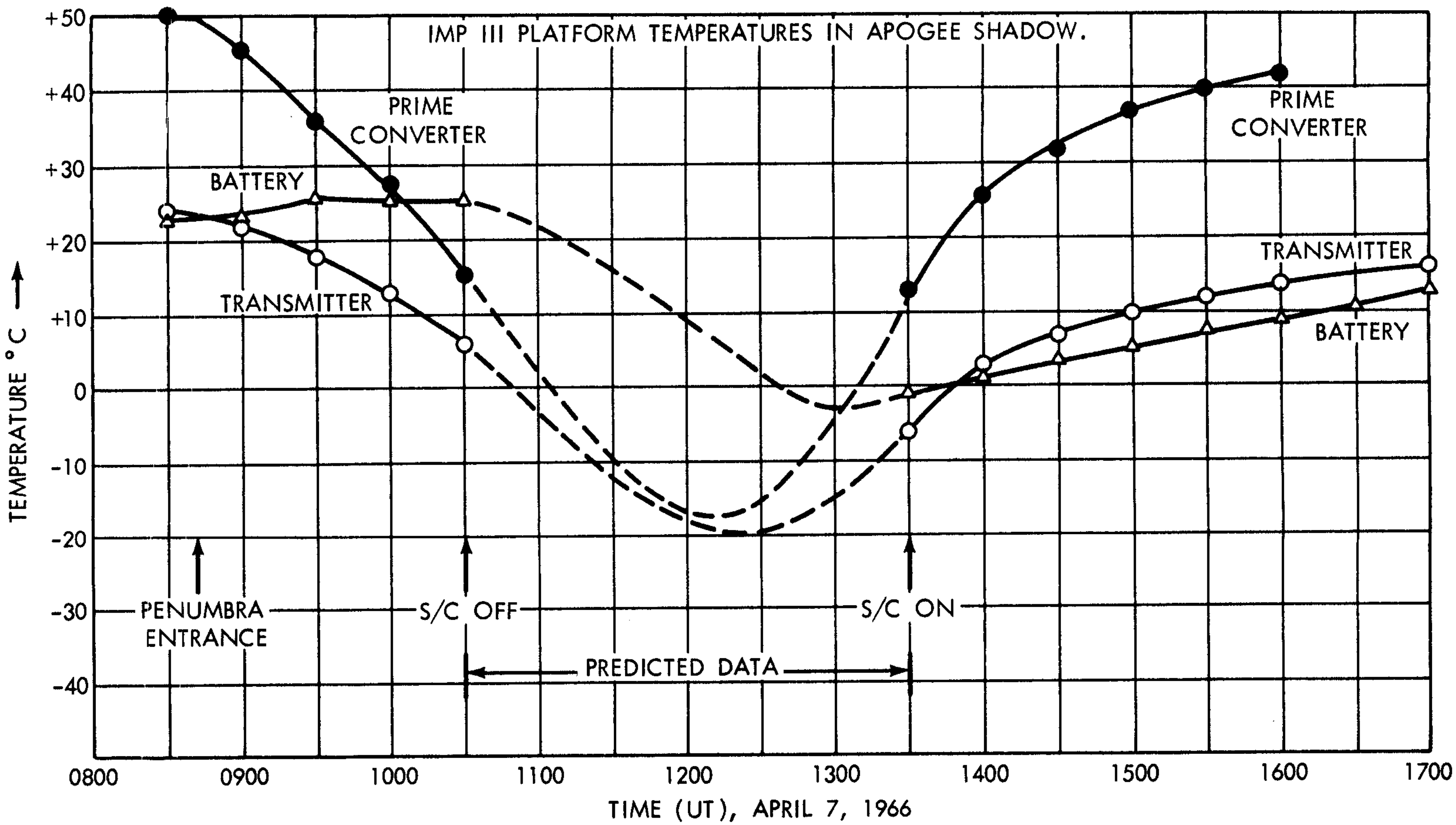

Figure 9—Platform Temperatures in Apogee Shadow.

the pulsing of the battery which occurred about 1 March. At this time the battery temperature was +10°C. Since the two-step voltage regulator would not revert to the higher charging voltage after the pulsing ceased unless the Battery began to accept a current in excess of about 100 milliamperes, and since the battery would not accept a high current at the relatively cold temperature of +10°C, the regulator would stay at the lower voltage level and the battery would remain in a state of partial discharge.

SPACECRAFT PERFORMANCE

During the launch phase, problems occurred in three experiments. They included:

- the failure of the MIT Plasma Probe experiment
- the failure of one of two flux-gate Magnetometers
- some minor problems with the University of Chicago R vs dE/dx experiment.

In addition, the Ames Proton Analyzer provided no data throughout the entire mission but its date of failure cannot be established except to place it within about the first two months following launch.

A number of spurious command-offs of the transmitter have occurred at random times causing the loss of a total of a few hours of data.

The above anomalies are discussed in detail in Reference 1. No changes in the status of these problems nor new problems occurred during the remainder of the first year.

CONCLUDING REMARKS

The IMP III spacecraft has exceeded the mission objective of one year operation in orbit. As of this writing (mid-July, 1966) it has transmitted data for over 9700 hours or about 13-1/2 months. At this time, 7 of 9 experiments continue to produce excellent data. There have been <u>no detectable failures</u> of any spacecraft instrument which includes the telemetry, data handling, power, programming, optical aspect and performance parameter systems (i.e., everything exclusive of experiments).

The failure of the two "solar wind" experiments has been the only disappointing feature of the entire mission.

Since the spacecraft operation continues to be satisfactory and since the experimenters have expressed a desire to continue the mission, the tracking and data acquisition effort has been extended. It is hoped that useful operation will continue for perhaps 6 to 12 months beyond the original goal of one year.

REFERENCES

1. Carr, F. A., "Interim Flight Report, IMP III — Explorer XXVIII," GSFC Document X-724-66-121, March, 1966.

2. Private Communication with M. Coyle, Code 713, GSFC, July, 1966.

3. Private Communication with K. Sizemore, Code 724, GSFC, July, 1966.

APPENDIX A

IMP III Undervoltage Turn-Offs

No.	Signal Lost Date (GMT)	Signal Lost Time (GMT)	Signal Acq. Date (GMT)	Signal Acq. Time (GMT)	Recycle Time (hh:mm)	Operation Prior to Turn-Off: Days	Hours	Min.
1	4/7/66	1029	4/7/66	1325	2:54	312	22	29
2	5/4	1057	5/4	1354	2:57	26	21	32
3	5/12	0715	5/12	1014	2:59	8	17	21
4	5/16	1351	5/16	1648	2:57	3	02	57
5	5/17	1836	5/17	2132	2:56	1	1	48
6	5/18	1802	5/18	2059	2:57		20	30
7	5/19	1452	5/19	1749	2:57		17	53
8	5/20	1019	5/20	1317	2:58		16	30
9	5/21	2300	5/22	0151	2:51		33	43*
10	5/22	1533	5/22	1831	2:58		13	42
11	5/23	0733	5/23	1033	3:00		13	02
12	5/23	2309	5/24	0206	5:57		12	36
13	5/24	1429	5/24	1726	2:57		12	26
14	5/25	0547	5/25	0844	2:57		12	21
15	5/25	2107	5/26	0004	2:57		12	23
16	5/26	1217	5/26	1514	2:57		12	13
17	5/27	0345	5/27	0642	2:57		12	31
18	5/27	1907	5/27	2204	2:57		12	25
19	5/28	1013	5/28	1310	2:57		12	09
20	5/29	0116	5/29	0413	2:57		12	06
21	5/29	1619	5/29	1916	2:57		12	06
22	5/30	0727	5/30	1025	2:58		12	11
23	5/30	2248	5/31	0145	2:57		12	23
24	5/31	1428	5/31	1728	3:00		12	43
25	6/1	0625	6/1	0923	2:58		12	57
26	6/1	2330	6/2	0227	2:57		14	07
27	6/2	1635	6/2	1932	2:57		14	08
28	6/3	1009	6/3	1309	3:00		14	37
29	6/4	0420	6/4	0713	2:57		15	11
30	6/4	2323	6/5	0219	2:56		16	10

IMP III Undervoltage Turn-Offs (Continued)

No.	Signal Lost Date Time (GMT)		Signal ACQ. Date Time (GMT)		Recycle Time (hh:MM)	Operation Prior to Turn-Off		
						Days	Hours	Min.
31	6/5/66	2014	6/5/66	2311	2:57		17	55
32	6/6	2042	6/6	2338	2:56		20	51
33	6/8	1049	6/8	1346	2:57	1	11	11
34	6/15	1249	6/15	1550	3:01	6	23	03

NOTE: Thru 6/15/66, 103 hours, 37 minutes of data lost due to 35 undervoltage turn-offs & recycles (Recharge of battery).

*One turn-off probably not observed/reported.