Presented herein are central station test data derived from the ALSEP Array E thermal vacuum test program. The test data were correlated with analytical flight predictions with the primary purpose being to accurately predict central station temperatures for operation at Taurus-Littrow, the Apollo 17 landing site.

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1.0 Introduction

The central station closed design (north side open) will be employed for Array E since the Apollo 17 landing site (Taurus-Littrow, 20°09'50.5" N, 30°44'58.3" E) will be located at a latitude greater than 5 degrees from the lunar equator. Had the landing site been within 5 degrees of the equator, then the central station open design (North and South sides open) would have been used.

Deployment constraints dictate that the C/S open side will face in a northerly direction in order to prevent direct solar impingement with the C/S radiator plate, which if allowed to occur, could result in C/S electronic component excessive temperatures. The other three sides of the C/S will be comprised of multilayer insulation curtains.

Besides designing the central station to successfully withstand direct solar heating and radiation emissions from the hot lunar surface during the lunar day, considerations were given also for survival at lunar night when the lunar surface temperature will drop to -300°F. Dependable operation of the central station electronics is in part dependent upon maintaining the radiator plate average temperature within the relatively narrow temperature envelope of 0 to 135°F throughout both lunar day and night operation. To achieve this design goal, the following thermal design objectives were established:

(1) Comprehensively defining electronic power dissipation profiles for various modes of operation and RTG output power levels.

(2) A C/S thermal design, based on results of a thermal math model representing the closed configuration, corresponding to the Flight Acceptance Test thermal vacuum environment.

(3) A correlation of analytically and experimentally derived C/S thermal performance data.

(4) Based on (3), an extrapolation of analysis/testing to thermally design the C/S for the Taurus-Littrow landing site.

2.0 Summary

Results from the ALSEP Array E central station (C/S) thermal analysis and testing indicate that the C/S predicted lunar performance will conform to standards set forth in paragraph 3.2.1, Thermal Interface, Subpackage #1, of document number AL 240000, "Structure Thermal Subsystem Specification," SCN #1, approved 15 October 1970.

Table 2-1 summarizes results from thermal analysis and testing and also includes C/S thermal performance predictions for lunar operation at Taurus-Littrow. It is noted from the table that there is a close correlation between C/S analytical predictions and test results for the Flight Acceptance Test thermal environment. Average lunar night thermal plate temperatures for the chamber thermal analysis and test were 33 and 22°F, respectively; for lunar noon, analytical and test thermal plate average temperatures were 100 and 104°F, respectively. The C/S mask width was 2.9 inches for both the pretest thermal analysis and chamber test. The PDM panel temperature corresponding to chamber lunar noon conditions were 238°F for the analysis and 225°F for the test.

Predicted average thermal plate temperatures for C/S operation at Taurus-Littrow are 104°F during lunar noon and 19°F at night for a 2.9 inch thermal plate mask width. The PDM panel predicted maximum temperature for lunar noon operation with the 21 watt dump being activated, is 322°F.

In summarizing, the accuracy of the Array E C/S thermal math model was substantiated with a good correlation between analytical and test results. Since all central station analytical, test, and predicted temperatures fell within established temperature tolerances, the ALSEP Array E central Station (C/S) pre-flight thermal design objectives have been fulfilled.

TABLE 2-1

HIGHLIGHTS OF ARRAY E CENTRAL STATION THERMAL DESIGN/ANALYSIS/TEST

	Flight Acceptance Test Analytical Predictions		Flight Acceptance Test Results		Predicted Lunar Thermal Performance	
Parameter	Lunar Noon	Lunar Night	Lunar Noon	Lunar Night	Lunar Noon	Lunar Night
RTG Output Power, Watts	74.0	74.0	73.3	73.3	74.0	74.0
Reserve Power, Watts	33.8	21.6	35.7	20.7	36.4	21.4
Total Internal C/S PWR Disp, Watts	27.6	42.4	29.5	41.5	29.5	42.2
Thermal Plate Mask Width, Inches	2.9	2.9	2.9	2.9	2.9	2.9
Thermal Plate Avg. Temp., °F	100	33	104	22	123*	19
Total PDM Panel PWR Disp., Watts	22.5	0	22.2	0	22.8	0
PDM Panel Temperature, F	238	-190	225	-185	284**	-200

NOTE: LSP IS IN STANDBY MODE FOR ALL CASES.

* Terrain effects included, level deployment.
** Non-degraded PDM panel ($\alpha = 0.2$).

3.0 ALSEP Electronic Power Levels

Thermal design total internal power dissipations for the C/S are presented in Table 1 for nominal operating conditions (LSP in standby).

TABLE 3-1

Central Station Thermal Design Power Levels
(Nominal Operating Conditions)

Lunar Environment	RTG Output (watts)	C/S Internal Power Dissipation (watts)
Lunar night	74.0 (BOM)*	42.2
Lunar night	71.0 (EOM)	39.4
Lunar noon	74.0 (BOM)	29.5
Lunar noon	71.0 (EOM)	27.5

*BOM and EOM denote beginning of mission and end of mission, respectively.

Maximum internal C/S power dissipation occurs when all experiments including the LSP are operating during lunar noon. The resulting C/S internal power dissipation is 30.4 watts corresponding to a 74 watt RTG output.

The maximum PDM panel dissipation is 40.2 watts which reflects activation of the 21.0 watt commandable dump and all of the experiments off. The condition occurs during lunar noon with a 74 watt RTG output.

Experiment power loads, as shown in Table 3-2, are derived by monitoring reserve power changes resulting from placing each experiment in different modes of operation, i.e., functional, standby, and off modes. The reserve power change includes the experiment load and associated PCU conversion loss. Assuming that the conversion loss is approximately 12% of the reserve power change, the actual experiment load can be determined.

TABLE 3-2

ALSEP ARRAY E
EXPERIMENT POWER LOADS

EXPERIMENT	LUNAR NOON POWER LOADS		LUNAR NIGHT POWER LOADS	
	ON (watts)	STANDBY (watts)	ON (watts)	STANDBY (watts)
LMS	7.4	6.2	7.3	6.1
LEAM	2.7	1.6	5.3	6.1
HFE	3.4	3.9	5.3	3.6
LSG	8.9	0	8.3	0
LSP*	3.9	0	4.0	0
TOTALS	26.3	11.7	31.2	15.8

*LSP in standby mode for normal operation.

TABLE 3-3

ALSEP - ARRAY E
DATA SUBSYSTEM POWER LOADS

COMPONENT	NOON POWER DISSIPATION (watts)	NIGHT POWER DISSIPATION (watts)
Receiver	0.8	0.8
Command Decoder	0.7	0.7
Data Processor	2.0	2.0
PDU[1]	1.8	2.5
Transmitter[2]	8.2	8.1
Diplexer Switch	0.1	0.1
TOTALS	13.6	14.2

Notes:

1. Includes data subsystem I^2R cable losses.
2. Includes transmitter output RF energy of 0.8 watts for lunar noon and 0.9 watts for lunar night.

Table 3-3 presents power dissipations used for the data subsystem. Cable losses associated with the data sub-system are included in the PDU power consumption. The transmitter thermal dissipation is the Table 3-3 value less 0.8 watts of output (RF) energy for lunar noon and 0.9 watts for lunar night.

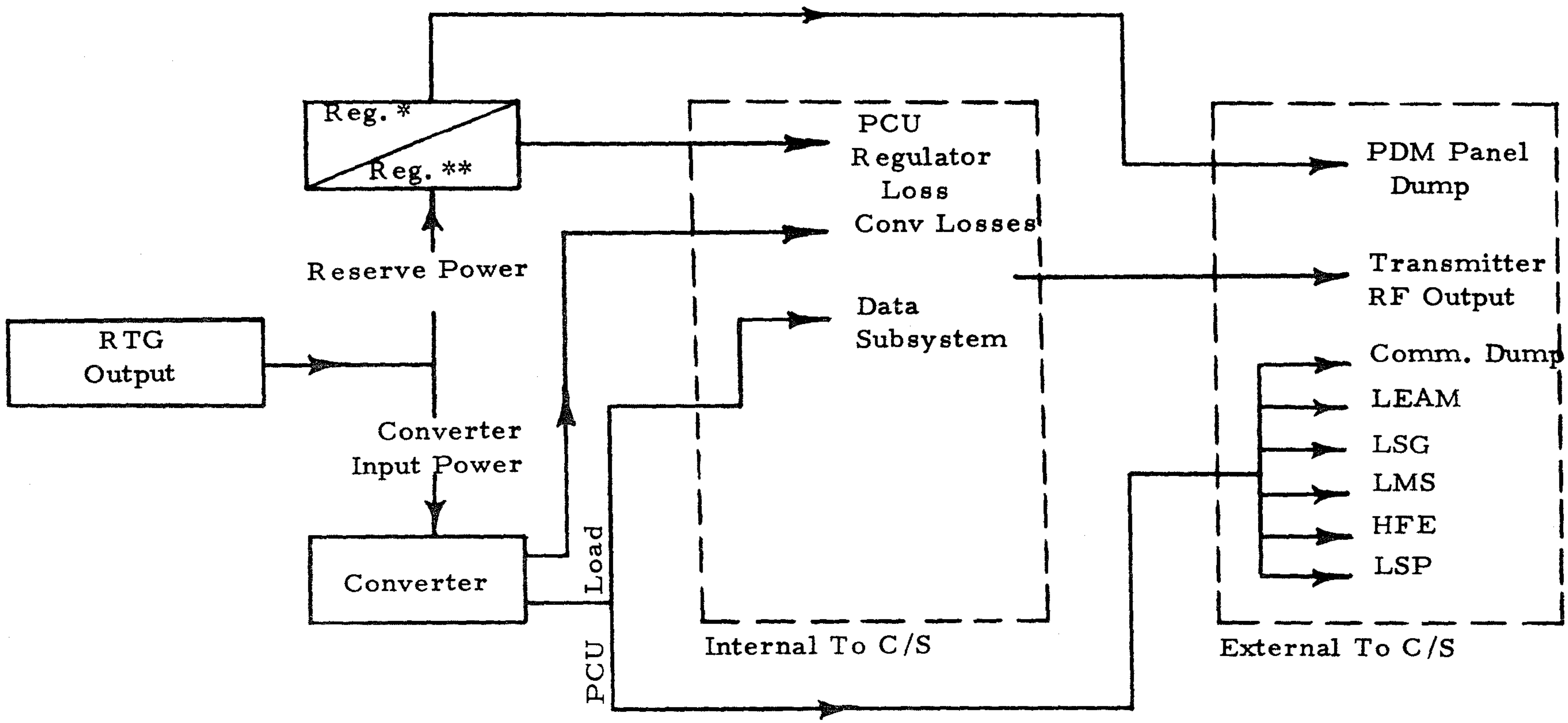
Shown in Figure 3-1 is a block diagram describing the allocation of electronic power for Array E. RTG output power is divided between reserve power and converter input power. Reserve power is sub-divided between PCU regulator loss, which is internal to the C/S, and PDM panel power dissipation, external to the C/S. The converter input power consists of conversion losses, data subsystem and LSP C/S electronics. Externally dissipated converter input power includes commandable dumps, experiments, and transmitter RF power.

Conversion losses are calculated by taking 12.2% of the PCU load (total experiment plus data subsystem loads) and adding 2.0 watts. The summation of experiment, data subsystem, and conversion losses is described as converter input power. Reserve power equals RTG input power minus converter input power. Reserve power is allocated between PCU regulator and PDM panel power dissipations.

Total PCU internal dissipation can be determined by using Figure 3-2. Once the PCU load is established, the conversion loss is calculated and the converter input power is determined. Figure 3-2 is then entered at the appropriate converter and RTG power levels, and total PCU loss is read from the curve ordinate. Regulator power dissipation is that amount of total PCU power consumption in excess of conversion losses. Figure 3-3 is used to determine the PCU load.

Figure ...

ALSEP ARRAY E
CENTRAL STATION POWER DISSIPATION BLOCK DIAGRAM



* Activation of the day regulator (APM on) requires a reserve power minimum of 2 watts and a thermal plate average temperature increase to 80°F. Under these conditions, excess power is dumped externally to the PDM panel.

** Activation of the 65 watt night regulator (APM off) requires that the thermal plate average temperature decrease to 60°F. For night-time operation all excess power is dissipated internally to maintain temperature control.

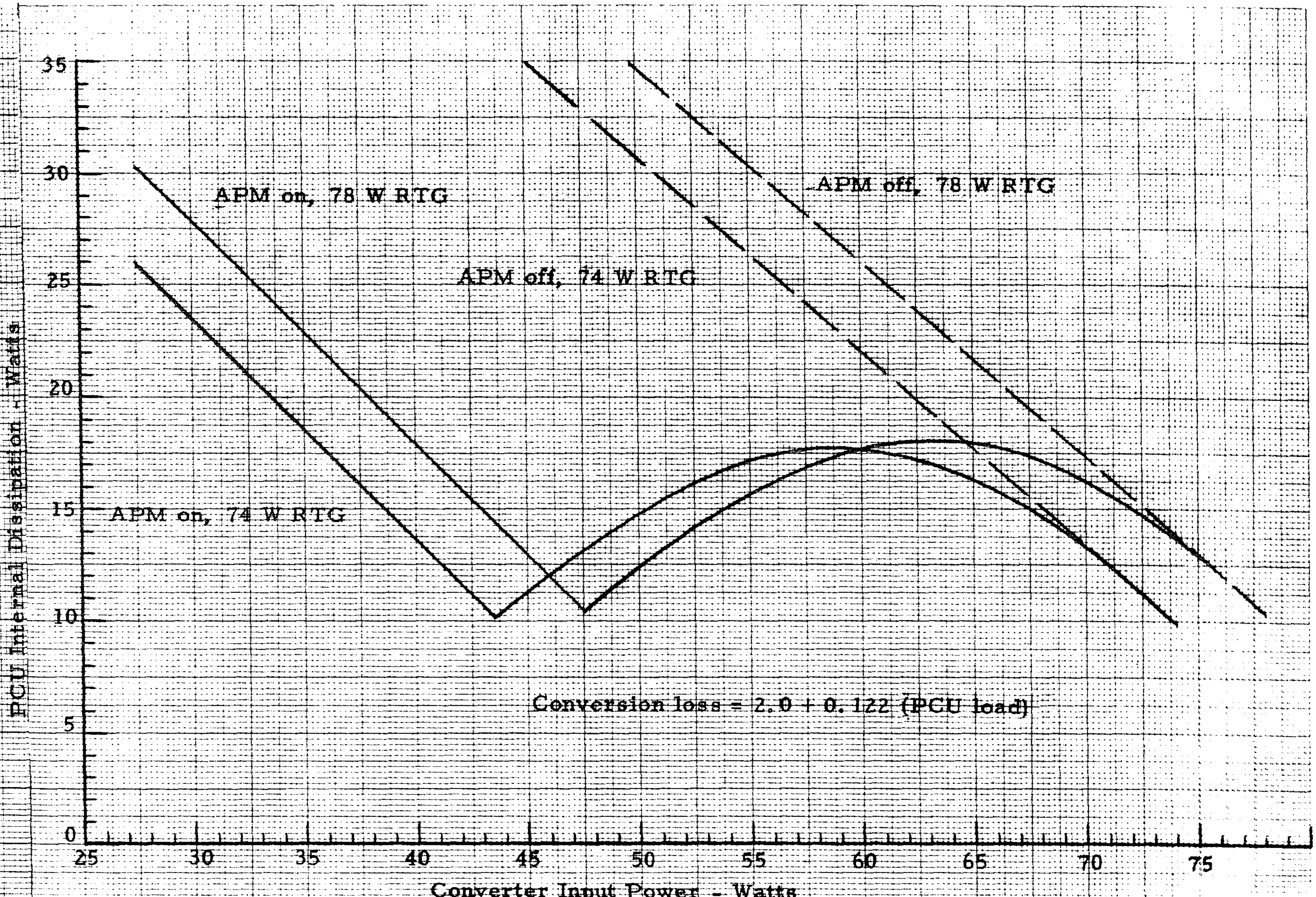


Figure 3-2. ALSEP Array E C/S Calibration and Verification Test Results

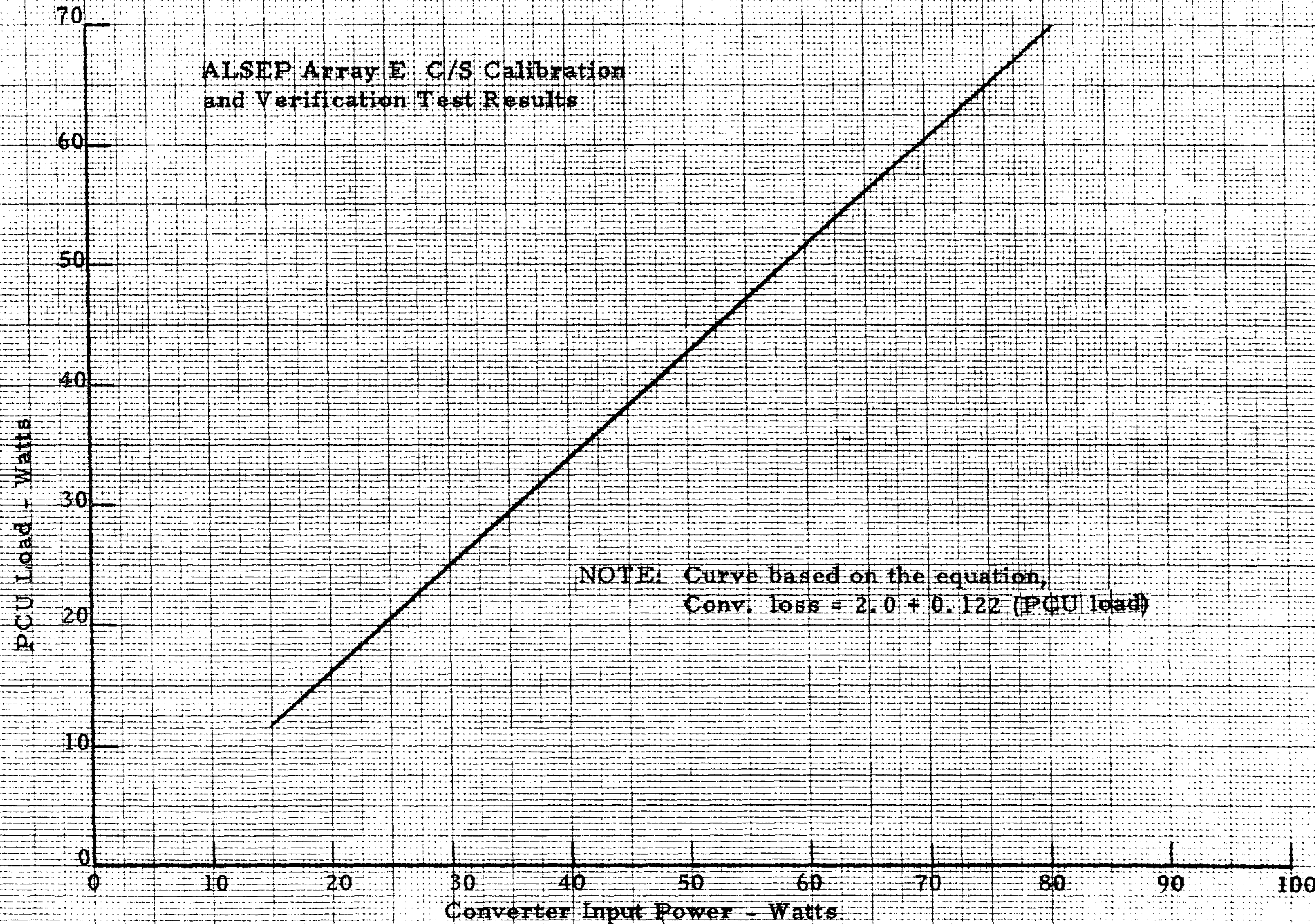


Figure 3-3. PCU Load Determination

The quantity of reserve power minus regulator loss is diverted to the PDM panel. However only 85% of the PDM load is dissipated on the panel and the remainder is cable I^2R loss, which is interior (5%) and exterior (10%) to the Central Station.

The power levels presented in Tables 3-1 through 3-3 represent the latest compilation and were the basis for the final Array E Central Station thermal design.

4.0 C/S Thermal Design/Analysis

As in other ALSEP central station thermal designs, one of the primary objectives for the Array E design was to insure that the radiator plate average temperature would remain within the temperature envelope of 0 to 135°F throughout lunar day and night operation. To achieve this goal, a central station closed design will be used.

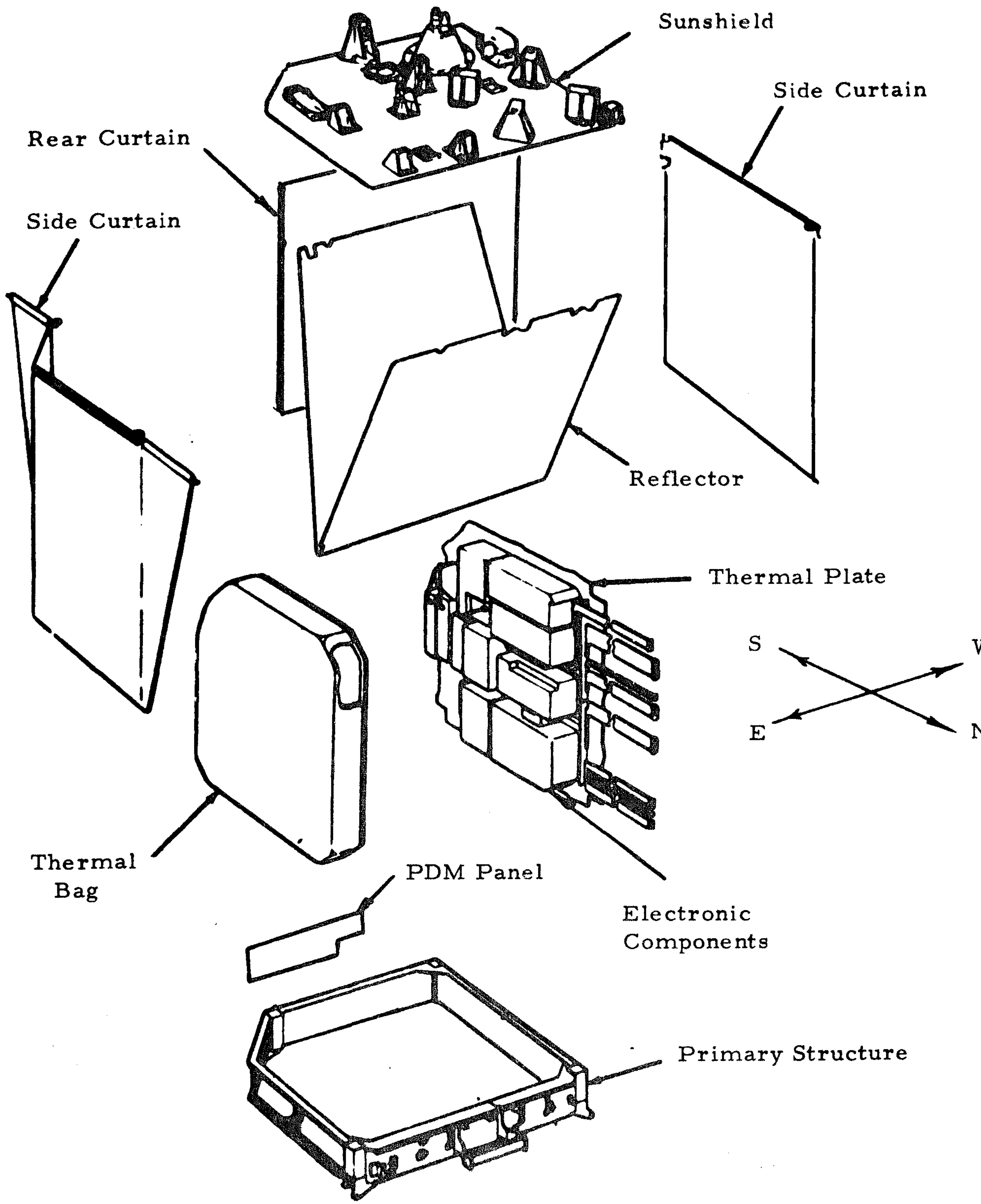
Figure 4-1 presents an exploded schematic of the central station closed design with related compass points that are applicable for deployment at Taurus-Littrow, the Apollo 17 landing site. Had the projected deployment latitude been within 5 degrees of the lunar equator, then the C/S open design would have been used.

Reference 12 presented results of an analysis conducted with the objective of updating both the C/S open and closed design steady state thermal math models for Arrays A-2 and D. Included in the analysis were detailed calculations which reflected the techniques used in deriving the critical radiosity networks of the thermal math models.

It was the radiosity network of the Array E C/S closed design steady state thermal math model that was modified for the final update effort. All other aspects of the model such as insulation mask unit resistance, effective lunar surface temperature, and calculated conductive resistances were not changed for the final model.

In order to be conservative, original Flight 1 temperature predictions were based upon the assumption that the internal surface of the C/S side curtains were completely diffuse, i.e., that the specular reflectance was zero. However, subsequent flight data indicated that the side curtain surfaces were partially specular, which meant that a modification to the radiosity network of the C/S enclosure could be used to correlate analytical results to flight data. For the latest update of the Array E C/S steady state thermal math model, the radiation conductances between the internal surfaces of the side curtains and the lunar surface were varied through a trial and error process with the intent being to correlate analytical results with flight data from previous flights.

Figure 4-1. Array E Closed Design Central Station



Figures 4-2 and 4-3 illustrate the resulting mask/power/temperature relationships which are applicable for the Array E central station closed design. The primary difference between the results of Figures 4-2 and 4-3 and the results of Reference 13 is that the final lunar noon radiator plate predicted temperatures are approximately 10°F lower than those of Reference 13. As expected, based upon previous analyses, the night temperatures were not appreciably affected by the modification of the radiosity network. In general, results of the radiosity network modification study indicate that the specular reflectance of the internal surfaces of the side curtains is somewhat higher than had originally been assumed.

Figure 4-4 was included so that a temperature correction factor could be applied to the curves of Figures 4-2 and 4-3 in order to account for off-equatorial deployments. Results of Figures 4-2 and 4-3 are valid only for landing site latitudes from zero to five degrees and for level terrain. For landing site latitudes greater than five degrees, a temperature correction factor should be taken from Figure 4-4 and then applied to the results of Figures 4-2 and 4-3. The temperature correction factor accounts for latitude dependent effects such as varying solar loads and lunar surface temperatures.

Table 4-1 presents a comprehensive summary of the Array E central station thermal performance. Radiator plate and PDM panel temperature predictions are given for various cases based upon the latest power compilations of the central station, the experiments, and the RTG. Two types of cases are given: (1) BOM, Beginning of Mission which corresponds to an RTG output of 74.0 watts and (2) EOM, End of Mission which is based on an RTG output of 71.0 watts.

The first four cases represent nominal operating conditions wherein the LSP is placed in the standby mode. Cases 1 and 2 represent nominal night conditions that are expected to be experienced at the end of the first lunar night (BOM) and at the end of two years (EOM). Note that the RTG output is expected to drop from 74.0 watts to 71.0 watts after two years of operation. The corresponding decrease in the central station internal thermal dissipation is predicted to be 3.0 watts to 39.2 watts with a resulting radiator plate average temperature decrease of 9°F to 10°F. Predicted temperatures for the PDM panel for the two night cases are -200°F, since in both night cases, the PDM power dissipation is predicted to be negligible.

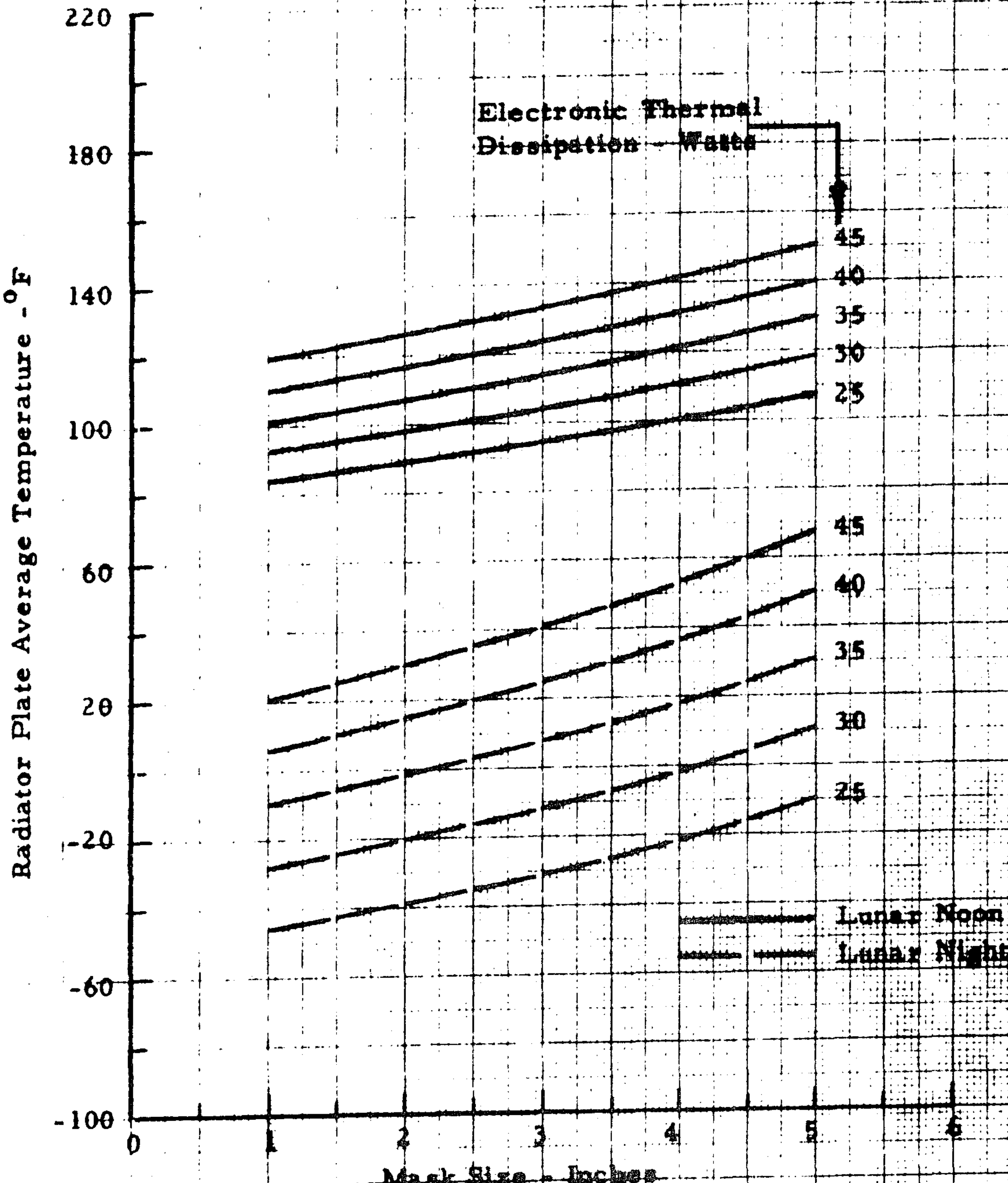


Figure 4-2. Central Station Radiator Plate Average Temperature as a Function of Mask Size, Closed Design.

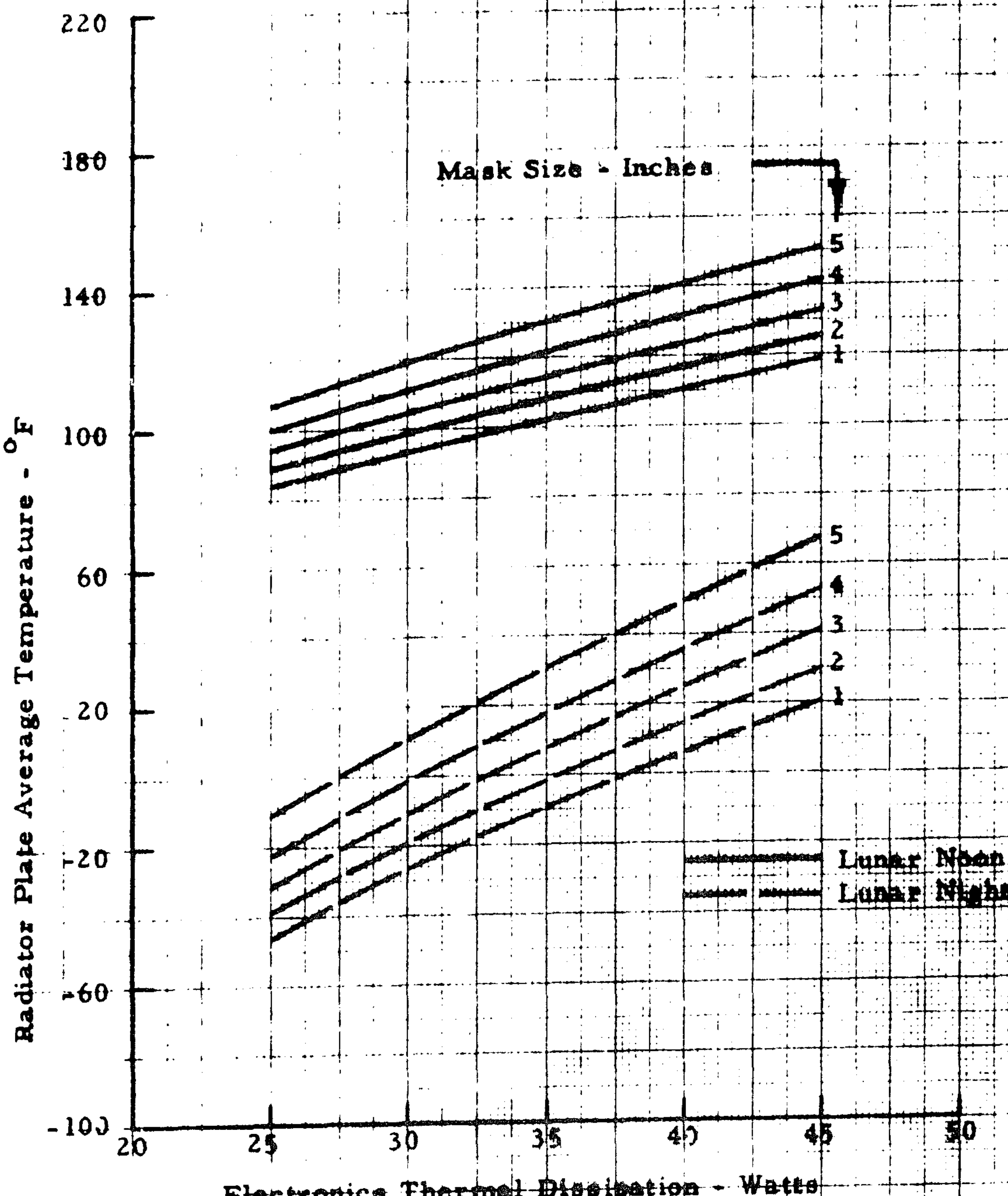


Figure 4-3. Central Station Radiator Plate Average Temperature as a Function of Electronics Thermal Dissipation, Closed Design.

NOTE: Temperature correction factors should be applied only to T/P temperature for lunar day since night temperatures are non-latitude dependent.

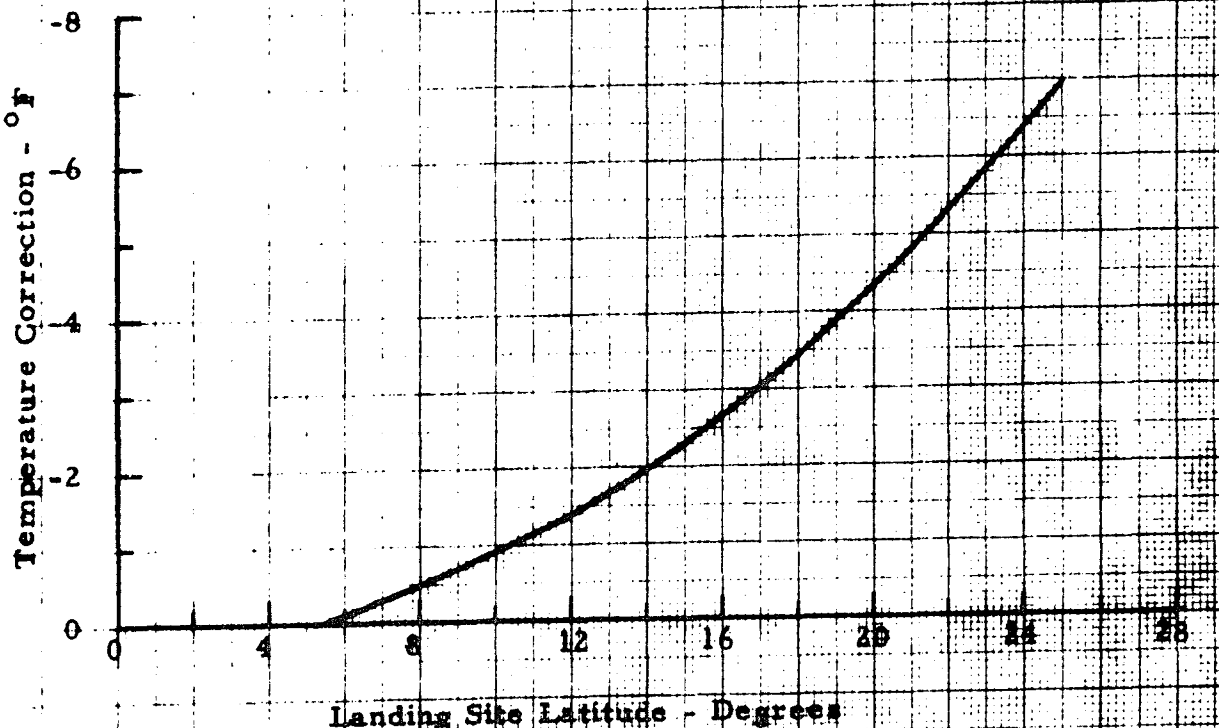


Figure 4-4. Temperature Correction for Closed C/S at Latitudes Greater Than 5 Degrees.

TABLE 4-1

ALSEP - ARRAY E CENTRAL STATION
THERMAL PERFORMANCE PREDICTIONS

PARAMETER	CASE 1 Night, EOM LSP stby, 71.0 W RTG	CASE 2 Night, BOM LSP stby, 74.0 W RTG	CASE 3 Noon, EOM LSP stby, 71.0 W RTG	CASE 4 Noon, BOM LSP stby, 74.0 W RTG	CASE 5 Noon, BOM LSP ON 74.0 W RTG	CASE 6 Noon, BOM EXPS OFF 21.0 W DMP 74.0 W RTG
EXPERIMENT LOAD DETERMINATION						
LMS	7.29	7.29	7.38	7.38	7.38	NO EXPS
LEAM	5.27	5.27	2.72	2.72	2.72	
HFE	6.32	6.32	3.42	3.42	3.42	21.0 DUMP
LSG	8.34	8.34	8.34	8.87	8.87	
LSP	0	0	0	0	3.90	
TOTAL EXP	27.22	27.22	22.39	22.39	26.29	21.0
RESERVE POWER DETERMINATION						
C/S	14.2	14.2	13.6	13.6	13.6	13.6
EXPS	30.9	30.9	18.2	18.2	26.3	21.0
CONV	7.5	7.5	5.8	5.8	6.9	6.2
RTG-RP	52.6	52.6	37.6	37.6	46.8	40.8
RTG	71.0	74.0	71.0	74.0	74.0	74.0
RP	18.4	21.4	33.4	36.4	27.2	33.2
C/S INTERNAL POWER DISSIPATION						
PCU DISP	25.9	28.9	12.6	15.4	12.6	13.1
C/S - XMTR RAD	13.3	13.3	12.8	12.8	12.8	12.8
EXP CSE	0	0	0	0	3.9	0
CABLES INT.	0	0	1.3	1.3	1.1	2.4
INT DISP	39.2	42.2	26.7	29.5	30.4	28.3
EXTERNAL POWER DISSIPATION & POWER CHECK						
EXP-EXP CSE	30.9	30.9	18.2	18.2	22.4	0
PDM	0	0	22.6	22.8	18.3	40.2
CABLES EXT.	0	0	2.7	2.7	2.1	4.7
XMTR RAD	0.9	0.9	0.8	0.8	0.8	0.8
EXT DISP	31.8	31.8	44.3	44.5	43.6	45.7
INT DISP	39.2	42.2	26.7	29.5	30.4	28.3
TOTAL	71.0	74.0	71.0	74.0	74.0	74.0
Radiator Plate Avg. Temp. - °F	10	19	98	104	106	102
PDM Panel Temp. - °F	-200	-200	280	281	270	322

NOTE:
(1) All values are in watts unless otherwise designated.
(2) BOM - Beginning of Mission
(3) EOM - End of Mission
(4) PDM - Panel temperatures are for 10% blockage and dust degraded surface (α = 1.0).

Cases 3 and 4 were based on nominal noon conditions with the LSP in the standby mode of operation. The two cases represent conditions that are expected to exist at the beginning of the mission and at the end of the two year life mission. The thermal dissipations of the data subsystem, the experiments, and the PCU conversion losses are predicted to remain constant for lunar noon operation throughout the first two years of operation. The three watt deterioration in the RTG output will be reflected in the change of the reserve power and the PCU dissipation. Considering the overall effect upon the central station thermal performance due to the RTG output deterioration, the PDU power dissipation will remain essentially constant at slightly under 23 watts during the two year life mission and the central station internal thermal dissipation will decrease from 29.5 to 26.7 watts. Table 4-1 shows that the predicted radiator plate temperature will decrease from 104°F (BOM) to 98°F(EOM) after two years of operation. The corresponding PDM panel temperatures will be 281°F (BOM) and 280°F(EOM). The PDM panel temperatures were based on 10% panel blockage and a fully dust degraded surface with a solar absorptance of one.

Case 5 represents the lunar noon worst case condition with LSP being turned on and with no commandable dump being activated. The corresponding lunar noon internal thermal dissipation of the central station is predicted to be 30.4 watts which will result in a radiator plate average temperature of 106°F. By activating the 21.0 watt dump and turning off all of the experiments (Case 6) a decrease of central station internal thermal dissipation to 28.3 watts will be observed with a related radiator plate average temperature of 102°F, a 4°F improvement over the worst case condition. In activating the 21 watt dump and turning off all of the experiments, an additional 21.9 watts will be dissipated within the PDM panel with a resultant panel maximum temperature of 322°F which is well below the design goal maximum of 350°F.

4.1 C/S Radiator Plate Mask Sizing

The central station radiator plate temperature is dependent upon a number of parameters such as electronic power dissipation, experiment power demands, RTG output power, landing site latitude, and the use of PDM commandable dumps and the APM. The C/S thermal design objective of maintaining the lunar day to night radiator plate average temperature within the relatively narrow temperature envelope of 0 to 135°F, is achieved by optimizing the radiator plate mask width based upon the combined influences of the aforementioned parameters.

Table 4-2 presents the thermal design cases used to determine the closed design central station mask size corresponding to the Taurus-Littrow landing site. Case 1 highlights the Array E Flight Acceptance Test lunar night condition for a mask size of 2.9 inches and a C/S internal dissipation of 41.5 watts. The average thermal plate temperature was 22°F. Case 2 corrects Case 1 by accounting for input power differences between the chamber and "real moon". The predicted RTG output for lunar performance is 74.0 watts at the beginning of the mission while the test level at lunar night was 73.3 watts. The RTG power level was increased by 0.7 watt to account for the difference. For a mask size of 2.9 inches and a revised C/S internal dissipation of 42.2 watts, the corrected average thermal plate temperature corresponding to the chamber lunar night was 24°F.

Case 3 modifies Case 2 by considering environmental discrepancies between the thermal vacuum chamber and the "real moon". The primary discrepancy is that the cryowall can not attain temperatures associated with space. Minimum cryowall temperatures using liquid nitrogen are approximately -320°F while the effective space temperature is -460°F. The Central Station average thermal plate temperature is lowered by 3°F to account for this difference. In addition to the environmental differences, an adjustment in the lunar night thermal plate temperature was made in order to account for the addition of a copper/byrillium grounding strap that is connected between the thermal plate and the shields within the geophone cable connector. Thermal performance effects caused by the post test addition of the strap are expected to be negligible for lunar noon, however, an average decrease in the thermal plate temperature of 2°F is predicted for central station lunar night operation. For a mask width of 2.9 inches and a C/S internal dissipation of 42.2 watts, the corrected "real moon" average thermal plate temperature corresponding to lunar night was 19°F.

TABLE 4-2

ARRAY E C/S MASK THERMAL DESIGN CASES

	Case 1 Chamber Lunar Night	Case 2 Corrected Chamber Lunar Night	Case 3 Corrected "Real Moon" Lunar Night	Case 4 Predicted "Real Moon" Lunar Day
RTG Input PWR (Watts)	73.3	74.0	74.0	74.0
Reserve Power (Watts)	20.7	21.4	21.4	36.4
Conv Input Power (Watts)	52.6	52.6	52.6	37.6
C/S Int DISP (Watts)	41.5	42.2	42.2	29.5
Mask Size (Inches)	2.9	2.9	2.9	2.9
Thermal Plate Avg Temp (^{o}F)	22	24	19	104

NOTES: (1) LSP IN STANDBY

Case 4 represents the lunar noon thermal performance prediction for the Central Station deployed at Taurus-Littrow. For a total internal power dissipation of 29.5 watts, the mask width of 2.9 inches establishes the average upper-bound thermal plate temperature level at 104°F.

5.0 PDM Panel Thermal Design/Analysis

A detailed thermal design/analysis was performed on the PDM panel which is presented in Reference 4. PDM temperature levels are dependent on numerous parameters including PDM power dissipation, landing site latitude, dust degradation, panel burial in the lunar soil (referred to as panel blockage), and orientation of the panel with respect to the sun (referred to as deployment configuration.) The power dissipation is in turn a function of experiment power load, experiments going on standby, and PDM thermal control power dumps being activated. The current central station (C/S) deployment configuration has the PDM panel facing the sun, which raises the panel temperature due to the increased energy which the panel must reject to space during the day. If the panel is partially buried in the lunar soil (as occurred in ALSEP Flight 1), the panel temperature will rise due to the increase in the power-to-radiating-area ratio.

In view of the many variables affecting the PDM thermal performance, a set of realistic worst-case deployment and operating conditions were chosen as the basis for the Array E temperature predictions.

Figures 5-1 through 5-3 summarize Reference 4 by showing PDM panel temperatures at lunar noon as a function of power dissipation, latitude, dust degradation, and blockage. The PDM thermal design, condition considers the panel to be 10% blocked by the lunar surface and 100% degraded by dust. Maximum allowable temperature levels for the PDM panel are 350 °F as defined in Reference 3.

For specific PDM predicted temperatures for lunar operation, refer to Table 4-1. Values in Table 4-1 include temperature adjustments which were made in order to account for the Taurus-Littrow terrain effects and the effects of tilting the C/S open side array from the lunar surface by 7 degrees. The combined effect of these two considerations was to lower the values of Figures 5-1 and 5-2 by 2 °F. At the beginning of the mission, i.e., the Apollo 17 first lunation, the anticipated nominal PDM temperatures for night and day are shown to be -200 and 281 °F, respectively. The predicted maximum temperature of 281 °F is 69 °F below the maximum allowable temperature which was established in Reference 3.

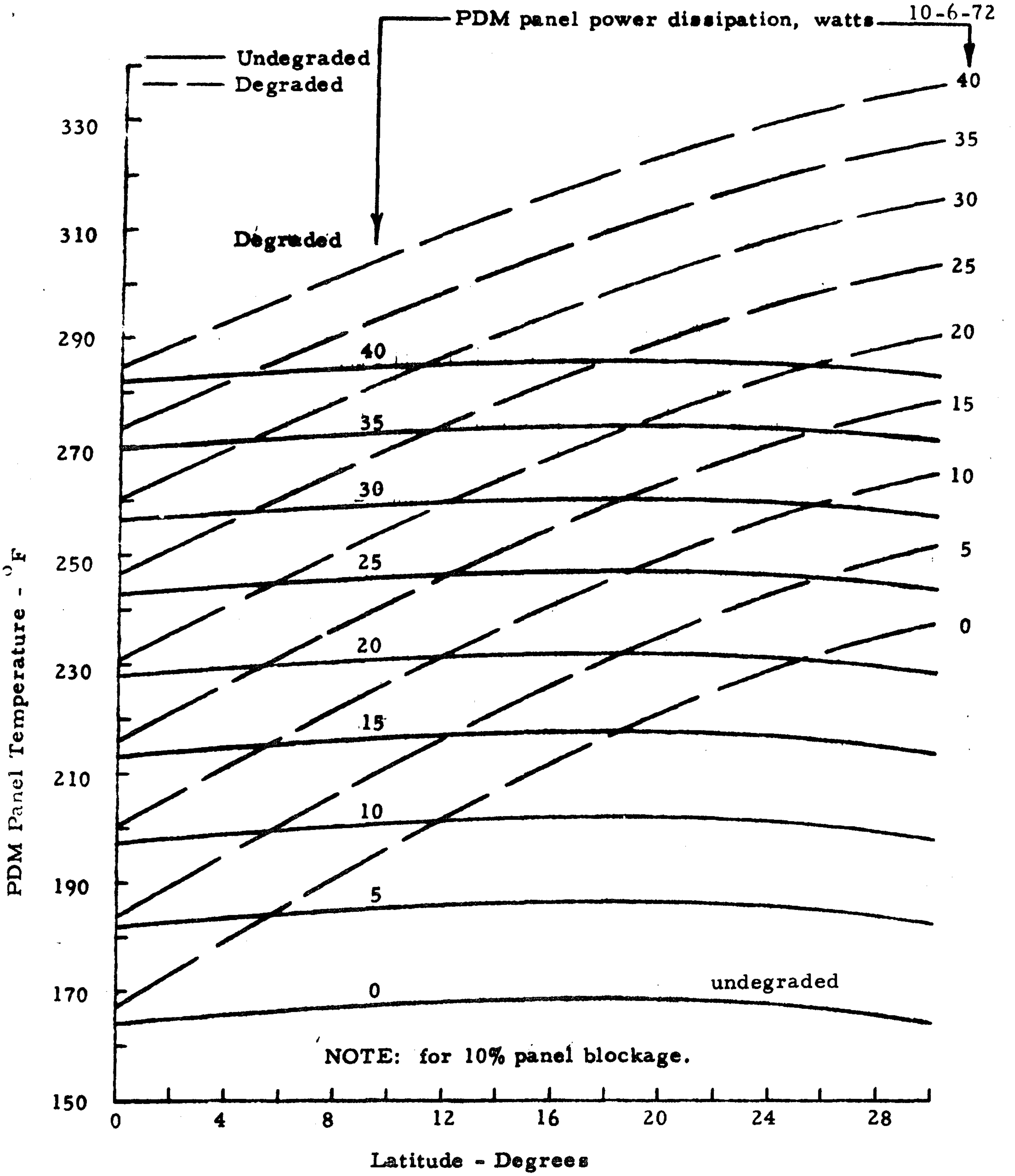


Figure 5-1. PDM Panel Predicted Temperature, Array E, Lunar Noon

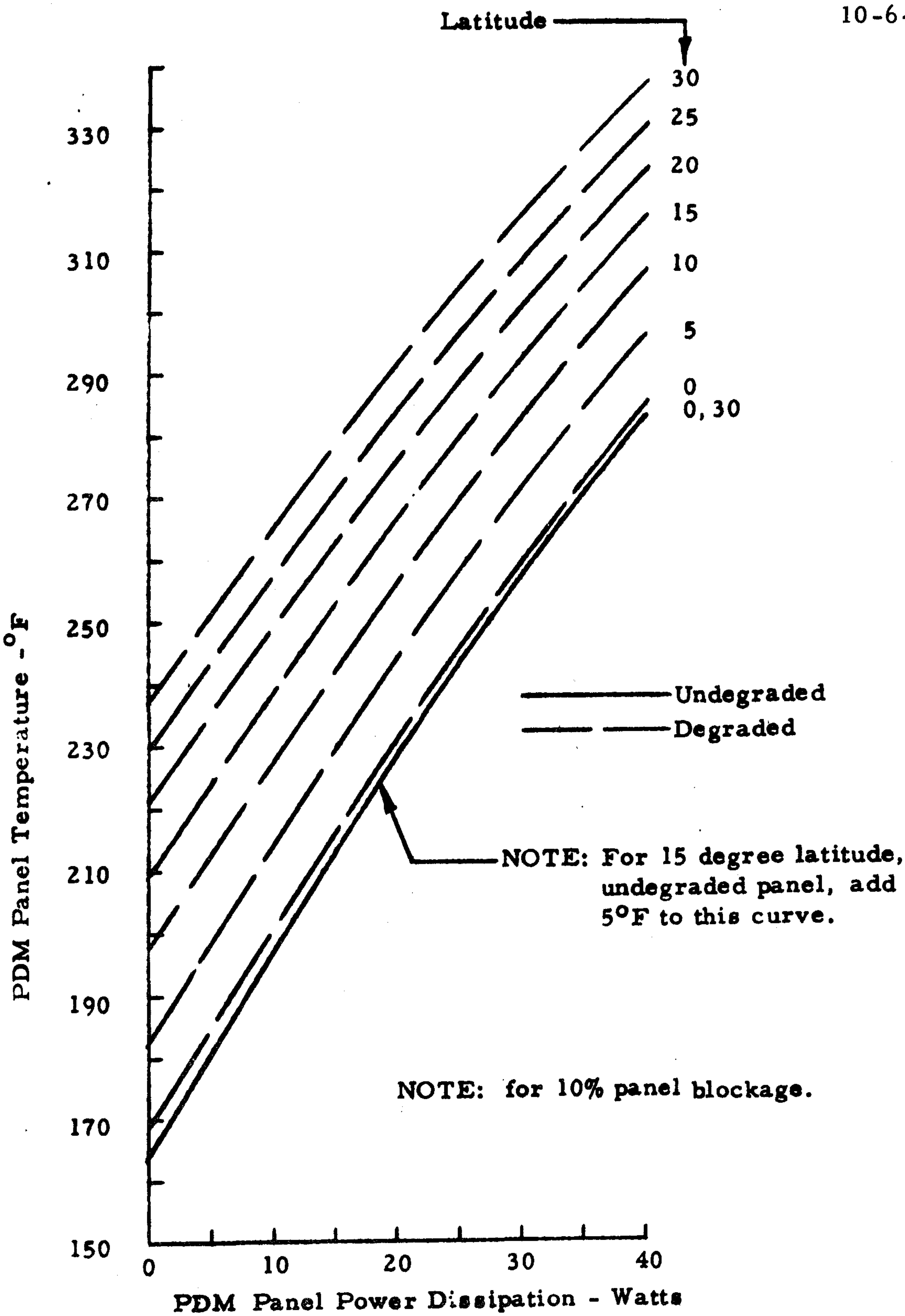


Figure 5-2. Array E PDM Panel Temperature as a Function of PDM Panel Power Dissipation and Latitude, Lunar Noon.

NOTES: 1. **Temperature correction is added to or subtracted from** Figures 5-1 & 5-2 values, **as indicated.**

2. **Values apply for all latitudes and for both undegraded** and degraded **panel solar absorptance.**

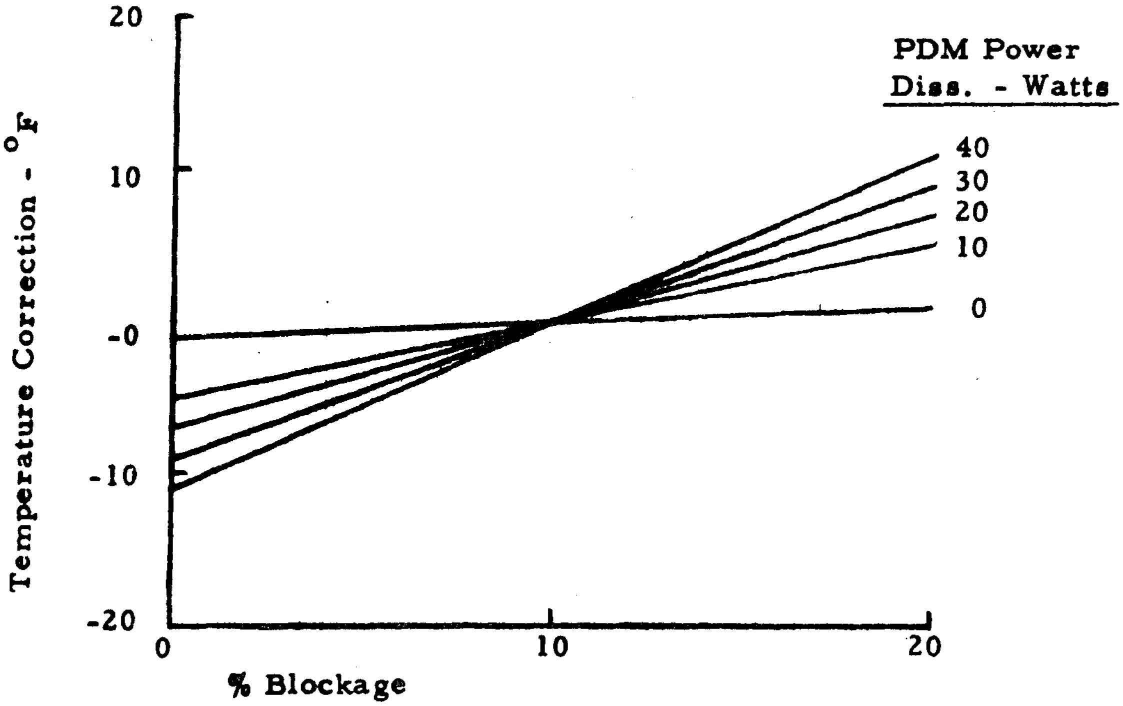


Figure 5-3. **PDM Panel Temperature Correction for Panel Blockage Other than 10%.**

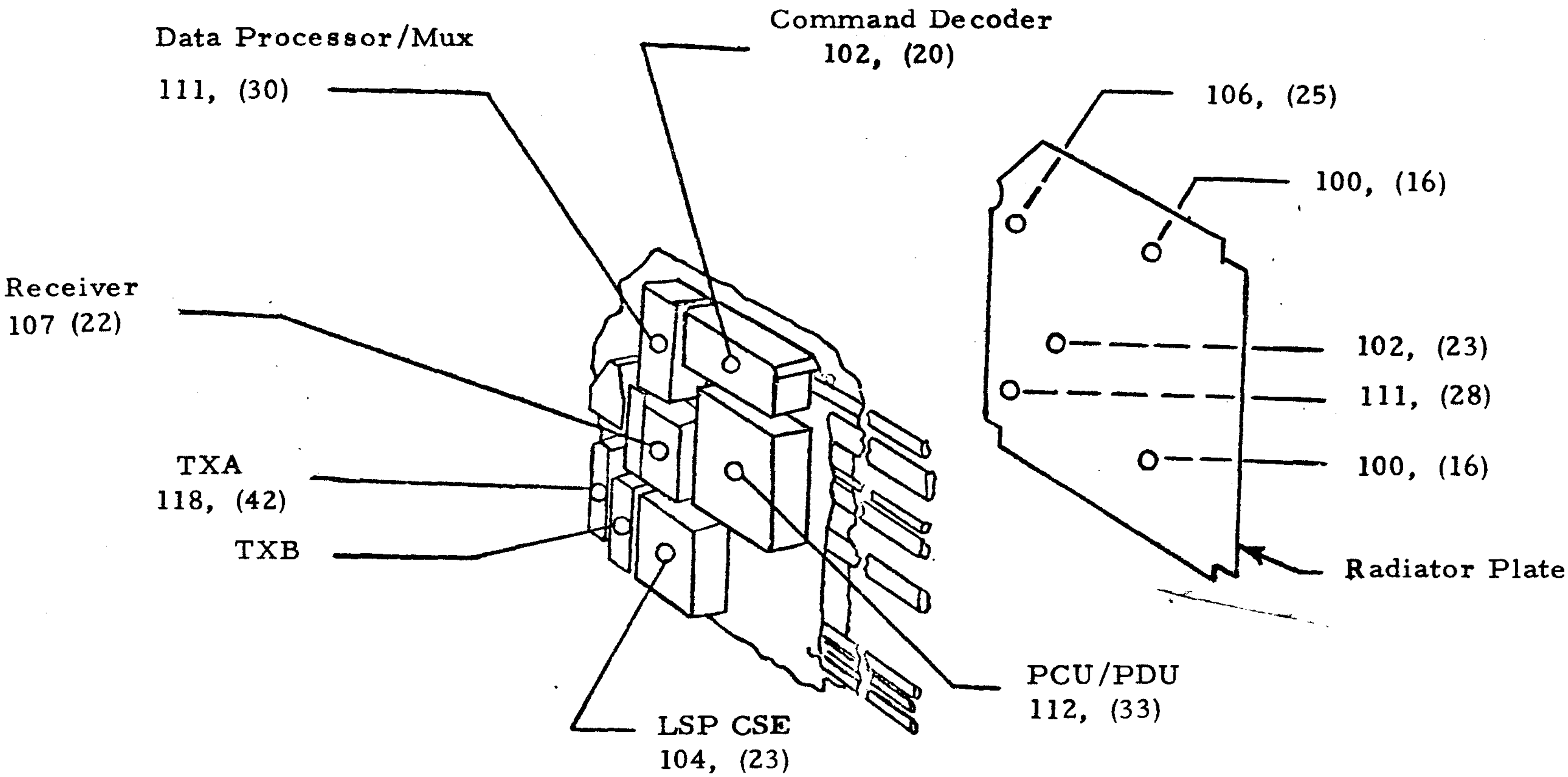
6.0 Qual/Flight Acceptance/Lunar Predictions Correlation

Flight acceptance testing was conducted in the BxA 20 x 27' thermal vacuum (T/V) chamber during the period from 7/1/72 through 7/12/72. Lunar noon equilibrium conditions were approximated at 0100, 7/6/72, and lunar night stabilization conditions were taken to occur at 2200, 7/10/72.

The test configuration was essentially the same as that tested during qualification testing except that the Lunar Seismic Profiling Experiment (LSPE) was included in the array of five experiments that was tested during qualification testing but not in flight acceptance testing. The four experiments that were flight tested were: (1) the Lunar Mass Spectrometer (LMS), (2) Lunar Ejecta and Meteorites Experiment (LEAM), (3) Heat Flow Experiment (HFE), and (4) the Lunar Surface Gravimeter (LSG).

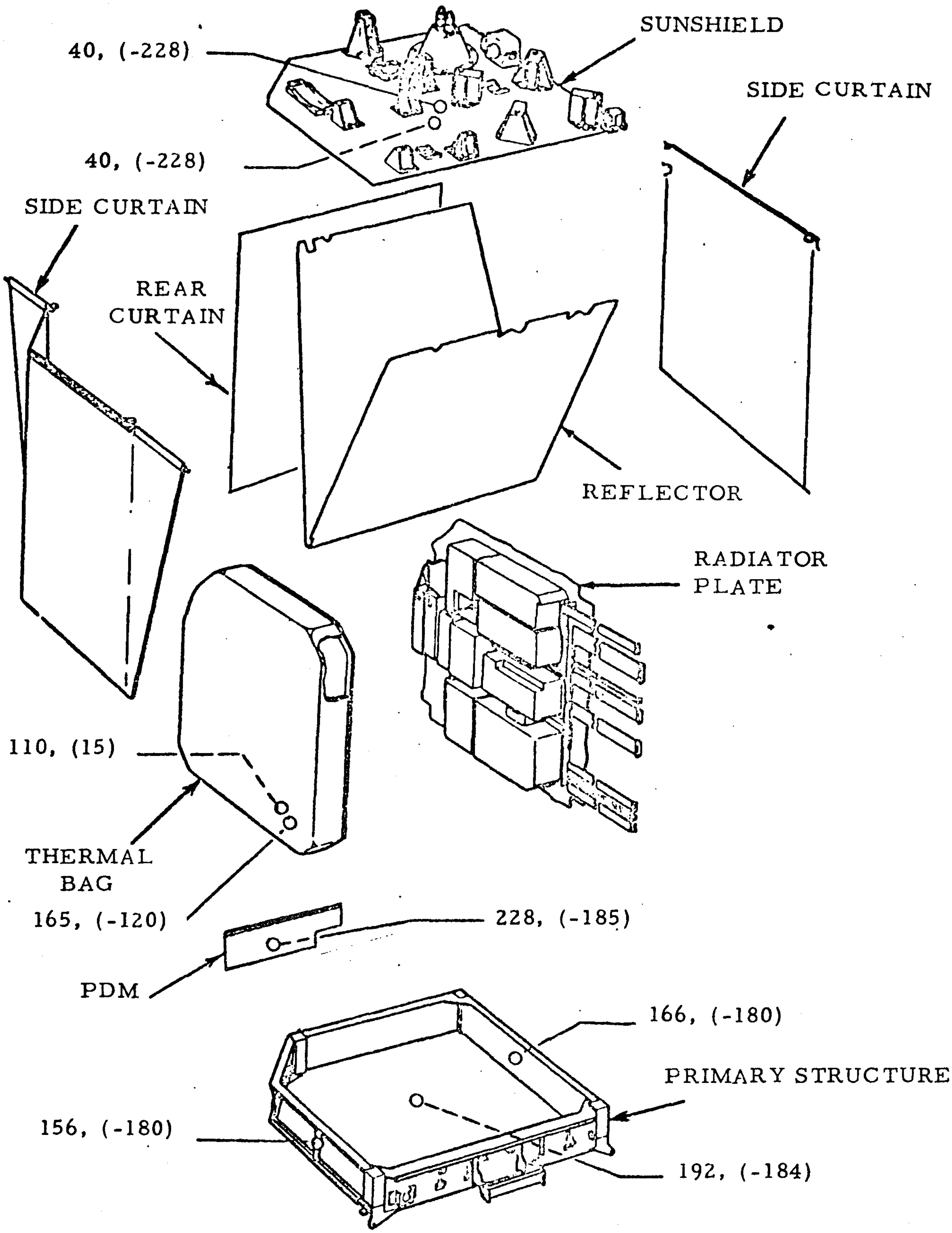
Central station temperature and power data that were recorded during the lunar noon and lunar night equilibrium conditions are presented both tabularly and schematically. Table 6-1 summarizes the central station recorded thermal results that are applicable for both stabilization periods. Central station temperatures at specific physical locations are schematically illustrated in Figures 6-1 and 6-2.

Figures 6-1 and 6-2 illustrate simulated lunar day and night equilibrium temperatures for various central station locations. Two of the most critical temperatures of the central station are the PDM resistor panel and radiator plate average temperatures. For the PDM resistor panel, the simulated noon temperature was 228°F with the night temperature being -185°F. The radiator plate average temperature was 104°F for noon, whereas, a temperature of 22°F occurred at simulated lunar night. In both cases, recorded temperatures were well within previously established tolerances.



XXX Acceptance, noon
(XXX) Acceptance, night

Figure 6-1. Central Station Radiator Plate and Electronics Temperatures (°F), Array E T/V Flight Acceptance Test.



Note: XXX lunar noon
(XXX) lunar night

Figure 6-2. Selected C/S Component Temperatures (°F), Array E T/V Flight Acceptance Test.

TABLE 6-1
ALSEP ARRAY E CENTRAL STATION
FLIGHT ACCEPTANCE TEST TEMPERATURE RESULTS

HK	Measurement	Acceptance Noon (°F)	Acceptance Night (°F)
4	Plate Temp #1	100	16
15	Bottom Temp	192	-184
16	Rcvr Case Temp	107	22
18	Xmtr A Hot Spot	118	42
19	Xmtr A Case Temp	116	42
25	LSP Elect Temp	104	23
27	Sunshield Top Temp	40	-228
28	Plate Temp #2	102	23
31	Xmtr B Hot Spot	-	-
32	Xmtr B Case Temp	-	-
33	DP Base Temp	104	23
34	DP Int. Temp	111	30
42	Sunshield Under Temp	40	-228
43	Plate Temp #3	100	16
48	CD Temp B	102	-
49	CD Temp A	-	20
58	Plate Temp #4	111	28
59	Left Struct Temp	156	-180
60	Inner Bag Temp	110	15
61	PC#1 APM Temp	109	29
62	PDU A Temp	112	33
63	PDU B Temp	111	32
64	PC#2 APM Temp	-	-
71	Plate Temp #5	106	25
72	Outer Bag Temp	165	-120
77	PC#1 Reg Temp	117	50
78	PC#2 Reg Temp	-	-
87	RT Struct Temp	166	-180
88	PDM Temp	228	-185

NOTES: (1) Average Thermal Plate Temperatures
Acceptance Noon: 104°F
Acceptance Night: 22°F
Allowable Temperature Swing = 0 to 135°F (AL 240000)

(2) PDM Panel Flight Acceptance Noon Temperature = 228°F.
Maximum Allowable PDM Temperature = 350°F (AL240000)

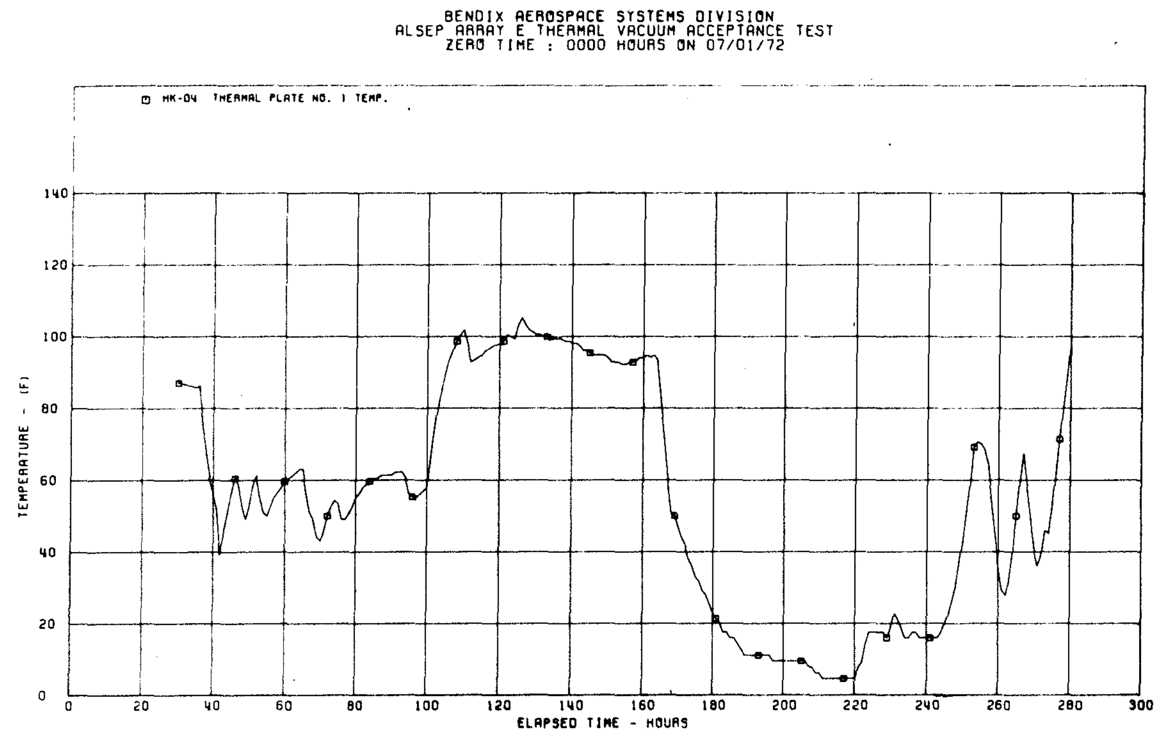
Array E Flight Acceptance Test results are graphically shown in Figures 6-3 through 6-14. Figures 6-3 through 6-13 present temperature profiles at various points of interest on the C/S such as the thermal plate, electronic components, primary structure, PDM panel, etc. Figure 6-14 presents the RTG hot and cold frame temperatures derived from the Array E Flight Acceptance Test.

Table 6-2 presents the central station thermal performance correlation between the test results and the flight predictions. For the sake of brevity, only the highlights of the qualification and flight acceptance testing are presented in the table. It is noted that a thermal plate mask width of 2.9 inches was used both during qualification and flight acceptance testing. Since the day to night thermal plate temperature swing is predicted to be centered essentially within the specification limits of 0 to 135°F, the thermal plate mask width of 2.9 inches will be used for lunar operation. Although the flight predicted temperatures presented in the table do not include the Taurus-Littrow terrain effects, the final temperature predictions which do account for terrain effects, are not sufficiently different from those presented in Table 6-2 to justify a change in the mask width of the flight model.

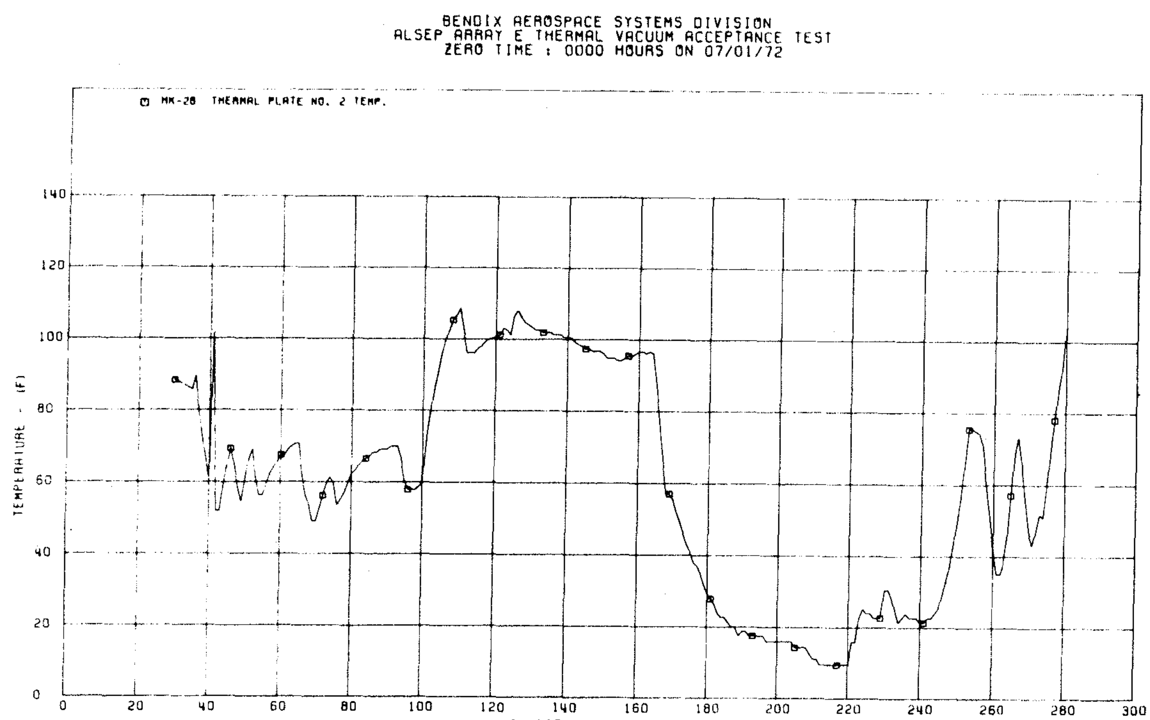
With reference to the terrain of the Apollo 17 landing site, a thermal study was undertaken to determine the Taurus-Littrow input on the C/S thermal performance. Based upon material contained in References 1 and 2, the mountainous lunar terrain will influence ALSEP temperature's significantly more than has been the case for previous Apollo flights.

Emphasis is placed on the mountainous terrain north of the landing site since the central station open side will face due north after deployment. The overall effect of the mountains in the north will be to decrease the central station thermal plate view to space and to increase the thermal plate view to the hot lunar surface. This combined effect will significantly increase the lunar noon thermal plate temperatures to values higher than had been predicted previously.

Figure 6-3. Array E Flight Acceptance T/V Test Results

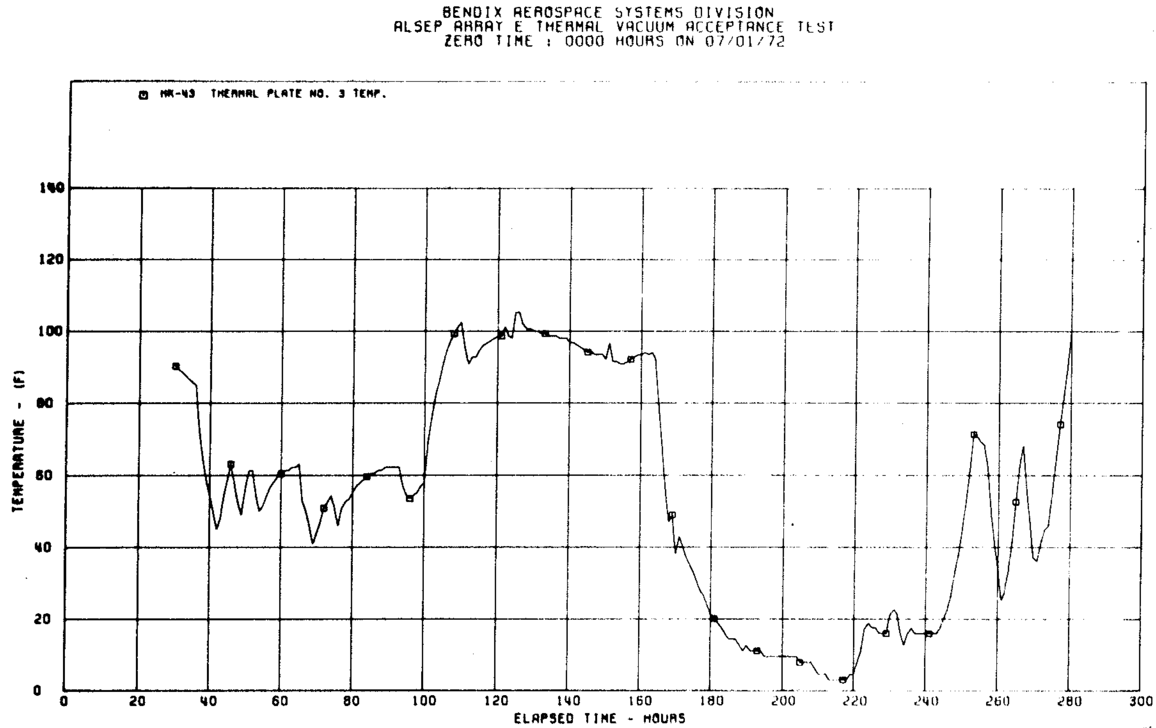


Thermal Plate Temperature

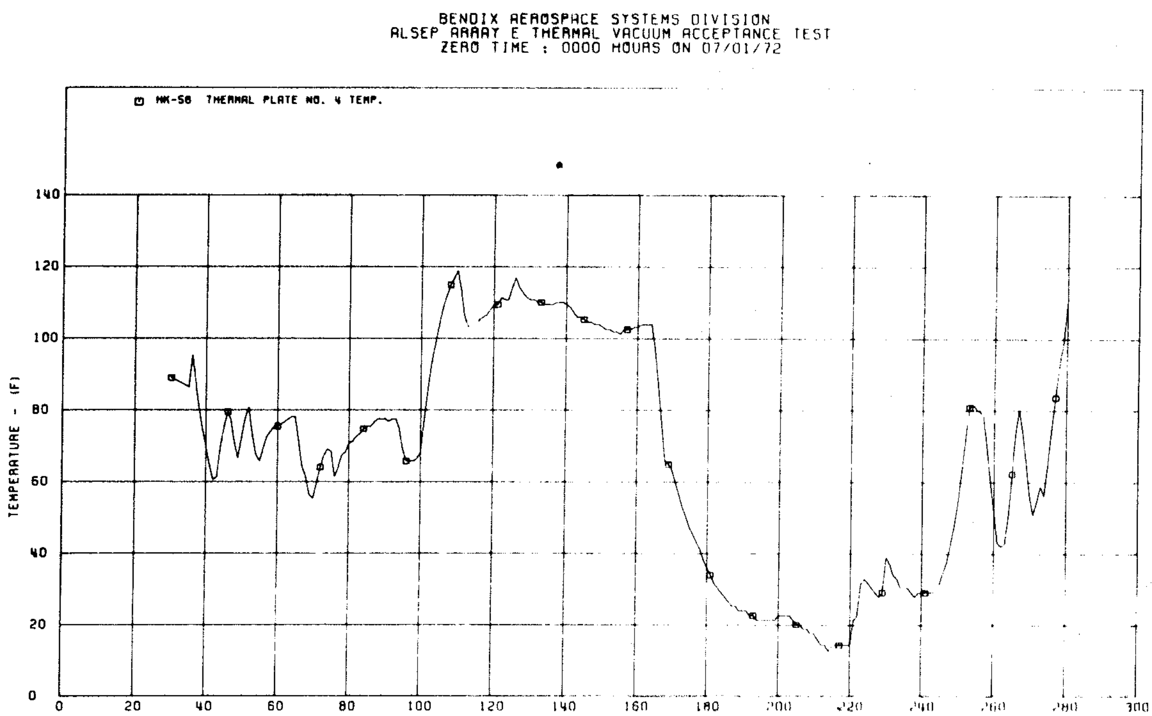


Thermal Plate Temperature

Figure 6-4. Array E Flight Acceptance T/V Test Results

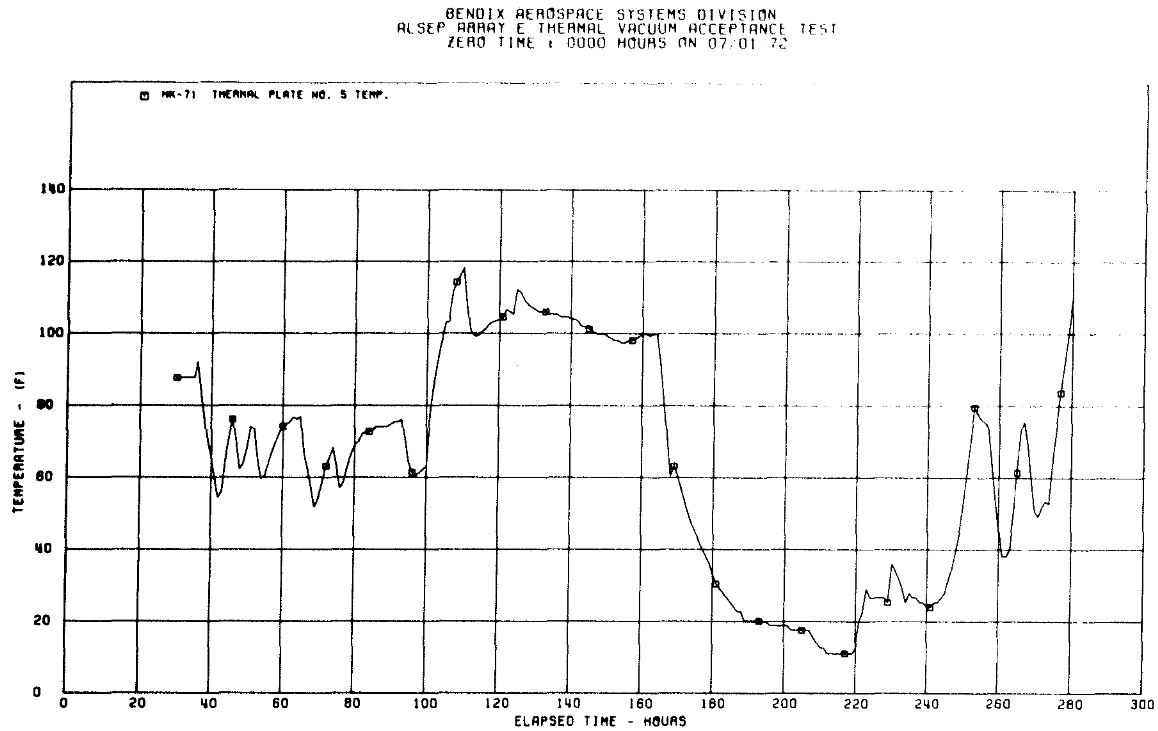


Thermal Plate Temperature

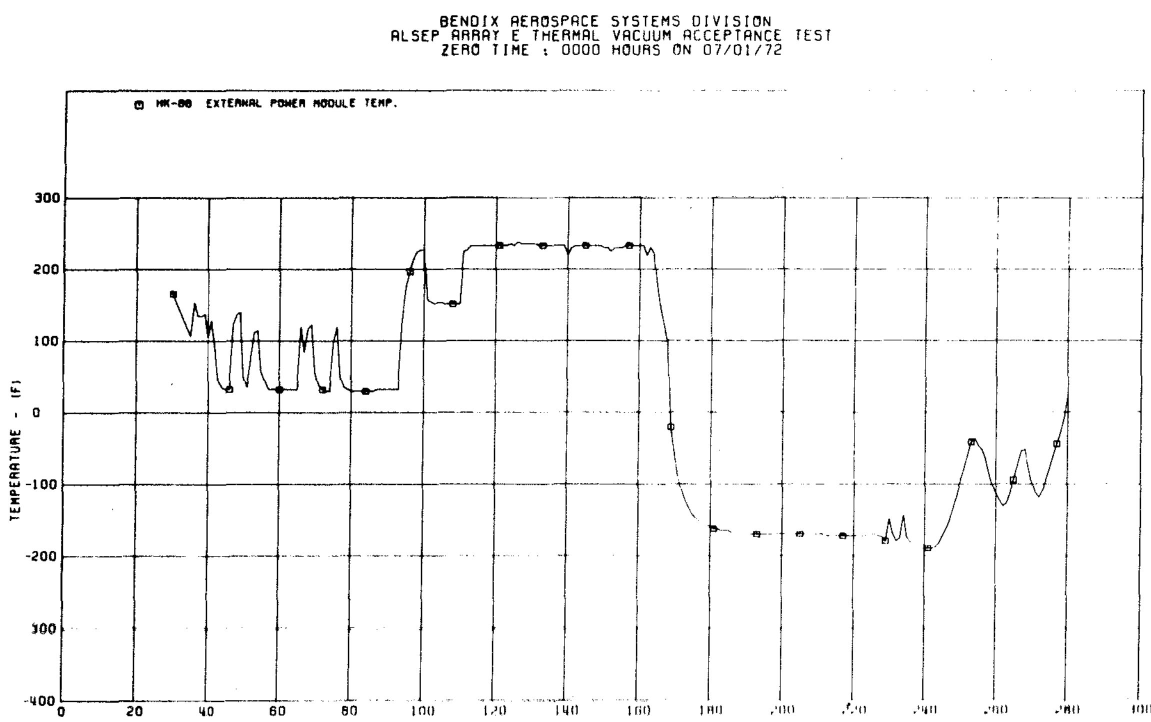


Thermal Plate Temperature

Figure 6-5. Array E Flight Acceptance T/V Test Results

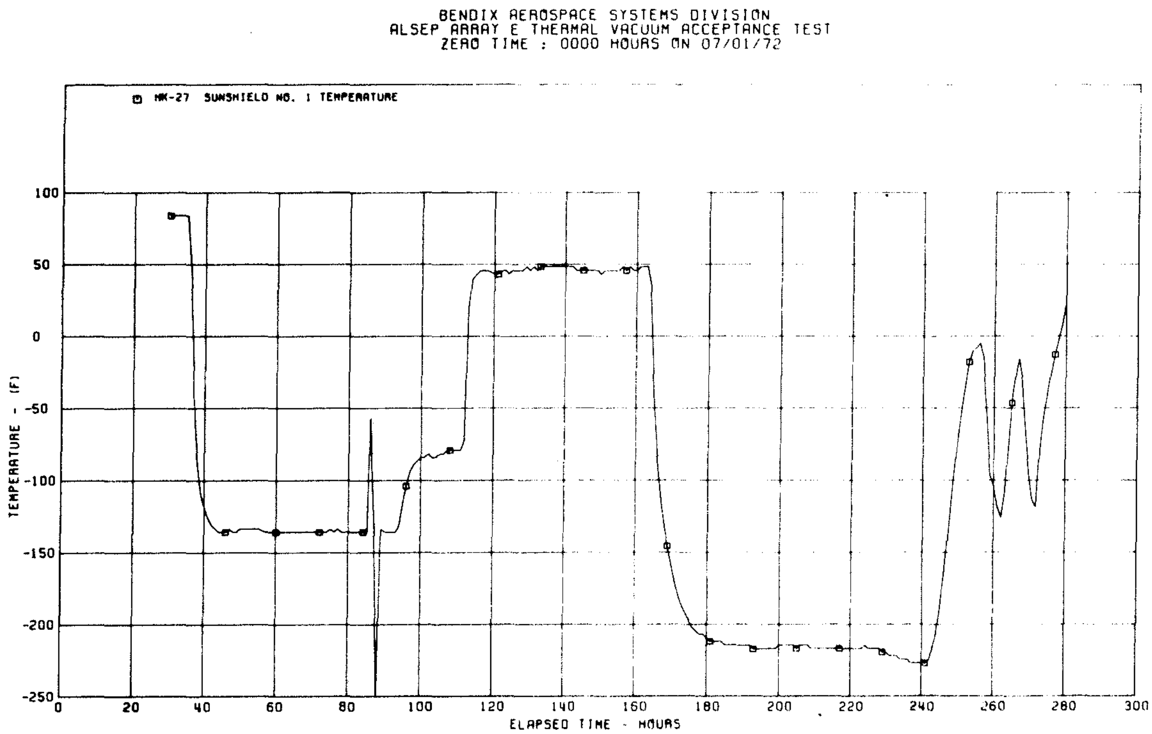


Thermal Plate Temperature

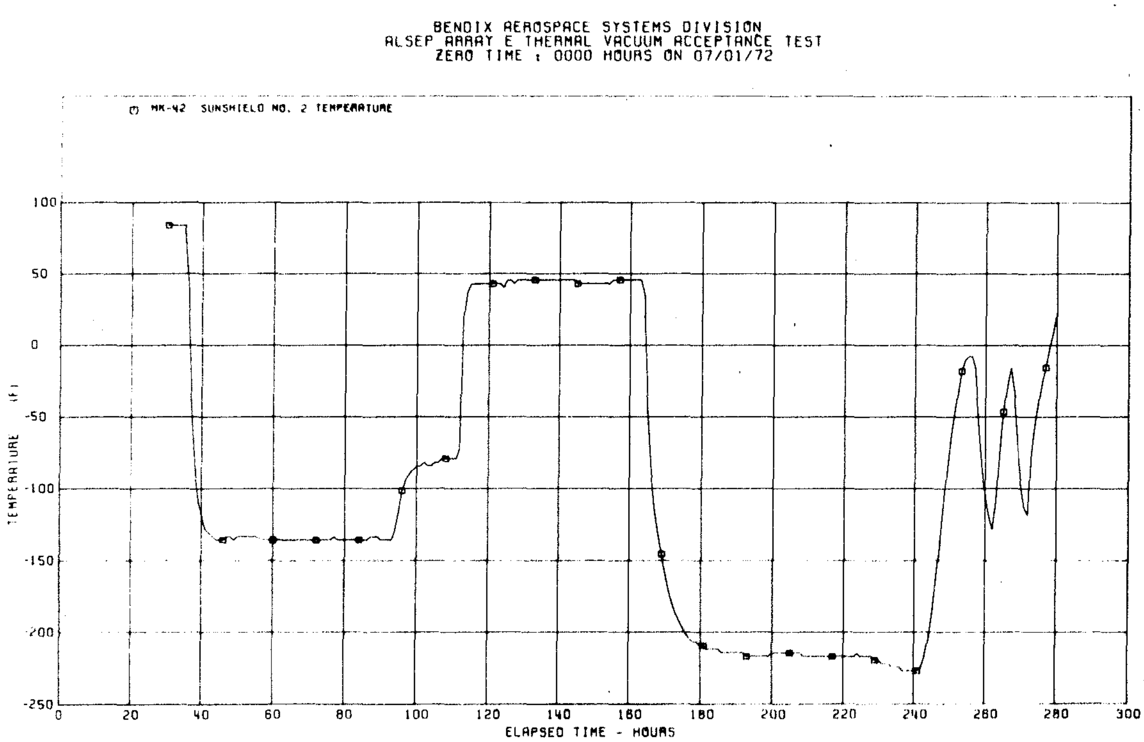


PDM Panel Temperature

Figure 6-6. Array E Flight Acceptance T/V Test Results

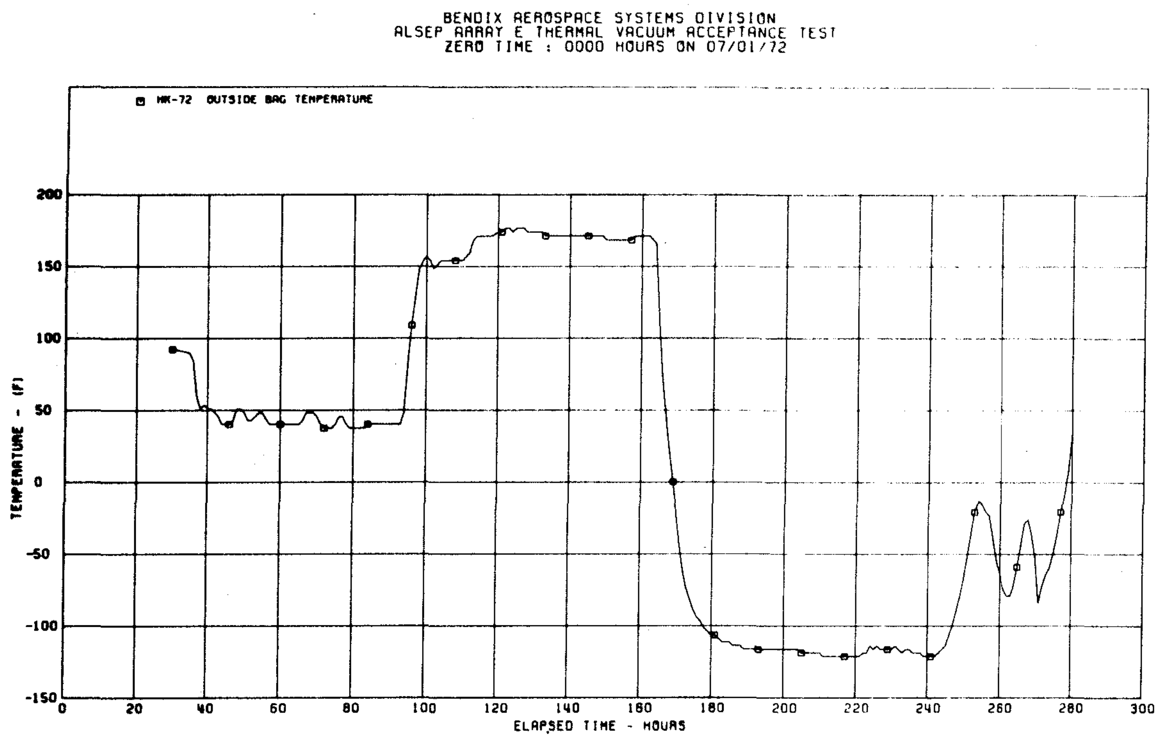


Sunshield Outer Temperature

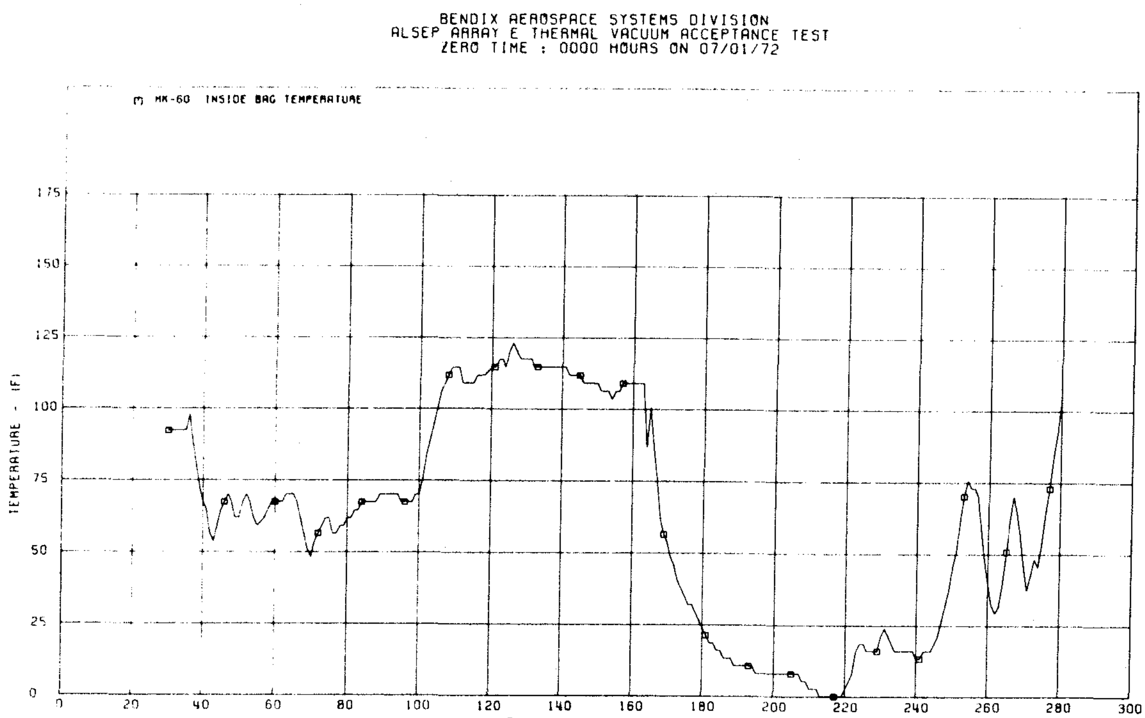


Sunshield Inner Temperature

Figure 6-7. Array E Flight Acceptance T/V Test Results

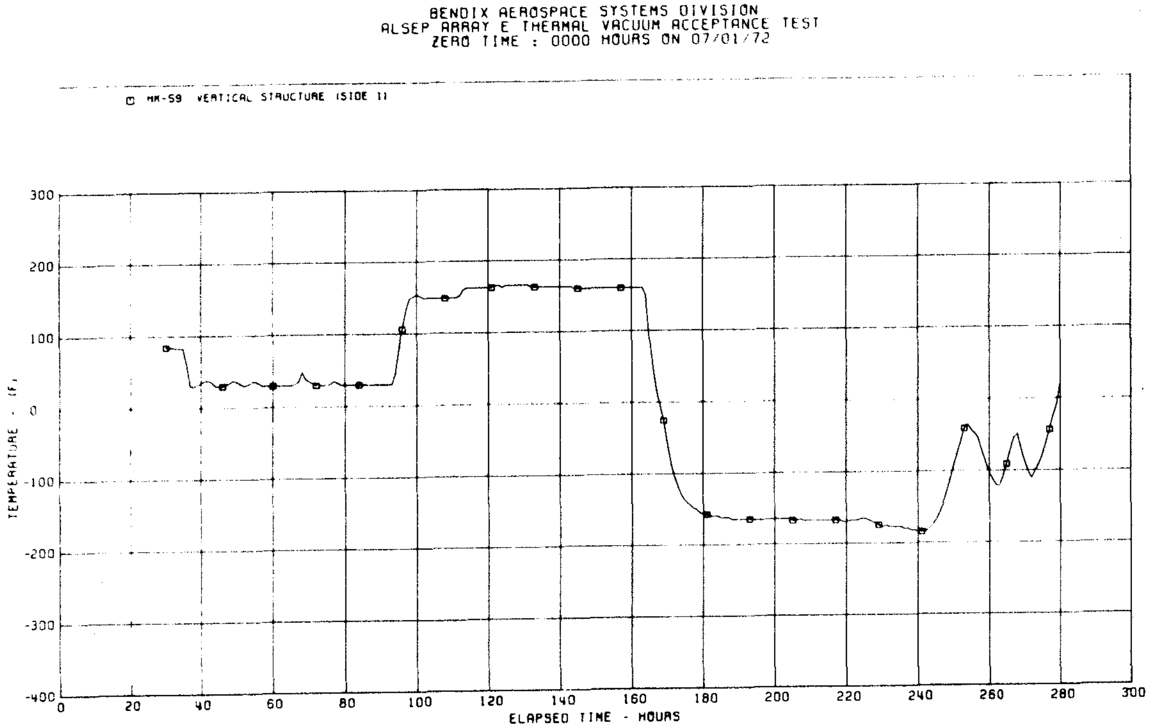


Thermal Bag Outer Temperature

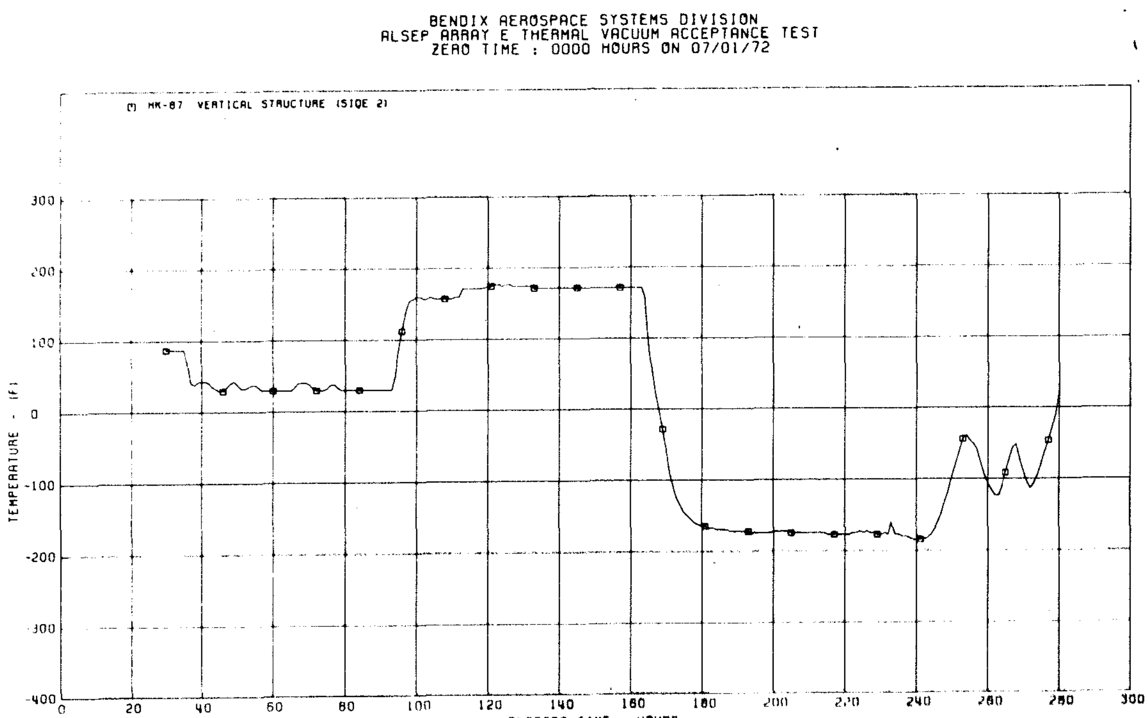


Thermal Bag Inner Temperature

Figure 6-8. Array E Flight Acceptance T/V Test Results



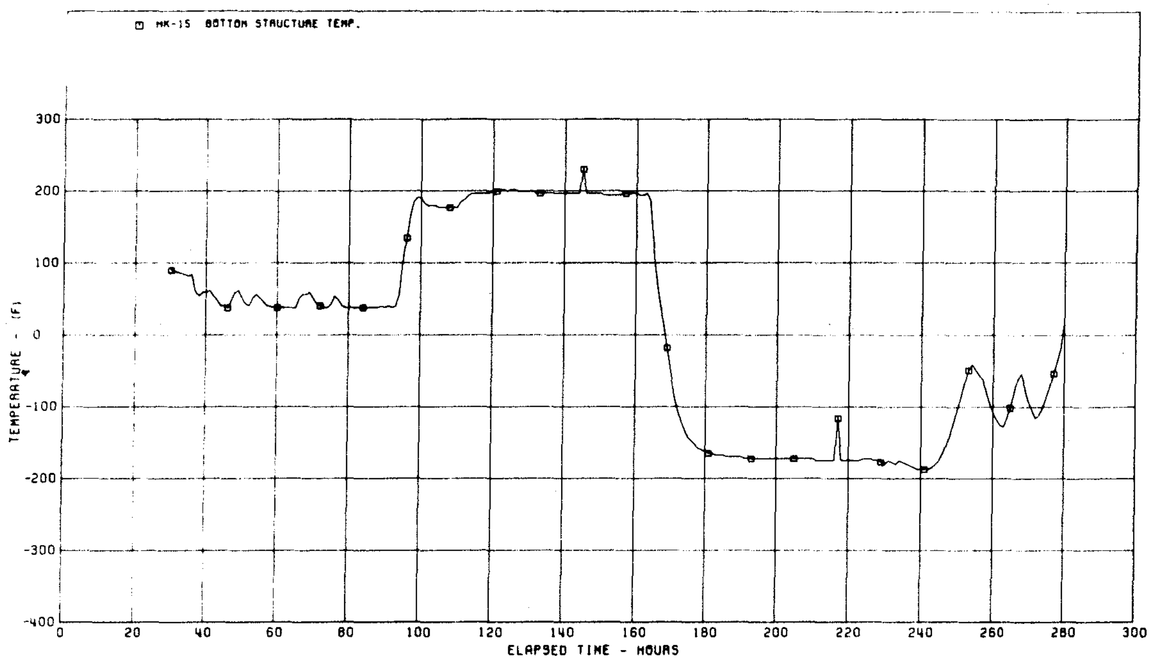
Structure Temperature, Side 1



Structure Temperature, Side 2

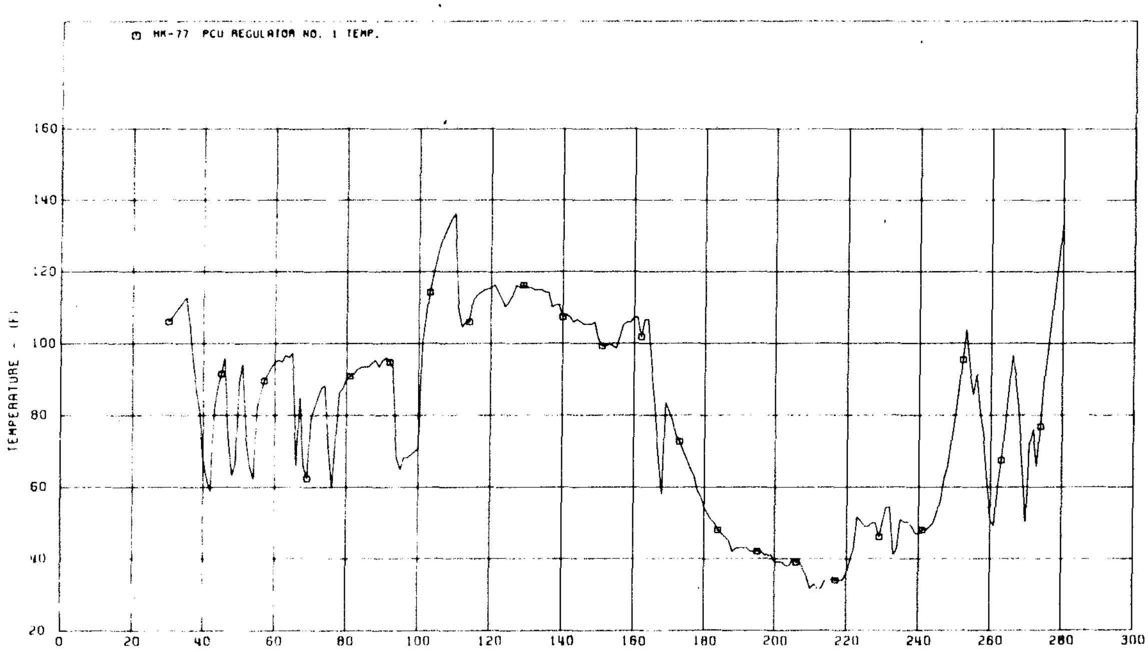
Figure 6-9. Array E Flight Acceptance T/V Test Results

BENDIX AEROSPACE SYSTEMS DIVISION
ALSEP ARRAY E THERMAL VACUUM ACCEPTANCE TEST
ZERO TIME : 0000 HOURS ON 07/01/72



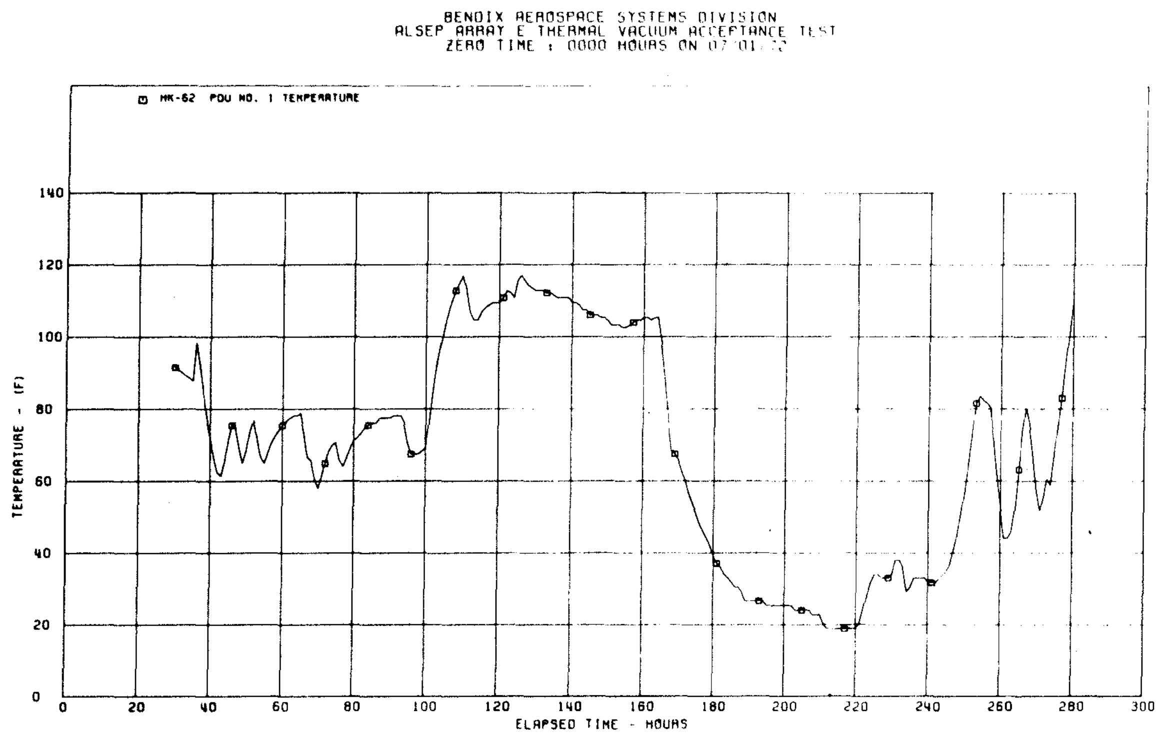
Structure Bottom Temperature

BENDIX AEROSPACE SYSTEMS DIVISION
ALSEP ARRAY E THERMAL VACUUM ACCEPTANCE TEST
ZERO TIME : 0000 HOURS ON 07/01/72

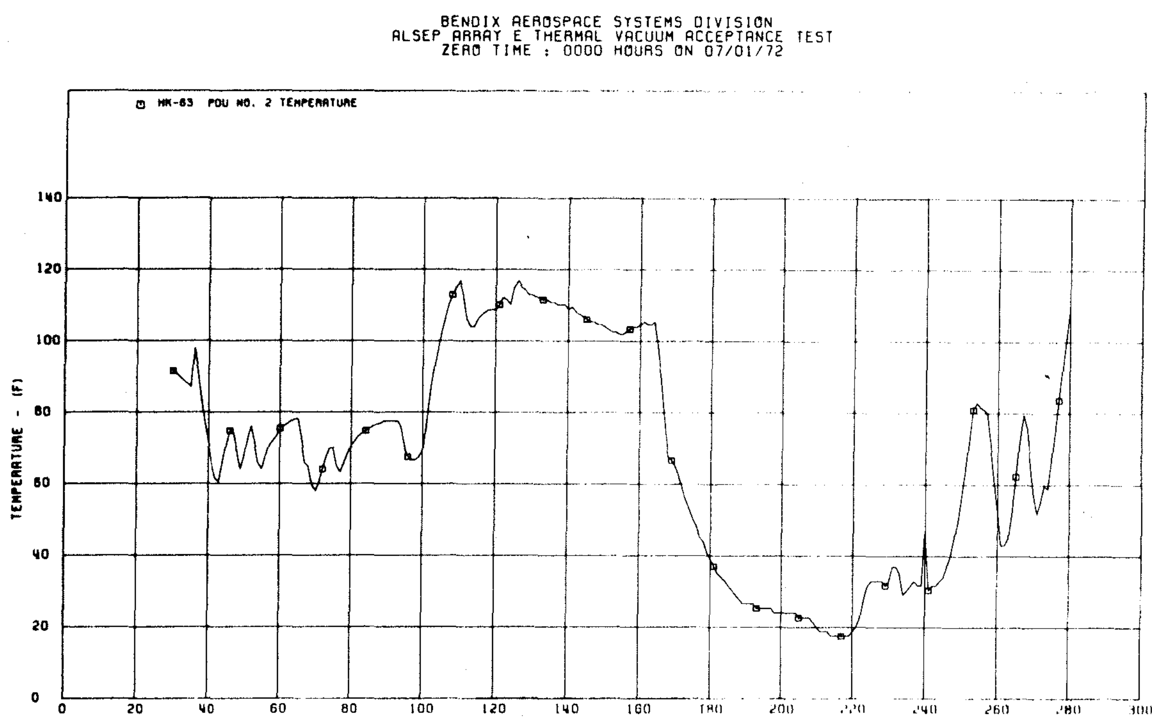


PCU Regulator Temperature

Figure 6-10. Array E Flight Acceptance T/V Test Results

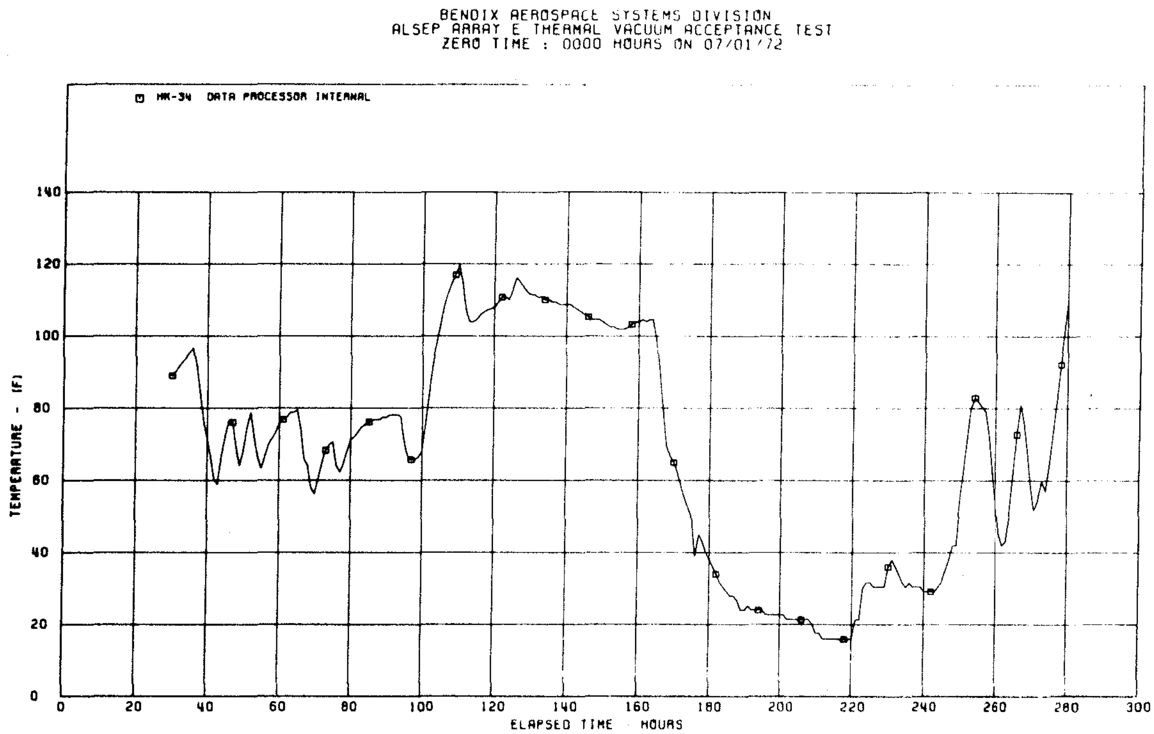


PDU Temperature

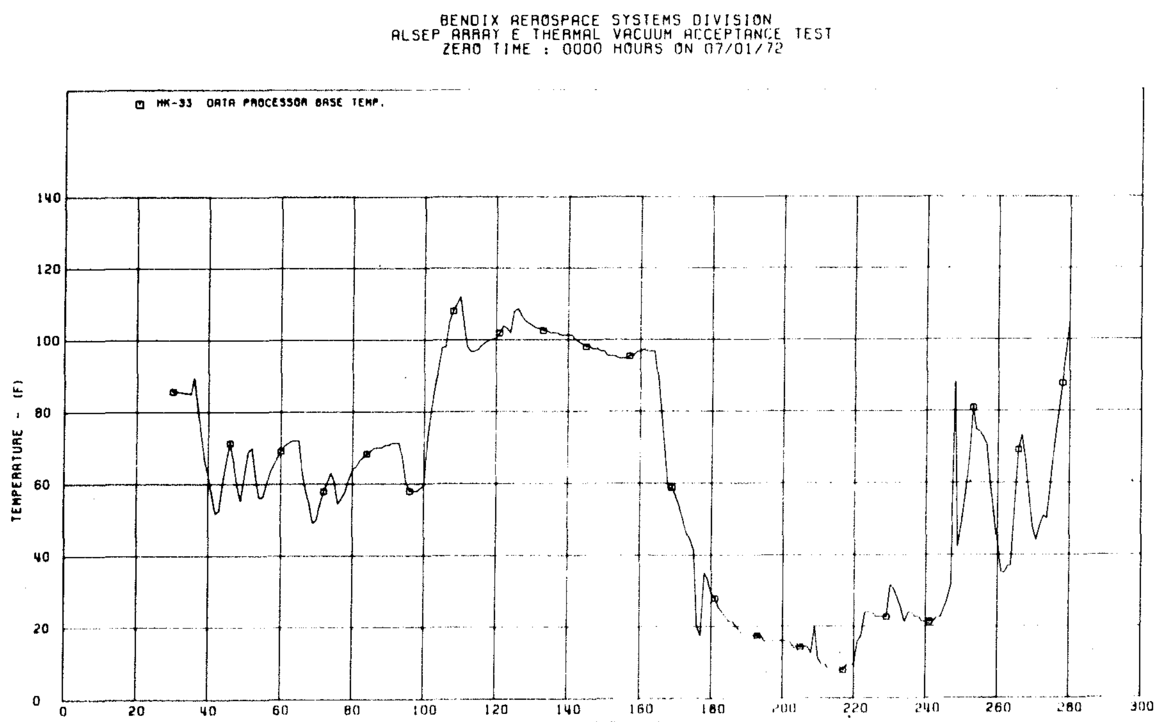


PDU Temperature

Figure 6-11. Array E Flight Acceptance T/V Test Results

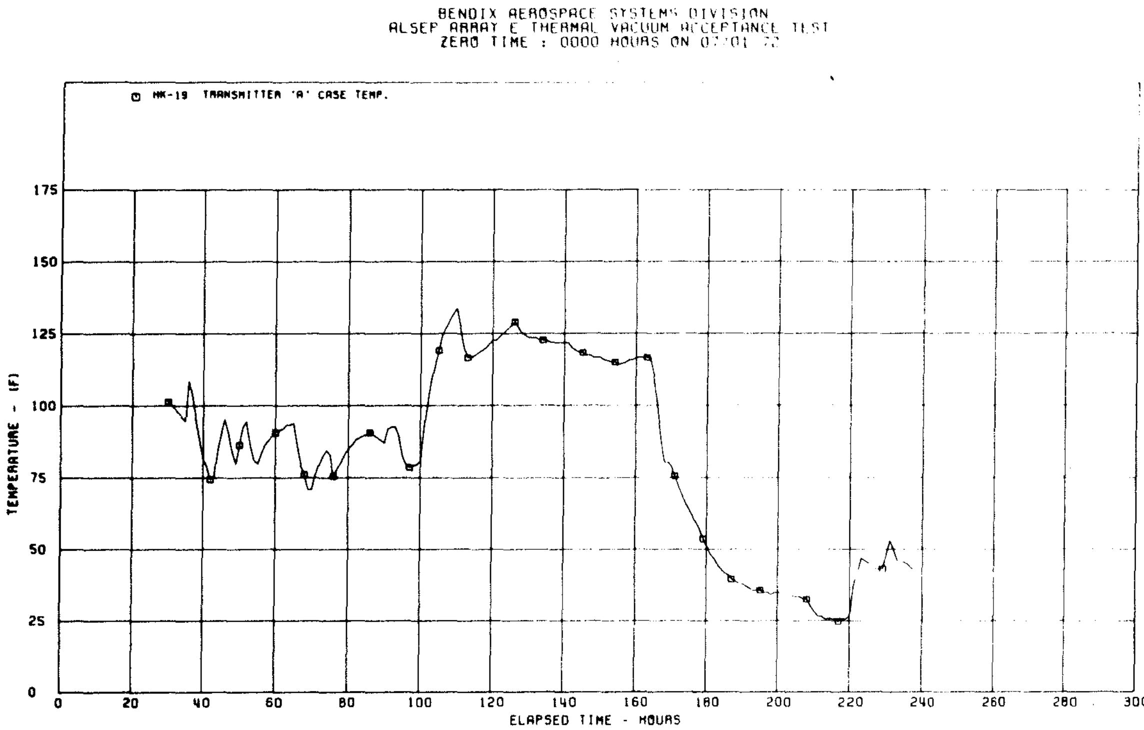


Data Processor Internal Temperature

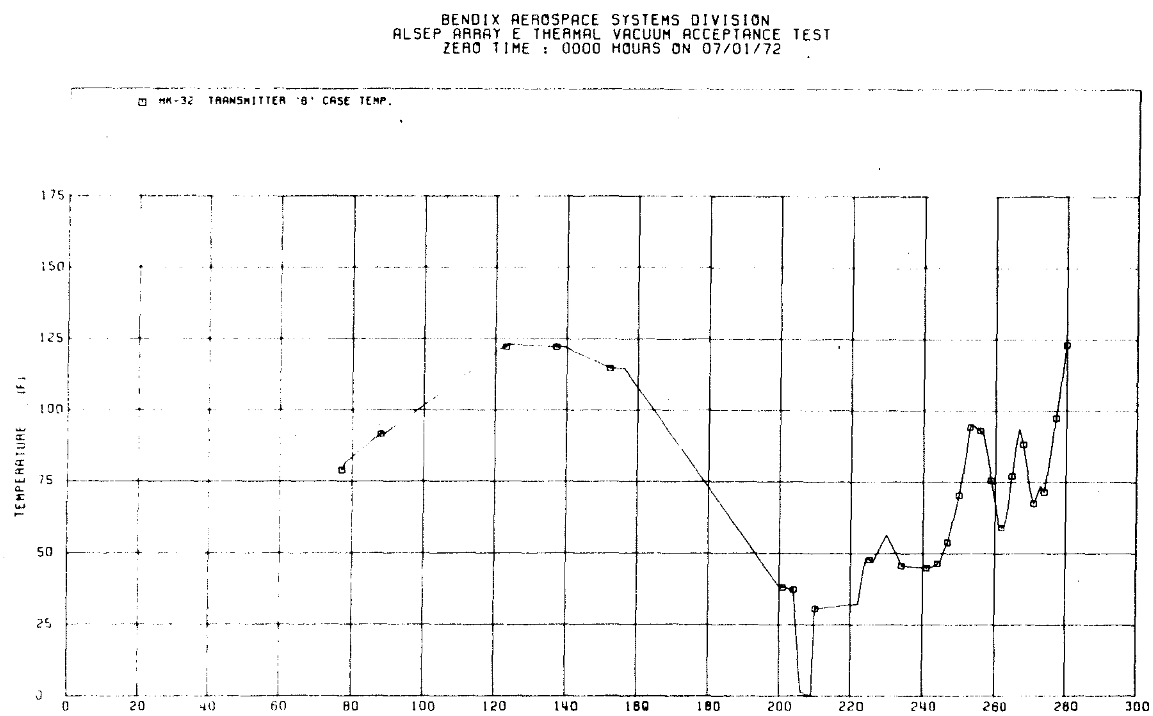


Data Processor Base Temperature

Figure 6-12. Array E Flight Acceptance T/V Test Results

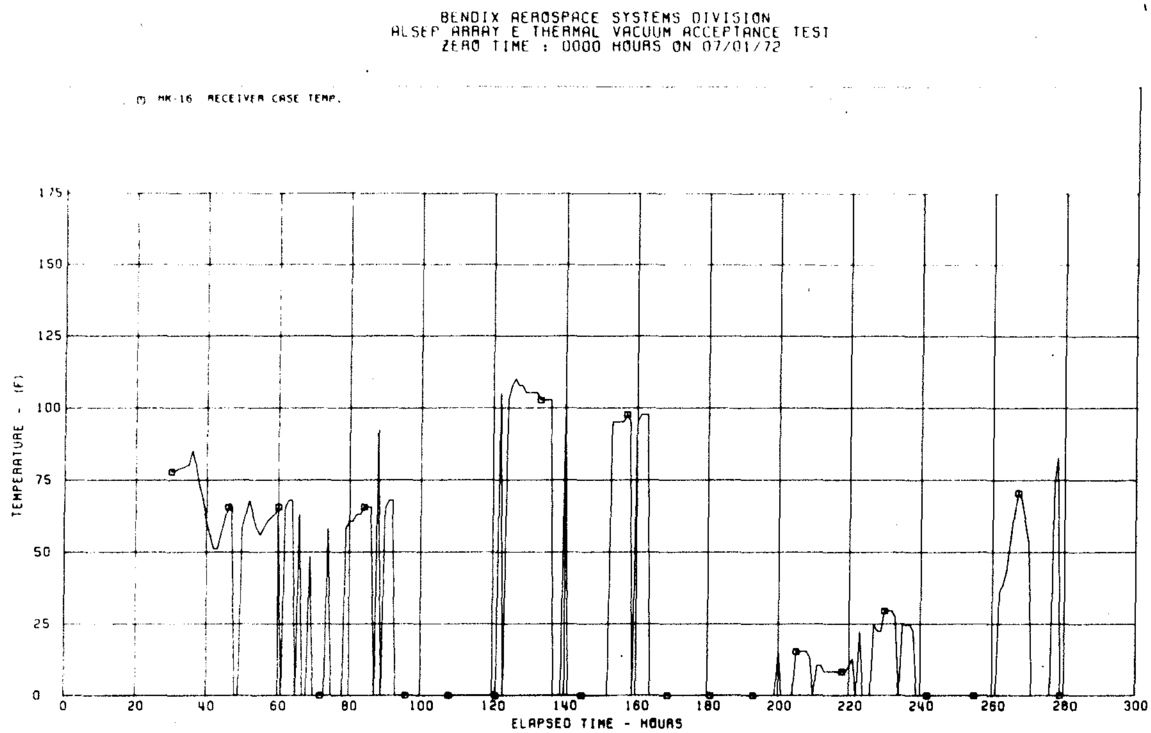


Transmitter "A" Case Temperature

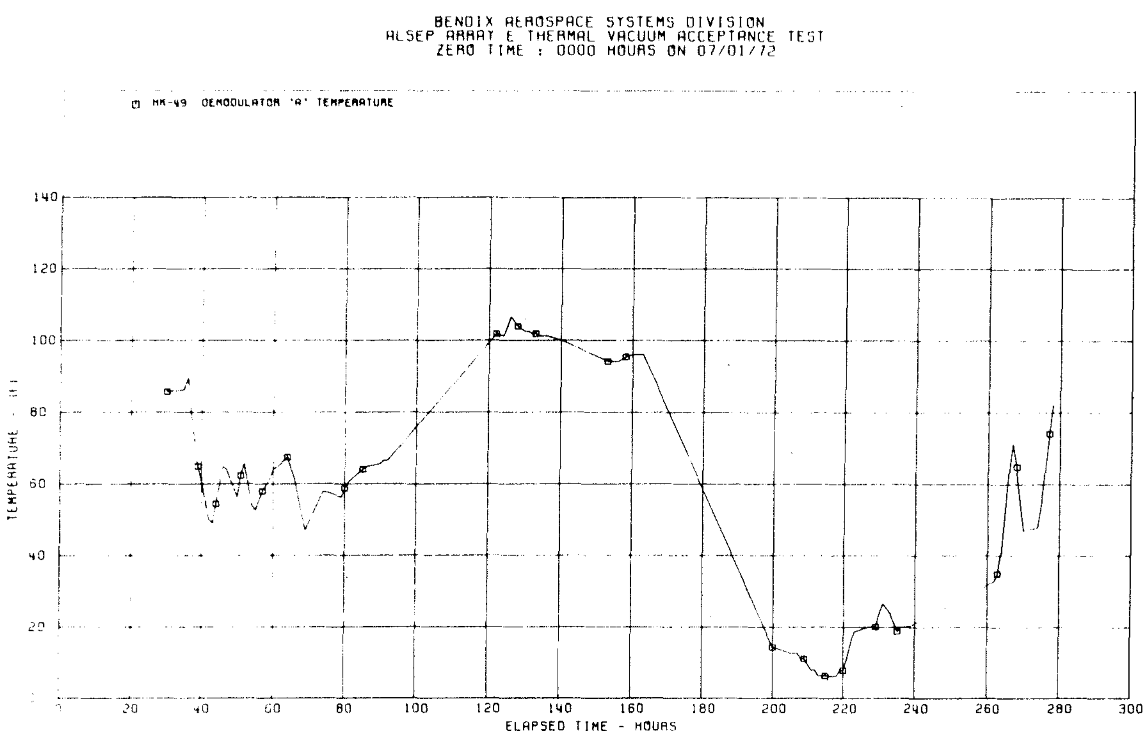


Transmitter "B" Case Temperature

Figure 6-13. Array E Flight Acceptance T/V Test Results

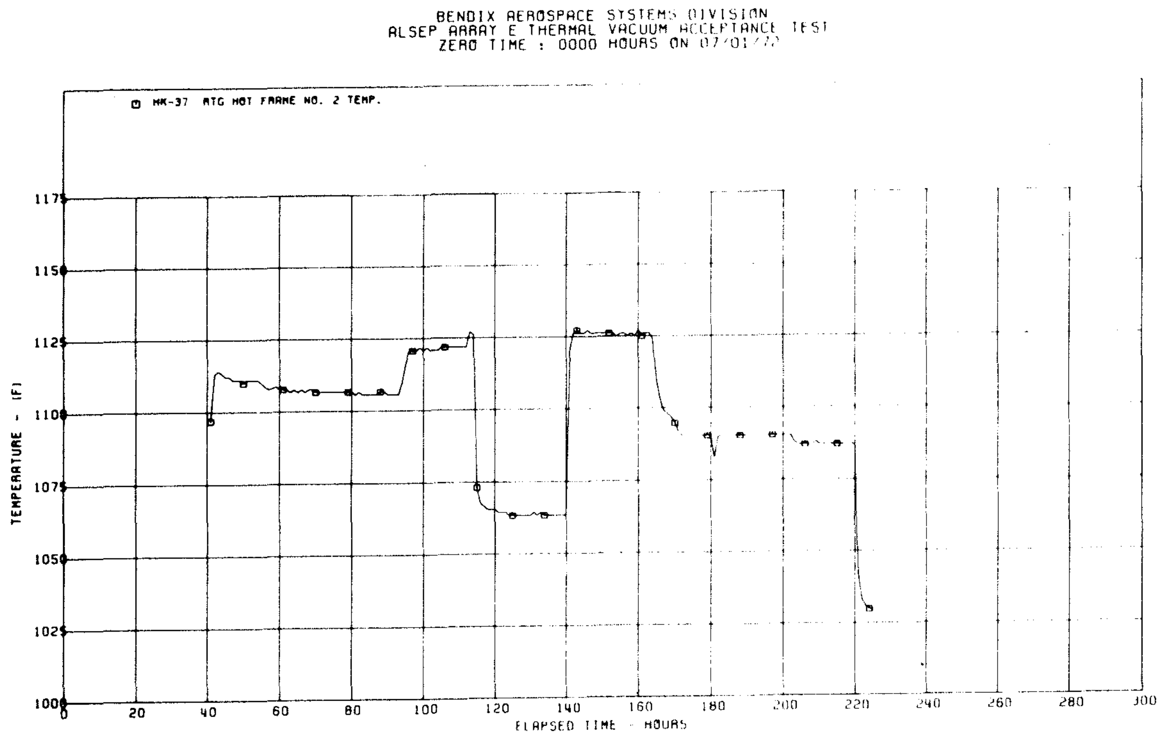


Receiver Case Temperature

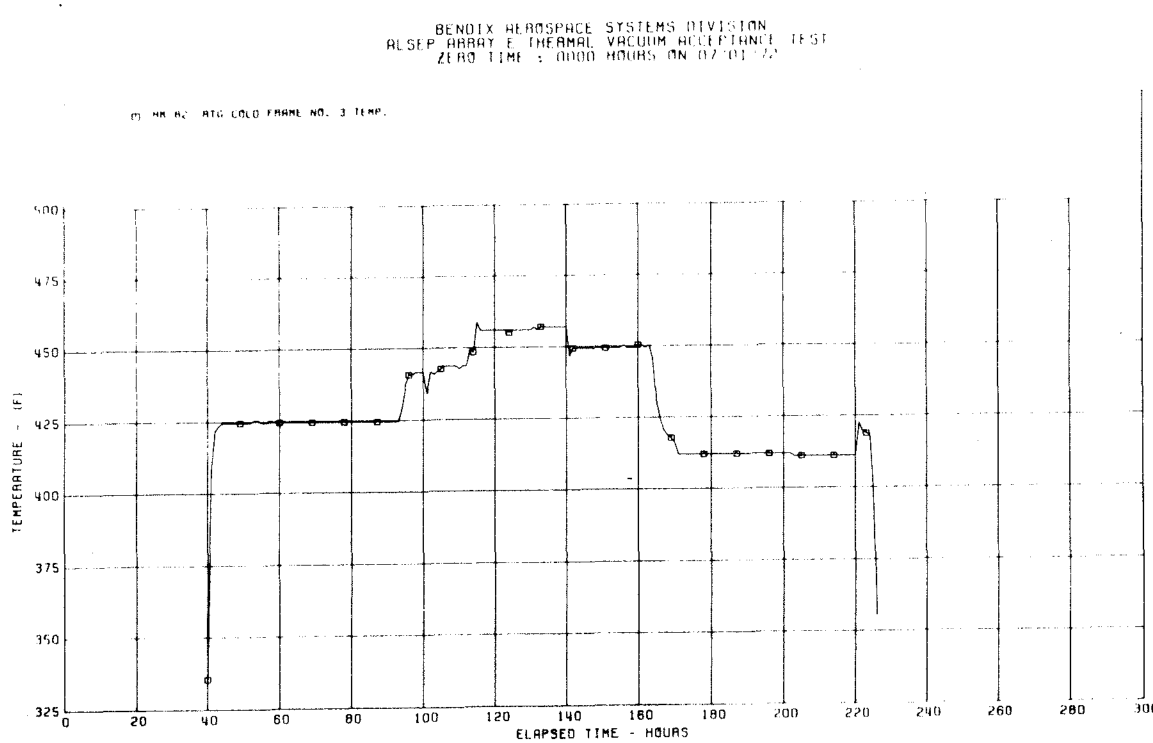


Demodulator "A" Temperature

Figure 6-14. Array E Flight Acceptance T/V Test Results



RTG Hot Frame Temperature



RTG Cold Frame Temperature

TABLE 6-2
CENTRAL STATION THERMAL PERFORMANCE CORRELATION

	Qualification Test Results			Flight Acceptance Test Results		Flight Predictions*	
Parameter	Lunar Noon	Lunar Night	Design Limit Noon	Lunar Noon	Lunar Night	Lunar Noon	Lunar Night
RTG Output Power, Watts	74.3	74.6	74.3	73.3	73.3	74.0	74.0
Reserve Power, Watts	32.0	21.0	33.0	35.7	20.7	36.4	21.4
Total Internal Power Disp., Watts	25.5	41.9	30.8	29.5	41.5	29.5	42.2
Thermal Plate Mask Width, Inches	2.9	2.9	2.9	2.9	2.9	2.9	2.9
Thermal Plate Avg Temp, °F	106	30	135	104	22	97*	19
Total PDM Panel Power Disp, Watts	22.9	0	22.4	22.2	0	22.8	0
PDM Panel Temp, °F	225	-165	248	225	-185	324**	-200

*Does not include Taurus-Littrow terrain effects.
**Temperature based on panel maximum power dissipation and dust degraded surface ($\alpha = 1.0$) with 10% panel blockage.

Figure 6-15 shows a north/south profile view of the terrain that will face ALSEP from the north. As shown in the figure, by projecting a line from the landing site to the top of the mountain ridge and then from the site to the base of the mountain, an angle of 15 degrees is formed. In reference 1, the thermal plate temperatures were based on a blockage angle of 15 degrees in order to be conservative. However, in the final terrain study, it was found that the effective blockage angle was slightly over 10 degrees which was the basis for the final flight predictions.

Figure 6-16 illustrates the effect of C/S tilt angle on thermal plate temperatures. The positive tilt angle indicates that the C/S open side would be tilted away from the lunar surface or away from the north mountains. With the C/S being deployed perfectly level, the predicted lunar noon temperature would be 123°F.

As was discussed in the Customer Acceptance Readiness Review, the C/S open side will be tilted 7 degrees away from the lunar surface. This will be facilitated by using a 7 degree shim underneath the sunshield bubble level and by inserting three inch blocks beneath the front side of the primary structure and the lunar surface. Under these conditions, the final lunar noon thermal plate temperature prediction is 104°F, which is a 19°F improvement over the level deployment case. The purpose of the C/S fix was to increase the C/S operational reliability over the two year mission life and to make more probable the achievement of a 5 year lifetime for ALSEP Array E.

Considered in Figure 6-17 is the effect of central station tilt angle on the PDM panel temperature. Predictions are given for a clean panel ($\alpha = 0.2$) and a fully dust degraded panel ($\alpha = 1.0$). In both cases, a lunar soil blockage of 10% was assumed. It is interesting to see that a clean panel will increase in temperature with an increase in C/S tilt angle while the reverse will be true for a dust degraded panel. The reason that these trends will occur is that

NOTE: The lunar terrain profile shown here reflects a vertical plane in a North-South direction.

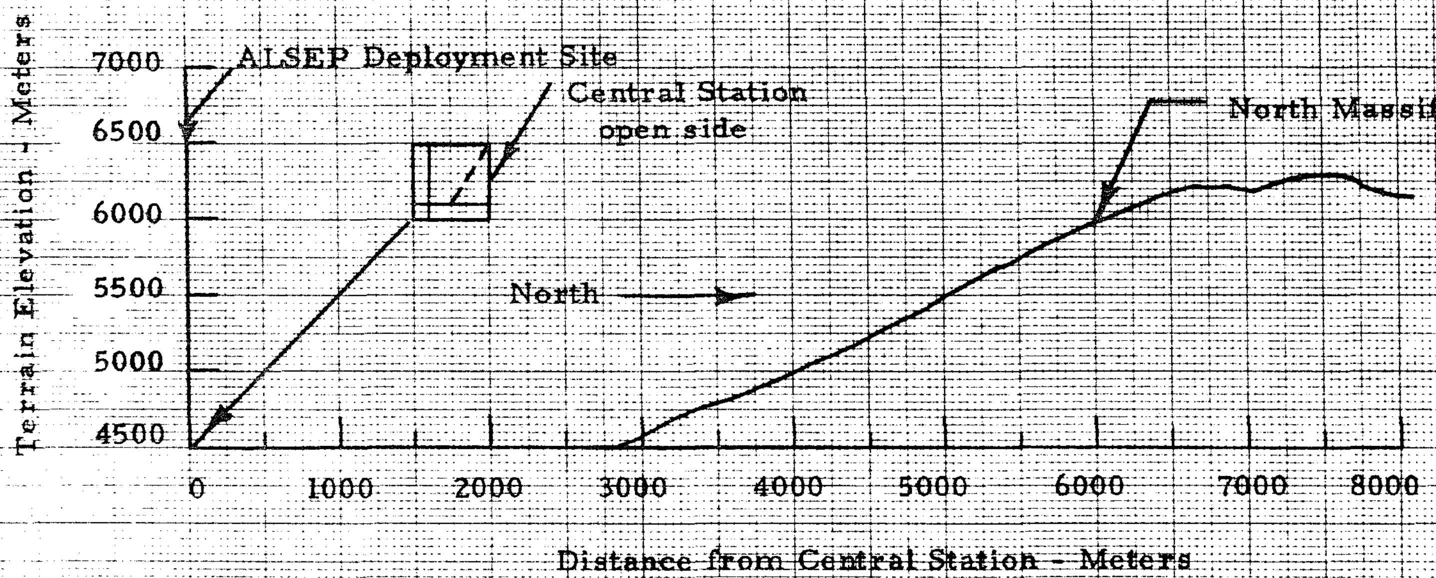


Figure 6-15. ALSEP Array E C/S Lunar Terrain, North.

NOTE: Positive tilt angle indicates that the C/S open side is tilted away from the lunar surface.

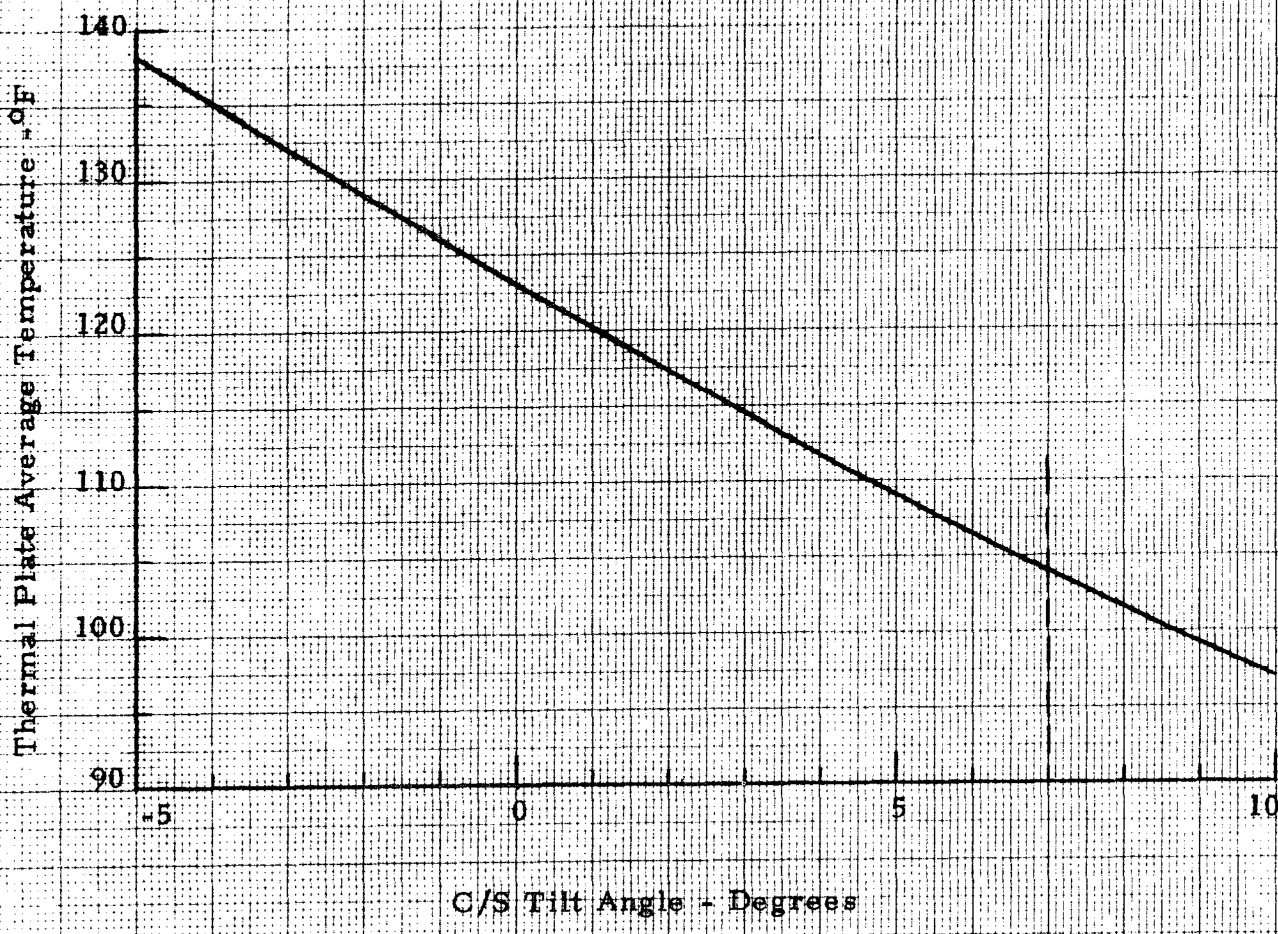


Figure 6-16. Effect of Array E Central Station Tilt Angle on Thermal Plate Temperatures.

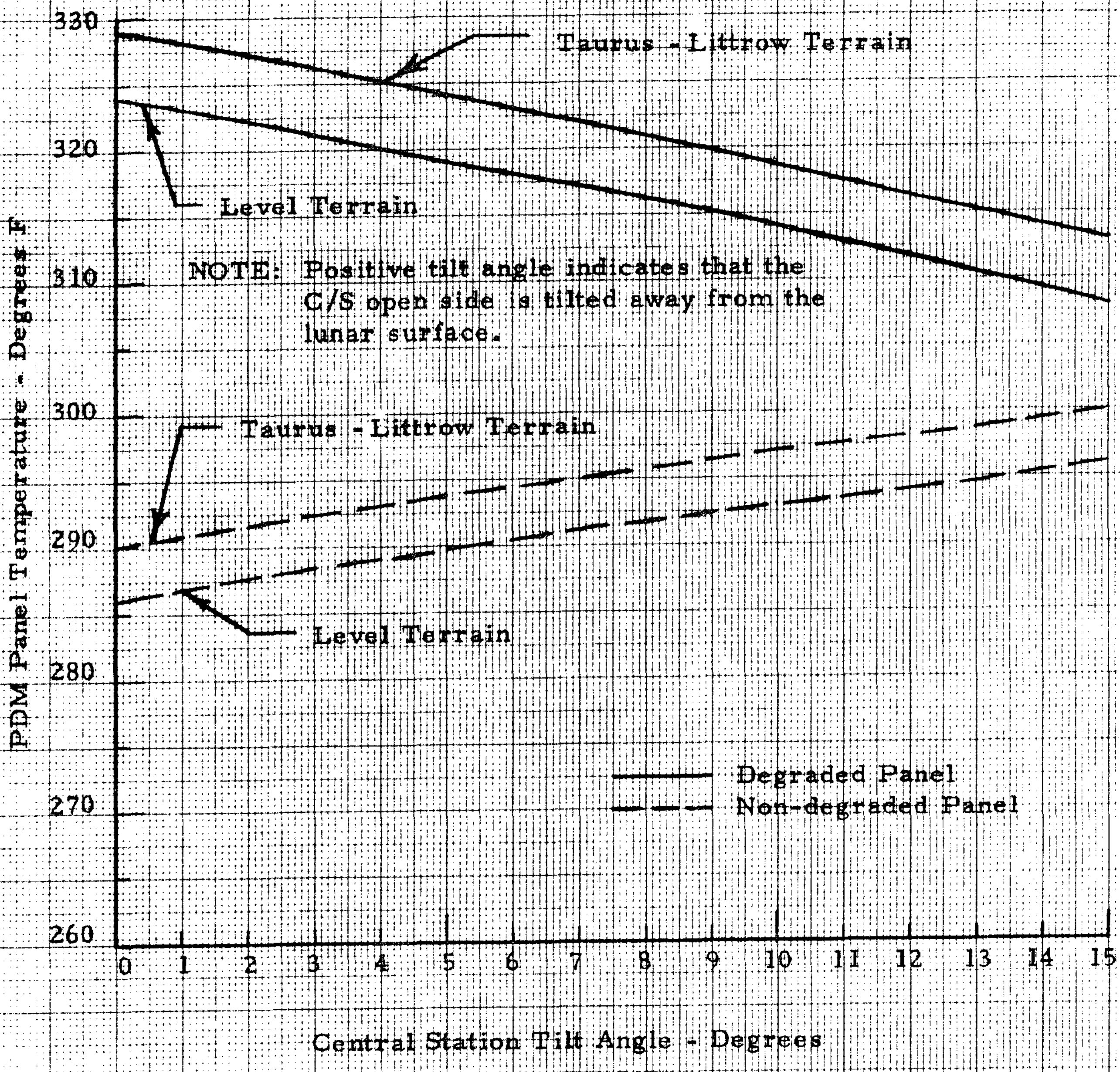


Figure 6-17. Effect of Array E Central Station Tilt Angle on PDM Panel Temperatures.

the primary mode of environmental heat transfer for the dust degraded panel will be solar heating as opposed to the radiative energy being exchanged between the panel and the lunar surface. For the clean panel, the overriding mode of heat transfer will be the thermal radiation between the panel and the lunar surface as the C/S tilt angle is increased. As shown in Figure 6-17, the PDM panel maximum temperature will be 322°F for the degraded panel and 295°F for the clean panel. Both predictions were based upon a C/S tilt angle of 7 degrees, a panel blockage of 10 percent and a PDM panel maximum power dissipation of 40.2 watts.

Presented in Table 6-3 is a summary of the thermal impact of Taurus-Littrow on central station thermal performance. Since the central station electronic temperatures are controlled by the C/S thermal plate temperature, it is possible to monitor the central station thermal performance by knowing the thermal plate average temperature. In Table 6-3, three cases were considered: (1) nominal operation, level deployment, and level terrain, (2) central station tilted 7° away from the north with the Taurus-Littrow terrain effects included, and (3) level deployment with Taurus-Littrow terrain effects included. For these three conditions, the predicted lunar noon thermal plate average temperatures are 97, 104 and 123°F, respectively. The corresponding temperatures for the PDM panel are 324, 322, and 329°F. For temperatures corresponding to central station tilt angles other than zero and 7°, refer to 6-16 and 6-17.

In summarizing, the central station fix of tilting the C/S 7° away from the north will result in a 19°F improvement for the thermal plate and a 7°F improvement for the PDM panel.

TABLE 6-3

THERMAL IMPACT OF TAURUS-LITTROW ON
C/S THERMAL PERFORMANCE

Parameter	Thermal Plate		PDM Panel	
	Noon	Night	Noon	Night
Nominal Operation Temps, °F	97	19	324	-200
Taurus-Littrow,* °F	104	19	322	-200
Taurus-Littrow,** °F	123	19	329	-200
Specification Limits	135	0	350	-225

Note: 1. Nominal operation implies C/S level deployment and level terrain.

2. *Temperatures based on C/S being tilted 7° away from the north, terrain effects included.

3. **Temperatures based on C/S level deployment with terrain effects included.

4. PDM panel lunar noon temperatures are based on panel maximum power dissipation and dust degraded surface (α = 1.0) with 10% panel blockage.

7.0 Conclusions

With the central station being tilted 7° away from the lunar surface, predicted thermal performance is considered excellent.
Since all central station predicted temperatures were shown to lie well within specification limits, it is concluded that all thermal design objectives for the ALSEP Array E central station have been fulfilled.

8.0 REFERENCES

(1) Butts, D., BxA IM 5032-88, "Lunar Terrain Effects on ALSEP Array E Central Station Thermal Performance," 30 August 1972.

(2) Taylor, G.S., and Watson, S.B., Bell Laboratories Memorandum, "A Computer-Generated Panorama from the Apollo 17 LM Landing Site - Case 40058," 31 August 1972.

(3) AL 240000, "Structure/Thermal Subsystem Specification," SCN #1 Approved 15 October 1970.

(4) Butts, D., BxA IM 5032-24, "ALSEP Array E T/V Qualification Test Results," 24 July 1972.

(5) Butts, D., BxA IM 5032-43, Rev. A, "ALSEP Array E T/V Flight Acceptance Test Results", 4 August 1972.

(6) Butts, D., BxA IM 9712-355, "Array E Central Station Thermal Performance", 27 May 1971.

(7) Granholm, E., BxA IM 9712-301, "ALSEP Array E, Central Station (C/S) Thermal Design", 22 April 1971.

(8) Granholm, E., BxA IM 9712-876, "ALSEP Array E, Central Station (C/S) Lunar Thermal Performance Predictions", 23 March 1972.

(9) Johnson, P., BxA IM 9712-79, "Temperatures Prediction for ALSEP Array A-2/HFE and D PDM Panels," 22 October 1970.

(10) Toups, K.A., North American Aviation, Inc., SID 65-1043-2, "CONFAC II - A General Computer Program for the Determination of Radiant-Interchange Configuration and Form Factors," October 1965.

(11) Colliott, H.E., The Bendix Corporation, Aerospace Systems Division, Ann Arbor, Michigan, Report No. 0214, "The Bendix Thermal Analyzer Program," 2 April 1965.

(12) Butts, D., BxA IM 9712-191, "Update of ALSEP Central Station Steady State Thermal Models, Arrays A-2/HFE and D," 1 February 1971.

(13) Butts, D., BxA IM 9712-91, "Central Station Mask/Power/Temperature Study for Arrays A-2/HFE and D," 11 November 1970.