Bendix

Aerospace Systems Division

PSEP QUAL, FLIGHT ACCEPTANCE AND QUAL RETEST THERMAL VACUUM CHAMBER TEST REPORT

NO.	REV. NO.
ATM-850	
PAGE ____ OF ____	
DATE 1-23-70	

This ATM summarizes test data derived from the PSEP Qualification, Flight Acceptance, and the Qualification Retest and compares these data with analytical predictions. The Qualification Retest was conducted so that an investigation could be made in order to determine the possible causes that could have resulted in the Apollo 11 PSEP over-temperature condition that occurred on the lunar surface following LM Ascent stage liftoff.

Prepared by: P. Johnson

Prepared by: W. Kornemann

Approved by: J. McNaughton

CONTENTS

CONTENTS (Cont'd)

CONTENTS (Cont'd)

CONTENTS (Cont'd)

CONTENTS (Cont'd)

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (Cont'd)

LIST OF ILLUSTRATIONS (Cont'd)

LIST OF ILLUSTRATIONS (Cont'd)

LIST OF ILLUSTRATIONS (Cont'd)

LIST OF ILLUSTRATIONS (Cont'd)

LIST OF ILLUSTRATIONS (Cont'd)

LIST OF TABLES

LIST OF TABLES

LIST OF TABLES

LIST OF TABLES

1.0 INTRODUCTION AND SUMMARY

In October, 1968, Bendix Aerospace Systems Division was contracted by MSC to provide a simplified scientific experiment package to replace the relatively complex Apollo Lunar Surface Experiments Package (ALSEP) on the Apollo 11 flight. The primary reason for developing this new package, referred to as the Early Apollo Scientific Experiments Package (EASEP), was to significantly reduce the experiment deployment effort required by the Apollo 11 astronauts. Two experiments comprised the EASEP: 1) the Passive Seismic Experiment Package (PSEP) which was to record seismic events during the lunar day with power supplied by two solar cell panels and 2) the Laser Ranging Retro-Reflector (LRRR) which was to reflect a laser beam to the beam's originating location on earth. This report relates only to the PSEP, with the specific purpose being to summarize the results from the Qualification (Qual) and Flight Acceptance tests in the Bendix 20' x 27' thermal vacuum (T/V) chamber which simulated the lunar environment.

The primary PSEP performance and system requirements were to design an experiment which would require minimum crew deployment effort and which would operate through at least one lunar day. A secondary design goal was lunar night survival by maintaining electronics temperatures above minimum allowable levels and thereby permitting operation during subsequent lunar days. In order to achieve these program objectives, an overall thermal control design was incorporated which was based on the following requirements and constraints:

1. Completely passive thermal control.
2. Average thermal plate temperature during the lunar day would not exceed 140°F.
3. Average thermal plate temperature during the lunar night would not fall below -65°F.
4. Isotope heater power of 30 ± 0.25 watts would be used for lunar night survival.

5. No dust or debris contamination of thermal control surfaces.

6. The deployment distance of PSEP from LM would be 70 to 100 feet.

7. PSEP would operate prior to LM ascent.

8. The PSEP non-operating temperatures in the LM SEQ bay would stay within 0°F to 160°F.

9. Minimum deployment effort would be required by the astronauts.

Two 15 watt radioisotope heaters provided sufficient power for lunar night survival, while layers of aluminized Kapton over insulation masks and shrouds provided protection against plume heating from the LM ascent stage exhaust.

The PSEP development program required Qualification (Qual) and Flight Acceptance T/V tests. Both tests showed that PSEP was thermally adequate and met all thermal performance requirements.

The PSEP design more than met mission objectives as the package transmitted useful engineering data into the sixth lunar day following turn on (146 days). However, the Flight model exhibited a thermal anomaly in the sense that the thermal plate average temperature exceeded the anticipated lunar noon level by approximately 50°F.

An investigation into the cause of the anomaly resulted in the conclusion that the high thermal plate temperatures were caused by a degradation of PSEP thermal control surfaces during LM ascent, with the contamination of the second surface mirrors by lunar dust and/or descent stage debris being the probable primary cause. One of the requirements stated in the PSEP Exhibit B specification and CP 100500 (Part 1) was that no allowance would be made in the design for the effect of dust on the performance of PSEP. Based on the findings of the post Apollo 11 thermal anomaly team, the PSEP actual deployment distance of 96 feet from LM was not sufficient to preclude the effect of dust or debris.

Since the ALSEP thermal control system is insensitive to dust and is well protected against contamination by debris at any deployment distance from LM, no similar thermal anomaly was anticipated or observed for the ALSEP package when deployed at a distance greater than 500 ft.

The two Qualification and one Flight Acceptance tests, which were performed during the PSEP program in the Bendix thermal vacuum chamber, are described briefly below:

1. Qualification Test - The Qual model was subjected to an accelerated lunar day-to-night cycle with the objective of verifying the system's thermal performance in lunar day and night environments.

2. Flight Acceptance Test - A lunar noon condition was imposed on the flight model with the purpose of verifying system start-up and operation in a lunar day environment.

3. Qualification Retest - The Qual model was retested as part of the thermal anomaly investigation, with the primary objective of evaluating the effect on PSEP thermal performance by the observed higher-than-predicted primary structure temperatures which occured during lunar operation. Secondary objectives were to verify the low thermal conductance of the thermal plate isolator bolts, verify the Solar Simulation in the T/V chamber, and evaluate the thermal effect of the Kapton plume heating protection.

Figures 1-1 to 1-3 illustrate the Qual and the Flight models deployed in the T/V chamber. Two photographs of the Qual retest model are shown in Figures 1-4 and 1-5.

Two lunar noon equilibrium operating conditions, listed below, were established during both the Qual and Flight tests for verifying the PSEP thermal design:

1. Lunar noon with no PDM (Power Dissipation Module) power dump.

2. Lunar noon with a 10 watt PDM power dump.

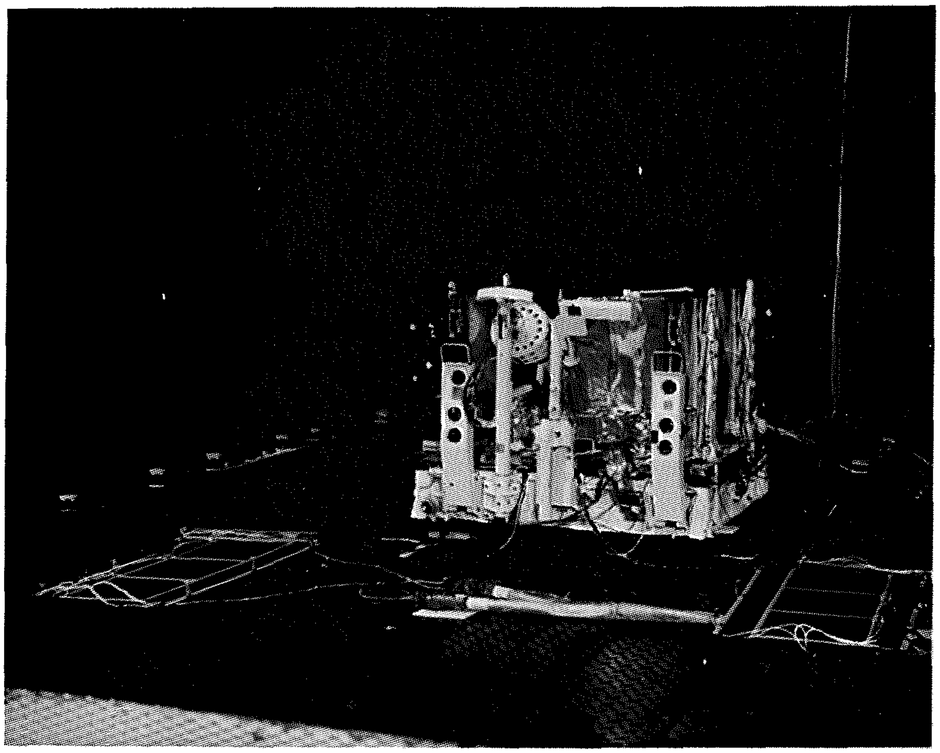


Figure 1-1. PSEP Qual Model Undeployed in Lunar Simulation Chamber

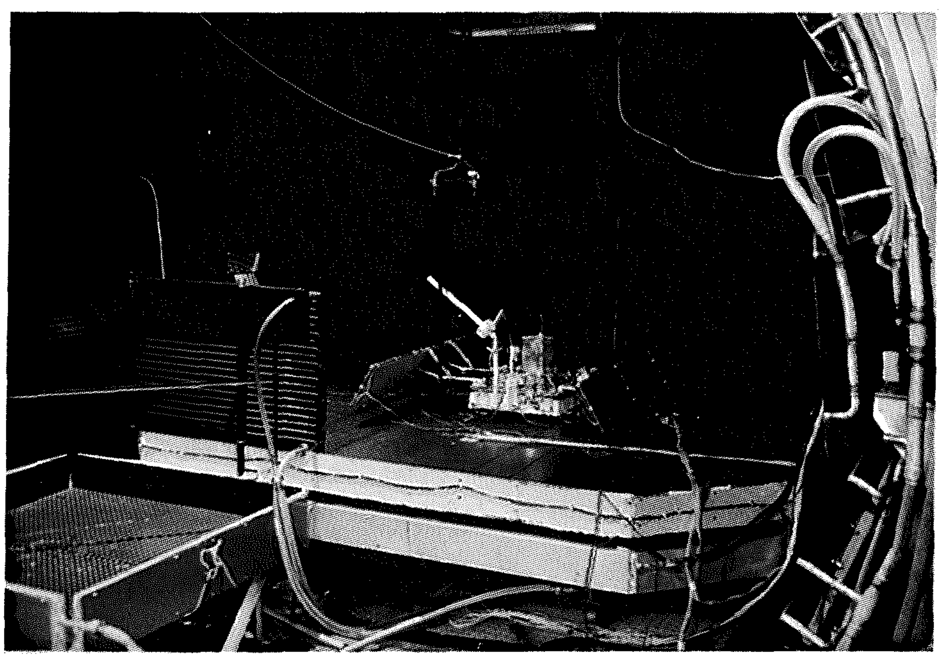


Figure 1 - 2 PSEP Qual Model Deployed in Lunar Simulation Chamber for Thermal Vacuum Test.

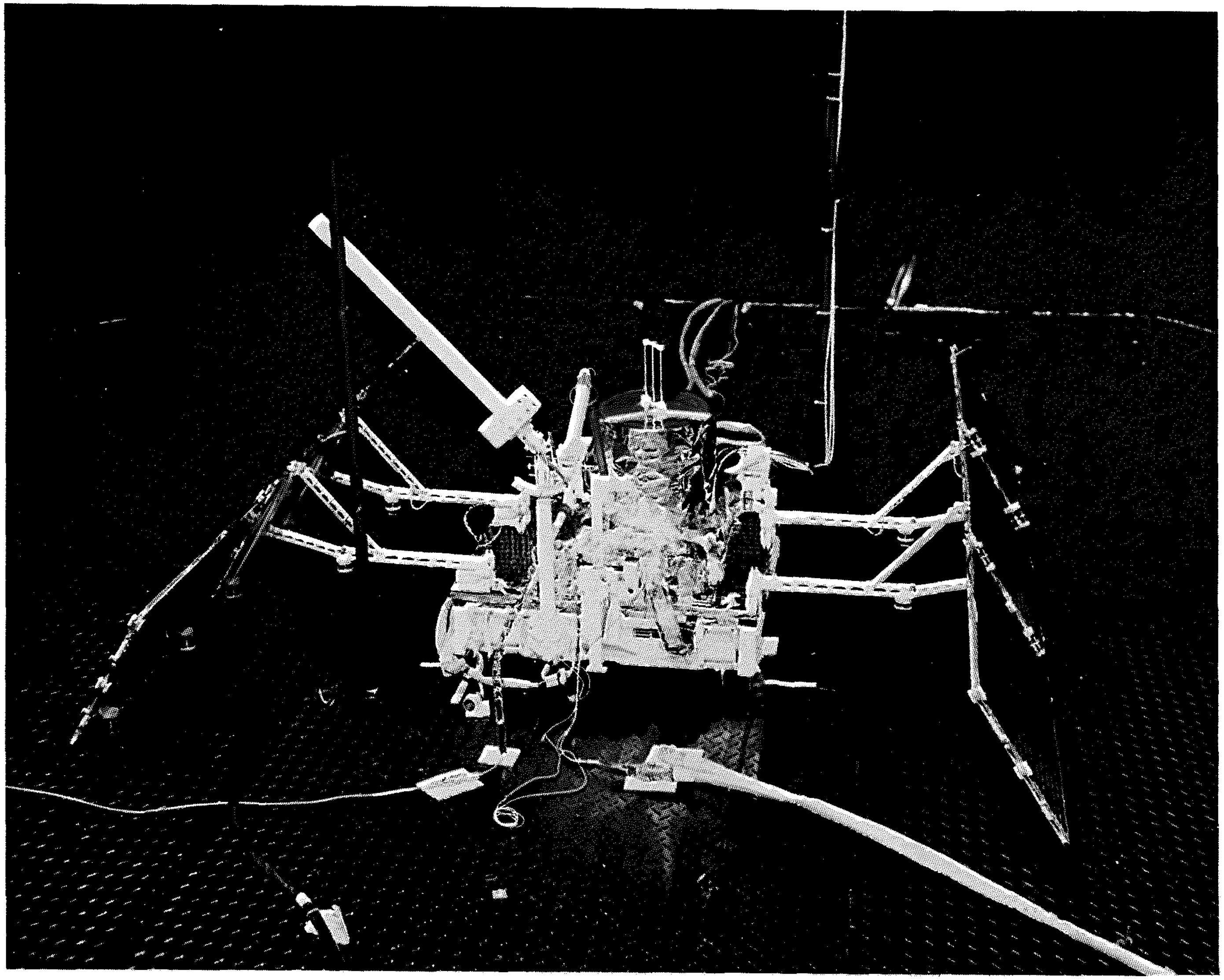


Figure 1-3. PSEP Flight Model Deployed in Lunar Simulation Chamber for Thermal Vacuum Test

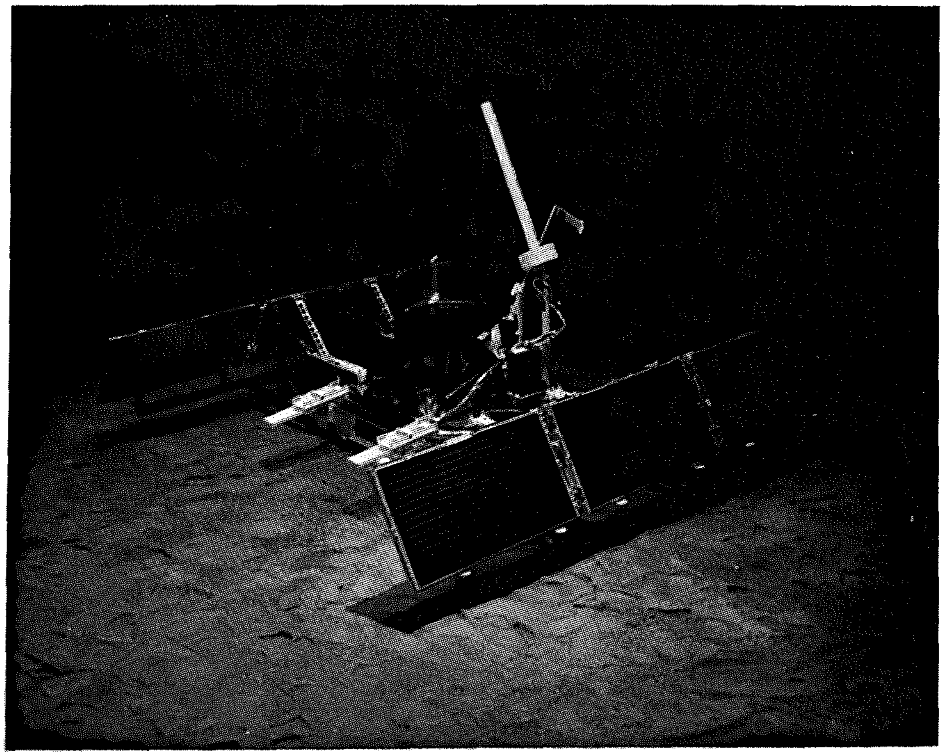


Figure 1 - 4. Deployed PSEP Qualification Model with Plume Heating Protection Shrouds Installed.

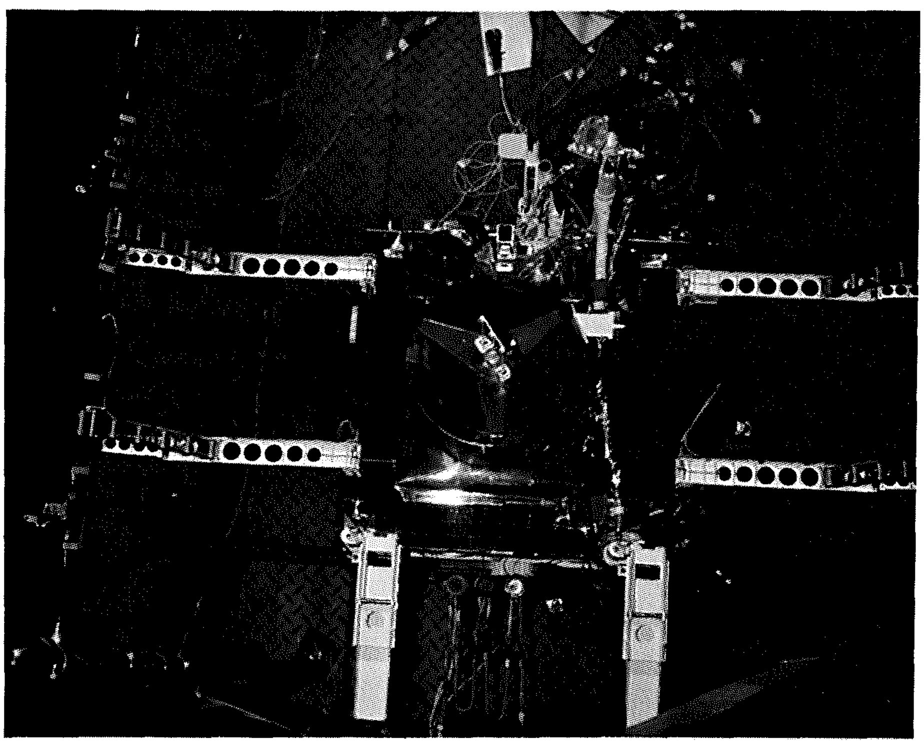


Figure 1 - 5. PSEP Qualification Model in the 20 by 27 Foot Chamber for Thermal Vacuum Retest.

A PDM power dump refers to a decrease in power dissipation at the thermal plate with an accompanying increase in dissipation on a panel attached to the exterior of the primary structure. Lunar night equilibrium was established only for the Qual test as there was no requirements for verifying lunar night thermal performance during Qual Retest and the Flight Acceptance Test.

Based on results from the first Qual test program, an additional 37 second-surface mirrors on the Flight model were exposed in order to center the lunar day to night thermal performance swing of PSEP between +140° and -65°F. As shown in Table 1-1, which gives a brief summary of T/V test results, a 13°F reduction in the thermal plate average temperature was realized at lunar noon by the Flight model in the T/V chamber. Actually, only 10°F of this improvement is valid since solar heating of the solar panels was not simulated during Flight testing, which caused the thermal plate to operate 3°F lower in temperature than for the predicted lunar environment. The reason for omitting solar heating of the panels is discussed in Section 2.1.2. A corresponding 5°F decrease in thermal plate temperature was predicted for lunar night on the moon due to the additional exposed mirror area.

Table 1-1 also compares Qual and Flight thermal plate test temperatures with predicted lunar performance at lunar noon and night equilibrium conditions. The temperatures compared favorably with the specification values of 140°F maximum at lunar noon and -65°F minimum at lunar night. The small differences between test and predicted lunar performance temperatures indicates that the lunar environment simulation in the T/V chamber was excellent. Predictions were based on undegraded or uncontaminated thermal control surfaces.

To protect PSEP mask and shroud insulation materials from heating effects by the LM exhaust gas plume, one and two layers of 5 mil aluminized Kapton were installed over all flight model insulation materials after completion of T/V testing, which caused a predicted 10°F increase in the thermal plate average temperature at lunar noon and no effect at night.

Two changes were incorporated into the Qual model prior to the thermal vacuum retest in order to make the Qual and Flight models equivalent. The first change was the addition of the aluminized Kapton

TABLE 1-1

SUMMARY OF PSEP PREDICTED AND T/V TEST RESULTS

Description	Date	Lunar Noon Temperature, °F	Lunar Night Temperature, °F	Remarks
1. Qualification Test Result	April 1969	143	-50	With radiator area of 1.9ft^2
2. Flight Acceptance	April 1969	130	-	Thermal plate radiator was increased for the Flight model from 1.9ft^2 to 2.15ft^2 in order to center the temperature range between +140°F and -65°F
3. Flight Prediction (Without Kapton)	April 1969	134	-58	With original second surface teflon shroud and correlated for actual lunar performance
4. Flight Prediction (With Kapton)	May 1969	144	-58	With Kapton shroud added
5. Qual Retest With Flight Configuration	September 1969	146	-	Actual retest result from BxA chamber tests during September 1969
6. Qual Retest Results with Structure at 200°F	September 1969	152	-	Actual retest results with primary structure (P/S) temperature at actual lunar surface conditions
7. Chamber D Test Results with P/S at 200°F	October 1969	143	-	Preliminary results from MSC using carbon arc solar simulation in Chamber D
8. Lunar Surface Flight Results	July to September 1969	190	-52	1st day maximum thermal plate maximum temperature and 3rd day temperature at 0° sun angle (lunar night) at turn on.
PSEP Specification (Without Kapton)	March 1969	140	-65	

plume heating protection system, while the second was the exposure of an additional 37 second surface mirrors by eliminating sections of the thermal plate masks.

As shown by the Table 1-1 comparison of the Flight test results (with 3°F added to account for Solar heating of the Solar panels) to the Qual retest results, a 13°F increase in average thermal plate temperature can be attributed to the addition of the Kapton plume heating protection. This is in good agreement with the predicted 10°F increase. Qual retest results also showed that the structure temperatures experienced on the moon, which were about 40°F higher than test levels, had only a 6°F effect on the PSEP thermal performance and therefore that the isolator bolts were effective in isolating the thermal plate from influence by the structure. Also, the solar simulation in the T/V chamber was verified.

Chamber D test results, shown in Table 1-1 for information purposes, agree quite well with the Qual and Flight test values from the Bendix T/V chamber.

This report also presents studies which were conducted to determine effects of various T/V chamber test parameters and conditions on the thermal performance of PSEP in the chamber and on the moon. Results from these studies are presented in Section 6 and show that the chamber lunar environment simulation was very satisfactory.

Sections 3, 4 and 5 contain general descriptions of test methods, of test results, and of the thermal models used for analytical predictions.

While this document presents thermal vacuum test results from the PSEP Qualification test, Flight test, and Qualification retest, ATM 851 presents the results from the thermal anomaly investigation and the correlation of flight data with predicted temperatures.

2.0 RESULTS AND CONCLUSIONS

2.1 Test Results

Predicted and test temperatures for the PSEP Qual, Flight Acceptance, and Qual Retest T/V chamber test phases are summarized. Anayltical predictions and subsequent post-test correlations with chamber test results were performed for equilibrium conditions at lunar noon with no PDM dump, lunar noon with a 10 watt PDM dump, and lunar night. Over-all test results revealed favorable temperature distributions on all PSEP components, and excellent temperature correlation was obtained with predicted values. All PSEP component temperatures were within operating limits established prior to testing.

Temperature predictions for PSEP operation in a real lunar environment are presented and compared with chamber test values.

2.1.1 Qualification Test

An accelerated lunar day-to-night test cycle was imposed on the PSEP Qual Model in the BxA 20 ft. x 27 ft. thermal vacuum chamber between 4/6/69 and 4/10/69. The model was a non-operating system which used mass and thermal simulation for Central Station electronics, Passive Seismic Experiment (PSE), radioisotope heaters, antenna, and Dust Detector Experiment. Solar cell panel assemblies, along with the structural and thermal control subsystems, reflected the PSEP Flight Model design. Lunar noon and night conditions were simulated with chamber lunar surface average temperatures of approximately 250°F and -300°F, respectively. Lunar noon Solar heating of the second-surface mirrors, insulation masks, heater shrouds, and the PSE shroud was simulated with infrared lamps at a level corresponding to one sun on the mirrors. Electrical heaters were used to drive the solar panels to their predicted lunar noon temperatures of 210°F ± 10°F and to simulate power dissipated by the PSE sensor, isotope heaters, and Central Station (C/S) electronic components. The following simulated lunar operating conditions were established to verify the PSEP thermal design:

1. Lunar noon equilibrium with no PDM power dump (established at 12:30 on 4/8/69).

2. Lunar noon equilibrium with a 10 watt PDM power dump (established at 18:30 on 4/8/69).

3. Lunar night equilibrium with only the isotope heaters operating (established at 08:30 on 4/10/69).

Figure 2-1 shows the temperature versus time response for various PSEP and T/V chamber components and depicts major events which occurred during testing. Specific temperatures at lunar noon and night for PSEP Qual components are presented in the following sections. Central Station thermal dissipations corresponding to the lunar noon and night test data are listed in Table 2-1.

TABLE 2-1

QUAL MODEL C/S THERMAL DISSIPATIONS IN WATTS

Description	Lunar Noon No Dump	Lunar Noon 10 w. Dump	Lunar Night
C/S Electronics and PSE Sensor	31.97	26.22	0
Isotope Heaters	29.57	29.63	30.53
Heat Leak from PDM Panel to Primary Structure	1.63	3.42	0

Since there was no PDM panel on the Qual Model, a heat leak from the panel to the primary structure was estimated and simulated with electrical heaters.

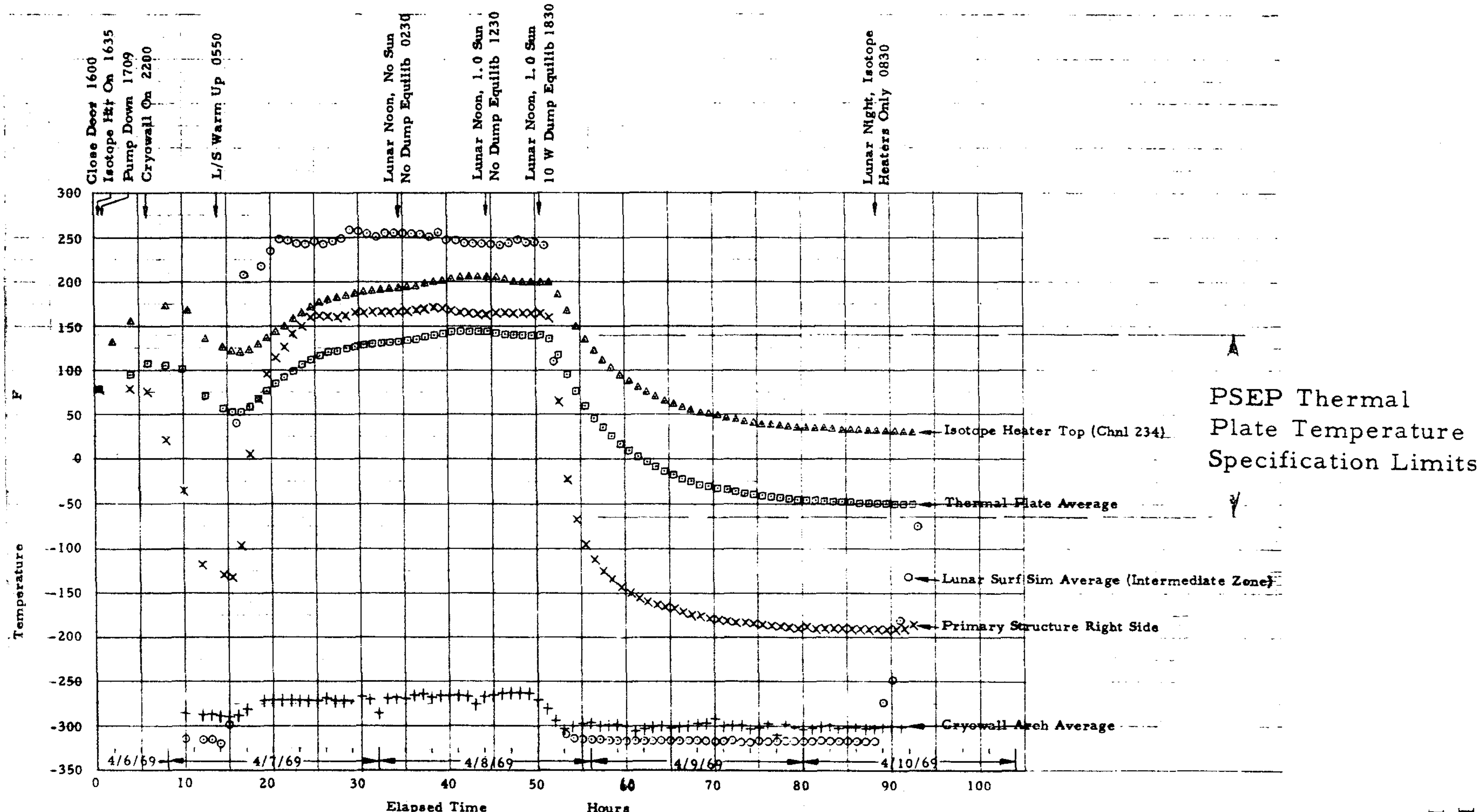


Figure 2-1. PSEP Qual Thermal Vacuum Test Temperature Histories

2.1.1.1 Thermal Plate and PSE Mounting Plate

Figures 2-2 and 2-3 illustrate the distribution of test temperatures over the thermal and mounting plates at lunar noon and lunar night. Thermal plate temperatures ranged from 150°F at noon (no dump) to -56°F at night (neglecting those temperature measurements adjacent to the tie-down bolts). Average thermal plate temperatures were 143°F at noon with no dump, 139°F at noon with the 10 watt dump activated, and -50°F at night.

Similarly, mounting plate temperatures ranged from 156°F at noon (no dump) to -56°F at night with averages of 142°F, 138°F, and -46°F.

2.1.1.2 Primary Structure

Primary Structure equilibrium temperatures, which ranged from 170°F at noon (10 watt dump activated) to -194°F at night, are shown in Figure 2-4. Averge temperatures for the structure sides and bottom were 161°F at noon with no dump, 163°F at noon with the 10 watt dump activated, and -192°F at night.

2.1.1.3 PSE Simulator and Shroud

Figure 2-5 shows temperature measurements over the PSE simulator and shroud external surface. The PSE reached a maximum temperature of 134°F at noon with no dump and dropped to -53°F at night.

2.1.1.4 Isotope Heaters, Shrouds and Masking

Figure 2-6 shows the temperature distribution over the isotope heaters and over the external surfaces of the heater shrouds. Heater temperatures ranged from 205°F at noon to 10°F at night. Figure 2-7 presents temperatures on the insulation masks, which ranged from 77°F at noon to -186°F at night.

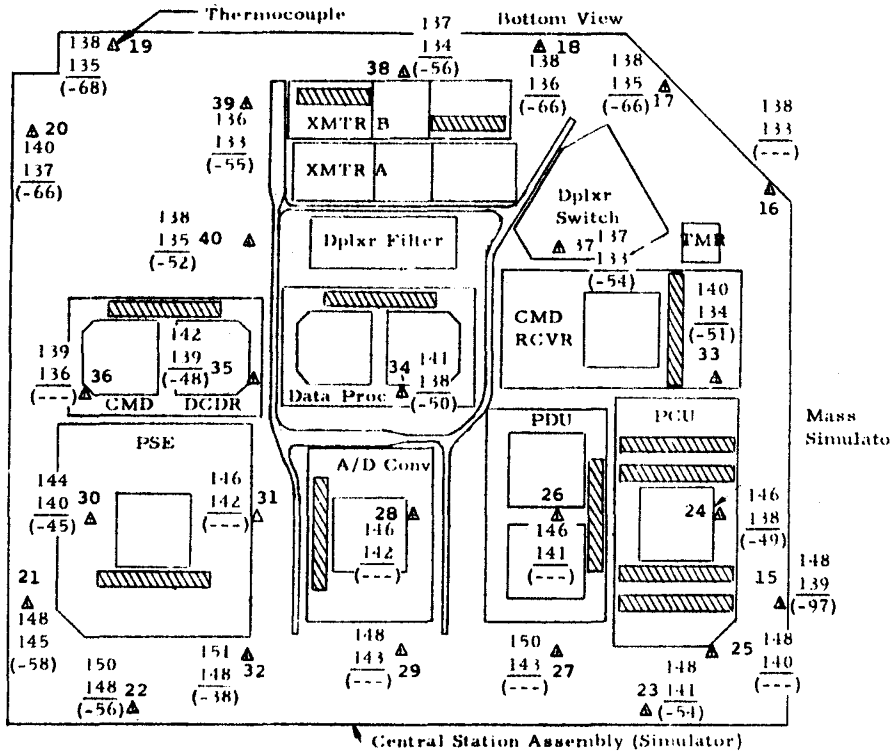
2.1.1.5 Solar Cell Panel and Panel Support Structure

Temperatures of the solar cell panels and panel support linkages are presented in Section 5.

2.1.1.6 Summary of Qual Central Station Test Temperatures

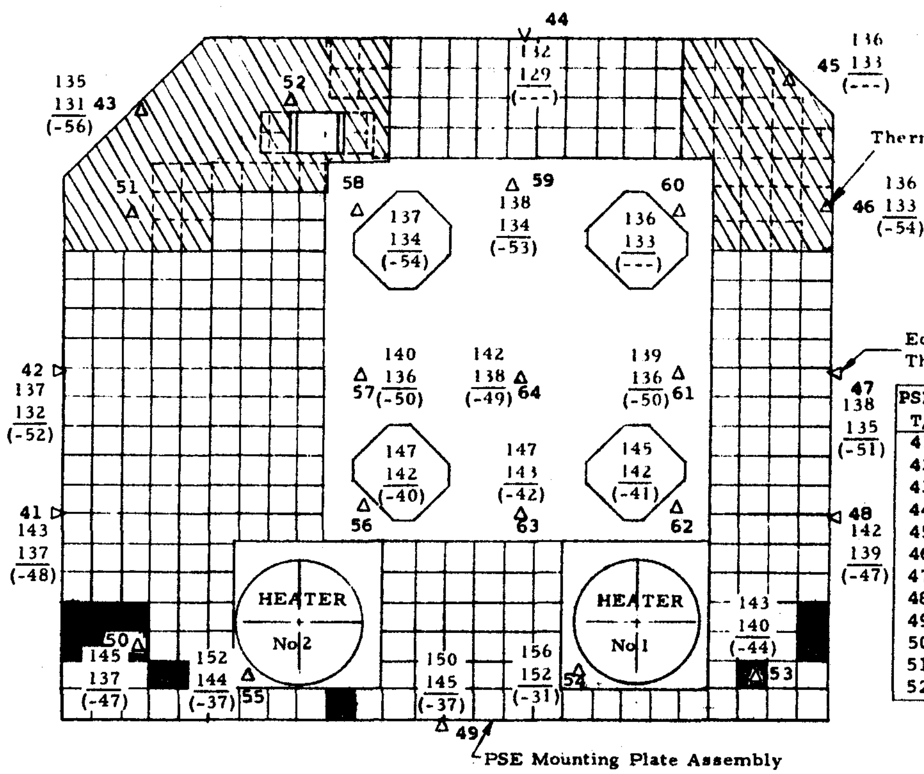
Table 2-2 summarizes measured temperatures for the various PSEP Central Station components at lunar noon and lunar night.

PSEP T/C	DAS CHNL
15	168
16	169
17	170
18	171
19	172
20	173
21	174
22	175
23	176
24	177
25	178
26	179
27	180
28	181
29	182
30	183
31	184
32	185
33	186
34	187
35	188
36	189
37	190
38	191
39	192
40	193



xxx Lunar Noon - No Dump (12:30 on 4/8/69)
xxx Lunar Noon-10W. Dump (18:30 on 4/8/69)
(xxx) Lunar Night (08:30 on 4/10/69)

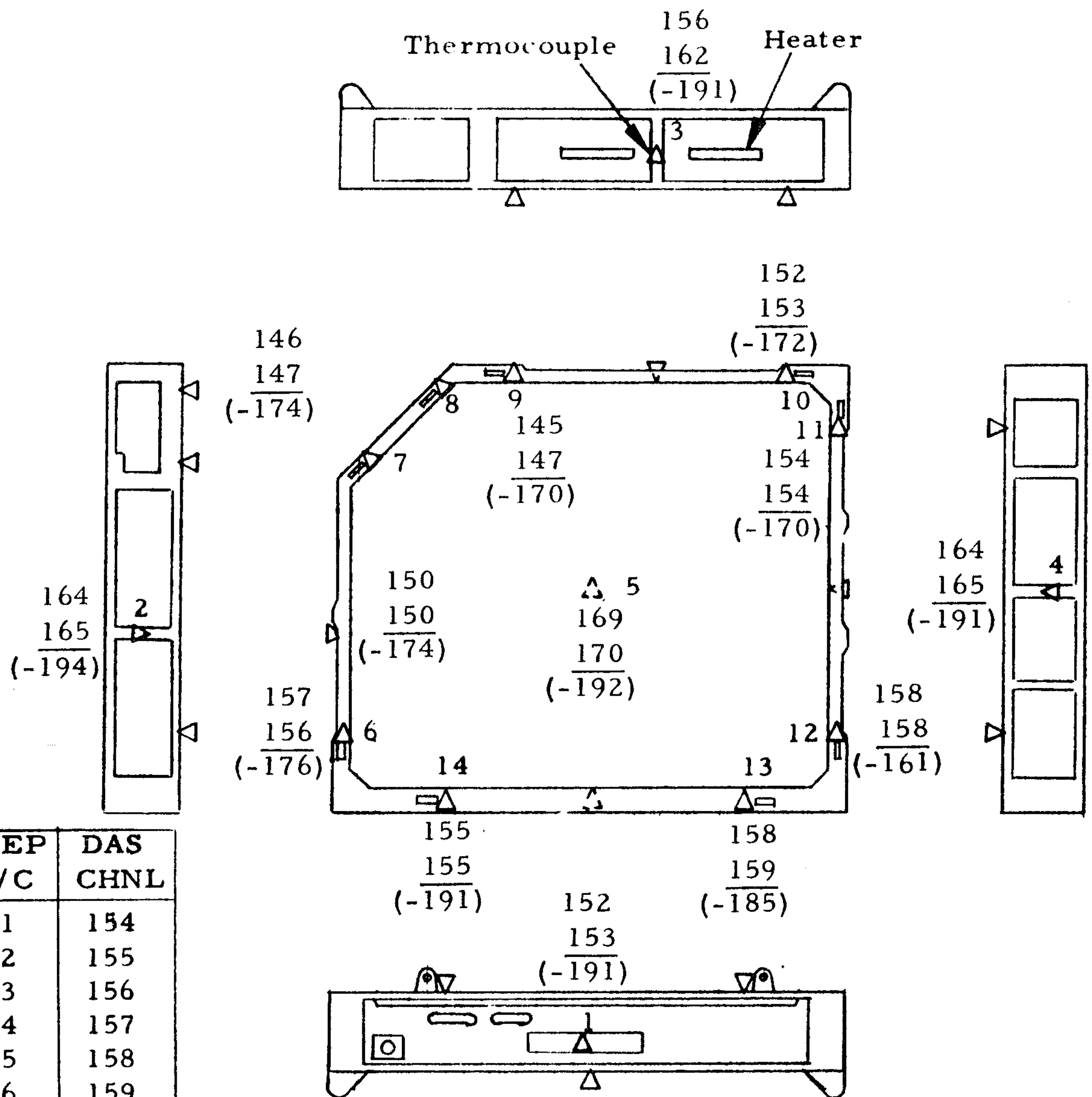
Figure 2-2. PSEP Qual Thermal Vacuum Test - Thermal Plate Test Temperatures, °F



PSEP T/C	DAS CHNL	PSEP T/C	DAS CHNL
41	194	53	206
42	195	54	207
43	196	55	208
44	197	56	209
45	198	57	210
46	199	58	211
47	200	59	212
48	201	60	213
49	202	61	214
50	203	62	215
51	204	63	216
52	205	64	217

xxx Lunar Noon-No Dump (12:30 on 4/8/69)
xxx Lunar Noon-10W. Dump (18:30 on 4/8/69)
(xxx) Lunar Night (08:30 on 4/10/69)

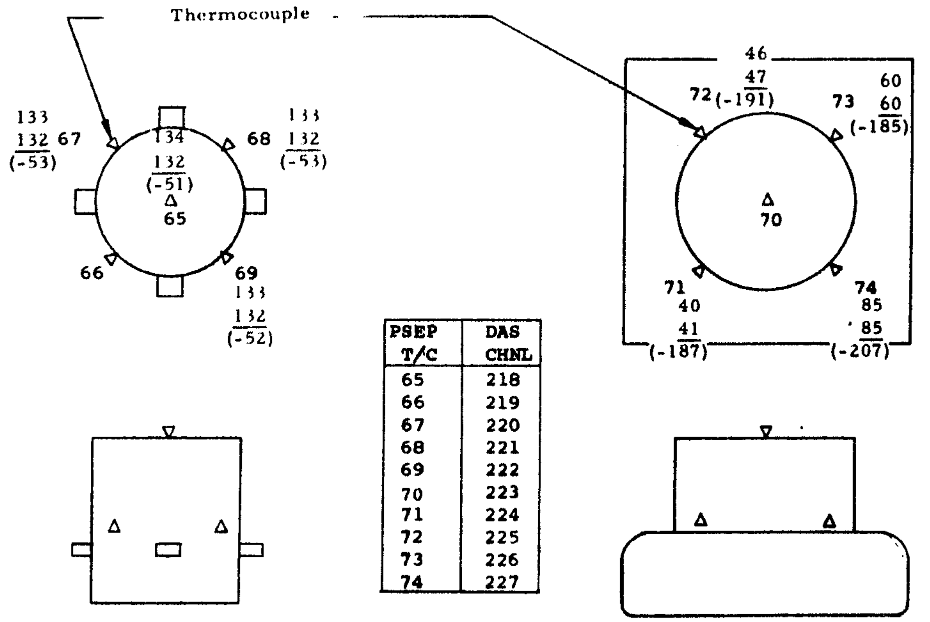
Figure 2-3. PSEP Qual Thermal Vacuum Test - PSE Mounting Plate Assembly Test Temperatures, °F



PSEP T/C	DAS CHNL
1	154
2	155
3	156
4	157
5	158
6	159
7	160
8	161
9	162
10	163
11	164
12	165
13	166
14	167

XXX Lunar Noon - No Dump (12:30 on 4/8/69)
XXX Lunar Noon - 10 W. Dump (18:30 on 4/8/69)
(XXX) Lunar Night (08:30 on 4/10/69)

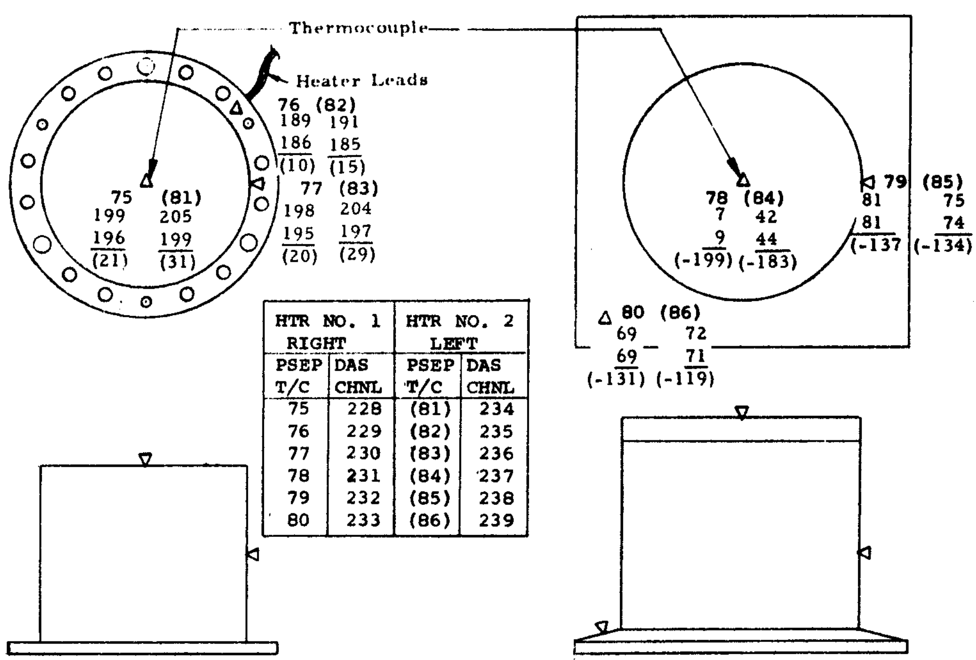
Figure 2-4. PSEP Qual Thermal Vacuum Test - Primary Structure Test Temperatures, °F



PSEP T/C	DAS CHNL
65	218
66	219
67	220
68	221
69	222
70	223
71	224
72	225
73	226
74	227

XXX Lunar Noon - No Dump (12:30 on 4/8/69)
XXX Lunar Noon - 10 W. Dump (18:30 on 4/8/69)
(XXX) Lunar Night (08:30 on 4/10/69)

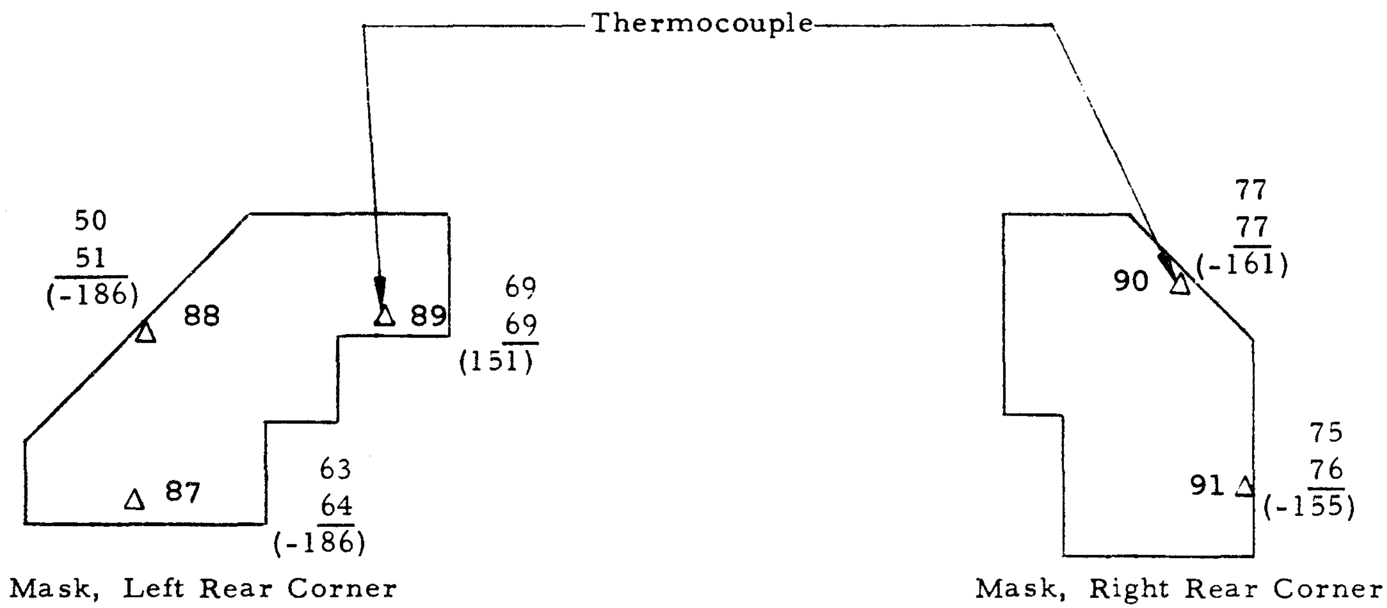
Figure 2-5. PSEP Qual Thermal Vacuum Test -
PSE Simulator and Shroud Test Temperatures, °F



HTR NO. 1 RIGHT		HTR NO. 2 LEFT	
PSEP T/C	DAS CHNL	PSEP T/C	DAS CHNL
75	228	(81)	234
76	229	(82)	235
77	230	(83)	236
78	231	(84)	237
79	232	(85)	238
80	233	(86)	239

XXX Lunar Noon - No Dump (12:30 on 4/8/69)
XXX Lunar Noon - 10 W. Dump (18:30 on 4/8/69)
(XXX) Lunar Night (08:30 on 4/10/69)

Figure 2-6. PSEP Qual Thermal Vacuum Test -
Isotope Heater and Shroud Test Temperatures, °F



PSEP, T/C	DAS CHNL
87	240
88	241
89	242
90	243
91	244

XXX Lunar Noon - No Dump (12:30 on 4/8/69)
XXX Lunar Noon - 10w. Dump (18:30 on 4/8/69)
(XXX) Lunar Night (08:30 on 4/10/69)

Figure 2-7. PSEP Qual Thermal Vacuum Test - Insulation Mask Test Temperatures, °F

TABLE 2-2

SUMMARY OF QUAL TEST TEMPERATURES

Component	Temperatures - °F		
	Lunar Noon No Dump	Lunar Noon 10 W. Dump	Lunar Night
Thermal Plate, average	143	139	-50
Mounting Plate, average	142	138	-46
Primary Structure Sides and Bottom, average	161	163	-192
Primary Structure Top Flange, average	153	153	-175
PSE Simulator, average	133	132	-52
PSE Shroud External Surface, average	32	32	-202
Isotope Heater No. 1, average	195	192	17
Isotope Heater No. 1 Shroud External Surface, average	52	52	-156
Isotope Heater No. 2, average	200	194	25
Isotope Heater No. 2 Shroud External Surface, average	63	63	-145
Mounting Plate Left Rear Mask, average	61	61	-174
Mounting Plate Right Rear Mask, average	76	76	-158

2.1.1.7 Qual Central Station Temperature Histories

Temperature histories for various PSEP Qual Central Station components are presented in Section 5.1.

2.1.2 Flight Acceptance Test

The Flight acceptance test was conducted between 4/11/69 and 4/22/69. However, after 4/15/69 the purpose of testing was to check the performance of specific electronic components. Since this report is concerned only with the over-all PSEP thermal performance, the Flight results presented here are for that portion of the test prior to 4/15/69.

Between 4/13/69 and 4/15/69, the PSEP Flight model was subjected to a simulated lunar noon environment in the T/V chamber with the lunar surface average temperature at 250°F. The model was an operating system except that electrical heaters simulated the power dissipated by the isotope heaters. Also, solar heating of the solar panels was not simulated to avoid the outgassing of material from the electrical heaters which was experienced in the Qual test. During the Qual test, outgas material condensed and formed undesirable oil films on PSEP equipment. Since solar panel solar heating was not simulated during the flight acceptance test, the Flight model thermal plate average temperature was about 3°F lower during testing than if solar heating of the solar panels had been simulated. Solar heating of the second-surface mirrors, insulation masks, heater shrouds, and the PSE shroud was simulated with infrared lamps at a level corresponding to one sun on the mirrors.

The following simulated lunar operating conditions were established to verify the Flight model thermal performance.

1. Lunar noon equilibrium with a 10 watt PDM power dump (established at 09:00 on 4/15/69).

2. Lunar noon equilibrium with no PDM power dump (established at 16:05 on 4/15/69).

Specific temperatures at lunar noon for PSEP Flight components are presented in the following sections, while corresponding Central Station thermal dissipations are listed in Table 2-3.

TABLE 2-3

FLIGHT MODEL C/S THERMAL DISSIPATIONS IN WATTS

Description	No Dump	10 W. Dump
C/S Electronics	31.2	25.6
PSE Sensor	0.7	0.7
Isotope Heaters	30.0	30.0
PDM Panel Resistors	5.0	10.5

2.1.2.1 Thermal Plate and Electronic Components

Figure 2-8 depicts the distribution of test temperatures over the thermal plate and electronic components for the no dump and 10 watt dump test phases at lunar noon. Temperature measurements ranged from 120°F to 138°F over the thermal plate for the no dump condition. Average thermal plate temperatures were 130°F with no dump and 124°F with the 10 watt dump activated. Similarly, electronics temperatures varied from 125°F to 167°F for the no dump condition and averaged 136°F with no dump and 128°F with the 10 watt dump activated.

2.1.2.2 Structure and Thermal Control Components

Lunar noon equilibrium temperatures for the primary structure, PDM panel, and thermal bag are presented in Figure 2-9. Structure temperatures, which ranged from 155°F to 160°F at noon, averaged 157° for both the dump and no dump conditions. The PDM panel temperature decreased from 180°F to 165°F when the 10 watt dump was deactivated.

2.1.2.3 Solar Panels

The solar panel temperatures, which averaged about 92°F during lunar noon testing, were significantly below the predicted 210°F ± 10°F since solar heating of the panels was not simulated.

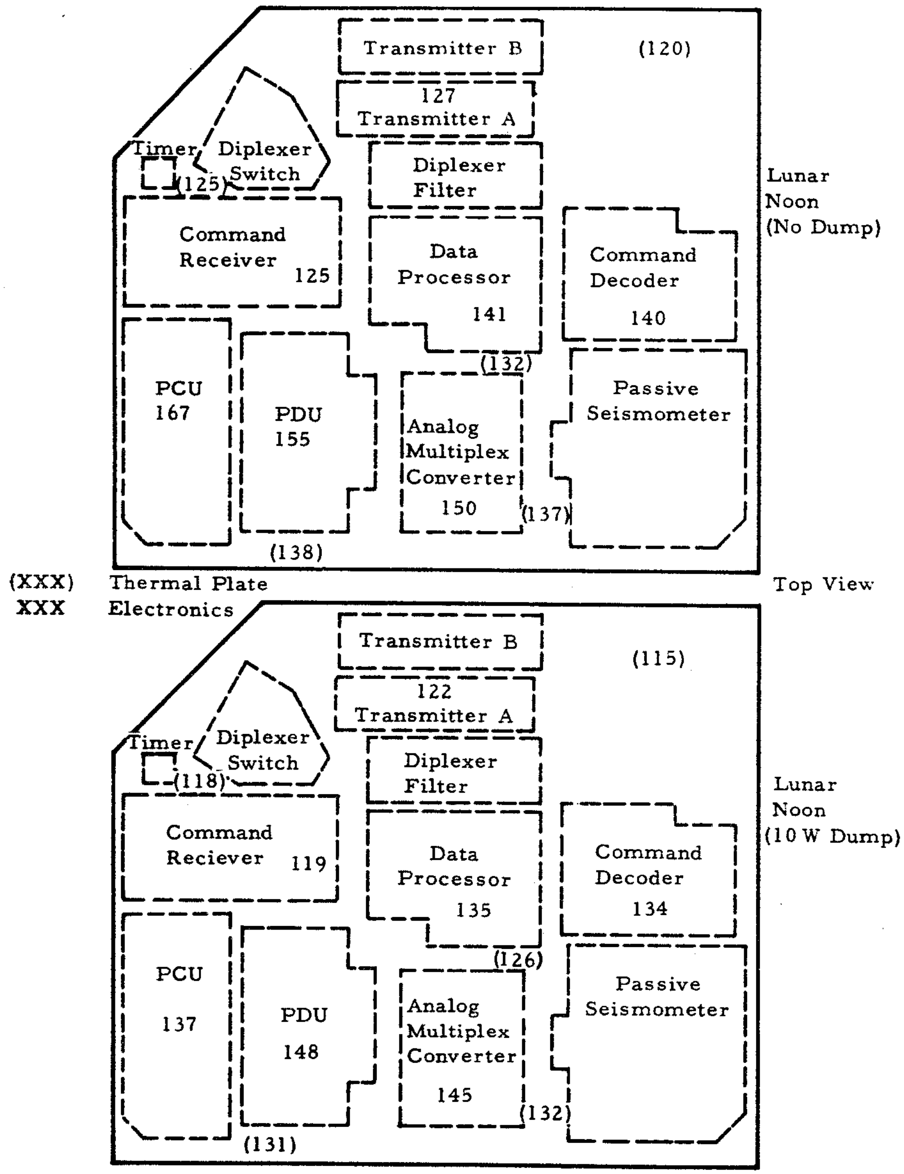


Figure 2-8. PSEP Flight Thermal Vacuum Test - Thermal Plate and Electronics Test Temperatures, °F

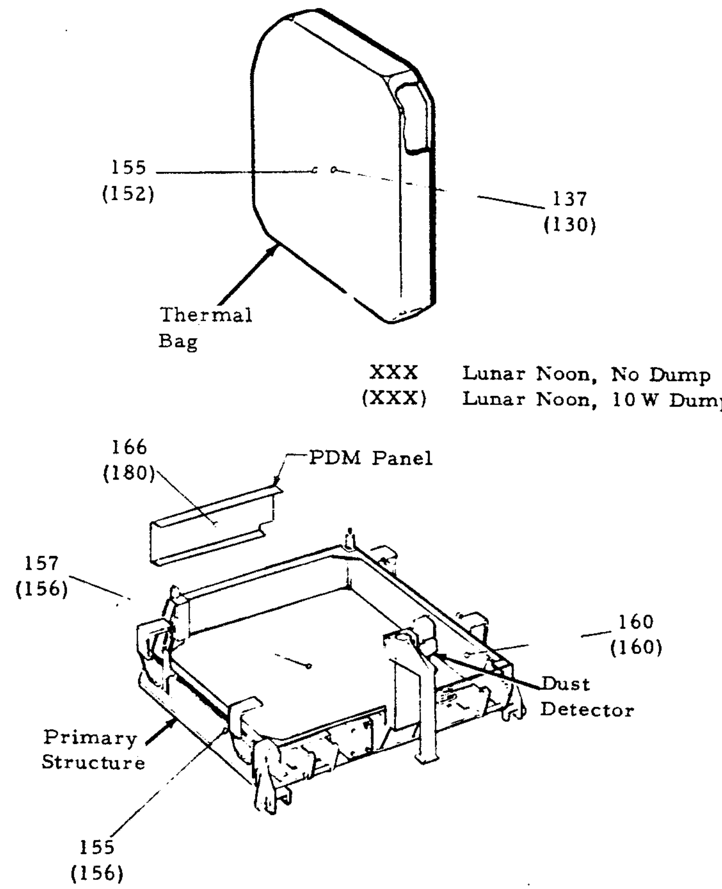


Figure 2-9. PSEP Flight Thermal Vacuum Test - Structure and Thermal Control Component Test Temperatures, °F

2.1.2.4 Summary of Flight Central Station Test Temperatures

Table 2-4 gives a brief summary of measured temperatures for the various Flight Central Station components at the lunar noon equilibrium conditions.

TABLE 2-4

SUMMARY OF FLIGHT TEST TEMPERATURES (°F)

Component	No Dump	10 W. Dump
Thermal Plate, average	130	124
Electronics, average	136	128
Primary Structure, average	157	157
PDM Panel	165	180
Thermal Bag, Exterior	154	152
Thermal Bag, Interior	137	130

2.1.3 Qualification Retest

The PSEP Qualification Retest was conducted in the Bendix T/V chamber with the same test setup used in the original Qual test. PSEP was placed in the same location on the lunar surface simulator and in the same location under the IR lamp array as in the original test. The number of thermocouples on PSEP was reduced, for cost and time reasons, to the point where only that data required was obtained. The equilibrium conditions were the same as in the original qualification test, with two additions: 1) A thermal equilibrium condition with the primary structure sides at the 195°F actual lunar noon temperature and 2) a thermal equilibrium condition with unheated solar panel simulators.

Table 2-5 lists the average temperatures of the PSEP components at the four thermal equilibrium conditions.

TABLE 2-5

QUAL RETEST COMPONENT AVERAGE TEMPERATURES AT THE FOUR THERMAL EQUILIBRIUM CONDITIONS

PSEP Component	Average Temperature - °F			
	No Sun	One Sun	One Sun With Heated Structure	One Sun With Cool Solar Panels
Thermal Plate near Components	132	146	152	151
Thermal Plate near Bolts	135	148	156	155
Solar Cell Panels (center T/C's Only)	190	194	194	150
Primary Structure (sides and bottom)	156	162	196	194
Primary Structure Flanges	146	153	178	176
PSE Mounting Plate	129	142	149	148
Left Mask over Mirrors	9	43	51	51
Isotope Heater Number 2 Shroud	40	61	65	65
PSE Simulator (one T/C only)	123	139	145	145
PSE Shroud-Top (one T/C only)	-120	-55	-50	-43
PSE Shroud-Side (Upper Section)	24	34	35	33
PSE Shroud-Side (Lower Section)	43	58	61	56
Isotope Heater Number 1 Top (one T/C only)	186	202	210	209
Isotope Heater Number 2 Top (one T/C only)	210	225	233	232
Isotope Heater Number 1 Shroud Top (one T/C only)	-52	2	7	11

2.1.3.1 Qual Retest Objectives

The primary objectives of the Qual retest were as follows:

1. Establish the effect of the higher-than-predicted primary structure temperatures on the average thermal plate temperature.

2. Determine the effect of the Kapton shrouds on the average thermal plate temperature.

Secondary objectives were to verify the low thermal conductance of the thermal plate isolator bolts, verify the T/V chamber solar simulation, and investigate the effect of solar cell panel temperature on the PSEP thermal performance.

2.1.3.2 Description of Test Events

PSEP was subjected to the following four thermal equilibrium conditions in the Bendix T/V chamber:

1. Lunar noon with no solar simulation, normal solar panel temperatures (185°F), and no additional heat to the primary structure (13:30 on 9/24/69).

2. Lunar noon with solar simulation, normal solar panel temperatures (185°F), and no additional heat to the primary structure (00:30 on 9/25/69).

3. Lunar noon with solar simulation, normal solar panel temperatures (185°F), and 195°F primary structure (13:30 on 9/25/69).

4. Lunar noon with solar simulation, solar panels at 150°F, and primary structure at 195°F (19·30 on 9/25/69).

2.1.3.3 Qual Retest Results

The thermal performance of the PSEP qualification model during the thermal vacuum retest was similar to its performance in the original qualification test. The addition of the Kapton shrouds (for plume heating protection) raised the average thermal plate temperature 13°F, while the exposure of 37 additional second surface mirrors reduced the average thermal plate temperature 10°F. These two changes produced the 3°F net increase in the Qual retest thermal plate average temperature over the Qual test results at the lunar noon (no dump) condition with normal primary structure and solar panel temperatures.

With the increase of the primary structure to 195°F (the actual lunar noon temperature experienced by the flight model on the lunar surface), the average thermal plate temperature increased only 6°F. These results are summarized in Tables 1-1 and 2-6.

The PSEP component temperature distributions at the four thermal equilibrium conditions are shown in Figures 2-10 through 2-14.

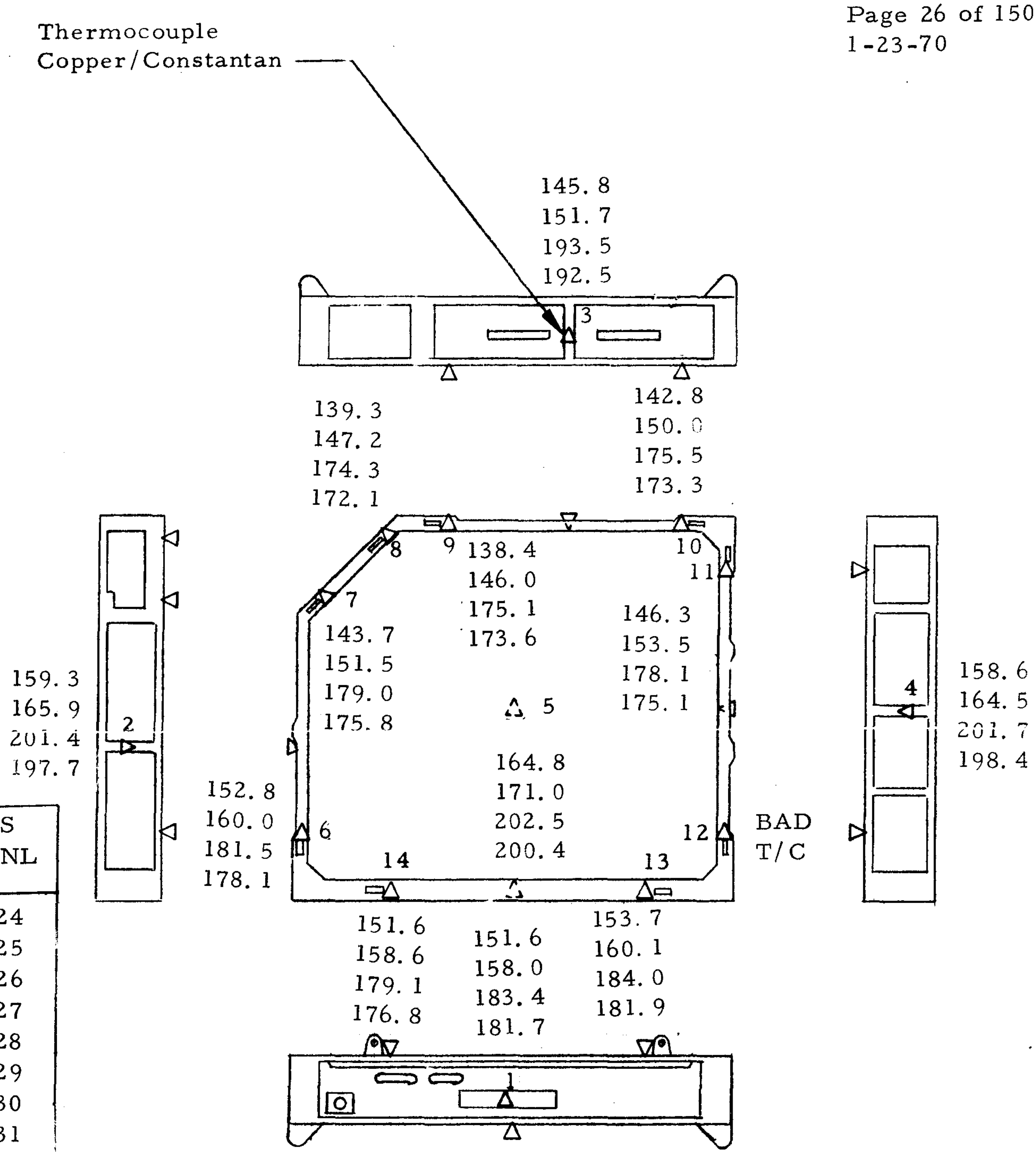
2.2 Comparison of Measured and Predicted Thermal Plate Temperatures

A brief comparison of measured and predicted thermal plate temperatures for the Qual, Flight, and Qual Retest models is shown in Table 2-6. Predicted values were obtained with analytical thermal models of the PSEP deployed in the T/V chamber and on the moon. As shown by the table, an estimated 6 to 8°F degradation in lunar noon thermal plate performance was predicted due to non-perfect mirror radiation properties and to predicted degradation of mirror solar absorptivity over the life of the PSEP mission. All values were based on no plume heating protection on the insulation mask and shroud material, except where plume heating protection is denoted. Plume heating protection consisted of two layers of 5 mil Kapton over all PSEP insulation surfaces normal to the direction of LM exhaust gas flow and one 5 mil layer over insulation surfaces parallel to the flow.

The 130°F and 124°F thermal plate temperatures from the Flight T/V chamber test would have been approximately 3°F higher if solar heating of the solar panels had been simulated. The Flight model with plume heating protection was the final PSEP design.

2.3 Summary of T/V Chamber Test Conditions

Table 2-7 summarizes T/V chamber conditions for the Qual test, Flight Acceptance test, and Qual Retest. Lunar surface and cryowall temperatures are averages of numerous measurements. The table indicates the various equilibrium conditions established for each test. Note that lunar night equilibrium was established only for the Qual test.



P T/C	DAS CHNL
1	124
2	125
3	126
4	127
5	128
6	129
7	130
8	131
9	132
10	133
11	134
12	135
13	136
14	137

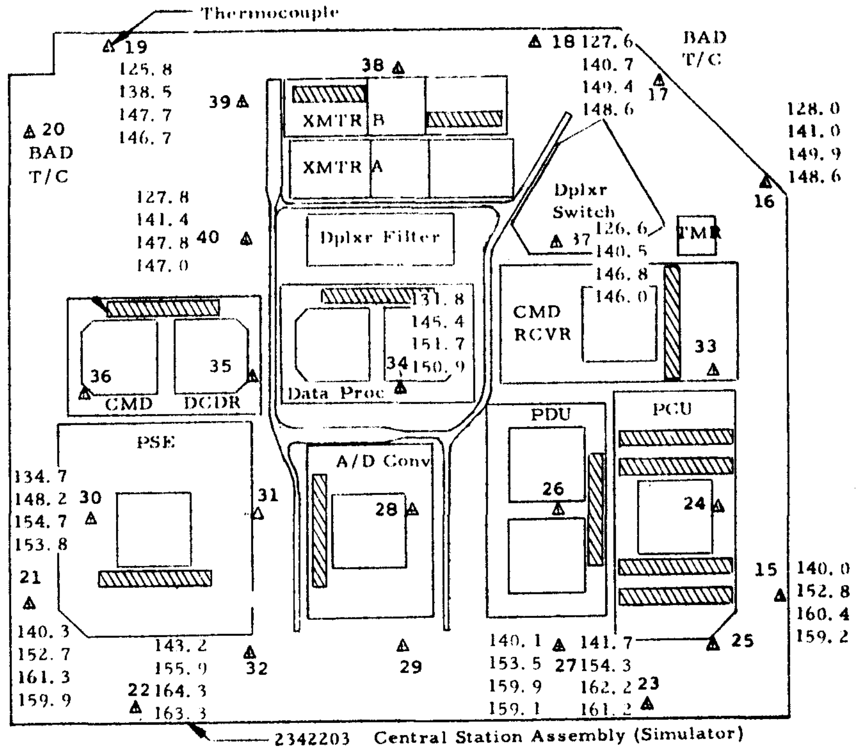
XXX. X Lunar Noon, No Sun (13:30 on 9/24/69)
XXX. X Lunar Noon With Sun (00:30 on 9/25/69)
XXX. X Lunar Noon With P/S Heaters on (13:30 on 9/25/69)
XXX. X Lunar Noon With P/S Heaters on and Solar Panels Off (19:30 on 9/25/69

PSEP QUAL THERMAL VACUUM RETEST

[illegible]ARY STRUCTURE TEST TEMPERATURES - °F

Figure 2-10

PSEP T/C	DAS CHNL
15	160
16	161
17	162
18	163
19	164
20	165
21	166
22	167
23	168
27	169
30	170
34	171
37	172
40	173

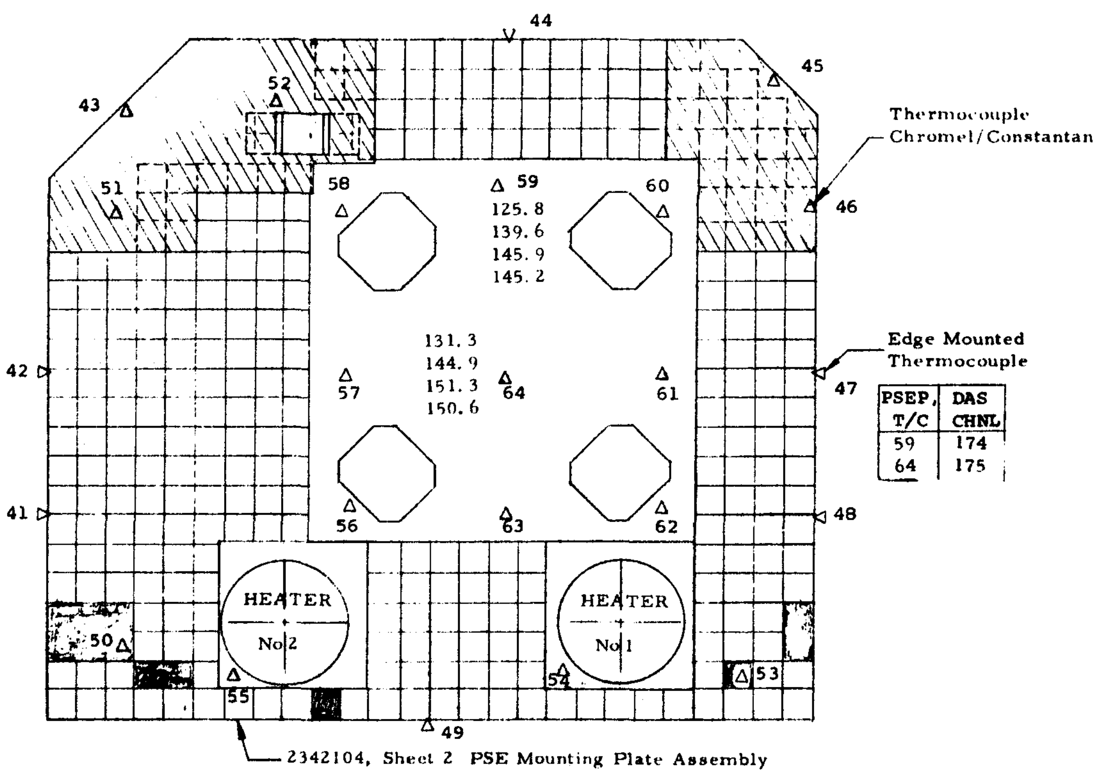


PSEP QUAL THERMAL VACUUM RETEST

XXX. X Lunar Noon No Sun (13:30 on 9/24/69)
XXX. X Lunar Noon With Sun (00:30 on 9/25/69)
XXX. X Lunar Noon With P/S Heaters on (13:30 on 9/25/69)
XXX. X Lunar Noon With P/S Heaters on and Solar Panels Off (19:30 on 9/25/69)

THERMAL PLATE TEST TEMPERATURES - °F

Figure 2-11



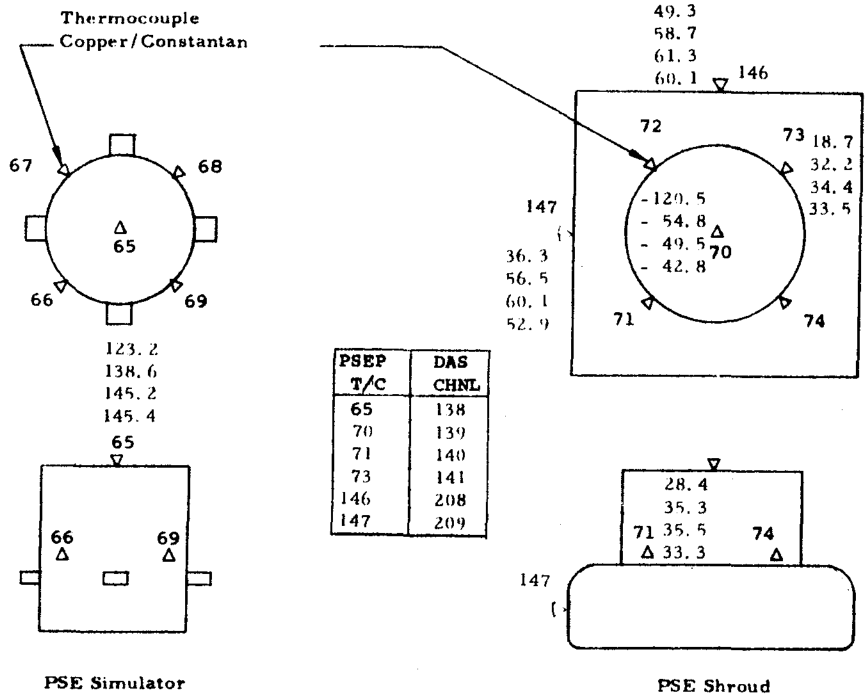
PSEP T/C	DAS CHNL
59	174
64	175

PSEP QUAL THERMAL VACUUM RETEST

XXX. X Lunar Noon, No Sun (13:30 on 9/24/69)
XXX. X Lunar Noon With Sun (00:30 on 9/25/69)
XXX. X Lunar Noon With P/S Heaters on (13:30 on 9/25/69)
XXX. X Lunar Noon With P/S Heaters on and Solar Panels Off (19:30 on 9/25/69

PSE MOUNTING PLATE ASSEMBLY TEST TEMPERATURES - °F

Figure 2-12



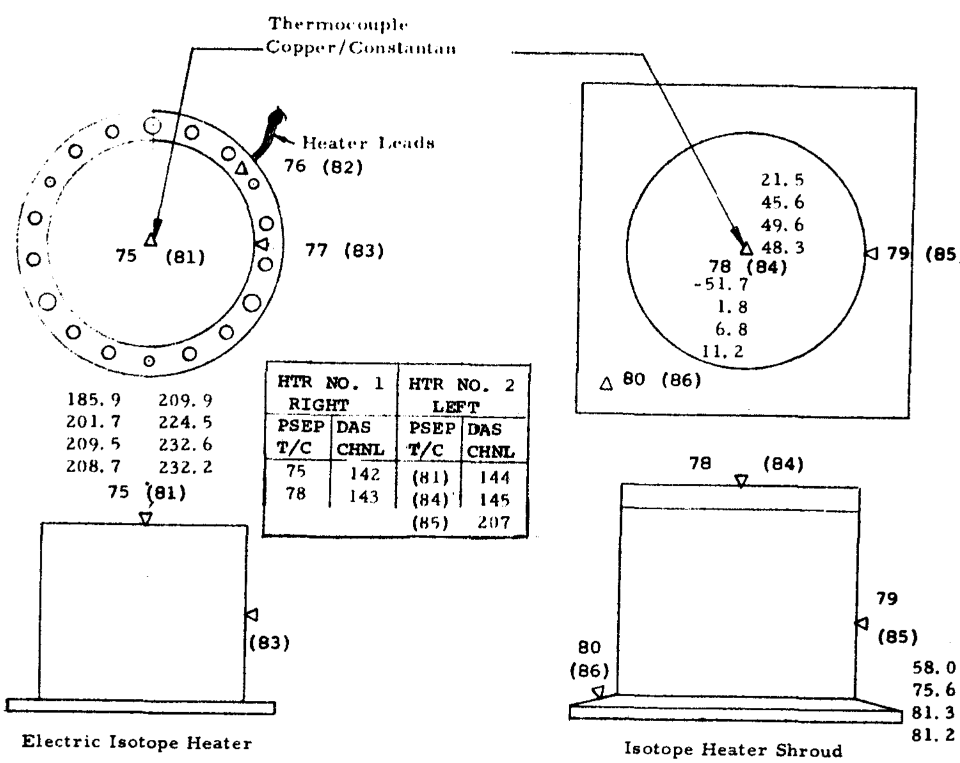
PSEP T/C	DAS CHNL
65	138
70	139
71	140
73	141
146	208
147	209

XXX.X Lunar Noon, No Sun (13:30 on 9/24/69)
XXX.X Lunar Noon With Sun (00:30 on 9/25/69)
XXX.X Lunar Noon With P/S Heaters on (13:30 on 9/25/69)
XXX.X Lunar Noon With P/S Heaters on and Solar Panels Off (19:30 on 9/25/69)

PSEP QUAL THERMAL VACUUM RETEST

PSE SIMULATOR AND SHROUD TEST TEMPERATURES - °F

Figure 2-13



HTR NO. 1 RIGHT		HTR NO. 2 LEFT	
PSEP T/C	DAS CHNL	PSEP T/C	DAS CHNL
75	142	(81)	144
78	143	(84)	145
		(85)	207

XXX.X Lunar Noon, No Sun (13:30 on 9/24/69)
XXX.X Lunar Noon With Sun (00:30 on 9/25/69)
XXX.X Lunar Noon With P/S Heaters on (13:30 on 9/25/69)
XXX.X Lunar Noon With P/S Heaters on and Solar Panels Off (19:30 on 9/25/69)

PSEP QUAL THERMAL VACUUM RETEST

ISOTOPE HEATER AND SHROUD TEST TEMPERATURES - °F

Figure 2-14

TABLE 2-6

COMPARISON OF MEASURED AND PREDICTED THERMAL PLATE TEMPERATURES

	Thermal Plate Average Temperature - ^{o}F				
Description	Noon No Dump	Noon 10 W. Dump	Night	Swing No Dump	Swing 10 W. Dump
Qual T/V Chamber Test Performance	143	139	-50	193	189
Qual Predicted T/V Chamber Performance - Mirror α/ϵ = .06/.80 (1)	140	132	-49	189	181
Qual Predicted Lunar Performance - Mirror α/ϵ = .06/.80 (1)	144	140	-53	197	193
Flight T/V Chamber Test	130	124	---	---	---
Flight Predicted T/V Chamber Performance - Mirror α/ϵ = .06/.80 (1)	134	128	-55	189	183
Flight Predicted Lunar Performance - Mirror α/ϵ = .06/.80 (1)	134	128	-58	192	186
Flight Predicted Lunar Performance - Mirror α/ϵ = .08/.80 (2)	142	136	-58	200	194
Flight Predicted Lunar Performance with Plume Heating Protection- Mirror α/ϵ = .06/.80 (1)	144	138	-58	202	196
Flight Predicted Lunar Performance with Plume Heating Protection - Mirror α/ϵ = .08/.80 (2)	150	144	-58	208	202
Qual Retest T/V Chamber Performance (Normal Structure and Solar Panel Temperature	146	---	---	---	---
Qual Retest T/V Chamber Performance (Structure at 195^{o}F and Solar Panels at Normal Temperatures)	152	---	---	---	---

NOTES:

(1) Nominal or estimated effective radiation properties for over-all mirror surface -- includes effect of gaps between mirrors and around mounting plate edges.

(2) Radiation properties for "degraded" mirror surface over the life of the mission.

(3) Lunar performance values were determined as follows: Temperatures were obtained with the analytical thermal model for a real lunar environment. These predictions were then adjusted by the amount of difference between expected chamber and actual test figures for the PSEP model in the T/V chamber.

TABLE 2-7

SUMMARY OF T/V CHAMBER TEST CONDITIONS

	PSEP Test					
	Qualification		Flight Acceptance		Qual Retest	
Condition	Noon	Night	Noon	Night	Noon	Night
Lunar Surface Temp., °F	250	-300	250	-	250	-
Cryowall Temp., °F	-300	-300	-300	-	-300	-
Solar Simulation, watts/ft^2	130	0	130	-	130	-
Chamber Pressure, torr	10^{-6}	10^{-6}	10^{-6}	-	10^{-6}	-
Lunar Noon Equilibrium Conditions Established						
No Solar Simulation	Yes	-	No	-	Yes	-
Solar Simulation (One Sun)	Yes	-	Yes	-	Yes	-
Solar Simulation (One Sun) with 10 Watt Dump	Yes	-	Yes	-	No	-
Solar Simulation (One Sun) with Primary Structure Heated	No	-	No	-	Yes	-

NOTE: One sun equals 130 watts/ft^2 incident radiation.

2.4 Conclusions

1. Thermal vacuum testing showed that the flight model thermal performance was well within the specification -65°F to 140°F thermal plate temperature range.

2. The 10 watt PDM dump on the Flight model improves (lowers) the lunar noon thermal plate temperature by 6°F.

3. The addition of the Kapton plume heating protection shrouds caused a 13°F increase in the PSEP Flight thermal plate average temperature.

4. The higher-than-predicted primary structure temperatures experienced on the moon caused a 6°F increase in the thermal plate average temperature.

5. The isolator bolts were very effective in isolating the thermal plate from influence by the primary structure.

6. The T/V chamber solar simulation adequately simulated solar heating of PSEP components on the lunar surface.

7. The Qual retest established that the PSEP thermal design was not the cause of the thermal anomaly experienced on the moon.

8. The Qual retest re-verified the PSEP thermal performance and the adequacy of the thermal design.

3.0 THERMAL ANALYSIS

All predicted temperatures in this document were derived with thermal analysis models of PSEP in the T/V chamber and on the lunar surface. The models have the capability of computing steady-state and/or transient response temperatures as a function of such critical parameters as C/S thermal dissipation, solar heating, and second-surface mirror area.

Brief descriptions of the PSEP nodal division, of the resistors connecting the nodes, and of the various heat inputs are presented in following sections along with some analysis techniques.

3.1 Thermal Models

Figures 3.1 and 3.2 illustrate deployed assembly and primary components of PSEP, while References 1 and 2 provide details on physical characteristics and functions of each component except for the second-surface mirrors, isotope heaters, PSE mounting plate, solar panels, and insulation shrouds. The second-surface mirrors consist of 8 mil thick Corning 7940 fused silica with silver vacuum-deposited on one side. There are 310 one inch square mirrors fastened to the upper surface of the PSE mounting plate, with the purpose of minimizing absorbed solar energy while radiating the heat dissipated by the C/S electronics and heaters to space.

Two isotope heaters are fastened to the top surface of the mounting plate to maintain the C/S electronics at temperatures above critical levels during lunar night. The PSE mounting plate is a honeycomb structure which provides support for the PSE sensor. Filtered silicon solar cells are supported in six panels and generate power for PSEP operation during the lunar day. These panels are deployed in two groups of three at a distance from the C/S so as not to interfere with the rejection of thermal energy to space by the mirrors (see Figure 3-1). Insulation shrouds over the PSE sensor and heaters serve to isolate these three components from environmental effects.

Thermal models for temperature predictions at operating conditions in the vacuum chamber and on the real lunar surface are described below.

3.1.1 Thermal Model for T/V Chamber Test Environment

The thermal model consists of a network of isothermal nodes connected by heat transfer resistance paths which is processed by a computer program. Solar and thermal heat loads are input to specific nodes.

3.1.1.1 Nodal Designation

PSEP components were divided into isothermal nodes as identified in Figures 3-3 to 3-8 and as listed in Table 3-1. The horizontal portion of the lunar surface simulator was treated as one node (99), while the simulator

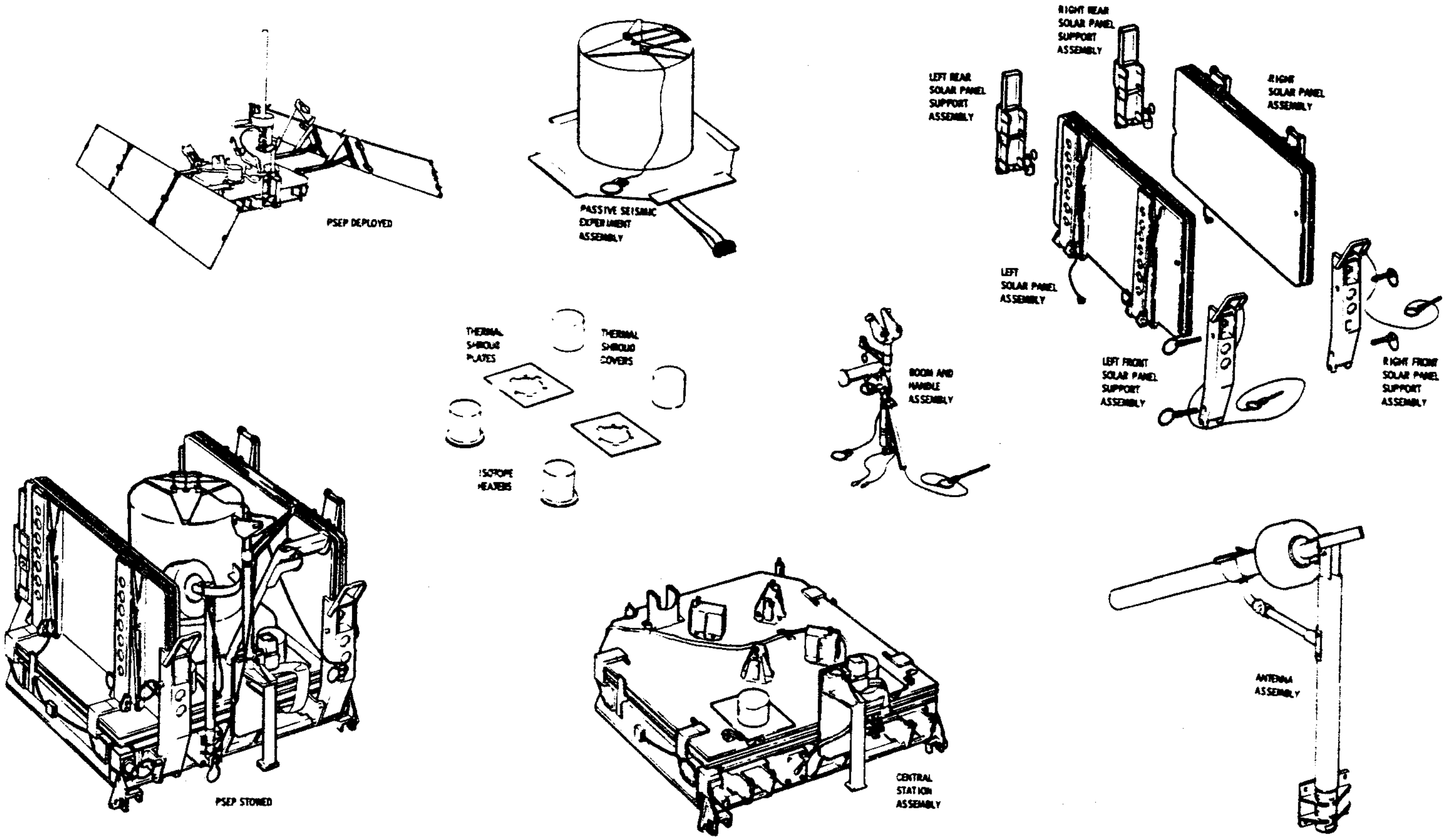


Figure 3-1. PSEP Deployed and Undeployed Assemblies

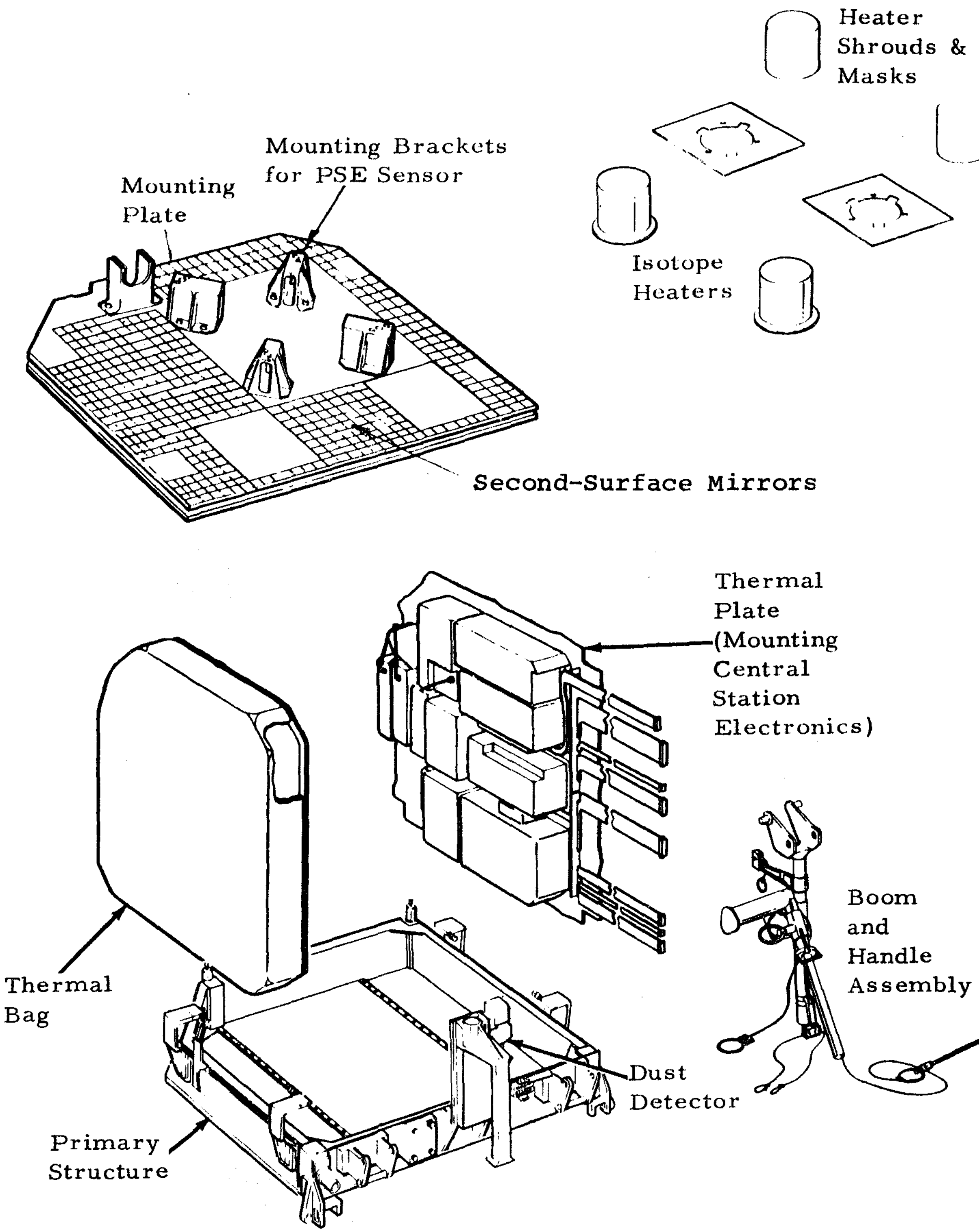


Figure 3-2. Primary Components of
PSEP Thermal Control System

XXX Thermal Plate and Mounting Plate Nodes (Solid Line Outline)
(XXX) Electronic Component Nodes (Broken Line Outline)
Note: Thermal Plate Nodes are 116-129
Mounting Plate Nodes are 16-29
Electronic Component Nodes are 130-141

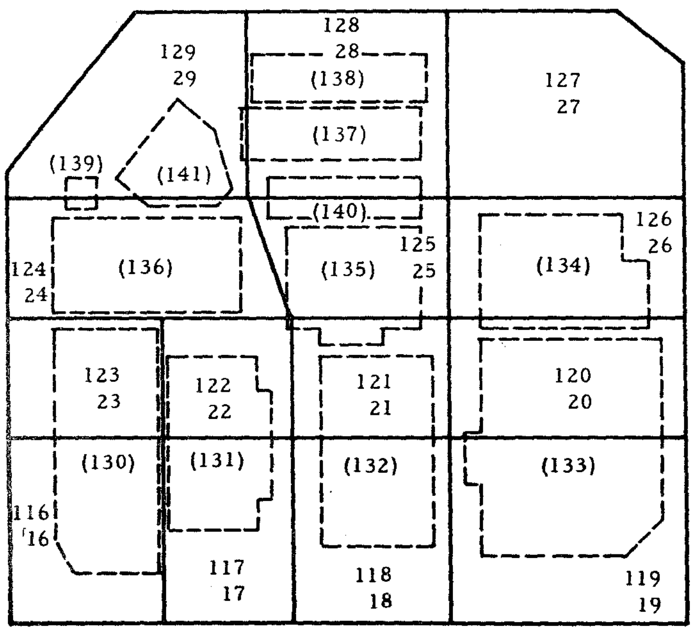
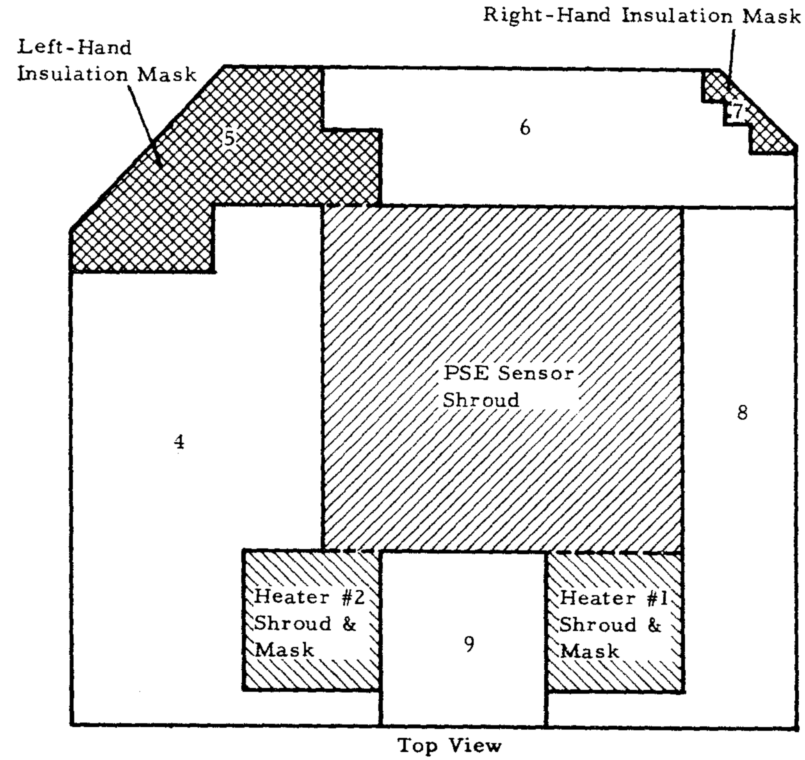


Figure 3-3. Thermal Plate, Mounting Plate, and Electronic Components Nodal Designation



Notes:
(1) Second-surface mirror nodes are represented by un-shaded areas.
(2) Shaded areas outline the top views of the insulation masks and shrouds.
(3) The insulation mask outlines shown are for the Flight model. Masks for the Qual model were larger.

Figure 3-4. Second-Surface Mirror and Insulation Mask Nodal Designation

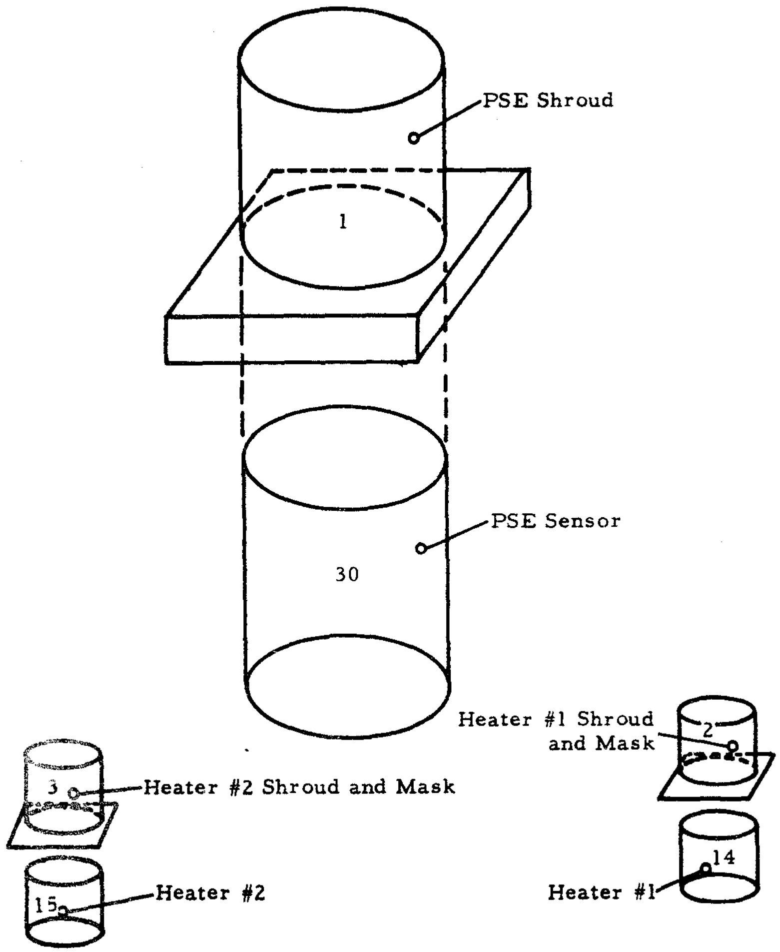


Figure 3-5. PSE Sensor, Isotope Heaters, and Insulation Shrouds Nodal Designation

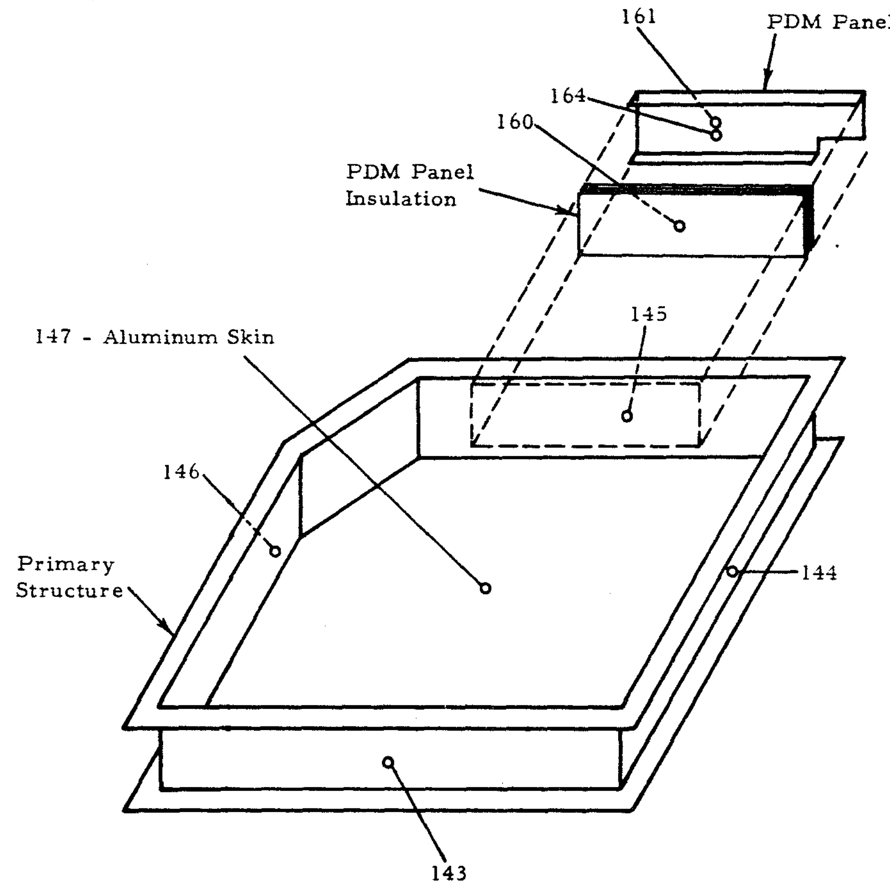


Figure 3-6. Primary Structure and PDM Panel Nodal Designation

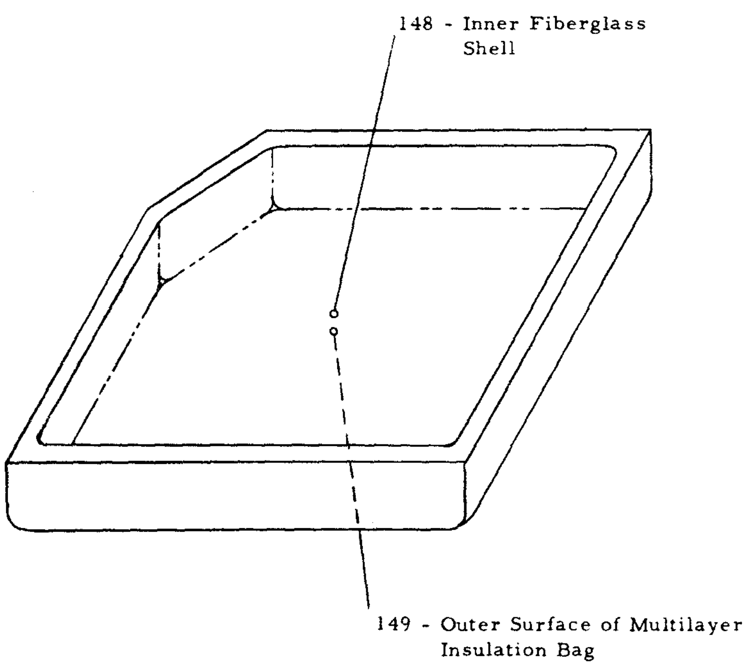


Figure 3-7. Thermal Bag Nodal Designation

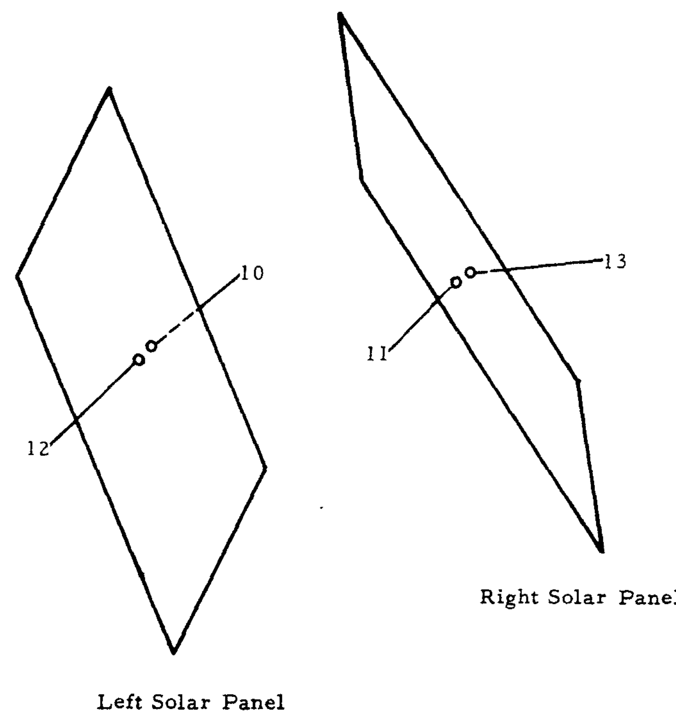


Figure 3-8. Solar Panel Nodal Designation

TABLE 3-1

LIST OF NODES FOR PSEP THERMAL MODELS

Thermal Model Node No.	Description
1	PSE Insulation Shroud
2	Heater #1 Insulation Shroud
3	Heater #2 Insulation Shroud
4	Second-Surface Mirrors on Left Side of Mounting Plate
5	Insulation Mask on Left Rear Corner of Mounting Plate
6	Second-Surface Mirrors at Rear of Mounting Plate
7	Insulation Mask on Right Rear Corner of Mounting Plate
8	Second-Surface Mirrors on Right Side of Mounting Plate
9	Second-Surface Mirrors at Front of Mounting Plate
10	Back Surface of Left Solar Panel
11	Back Surface of Right Solar Panel
12	Front Surface of Left Solar Panel
13	Front Surface of Right Solar Panel
14	Radioisotope Heater #1
15	Radioisotope Heater #2
16	PSE Mounting Plate
17	
18	
19	
20	
21	
22	
23	
24	
25	
26	
27	
28	
29	
30	PSE Sensor

Thermal Model Node No.	Description
*50	Lunar Subsurface Model
*51	
*52	
*53	
*54	
*55	
*56	
*57	
*58	
*59	
*60	
*61	
*62	
*63	
*64	
*65	
*66	
*67	
*68	
*69	
*70	
*71	
**96	Lunar Surface Simulator Lip
99	Lunar Surface Simulator or Real Lunar Surface
100	T/V Chamber Cryowall or Space
116	Thermal Plate
117	
118	
119	
120	

*Applicable only to thermal model on lunar surface.

**Applicable only to thermal model in T/V chamber.

Thermal Model Node No.	Description
121	Thermal Plate
122	
123	
124	
125	
126	
127	
128	
129	
130	Power Control Unit (P. C. U.)
131	Power Distribution Unit (P. D. U.)
132	Analog Multiplex Converter
133	Passive Seismometer
134	Command Decoder
135	Digital Data Processor
136	Command Receiver
137	Transmitter A
138	Transmitter B
139	Timer
140	Diplexer Filter
141	Diplexer Switch
143	Primary Structure Front
144	Primary Structure Right Side
145	Primary Structure Rear
146	Primary Structure Left Side
147	Primary Structure Bottom
148	Thermal Bag Internal Surface
149	Thermal Bag External Surface
***160	PDM Panel Insulation
***161	PDM Panel Front Surface
***164	PDM Panel Rear Surface

***Not applicable to Qual thermal model in T/V chamber.

lip was considered a second node (96). A single node (100) represented the T/V chamber cryowall. Nodes 160, 161, and 164, which represent the PDM panel insulation and PDM panel, applied only for the flight model since the panel and insulation were not installed on the Qual model.

3.1.1.2 Resistance Paths

Conduction and radiation resistors interconnect all nodes to form a network analogous to an electrical circuit, where voltage and current are replaced by temperature and heat transfer rate, respectively. General techniques used to evaluate resistors are presented in References 2 and 3. Tables 3-2 to 3-8 summarize resistor values for Qual and Flight nodes in both T/V chamber test and real lunar environments. For each resistor, a table identifies the thermal analyzer resistor number, the nodes connected by the resistor, the components involved, the type of heat transfer involved, and the resistor value. Table 3-2 lists resistors common to all thermal models, with a few exceptions noted. Tables 3-3 to 3-8 present resistors which apply only to radiation interchange between the PSEP insulation shrouds, insulation masks, mirrors, structure, solar panels, moon (or lunar simulator), and space (or cryowall). A description of these radiation interchange resistors is presented in Table 3-3, while Tables 3-4 to 3-8 list thermal model resistor values for the various Qual and Flight models in the T/V chamber test and real lunar environments. Consequently, a complete set of resistors for any model is comprised of the values from Table 3-2 and from one of the Tables 3-4 to 3-8.

As noted in Table 3-2, resistors 68 and 69 which represent the resistances of the two insulation masks are different for the Qual and Flight models. This resulted from the exposure of 37 additional mirrors and consequent reduction in mask sizes on the Flight model.

3.1.1.3 Thermal Analyzer Computer Program

Data on nodes and resistors were input to the "Thermal Analyzer" computer program (described in reference 4) along with information on solar, electronic, and PDM panel heating. For steady-state computations the program, which employs a finite difference technique, performs successive energy balances on each node to establish node temperatures until the heat flow at each node is zero. For transient solutions the program determines the finite time steps required for a stable solution and calculates the temperature response of each node over a specified time interval.

3.1.2 Thermal Model for Real Lunar Environment

The thermal model for the actual lunar environment is basically equivalent to the previous model with the following exceptions:

1. A lunar subsurface model, described in Section 3.6, replaced the test lunar surface simulator model.

TABLE 3-2

RESISTORS APPLICABLE TO ALL PSEP THERMAL MODELS IN T/V CHAMBER TEST AND REAL LUNAR ENVIRONMENTS

Res. No.	Nodes	Description	Cond. or Rad.	Resistor Value (1) Test & Moon
1	16-17	Mounting Plate Node Connections	Cond.	1.735
2	16-23			1.976
3	17-18			1.147
4	17-22			4.088
5	18-19			1.828
6	18-21			2.566
7	19-20			2.462
8	20-21			4.890
9	20-26			2.236
10	21-22			3.630
11	21-25			1.741
12	22-23			2.274
13	22-24			2.774
14	23-24			1.341
15	24-25			5.374
16	24-29			.952
17	25-26			4.034
18	25-28			1.567
19	26-27			.990
20	27-28			2.462
21	28-29			2.234
22	16-116	Mounting Plate to Thermal Plate		.310
23	17-117			.632
24	18-118			.397
25	19-119			.236
26	20-120			.481
27	21-121			1.219
28	22-122			.943
29	23-123			.593
30	24-124			.453
31	25-125			1.098
32	26-126			.482

Note: (1) Conduction resistors are normal resistances with the units of hr-°F/Btu, while radiation resistors are reciprocals of resistance (conductance) with the units of ft^2.

Res. No.	Nodes	Description	Cond. or Rad.	Resistor Value (1) Test & Moon
33	27-127	Mounting Plate to Thermal Plate	Cond.	.245
34	28-128			.325
35	29-129			.325
36	127-145	Thermal Isolators		92.0
37	129-145			92.0
38	129-146			92.0
39	129-146			92.0
40	116-146			92.0
41	116-143			92.0
42	119-143			92.0
43	119-144			92.0
44	127-144			92.0
45	14-17	Heater #1 to Mounting Plate		.276
46	15-19	Heater #2 to Mounting Plate		.276
47	30-27	PSE Sensor to Mounting Plate		5.15
48	30-28			5.15
49	30-21			5.15
50	30-20			5.15
51	4-16	Mirrors to Mounting Plate		.057
53	4-22			.050
54	4-23			.050
55	4-24			.067
56	4-29			.050
57	6-28			.050
58	6-27			.050
59	8-19			.050
60	8-20			.050
61	8-26			.050
63	9-18			.061
65	1-30	PSE Shroud		113.1
66	2-14	Heater #1 Shroud		141.5
67	3-15	Heater #2 Shroud		141.5

Res. No.	Nodes	Description	Cond. or Rad.	Resistor Value (1) Test & Moon
*68	5-29	Left Insulation Mask	Cond.	93.54
**68	5-29	Left Insulation Mask		122.3
*69	7-27	Right Insulation Mask		132.2
**69	7-27	Right Insulation Mask		982.1
76	130-116	Electronic Components to Thermal Plate		1.380
77	130-123			1.380
78	131-117			7.200
79	131-122			7.200
80	132-118			4.530
81	132-121			6.800
82	133-119			2.660
83	133-120			2.660
84	134-120			1.630
85	134-126			4.880
86	135-121			32.150
87	135-125			8.037
88	139-124			5.000
89	139-129			5.000
90	136-124			1.670
91	138-129			.180
92	137-128			.180
93	116-117	Thermal Plate Node Connections		.760
94	117-118			.727
95	118-119			1.052
96	120-121			1.549
97	121-122			1.070
98	122-123			1.119
99	124-125			1.703
100	125-126			1.617
101	127-128			1.151
102	128-129			1.025

*Qual Model Only
**Flight Model Only

Res. No.	Nodes	Description	Cond. or Rad.	Resistor Value (1) Test & Moon
103	116-123	Thermal Plate Node Connections (Cont.)	Cond.	.838
104	117-122			1.283
105	118-121			.806
106	119-120			.598
107	124-129			.588
108	125-128			.659
109	126-127			.598
110	123-124			.677
111	122-124			1.037
112	121-125			.651
113	120-126			.484
117	140-125	Electronic Components to Thermal Plate		5.000
118	140-128			5.000
119	141-124			5.000
120	141-129			5.000
121	10-12	Solar Panel Node Connections		.05
122	11-13			.05
(2)123	161-164	PDM Panel Node Connection		.05
(2)124	145-164	Structure to PDM Panel		4.004
142	143-116	Primary Structure to Thermal Plate	Rad.	202×10^{-7}
143	143-117			133×10^{-7}
144	143-118			208×10^{-7}
145	143-119			283×10^{-7}
146	144-119			134×10^{-7}
147	144-120			9×10^{-6}
148	144-126			9×10^{-6}
149	144-127			134×10^{-7}
150	145-127			207×10^{-7}
151	145-128			187×10^{-7}
152	146-129			250×10^{-7}
153	146-124			91×10^{-7}
154	146-123			91×10^{-7}
155	146-116			136×10^{-7}

Note: (2) Does not apply for Qual Model in T/V Chamber.

Res. No.	Nodes	Description	Cond. or Rad.	Resistor Value (1) Test & Moon
156	116-148	Thermal Plate to Thermal Bag	Rad.	.07900
157	117-148			.05175
158	118-148			.08200
159	119-148			10950
160	120-148			.07425
161	121-148			.05575
162	122-148			.03500
163	123-148			.05350
164	124-148			.08250
165	125-148			.06175
166	126-148			.07425
167	127-148			.10950
168	128-148			.10025
169	129-148			.08050
(3)170	148-149	Thermal Bag Node Connection	Cond.	10.54
(4)170	148-149			51.70
171	143-149	Primary Structure to Thermal Bag	Rad.	.01750
172	144-149			.01520
173	145-149			.01380
174	146-149			.01660
175	147-149			.10850
176	143-144	Structure Node Connections	Cond.	15.891
177	144-145			16.700
178	145-146			21.040
179	146-143			13.990
180	147-143			1.486
181	147-144			2.461
182	147-145			[illegible]
183	147-146			1.992
(2)184	145-160	Structure to PDM Panel Insulation		51.400
193	135-143	Cabling from Electronic Components to Structure		617.0
194	134-143			493.0
195	131-143			117.0
196	132-143			[illegible]
197	130-143			[illegible]

Notes: (3) Lunar Noon Only
(4) Lunar Night Only

Res. No.	Nodes	Description	Cond. or Rad.	Resistor Value (1) Test & Moon
198	133-143	Cabling from Electronic Components to Structure (Cont.)	Cond.	112.3
(5)320	147-61	Structure to Moon		.10000
(6)328	147-99			33.3
(5)350	61-71	Real Moon Subsurface Model		.894
(5)351	71-70			1.788
(5)352	71-60			12.500
(5)353	70-69			2.012
(5)354	70-59			12.500
(5)355	69-68			2.459
(5)356	69-58			10.000
(5)357	68-67			2.905
(5)358	68-57			8.330
(5)359	67-66			3.576
(5)360	67-56			7.140
(5)361	66-65			4.917
(5)362	66-55			5.550
(5)363	65-64			7.375
(5)364	65-54			3.840
(5)365	64-63			11.622
(5)366	64-53			2.500
(5)367	63-62			27.715
(5)368	63-52			1.560
(5)369	62-50			.447
(5)370	62-51			.500
(5)371	61-99			50.000

Notes: (5) Real Moon Only
(6) T/V Chamber Test Only

TABLE 3-3

DESCRIPTION OF RESISTORS FOR RADIATION INTERCHANGE BETWEEN INSULATION SHROUDS, INSULATION MASKS, MIRRORS, PRIMARY STRUCTURE, SOLAR PANELS, MOON, AND SPACE

Resistor Nodes	Description
1-2	PSE Shroud to Heater #1 Shroud
1-3	PSE Shroud to Heater #2 Shroud
1-4	PSE Shroud to Second-Surface Mirrors
1-5	PSE Shroud to Left Insulation Mask
1-6	PSE Shroud to Second-Surface Mirrors
1-7	PSE Shroud to Right Insulation Mask
1-8	PSE Shroud to Second-Surface Mirrors
1-9	PSE Shroud to Second-Surface Mirrors
1-10	PSE Shroud to Left Solar Panel Back
1-11	PSE Shroud to Right Solar Panel Back
1-12	PSE Shroud to Left Solar Panel Front
1-13	PSE Shroud to Right Solar Panel Front
1-143	PSE Shroud to Primary Structure
1-144	PSE Shroud to Primary Structure
1-146	PSE Shroud to Primary Structure
1-96	PSE Shroud to Lunar Simulator Lip
1-99	PSE Shroud to Lunar Simulator or Moon
1-100	PSE Shroud to T/V Chamber Cryowall or Space
2-3	Heater #1 Shroud to Heater #2 Shroud
2-4	Heater #1 Shroud to Mirrors
2-5	Heater #1 Shroud to Left Insulation Mask
2-6	Heater #1 Shroud to Mirrors
2-8	Heater #1 Shroud to Mirrors
2-9	Heater #1 Shroud to Mirrors
2-10	Heater #1 Shroud to Left Solar Panel Back
2-11	Heater #1 Shroud to Right Solar Panel Back
2-146	Heater #1 Shroud to Primary Structure
2-96	Heater #1 Shroud to Lunar Simulator Lip
2-99	Heater #1 Shroud to Lunar Simulator or Moon
2-100	Heater #1 Shroud to Cryowall or Space
3-4	Heater #2 Shroud to Mirrors
3-6	Heater #2 Shroud to Mirrors
3-7	Heater #2 Shroud to Right Insulation Mask
3-8	Heater #2 Shroud to Mirrors
3-9	Heater #2 Shroud to Mirrors
3-10	Heater #2 Shroud to Left Solar Panel Back
3-11	Heater #2 Shroud to Right Solar Panel Back
3-144	Heater #2 Shroud to Primary Structure
3-96	Heater #2 Shroud to Lunar Simulator Lip
3-99	Heater #2 Shroud to Lunar Simulator or Moon
3-100	Heater #2 Shroud to Cryowall or Space
4-5	Second-Surface Mirrors to Left Insulation Mask
4-6	Second-Surface Mirrors to Mirrors
4-8	Second-Surface Mirrors to Mirrors
4-9	Second-Surface Mirrors to Mirrors
4-10	Second-Surface Mirrors to Left Solar Panel Back
4-11	Second-Surface Mirrors to Right Solar Panel Back
4-12	Second-Surface Mirrors to Left Solar Panel Front
4-13	Second-Surface Mirrors to Right Solar Panel Front
4-146	Second-Surface Mirrors to Primary Structure
4-96	Second-Surface Mirrors to Lunar Simulator Lip
4-99	Second-Surface Mirrors to Lunar Simulator or Moon
4-100	Second-Surface Mirrors to Cryowall or Space
5-9	Left Insulation Mask to Mirrors
5-10	Left Insulation Mask to Left Solar Panel Back
5-11	Left Insulation Mask to Right Solar Panel Back
5-96	Left Insulation Mask to Lunar Simulator Lip
5-99	Left Insulation Mask to Lunar Simulator or Moon
5-100	Left Insulation Mask to Cryowall or Space
6-8	Second-Surface Mirrors to Mirrors
6-9	Second-Surface Mirrors to Mirrors
6-10	Second-Surface Mirrors to Left Solar Panel Back
6-11	Second-Surface Mirrors to Right Solar Panel Back
6-96	Second-Surface Mirrors to Lunar Simulator Lip
6-99	Second-Surface Mirrors to Lunar Simulator or Moon
6-100	Second-Surface Mirrors to Cryowall or Space
7-10	Right Insulation Mask to Left Solar Panel Back
7-11	Right Insulation Mask to Right Solar Panel Back
7-99	Right Insulation Mask to Lunar Simulator or Moon
7-100	Right Insulation Mask to Cryowall or Space
8-9	Second-Surface Mirrors to Mirrors
8-10	Second-Surface Mirrors to Left Solar Panel Back
8-11	Second-Surface Mirrors to Right Solar Panel Back
8-144	Second-Surface Mirrors to Primary Structure
8-96	Second-Surface Mirrors to Lunar Simulator Lip
8-99	Second-Surface Mirrors to Lunar Simulator or Moon
8-100	Second-Surface Mirrors to Cryowall or Space
9-10	Second-Surface Mirrors to Left Solar Panel Back
9-11	Second-Surface Mirrors to Right Solar Panel Back
9-96	Second-Surface Mirrors to Lunar Simulator Lip
9-99	Second-Surface Mirrors to Lunar Simulator or Moon
9-100	Second-Surface Mirrors to Cryowall or Space
10-11	Left Solar Panel Back to Right Solar Panel Back
10-12	Left Solar Panel Back to Left Solar Panel Front
10-13	Left Solar Panel Back to Right Solar Panel Front
10-143	Left Solar Panel Back to Primary Structure
10-144	Left Solar Panel Back to Primary Structure
10-145	Left Solar Panel Back to Primary Structure
10-146	Left Solar Panel Back to Primary Structure
10-161	Left Solar Panel Back to PDM Panel
10-164	Left Solar Panel Back to PDM Panel
10-96	Left Solar Panel Back to Lunar Simulator Lip
10-99	Left Solar Panel Back to Lunar Simulator or Moon
10-100	Left Solar Panel Back to Cryowall or Space
11-12	Right Solar Panel Back to Left Solar Panel Front
11-13	Right Solar Panel Back to Right Solar Panel Front
11-143	Right Solar Panel Back to Primary Structure
11-144	Right Solar Panel Back to Primary Structure
11-145	Right Solar Panel Back to Primary Structure
11-146	Right Solar Panel Back to Primary Structure
11-161	Right Solar Panel Back to PDM Panel
11-164	Right Solar Panel Back to PDM Panel

TABLE 3-3 (Cont.)

Resistor Nodes	Description
11-96	Right Solar Panel Back to Lunar Simulator Lip
11-99	Right Solar Panel Back to Lunar Simulator or Moon
11-100	Right Solar Panel Back to Cryowall or Space
12-13	Left Solar Panel Front to Right Solar Panel Front
12-143	Left Solar Panel Front to Primary Structure
12-144	Left Solar Panel Front to Primary Structure
12-146	Left Solar Panel Front to Primary Structure
12-96	Left Solar Panel Front to Lunar Simulator Lip
12-99	Left Solar Panel Front to Lunar Simulator or Moon
12-100	Left Solar Panel Front to Cryowall or Space
13-143	Right Solar Panel Front to Primary Structure
13-144	Right Solar Panel Front to Primary Structure
13-146	Right Solar Panel Front to Primary Structure
13-96	Right Solar Panel Front to Lunar Simulator Lip
13-99	Right Solar Panel Front to Lunar Simulator or Moon
13-100	Right Solar Panel Front to Cryowall or Space
143-144	Primary Structure to Primary Structure
143-146	Primary Structure to Primary Structure
143-96	Primary Structure to Lunar Simulator Lip
143-99	Primary Structure to Lunar Simulator or Moon
143-100	Primary Structure to Cryowall or Space
144-96	Primary Structure to Lunar Simulator Lip
144-99	Primary Structure to Lunar Simulator or Moon
144-100	Primary Structure to Cryowall or Space
145-160	Primary Structure to PDM Panel Insulation
145-164	Primary Structure to PDM Panel Insulation
145-96	Primary Structure to Lunar Simulator Lip
145-99	Primary Structure to Lunar Simulator or Moon
145-100	Primary Structure to Cryowall or Space
146-96	Primary Structure to Lunar Simulator Lip
146-99	Primary Structure to Lunar Simulator or Moon
146-100	Primary Structure to Cryowall or Space
147-96	Primary Structure to Lunar Simulator Lip
147-99	Primary Structure to Lunar Simulator or Moon
147-100	Primary Structure to Cryowall or Space
160-164	PDM Panel Insulation to PDM Panel
160-99	PDM Panel Insulation to Lunar Simulator or Moon
160-100	PDM Panel Insulation to Cryowall or Space
161-96	PDM Panel to Lunar Simulator Lip
161-99	PDM Panel to Lunar Simulator or Moon
161-100	PDM Panel to Cryowall or Space
164-96	PDM Panel to Lunar Simulator Lip
164-99	PDM Panel to Lunar Simulator or Moon
164-100	PDM Panel to Cryowall or Space

TABLE 3-4

RESISTORS APPLICABLE TO PSEP QUAL THERMAL MODEL IN T/V CHAMBER TEST ENVIRONMENT

Res. No.	Nodes		Value ft^2
400	1	2	0.02955
401	1	3	0.03547
402	1	4	0.05935
403	1	5	0.01092
404	1	6	0.02438
405	1	7	0.01267
406	1	8	0.03357
407	1	9	0.05793
408	1	10	0.03227
409	1	11	0.03924
410	1	12	0.00095
411	1	13	0.00095
412	1	143	0.00061
413	1	144	0.00231
414	1	146	0.00202
415	1	96	0.03759
416	1	99	0.42879
417	1	100	1.65349
418	2	3	0.00256
419	2	4	0.02098
420	2	8	0.00063
421	2	9	0.01444
422	2	10	0.00528
423	2	11	0.00182
424	2	96	0.00374
425	2	99	0.04263
426	2	100	0.16407
427	3	4	0.00643
428	3	8	0.01499
429	3	9	0.01415
430	3	10	0.00183
431	3	11	0.00536
432	3	96	0.00361
433	3	99	0.04142
434	3	100	0.15974
435	4	8	0.00075
436	4	9	0.00174
437	4	10	0.01138
438	4	11	0.00199
439	4	146	0.00069
440	4	96	0.00209
441	4	99	0.03047
442	4	100	0.66277
443	5	10	0.00221
444	5	11	0.00050
445	5	99	0.00600
446	5	100	0.15503
447	6	10	0.00156
448	6	11	0.00138
449	6	96	0.00056
450	6	99	0.00776
451	6	100	0.18800
452	7	11	0.00147
453	7	99	0.00453
454	7	100	0.10412
455	8	9	0.00097
456	8	10	0.00092
457	8	11	0.00525
458	8	96	0.00101
459	8	99	0.01449
460	8	100	0.28642
461	9	10	0.00146
462	9	11	0.00155
463	9	96	0.00099
464	9	99	0.01211
465	9	100	0.15993
466	10	11	0.01339
467	10	12	0.00102
468	10	13	0.00102
469	10	143	0.00640
470	10	144	0.00095
471	10	145	0.00346
472	10	146	0.05040
473	10	96	0.04545
474	10	99	1.01613
475	10	100	0.78528
476	11	12	0.00102
477	11	13	0.00102
478	11	143	0.00561
479	11	144	0.04794
480	11	145	0.00445
481	11	146	0.00101
482	11	96	0.04548
483	11	99	1.01666
484	11	100	0.78320
485	12	13	0.00270
486	12	96	0.26004
487	12	99	0.92489
488	12	100	4.28049
489	13	96	0.26004
490	13	99	0.92489
491	13	100	4.28049
492	143	96	0.02217
493	143	99	0.29860
494	143	100	0.32816
495	144	96	0.00768
496	144	99	0.31028
497	144	100	0.22177
498	145	96	0.01744
499	145	99	0.23393
500	145	100	0.26266
501	146	96	0.01162
502	146	99	0.33837
503	146	100	0.24547
504	147	99	0.05829
505	147	100	0.00628

TABLE 3-5

RESISTORS APPLICABLE TO PSEP QUAL THERMAL MODEL IN REAL LUNAR ENVIRONMENT

Res. No.	Nodes		Value ft^2
400	1	2	0.02951
401	1	3	0.03544
402	1	4	0.05923
403	1	5	0.01090
404	1	6	0.02435
405	1	7	0.01266
406	1	8	0.03353
407	1	9	0.05790
408	1	10	0.03184
409	1	11	0.03881
410	1	143	0.00046
411	1	144	0.00211
412	1	146	0.00182
413	1	99	0.55438
414	1	100	1.56716
415	2	3	0.00255
416	2	4	0.02081
417	2	5	0.00036
418	2	8	0.00063
419	2	9	0.01444
420	2	10	0.00524
421	2	11	0.00178
422	2	146	0.00030
423	2	99	0.05512
424	2	100	0.15564
425	3	4	0.00642
426	3	6	0.00023
427	3	7	0.00032
428	3	8	0.01499
429	3	9	0.01415
430	3	10	0.00179
431	3	11	0.00532
432	3	144	0.00029
433	3	99	0.05352
434	3	100	0.15142
435	4	5	0.00020
436	4	6	0.00038
437	4	8	0.00073
438	4	9	0.00172
439	4	10	0.01131
440	4	11	0.00193
441	4	146	0.00065
442	4	99	0.02892
443	4	100	0.66680
444	5	10	0.00219
445	5	11	0.00049
446	5	99	0.00526
447	5	100	0.15636
448	6	8	0.00021
449	6	9	0.00036
450	6	10	0.00154
451	6	11	0.00136
452	6	99	0.00709
453	6	100	0.18949
454	7	10	0.00039
455	7	11	0.00146
456	7	99	0.00421
457	7	100	0.10481
458	8	9	0.00097
459	8	10	0.00090
460	8	11	0.00523
461	8	144	0.00028
462	8	99	0.01427
463	8	100	0.28792
464	9	10	0.00144
465	9	11	0.00153
466	9	99	0.01358
467	9	100	0.15962
468	10	11	0.01258
469	10	143	0.00597
470	10	144	0.00068
471	10	145	0.00194
472	10	146	0.04845
473	10	161	0.00116
474	10	164	0.00126
475	10	99	1.28502
476	10	100	0.56517
477	11	143	0.00522
478	11	144	0.04605
479	11	145	0.00124
480	11	146	0.00072
481	11	161	0.00150
482	11	164	0.00157
483	11	99	1.28471
484	11	100	0.56621
485	12	99	1.40987
486	12	100	4.05983
487	13	99	1.40987
488	13	100	4.05983
489	143	144	0.00028
490	143	146	0.00034
491	143	99	0.34790
492	143	100	0.30068
493	144	99	0.33880
494	144	100	0.19779
495	145	160	0.00109
496	145	164	0.08575
497	145	99	0.07950
498	145	100	0.07685
499	146	99	0.37854
500	146	100	0.21363
501	147	100	0.06501
502	160	164	0.01919
503	160	99	0.00031
504	161	99	0.13459
505	161	100	0.13237
506	164	99	0.00716
507	164	100	0.00480

TABLE 3-6

RESISTORS APPLICABLE TO PSEP FLIGHT THERMAL MODEL
WITH NO PLUME HEATING PROTECTION IN
T/V CHAMBER TEST ENVIRONMENT

Res. No.	Nodes		Value ft^2
400	1	2	0.02950
401	1	3	0.03547
402	1	4	0.05687
403	1	5	0.00835
404	1	6	0.03473
405	1	7	0.00170
406	1	8	0.03729
407	1	9	0.05602
408	1	10	0.03224
409	1	11	0.03917
410	1	12	0.00095
411	1	13	0.00095
412	1	143	0.00061
413	1	144	0.00230
414	1	146	0.00202
415	1	96	0.03756
416	1	99	0.42786
417	1	100	1.65648
418	2	3	0.00255
419	2	4	0.01994
420	2	5	0.00027
421	2	6	0.00028
422	2	8	0.00070
423	2	9	0.01397
424	2	10	0.00528
425	2	11	0.00182
426	2	146	0.00032
427	2	96	0.00373
428	2	99	0.04255
429	2	100	0.16550
430	3	4	0.00616
431	3	6	0.00033
432	3	8	0.01666
433	3	9	0.01368
434	3	10	0.00183
435	3	11	0.00536

Res. No.	Nodes		Value ft^2
436	3	144	0.00031
437	3	96	0.00361
438	3	99	0.04134
439	3	100	0.15887
440	4	6	0.00054
441	4	8	0.00080
442	4	9	0.00161
443	4	10	0.01091
444	4	11	0.00191
445	4	12	0.00025
446	4	13	0.00025
447	4	146	0.00066
448	4	96	0.00199
449	4	99	0.02890
450	4	100	0.63557
451	5	10	0.00169
452	5	11	0.00038
453	5	96	0.00031
454	5	99	0.00453
455	5	100	0.11864
456	6	8	0.00035
457	6	9	0.00050
458	6	10	0.00222
459	6	11	0.00196
460	6	96	0.00079
461	6	99	0.01093
462	6	100	0.26799
463	7	99	0.00060
464	7	100	0.01401
465	8	9	0.00105
466	8	10	0.00102
467	8	11	0.00584
468	8	144	0.00034
469	8	96	0.00111
470	8	99	0.01594
471	8	100	0.31814

Res. No.	Nodes		Values ft^2
472	9	10	0.00141
473	9	11	0.00150
474	9	96	0.00095
475	9	99	0.01164
476	9	100	0.15473
477	10	11	0.01339
478	10	12	0.00102
479	10	13	0.00102
480	10	143	0.00640
481	10	144	0.00095
482	10	145	0.00196
483	10	146	0.05040
484	10	161	0.00126
485	10	164	0.00088
486	10	96	0.04543
487	10	99	1.01579
488	10	100	0.77996
489	11	12	0.00102
490	11	13	0.00102
491	11	143	0.00561
492	11	144	0.04794
493	11	145	0.00125
494	11	146	0.00101
495	11	161	0.00159
496	11	164	0.00108
497	11	96	0.04546
498	11	99	1.01636
499	11	100	0.78111
500	12	13	0.00270
501	12	143	0.00036
502	12	144	0.00029
503	12	146	0.00033
504	12	96	0.25998
505	12	99	0.92278
506	12	100	4.27647

Res. No.	Nodes		Value ft^2
507	13	143	0.00036
508	13	144	0.00029
509	13	146	0.00033
510	13	96	0.25998
511	13	99	0.92278
512	13	100	4.27647
513	143	144	0.00038
514	143	146	0.00045
515	143	96	0.02216
516	143	99	0.29842
517	143	100	0.32692
518	144	96	0.00767
519	144	99	0.31017
520	144	100	0.22061
521	145	160	0.00072
522	145	164	0.07741
523	145	96	0.00517
524	145	99	0.06683
525	145	100	0.08308
526	146	96	0.01162
527	146	99	0.33824
528	146	100	0.24400
529	147	96	0.00044
530	147	99	0.05829
531	147	100	0.00604
532	160	164	0.01270
533	160	99	0.00283
534	160	100	0.00328
535	161	96	0.00904
536	161	99	0.11282
537	161	100	0.14201
538	164	96	0.00052
539	164	99	0.03294
540	164	100	0.03836

TABLE 3-7

RESISTORS APPLICABLE TO PSEP FLIGHT THERMAL MODEL WITH NO PLUME HEATING PROTECTION IN REAL LUNAR ENVIRONMENT

Res. No.	Nodes		Value ft^2	Res. No.	Nodes		Value ft^2	Res. No.	Nodes		Value ft^2
400	1	2	0.02951	436	4	6	0.00053	472	10	146	0.04845
401	1	3	0.03543	437	4	8	0.00078	473	10	161	0.00116
402	1	4	0.05677	438	4	9	0.00160	474	10	164	0.00085
403	1	5	0.01135	439	4	10	0.01085	475	10	99	1.28498
404	1	6	0.03469	440	4	11	0.00185	476	10	100	0.56423
405	1	7	0.00227	441	4	146	0.00062	477	11	143	0.00522
406	1	8	0.03724	442	4	99	0.02772	478	11	144	0.04605
407	1	9	0.05599	443	4	100	0.63938	479	11	145	0.00121
408	1	10	0.03177	444	5	9	0.00028	480	11	146	0.00072
409	1	11	0.03873	445	5	10	0.00228	481	11	161	0.00150
410	1	143	0.00046	446	5	11	0.00051	482	11	164	0.00105
411	1	144	0.00210	447	5	99	0.00581	483	11	99	1.28468
412	1	146	0.00181	448	5	100	0.16079	484	11	100	0.56549
413	1	99	0.55406	449	6	8	0.00034	485	12	99	1.40987
414	1	100	1.55876	450	6	9	0.00050	486	12	100	4.05983
415	2	3	0.00255	451	6	10	0.00220	487	13	99	1.40987
416	2	4	0.01993	452	6	11	0.00194	488	13	100	4.05983
417	2	5	0.00388	453	6	99	0.01010	489	143	144	0.00028
418	2	6	0.00027	454	6	100	0.27004	490	143	146	0.00034
419	2	8	0.00066	455	7	11	0.00026	491	143	99	0.34790
420	2	9	0.01397	456	7	99	0.00076	492	143	100	0.30067
421	2	10	0.00524	457	7	100	0.01880	493	144	99	0.33880
422	2	11	0.00178	458	8	9	0.00104	494	144	100	0.19775
423	2	146	0.00030	459	8	10	0.00099	495	145	160	0.00072
424	2	99	0.05513	460	8	11	0.00581	496	145	164	0.07741
425	2	100	0.15601	461	8	144	0.00032	497	145	99	0.07941
426	3	4	0.00615	462	8	99	0.01585	498	145	100	0.07679
427	3	6	0.00032	463	8	100	0.31975	499	146	99	0.37854
428	3	8	0.01665	464	9	10	0.00140	500	146	100	0.21357
429	3	9	0.01368	465	9	11	0.00148	501	147	100	0.06501
430	3	10	0.00179	466	9	99	0.01313	502	160	164	0.01270
431	3	11	0.00532	467	9	100	0.15427	503	160	99	0.00027
432	3	144	0.00029	468	10	11	0.01257	504	161	99	0.13459
433	3	99	0.05352	469	10	143	0.00597	505	161	100	0.13236
434	3	100	0.15145	470	10	144	0.00068	506	164	99	0.00549
435	4	5	0.00036	471	10	145	0.00192	507	164	100	0.00390

TABLE 3-8

RESISTORS APPLICABLE TO PSEP FLIGHT THERMAL MODEL WITH PLUME HEATING PROTECTION IN REAL LUNAR ENVIRONMENT

Res. No.	Nodes		Value ft^2	Res. No.	Nodes		Value ft^2	Res. No.	Nodes		Value ft^2
400	1	2	0.05158	435	4	8	0.00038	470	10	164	0.00085
401	1	3	0.06199	436	4	9	0.00078	471	10	99	1.28231
402	1	4	0.07351	437	4	10	0.01049	472	10	100	0.55671
403	1	5	0.01476	438	4	11	0.00149	473	11	143	0.00522
404	1	6	0.04564	439	4	146	0.00060	474	11	144	0.04604
405	1	7	0.00298	440	4	99	0.02213	475	11	145	0.00121
406	1	8	0.04810	441	4	100	0.62361	476	11	146	0.00071
407	1	9	0.07235	442	5	10	0.00221	477	11	161	0.00149
408	1	10	0.04150	443	5	11	0.00045	478	11	164	0.00105
409	1	11	0.05062	444	5	99	0.00476	479	11	99	1.28152
410	1	143	0.00059	445	5	100	0.15784	480	11	100	0.55659
411	1	144	0.00275	446	6	9	0.00024	481	12	99	1.40987
412	1	146	0.00237	447	6	10	0.00205	482	12	100	4.05983
413	1	99	0.72410	448	6	11	0.00176	483	13	99	1.40987
414	1	100	2.03706	449	6	99	0.00762	484	13	100	4.05983
415	2	3	0.00428	450	6	100	0.26304	485	143	144	0.00028
416	2	4	0.02625	451	7	11	0.00025	486	143	146	0.00034
417	2	5	0.00511	452	7	99	0.00059	487	143	99	0.34786
418	2	8	0.00064	453	7	100	0.01834	488	143	100	0.30057
419	2	9	0.01828	454	8	9	0.00051	489	144	99	0.33863
420	2	10	0.00682	455	8	10	0.00081	490	144	100	0.19727
421	2	11	0.00216	456	8	11	0.00552	491	145	160	0.00072
422	2	146	0.00039	457	8	144	0.00030	492	145	164	0.07741
423	2	99	0.07047	458	8	99	0.01220	493	145	99	0.07940
424	2	100	0.19949	459	8	100	0.30946	494	145	100	0.07676
425	3	4	0.00777	460	9	10	0.00106	495	146	99	0.37838
426	3	6	0.00022	461	9	11	0.00109	496	146	100	0.21314
427	3	8	0.02196	462	9	99	0.00751	497	147	100	0.06501
428	3	9	0.01784	463	9	100	0.13843	498	160	164	0.01270
429	3	10	0.00217	464	10	11	0.01239	499	160	99	0.00027
430	3	11	0.00685	465	10	143	0.00597	500	161	99	0.13458
431	3	144	0.00037	466	10	144	0.00067	501	161	100	0.13234
432	3	99	0.06776	467	10	145	0.00192	502	164	99	0.00548
433	3	100	0.19179	468	10	146	0.04844	503	164	100	0.00388
434	4	6	0.00027	469	10	161	0.00116				

2. Actual moon and space temperatures were used.

3. The bottom of the PSEP C/S rests on the lunar surface. During T/V testing, however, the bottom was supported 1.75 inches above the lunar surface simulator by several insulation blocks.

Tables 3-1 to 3-8 list nodes and summarize resistor values for the real moon analysis.

3.2 Analysis Methods

Analysis methods used to construct the thermal models are not presented here as they are outlined in detail in References 2 and 3.

3.3 Heat Inputs to Thermal Models

Five basic heat inputs to the thermal models exist:

1. Thermal dissipation from C/S electronic components.
2. Thermal dissipation of PSE sensor.
3. Thermal dissipation from isotope heaters.
4. Thermal dissipation at the PDM panel.
5. Solar Radiation.

Values for these heat sources at the lunar noon and night equilibrium conditions are listed in Tables 3-9 to 3-11 for the Qual and Flight models. The heat sources are defined along with the thermal model nodes which receive the thermal dissipation. The computer tables which distribute the heat to the nodes are also designated. Solar radiation to the mirrors and to the insulation masks and shrouds during testing was simulated by infrared heaters suspended above PSEP in the chamber. Solar heating of the lunar surface simulator was simulated by infrared heaters attached to the underside of the simulator. The importance of solar heating and other areas of lunar environment simulation is discussed in Reference 3.

For the Qual test, the heat leak from the PDM panel to the primary structure was simulated with heaters attached to the rear structure surface since the Qual model had no PDM panel. Also, the PSE sensor thermal dissipation of 0.7 watts was distributed among the electrical heaters which simulated the electronics.

TABLE 3-9

THERMAL DISSIPATION AND SOLAR RADIATION FOR PSEP QUAL MODEL IN T/V CHAMBER

Node	Heat Source	Table	Thermal Diss./Solar Rad. - Watts		
			Noon No Dump	Noon 10 W. Dump	Night
130	P. C. U.	1	14.17	8.47	0
131	P. D. U.	2	1.51	1.50	0
132	Analog Multiplex Converter	3	1.51	1.50	0
133	Passive Seismometer	4	3.80	3.80	0
134	Command Decoder	5	1.52	1.49	0
135	Data Processor	6	.635	.635	0
136	Command Receiver	7	.635	.635	0
138	Transmitter B	8	8.19	8.19	0
---	Electronics Total	-	31.97	26.22	0
1	Solar Radiation Absorbed by PSE Shroud	11	25.90	25.90	0
2	Solar Radiation Absorbed by Heater #1 Shroud	12	3.78	3.78	0
3	Solar Radiation Absorbed by Heater #2 Shroud	13	3.81	3.81	0
4	Solar Radiation Absorbed by Mirror Node 4	14	8.41	8.41	0
5	Solar Radiation Absorbed by Left Insulation Mask	15	5.90	5.90	0
6	Solar Radiation Absorbed by Mirror Node 6	16	2.29	2.29	0
7	Solar Radiation Absorbed by Right Insulation Mask	17	4.32	4.32	0
8	Solar Radiation Absorbed by Mirror Node 8	18	3.80	3.80	0
9	Solar Radiation Absorbed by Mirror Node 9	19	3.10	3.10	0
14	Radioisotope Heater #1	24	14.75	14.77	15.24
15	Radioisotope Heater #2	25	14.82	14.86	15.29
145	Heat Leak from PDM Panel	29	1.63	3.42	0

NOTES:

1. Absorbed solar radiation by second-surface mirrors is based on a mirror solar absorptivity of 0.06.
2. Above values were obtained from Reference 16 and the Qual test results.
3. Thermal dissipation from the PSE sensor is included in the values for the electronics.

TABLE 3-10

THERMAL DISSIPATION AND SOLAR RADIATION FOR PSEP FLIGHT MODEL IN T/V CHAMBER

Node	Heat Source	Table	Thermal Diss./Solar Rad. - Watts		
			Noon No Dump	Noon 10 W. Dump	Night
130	P. C. U.	1	13.78	8.18	0
131	P. D. U.	2	1.58	1.58	0
132	Analog Multiplex Converter	3	1.47	1.47	0
133	Passive Seismometer	4	3.70	3.70	0
134	Command Decoder	5	1.16	1.16	0
135	Data Processor	6	.53	.53	0
136	Command Receiver	7	.74	.74	0
138	Transmitter B	8	8.24	8.24	0
---	Electronics Total	-	31.20	25.60	0
161	PDM Panel	10	5.00	10.50	0
1	Solar Radiation Absorbed by PSE Shroud	11	25.34	25.34	0
2	Solar Radiation Absorbed by Heater #1 Shroud	12	3.78	3.78	0
3	Solar Radiation Absorbed by Heater #2 Shroud	13	3.78	3.78	0
4	Solar Radiation Absorbed by Mirror Node 4	14	8.09	8.09	0
5	Solar Radiation Absorbed by Left Insulation Mask	15	4.45	4.45	0
6	Solar Radiation Absorbed by Mirror Node 6	16	3.40	3.40	0
7	Solar Radiation Absorbed by Right Insulation Mask	17	.56	.56	0
8	Solar Radiation Absorbed by Mirror Node 8	18	4.31	4.31	0
9	Solar Radiation Absorbed by Mirror Node 9	19	3.13	3.13	0
12	Solar Radiation Absorbed by Left Solar Panel	22	0	0	0
13	Solar Radiation Absorbed by Right Solar Panel	23	0	0	0
14	Radioisotope Heater #1	24	15.00	15.00	15.00
15	Radioisotope Heater #2	25	15.00	15.00	15.00
30	PSE Sensor	30	.70	.70	0

NOTES:

1. Absorbed solar radiation by second-surface mirrors is based on a mirror solar absorptivity of 0.06.
2. Above electronics and PDM panel thermal dissipations are based on Reference 17.

TABLE 3-11

THERMAL DISSIPATION AND SOLAR RADIATION FOR PSEP FLIGHT MODEL ON MOON

Node	Heat Source	Table	Thermal Diss./Solar Rad. - Watts		
			Noon No Dump	Noon 10 W. Dump	Night
130	P. C. U.	1	13.78	8.18	0
131	P. D. U.	2	1.58	1.58	0
132	Analog Multiplex Converter	3	1.47	1.47	0
133	Passive Seismometer	4	3.70	3.70	0
134	Command Decoder	5	1.16	1.16	0
135	Data Processor	6	.53	.53	0
136	Command Receiver	7	.74	.74	0
138	Transmitter B	8	8.24	8.24	0
---	Electronics Total	-	31.20	25.60	0
161	PDM Panel	10	5.00	10.50	0
1	Solar Radiation Absorbed by PSE Shroud	11	38.15* 102.40**	38.15* 102.40**	0
2	Solar Radiation Absorbed by Heater #1 Shroud	12	6.09* 16.35**	6.09* 16.35**	0
3	Solar Radiation Absorbed by Heater #2 Shroud	13	6.09* 16.50**	6.09* 16.50**	0
4	Solar Radiation Absorbed by Mirror Node 4	14	8.00* 7.76**	8.00* 7.76**	0 0
5	Solar Radiation Absorbed by Left Insulation Mask	15	4.54* 14.12**	4.54* 14.12**	0
6	Solar Radiation Absorbed by Mirror Node 6	16	3.25* 3.25**	3.25* 3.25**	0
7	Solar Radiation Absorbed by Right Insulation Mask	17	.59* 1.76**	.59* 1.76**	0
8	Solar Radiation Absorbed by Mirror Node 8	18	4.22* 4.10**	4.22* 4.10**	0
9	Solar Radiation Absorbed by Mirror Node 9	19	3.02* 2.81**	3.02* 2.81**	0
12	Solar Radiation Absorbed by Left Solar Panel	22	341.3	341.3	0
13	Solar Radiation Absorbed by Right Solar Panel	23	341.3	341.3	0
14	Radioisotope Heater #1	24	15.00	15.00	15.00
15	Radioisotope Heater #2	25	15.00	15.00	15.00
30	PSE Sensor	30	.70	.70	0

NOTES:
1. *No plume heating protection.
2. **Plume heating protection system installed.
3. Absorbed solar radiation by second-surface mirrors is based on a mirror solar absorptivity of 0.06.
4. Above electronics and PDM panel thermal dissipations are based on Reference 17.

3.4 Radiation Properties of PSEP Surfaces

Radiation properties listed in Table 3-12 were used to evaluate radiation resistors for the Qual and Flight models, respectively. These values were sometimes difficult to establish accurately and may vary over the operational life of PSEP. However, good analytical predictions have been obtained with the listed properties.

3.5 Thermal Conductivity and Thickness of PSEP Insulation Materials

Values of thermal conductivity and thickness used in the thermal models for the various PSEP insulation materials are listed in Table 3-13.

3.6 Simulated Real Moon

For analysis predictions of PSEP steady-state thermal performance in an actual lunar environment, the lunar surface was simulated by a 1000 ft. x 1000 ft. "node" with a value of 1.0 for both solar absorptivity and thermal emissivity and at uniform temperatures of 250°F for noon and -300°F for night. In addition, the following modification was employed. When PSEP is deployed, the section of lunar surface directly under the primary structure will not be at the temperature of the remaining lunar surface since it exchanges heat with the structure bottom while being blocked-off from solar heating and from heat exchange with space. This lunar section is therefore strongly influenced by subsurface strata as well as by the surrounding lunar surface.

Consequently, the moon in the vicinity of PSEP was divided horizontally and vertically into a series of nodes (see Figure 3-9) to provide for this effect. "Infinite" nodes, which are unaffected by PSEP and which are at fixed temperatures, are connected to "active" nodes which are located directly beneath the primary structure. Active nodes are allowed to attain equilibrium temperatures along with nodes in the PSEP thermal model. Construction of this lunar "subsurface" model is described in Reference 5.

3.7 Evaluation of Flight Model PCU and PDM Thermal Dissipations

Thermal dissipations by the PCU and Power Dissipation Module (PDM) are plotted versus "reserve power" in Figure 3-10, where reserve power is defined as the difference between Central Station input power and PCU input power. Reserve power was obtained from HK measurements and thus provided the basis for evaluating PCU and PDM thermal dissipations. Figure 3-10 was constructed from information contained in Reference 17.

TABLE 3-12

RADIATION PROPERTIES OF PSEP QUAL AND FLIGHT MODEL SURFACES

Description of Surface	α	ϵ	Surface Finish Material
PSE Shroud Exterior	.15* .47**	.60* .80**	2.0 mil FEP Teflon 5.0 mil Kapton
Heater Shroud Exterior	.15* .47**	.60* .80**	0.5 mil Kapton 5.0 mil Kapton
Heater Mask Exterior	.15* .47**	.60** .80**	1.0 mil Kapton 5.0 mil Kapton
Second-Surface Mirrors	.06	.80	Corning 7940 Fused Silica
Insulation Mask Exterior	.15* .47**	.60* .80**	SiO over Aluminized Mylar 5.0 mil Kapton
Solar Panel Back	.30	.30	Anodized
Solar Panel Front	.80	.83	Filtered Silicon
Lunar Simulator	---	.891	Black Paint
Lunar Simulator Lip	---	.826	Black Paint
Real Lunar Surface	1.0	1.0	---
T/V Chamber Cryowall	---	.914	Black Paint
Space	1.0	1.0	---
Thermal Plate Bottom	---	.05	Aluminized
Primary Structure Exterior, Except Bottom	.20	.90	S13-G White Paint
Primary Structure Interior and Bottom	---	.05	Aluminized
Thermal Bag Interior	---	1.00	---
Thermal Bag Exterior	---	.50	---
PDM Panel Insulation	.15	.05	Aluminized Mylar
PDM Panel Front	.20	.90	S13-G White Paint
PDM Panel Back	.20	.80	Black Anodized

* No Plume Heating Protection
** Plume Heating Protection

α = Solar Absorptivity
ϵ = Thermal Emissivity

NOTES: (1) The 0.06 second-surface mirror solar absorptivity is an effective value since it accounts for gaps between the mirrors.

(2) The 0.60 value for Teflon thermal emissivity was used for temperature predictions. However, after the analyses were completed, an improved value of 0.70 was obtained. A brief investigation indicated that no significant difference in temperature predictions would occur by replacing the 0.60 figure with 0.70.

TABLE 3-13

THERMAL CONDUCTIVITY AND THICKNESS OF PSEP INSULATION MATERIALS

Description/Location of Insulation	Thickness Mils	Thermal Conductivity Btu/ft hr °F
PSE Shroud - 10 layers of aluminized mylar on sides with 40 layers of aluminized mylar and 9 layers of silk netting on base	500 (sides) 667 (base)	10^{-4} 10^{-3}
External layer of FEP Teflon over PSE shroud	2	.035
External layer of Kapton over PSE shroud (plume heating protection on Flight model)	5 (top) 10 (sides)	.097
Heater shrouds and masks - 40 layers of aluminized mylar and 32 layers of silk netting	667	10^{-3}
External layer of Kapton over heater shrouds and masks	0.5 (shrouds) 1.0 (masks)	.097
External layer of Kapton over heater shrouds and masks (plume heating protection on Flight model	5 (top of shrouds and masks) 10 (shroud sides)	.097
PSE mounting plate masks - 20 layers of aluminized mylar	333	10^{-3}
External layer of Kapton over mounting plate masks	1	.097
External layer of Kapton over mounting plate masks (plume heating protection on Flight Model)	10	.097
10 layers of aluminized mylar around edge of PSE mounting plate and on cutouts for solar panel support brackets	167	10^{-3}
External layer of Mylar on mounting plate edge insulation.	0.25	.086

NOTE: Each layer of aluminized mylar is 0.25 mils thick.

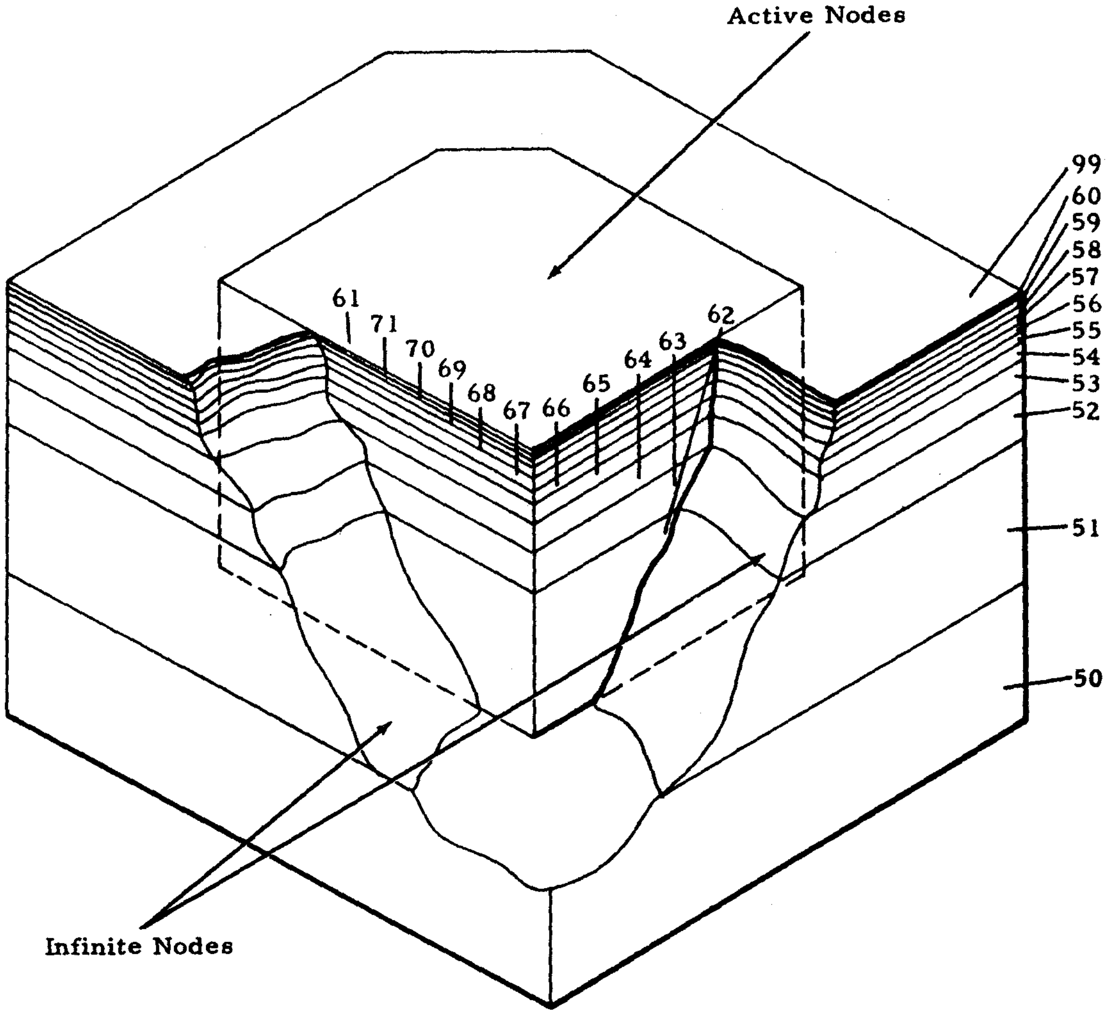


Figure 3-9. Lunar Subsurface Computer Model for Real Moon Analysis

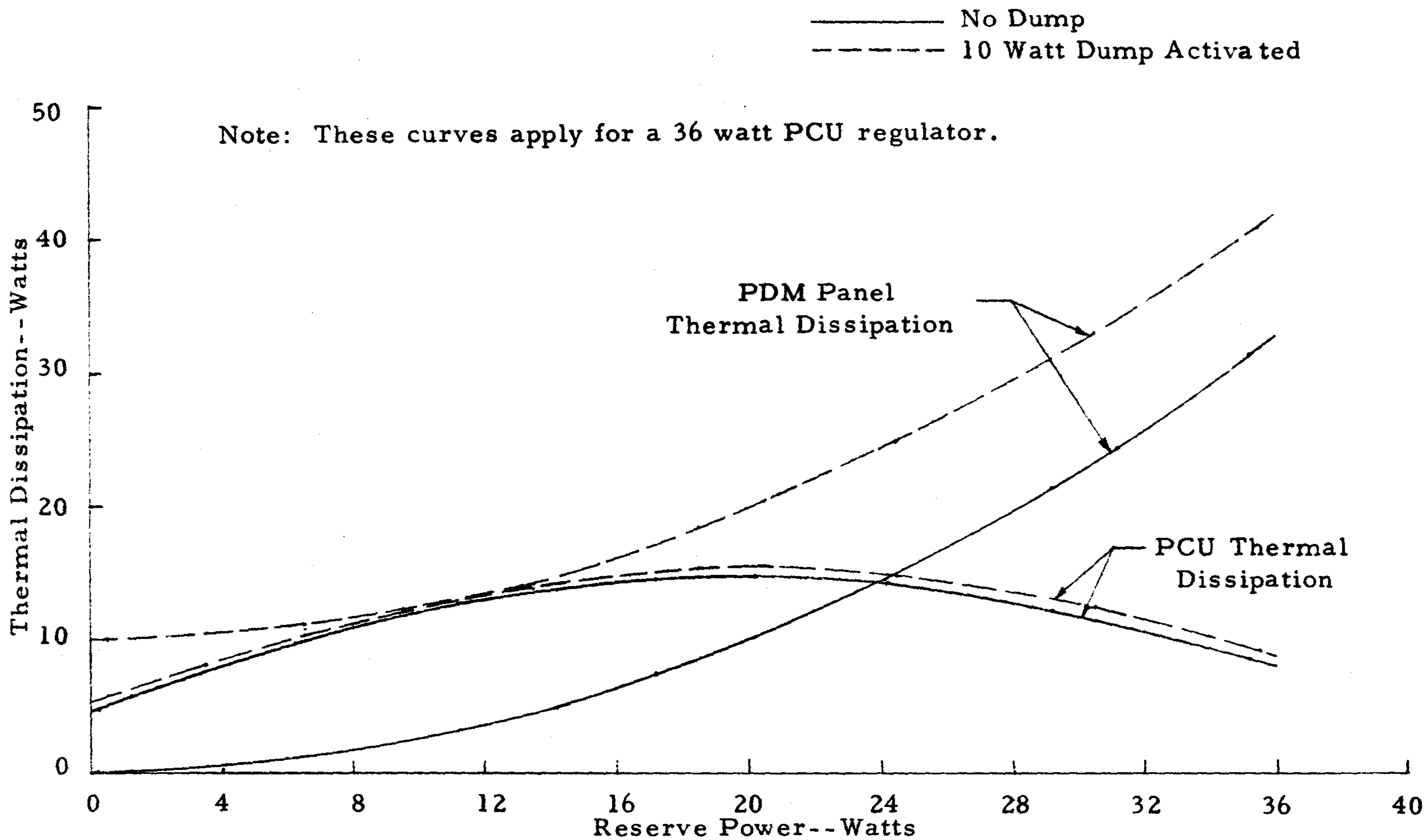


Figure 3-10. PCU and PDM Panel Thermal Dissipation vs Reserve Power for Flight Model

4.0 TEST METHODS

4.1 Qualification Test Procedure

A PSEP deployed system thermal vacuum Qualification (Qual) test was performed in the Bendix 20 ft. x 27 ft. lunar environment simulation chamber. The lunar environment was simulated by chamber pressure, cold shroud (cryowall) temperature, lunar surface temperature, and solar radiation. After the environmental system and PSEP turn-on were verified, the four steady-state conditions listed below were established.

1. Lunar noon with no sun and no power dump.
   (Equilibrium established at 02:30 on 4/8/69)

   Temperature of lunar simulator and lips = 250 ± 10°F

   Temperature of cryowall = -280 ± 40°F

   Simulated electronics and heaters turned on.

2. Lunar noon with one sun and no power dump.
   (Equilibrium established at 12:30 on 4/8/69).

   Temperature of lunar simulator and lips = 250 ± 10°F

   Temperature of cryowall = -280 ± 40°F

   Simulated electronics and heaters turned-on.

3. Lunar noon with one sun and 10 watt dump activated.
   (Equilibrium established at 18:30 on 4/8/69).

   Temperature of lunar simulator and lips = 250 ± 10°F

   Temperature of cryowall -280 ± 40°F

   Simulated electronics and heaters turned on.

4. Lunar night
   (Equilibrium established at 08:30 on 4/10/69)

   Temperature of lunar simulator and lips - -300 ± 20°F

   Temperature of cryowall - -280 ± 40°F

   Simulated electronics turned-off

   Simulated isotope heaters turned-on.

A pressure of 5 x 10^{-5} Torr or less was maintained for the duration of the test by the chamber pumping system. Space was simulated with the chamber cryowall cooled by liquid nitrogen (LN_2) and having a thermal emissivity in excess of 0.90. The lunar surface was simulated by an aluminum structure with "lips" which had an emissivity greater than 0.89. The lunar surface night temperature was achieved by pumping LN_2 through the surface, and lunar noon temperatures were achieved with an array of infrared lamps attached to the structure. Solar radiation was simulated with an array of tungsten filament quartz lamps supported above the PSEP model, and the level of energy absorbed by the surfaces was monitored and controlled by a radiometer calibrated to read energy absorbed by second-surface mirrors.

4.2 Flight Acceptance Test Procedure

The lunar noon environment simulation for the Flight Acceptance test was similar to that for the Qual test. Since no lunar night testing was performed, only the following three steady-state conditions were established.

1. Lunar noon with no sun and no power dump.
   (Equilibrium established at 22:00 on 4/14/69)

2. Lunar noon with one sun and 10 watt power dump.
   (Equilibrium established at 09:00 on 4/15/69).

3. Lunar noon with one sun and no power dump.
   (Equilibrium established at 16:00 on 4/15/69)

An Integrated Systems Test (IST) was performed at the lunar noon condition of one sun and no power dump.

4.3 Qualification Retest Procedure

The PSEP Qualification Thermal-Vacuum Retest was conducted in the Bendix 20 by 27 foot space simulation chamber with the same test setup that was used for the original qualification test. PSEP was placed in the same location on the lunar surface simulator and in the same location under the IR lamp array as was used in the original Qual test. The number of thermocouples on PSEP was reduced, for cost and time reasons, to the point where only that data required was obtained.

The environmental conditions were the same as in the original qualification test, with two additions. A thermal equilibrium condition with the primary structure at actual lunar noon temperatures (195°F) and a thermal equilibrium condition with the solar panel simulators cool were added.

As in all ALSEP and EASEP T/V tests, the cryowall was held at -300°F. The lunar surface simulator was +250°F for lunar noon conditions and -300°F for Lunar Night conditions. The solar simulation is discussed in detail in Section 6.5.2.2.

Two thermal equilibrium conditions without PSEP in the chamber and four equilibrium conditions with PSEP in the chamber were conducted as follows:

1. Lunar night without PSEP in the chamber (10:00 on 9/19/69).
2. Lunar noon with no solar simulation and without PSEP in the chamber (12:30 on 9/19/69).
3. Lunar noon with no solar simulation, PSEP in the chamber, Solar panel normal temperatures (185°F) and no additional heat to the primary structure (13:30 on 9/24/69).
4. Same as preceding except addition of solar simulation (00:30 on 9/25/69).
5. Lunar noon with solar simulation, PSEP in chamber. Solar panel normal temperatures (185°F) and primary structures at 195°F (13:30 on 9/25/69).

6. Lunar noon with solar simulation, PSEP in chamber. Solar panels at 150°F and primary structure at 195°F (19:30 on 9/25/69).

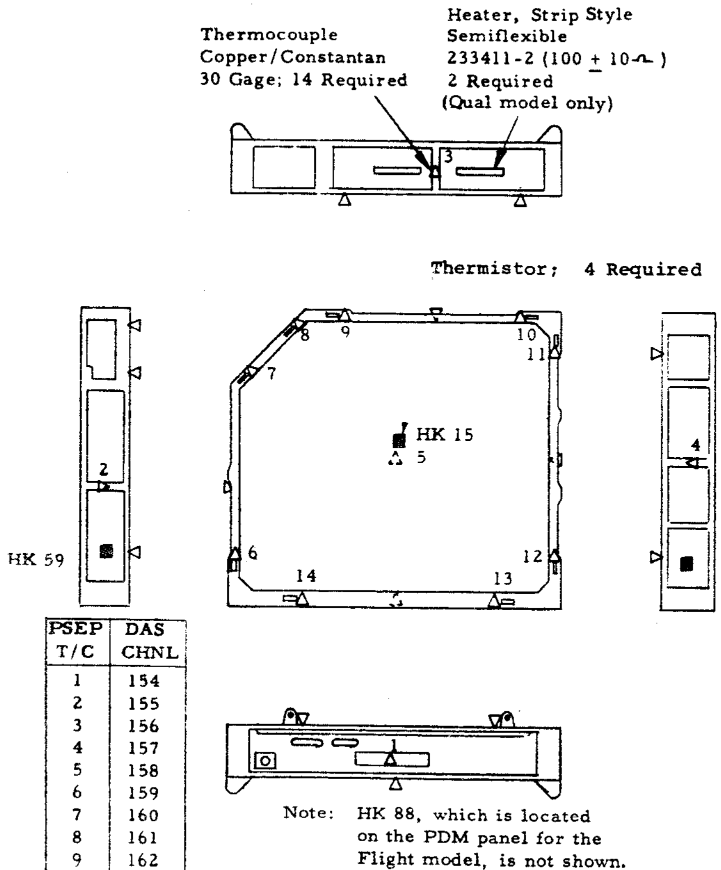
The PSEP Qualification Retest Model with Kapton shrouds is shown in Figure 1-4. The general position of PSEP in the same simulation chamber is shown in Figure 1-5.

4.4 PSEP Temperature Measurement Locations

The PSEP Qual model was instrumented with 115 thermocouples for temperature measurements with the Data Acquisition System (DAS), while the flight model had 35 thermistors for Housekeeping (HK) temperature measurements. Figures 4.1 through 4.7 show the thermocouple and some of the thermistor locations as well as the locations of the electrical heaters used to simulate the Qual test electronics and PDM panel thermal dissipations. Thermocouple identification numbersfor C/S components are denoted on the figures and in the figure titles. Of the thermistor locations not shown, two are on interior and exterior surfaces of the thermal bag, one is on the PDM panel, two are on the solar panels, three are on the dust detector, and 19 are on the electronic components.

4.5 Simulated Lunar Environment Temperature Measurement Locations

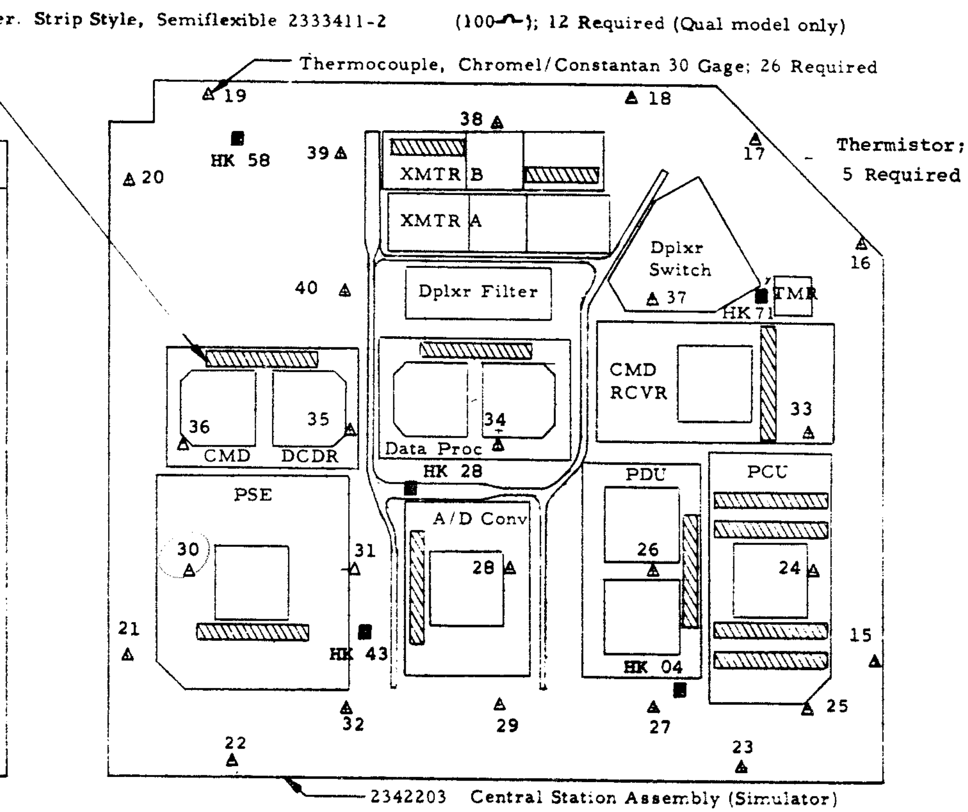
The lunar surface simulator was instrumented with 57 thermocouples as shown in Figure 4-8, while figure 4-9 depicts the distribution of 40 thermocouples over the T/V chamber cyrowall.



PSEP T/C	DAS CHNL
1	154
2	155
3	156
4	157
5	158
6	159
7	160
8	161
9	162
10	163
11	164
12	165
13	166
14	167

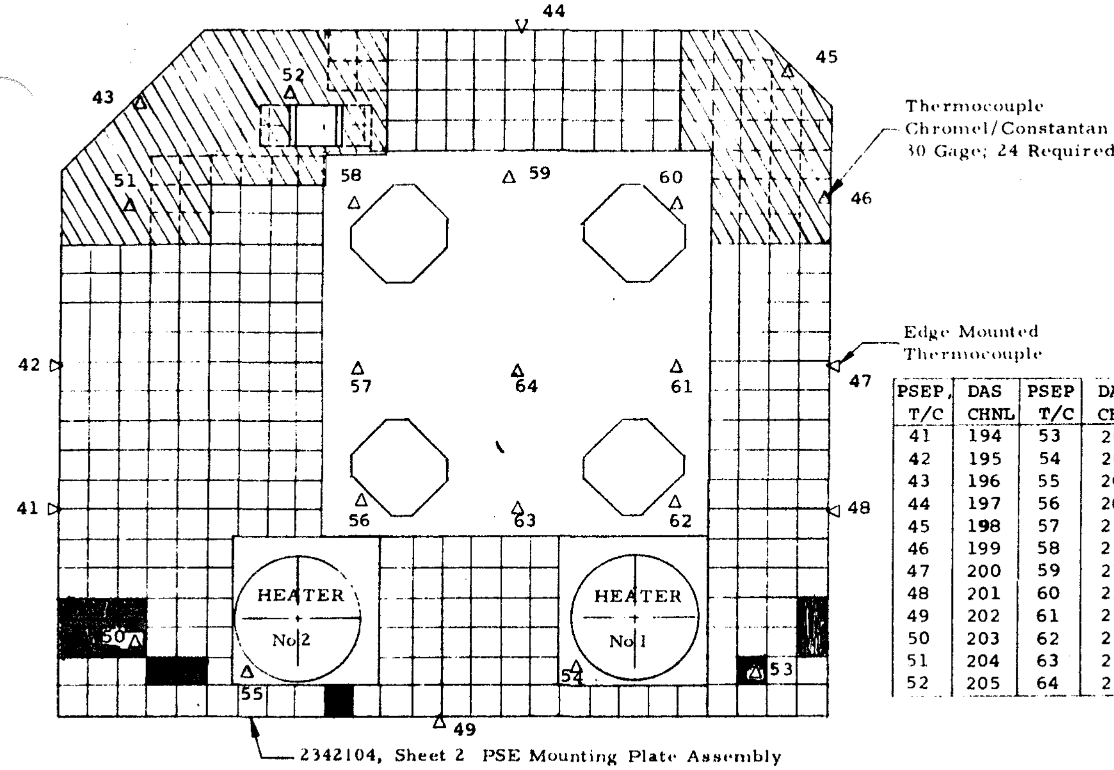
Figure 4-1. Thermocouple, Thermistor, and Heater Locations (1-14) - PSEP Primary Structure and PDM Resistor Panel

PSEP T/C	DAS CHNL
15	168
16	169
17	170
18	171
19	172
20	173
21	174
22	175
23	176
24	177
25	178
26	179
27	180
28	181
29	182
30	183
31	184
32	185
33	186
34	187
35	188
36	189
37	190
38	191
39	192
40	193



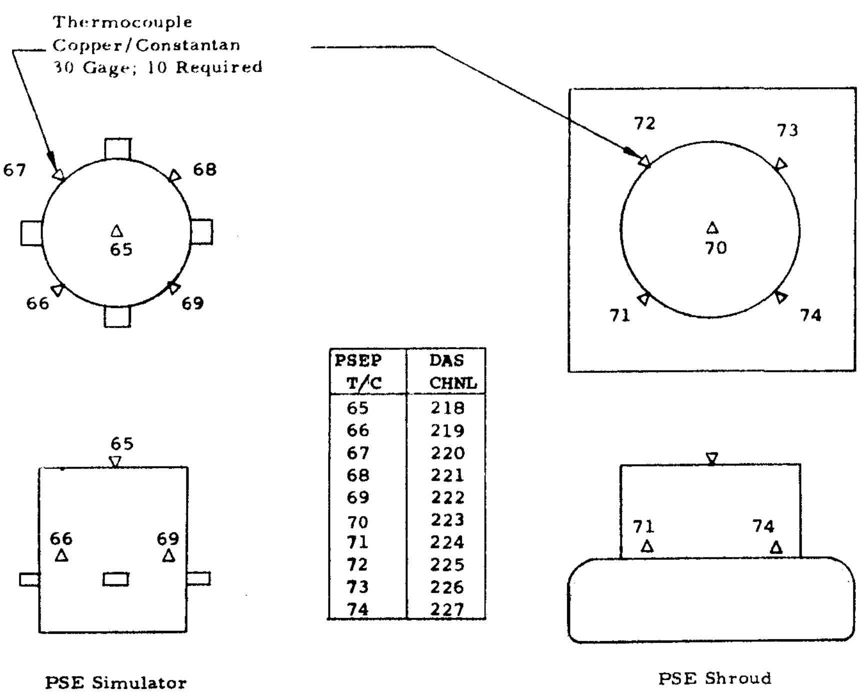
Note: Outlines of the electronic components are shown only to illustrate the simulation of the components with the heaters. HK measurement locations on the electronics are not shown.

Figure 4-2. Thermocouple, Thermistor, and Heater Locations (15-40) - PSEP Thermal Plate Assembly



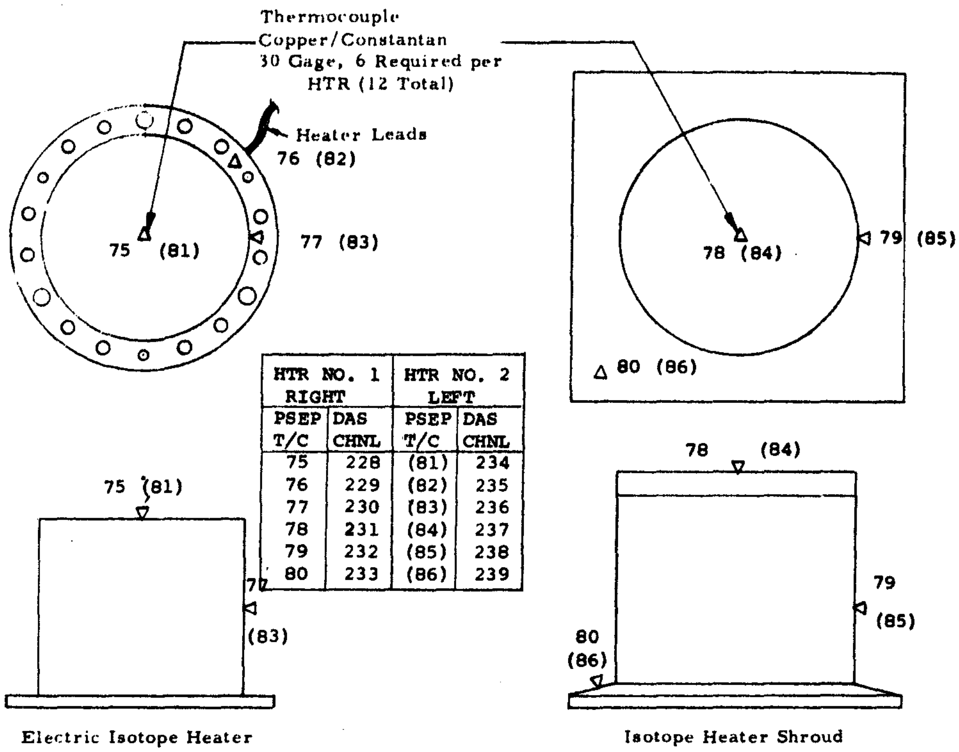
PSEP T/C	DAS CHNL	PSEP T/C	DAS CHNL
41	194	53	206
42	195	54	207
43	196	55	208
44	197	56	209
45	198	57	210
46	199	58	211
47	200	59	212
48	201	60	213
49	202	61	214
50	203	62	215
51	204	63	216
52	205	64	217

Figure 4-3. Thermocouple Locations (41-64) -
PSEP PSE Mounting Plate Assembly



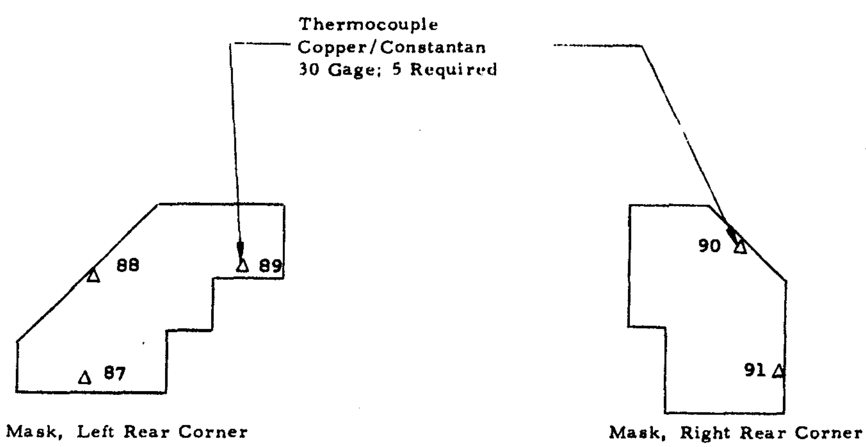
PSEP T/C	DAS CHNL
65	218
66	219
67	220
68	221
69	222
70	223
71	224
72	225
73	226
74	227

Figure 4-4. Thermocouple Locations (65-74) -
PSEP PSE Simulator and Shroud



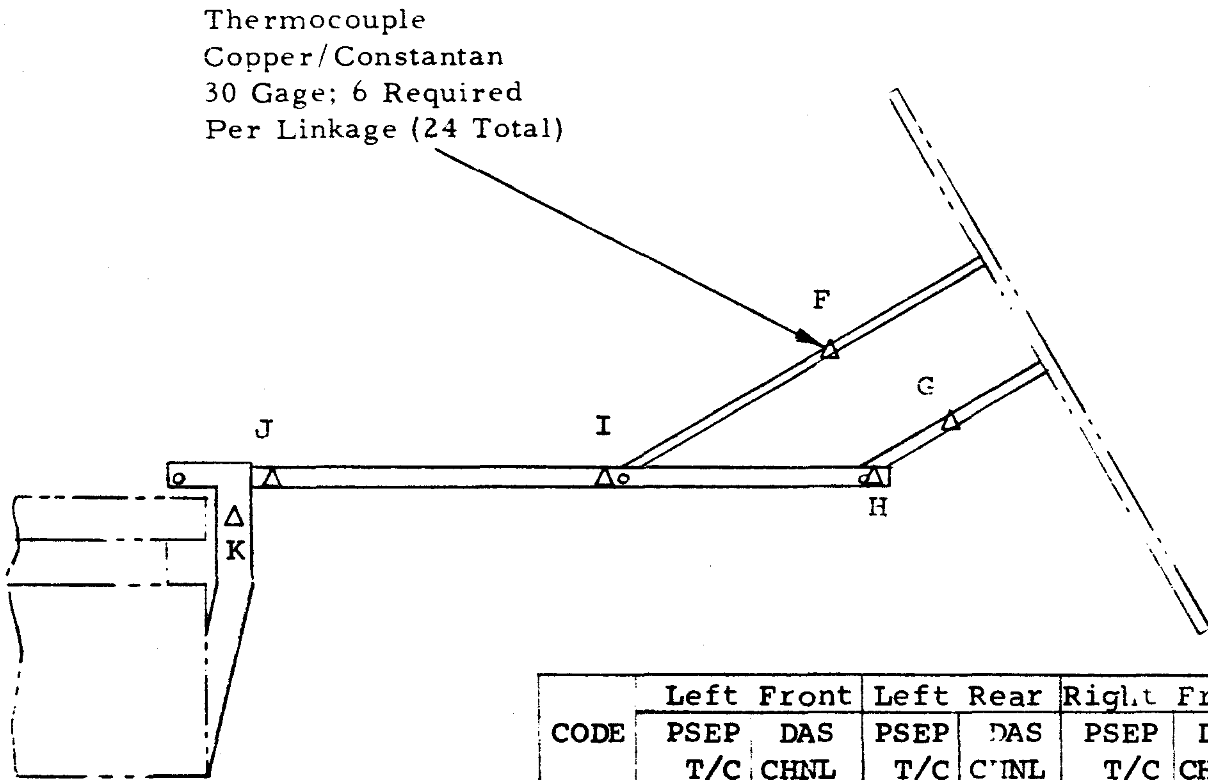
HTR NO. 1 RIGHT		HTR NO. 2 LEFT	
PSEP T/C	DAS CHNL	PSEP T/C	DAS CHNL
75	228	(81)	234
76	229	(82)	235
77	230	(83)	236
78	231	(84)	237
79	232	(85)	238
80	233	(86)	239

Figure 4-5. Thermocouple Locations (75-86) - PSEP Isotope Heater and Shroud



PSEP, T/C	DAS CHNL
87	240
88	241
89	242
90	243
91	244

Figure 4-6. Thermocouple Locations (87-91) - PSEP PSE Mounting Plate Masks



CODE	Left Front		Left Rear		Right Front		Right Rear	
	PSEP T/C	DAS CHNL	PSEP T/C	DAS CHNL	PSEP T/C	DAS CHNL	PSEP T/C	DAS CHNL
F	122	245	128	251	134	257	140	263
G	123	246	129	252	135	258	141	264
H	124	247	130	253	136	259	142	265
I	125	248	131	254	137	260	143	266
J	126	249	132	255	138	261	144	267
K	127	250	133	256	139	262	145	268

Note: HK 27 and HK 42 are not shown but are located on the left and right solar panels, respectively.

Figure 4-7. Thermocouple Locations (122-145) - PSEP Solar Cell Panel Deployment Linkage

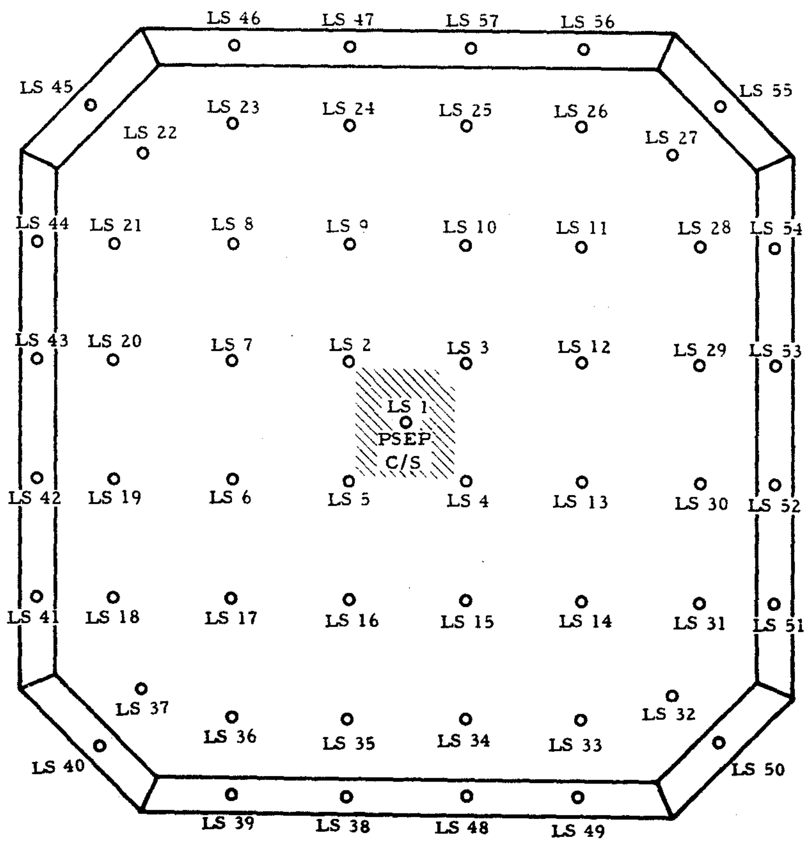


Figure 4-8. Lunar Surface Simulator Thermocouple Locations

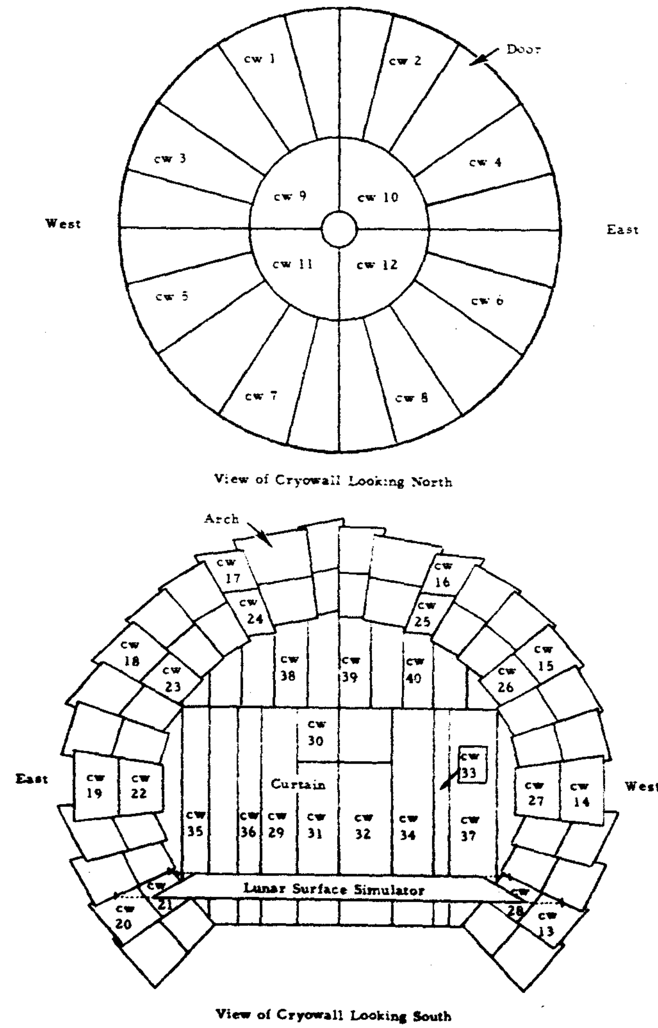


Figure 4-9. Cryowall Thermocouple Locations

5.0 TEST MEASUREMENTS

5.1 Qualification Test Measurements

Figures 5-1 through 5-14 show DAS temperature measurements versus time for the various PSEP Qual components. Power input to the electrical heaters is presented in Figures 5-15 to 5-17, and Figure 5-18 shows the effect of the 10 watt PDM panel dump on primary structure temperatures. Radiation absorbed by the test radiometers and the effect of the simulated solar heating on PSEP components are depicted in Figures 5-19 to 5-21. The effect of lunar environment simulation parameters (lunar surface simulator, cryowall, and solar heating) on thermal plate temperature is indicated in Figure 5-22. Significant test events are labeled on each figure.

Data Acquisition System (DAS) data at lunar noon and night equilibrium conditions are listed in Tables 5-1 and 5-2.

5.2 Flight Acceptance Test Measurements

Figures 5-23 to 5-25 show HK temperature measurements versus time for the PSEP Flight model thermal plate, electronics, thermal bag, and primary structure. Reserve power is also plotted in Figure 5-25. Not all measurements are illustrated in the figures--generally just maximum and minimum values are shown in order to bracket the range of temperature data. The specified equilibrium events are somewhat misleading since thermal equilibrium was generally not achieved but only approached. Consequently, equilibrium refers to conditions just prior to initiating a new phase of the test.

Housekeeping (HK) data at lunar noon equilibrium conditions are listed in Table 5-3. One sun and no sun refer to the on and off conditions of the tungsten filament quartz lamps which simulated solar radiation.

The power input to the PSEP Central Station remained a constant 37.2 watts during lunar noon testing, while the reserve power varied from 3.6 watts with the 10 watt dump activated to 13.7 watts with no dump.

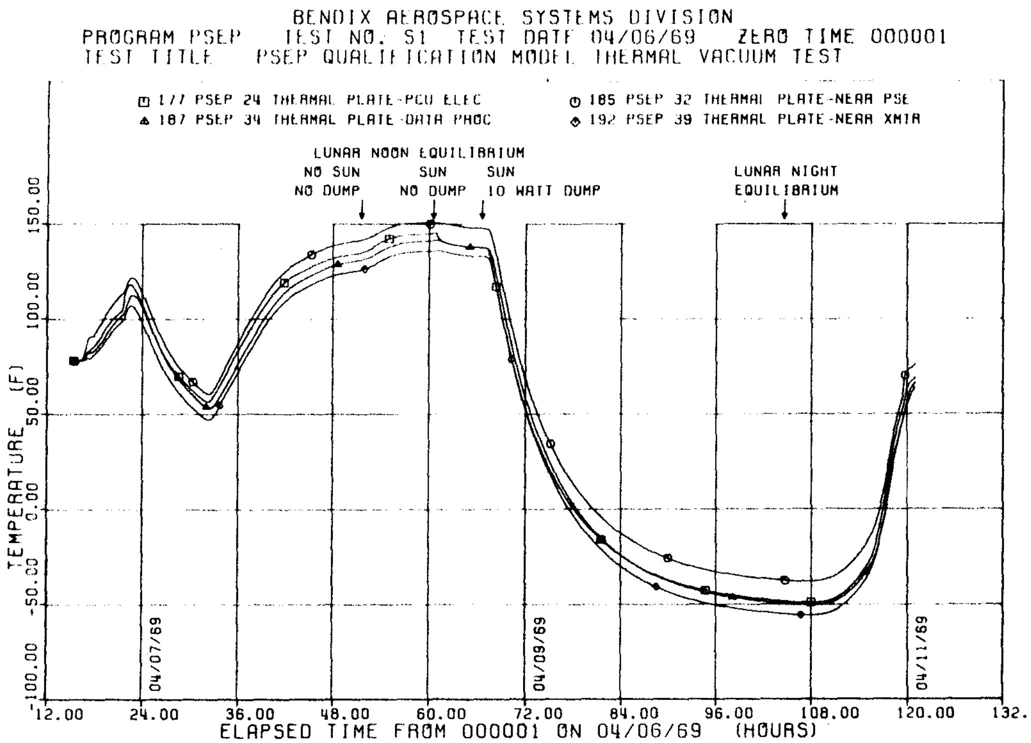


Figure 5-1. Qual Test Thermal Plate Temperatures

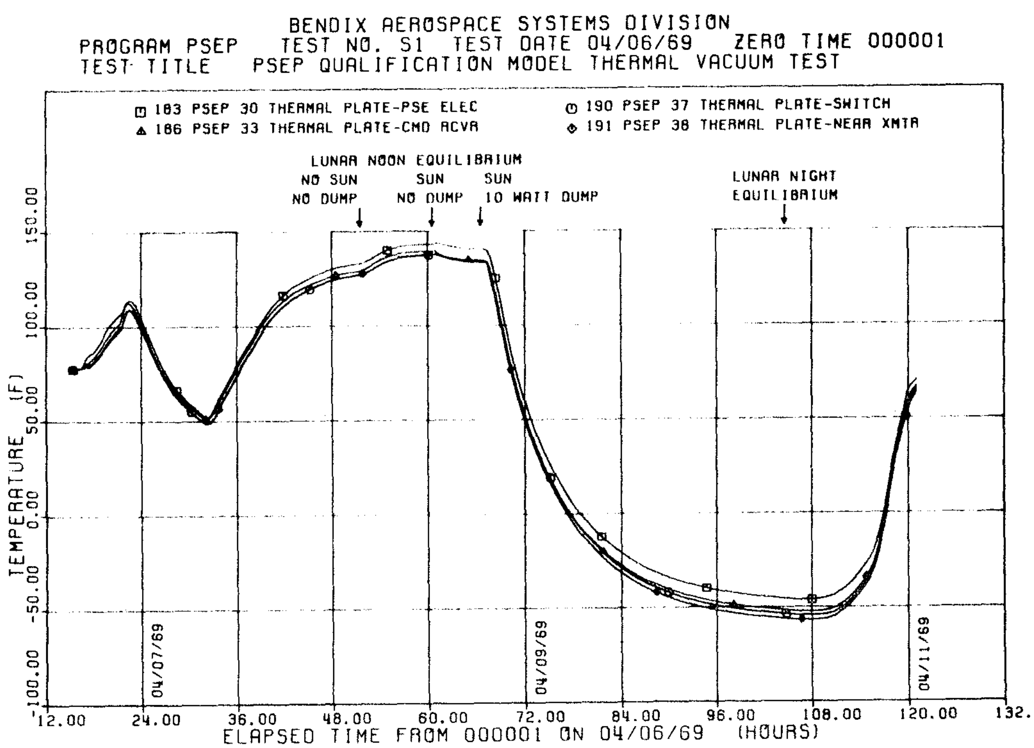


Figure 5-2. Qual Test Thermal Plate Temperatures

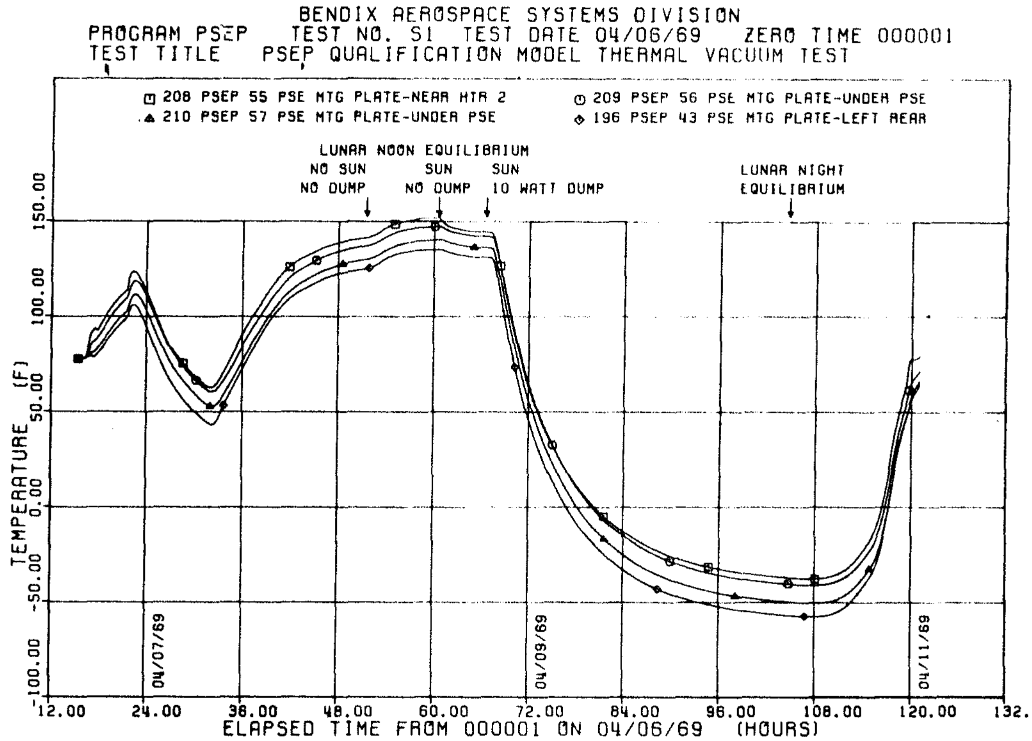


Figure 5-5. Qual Test Mounting Plate Temperatures

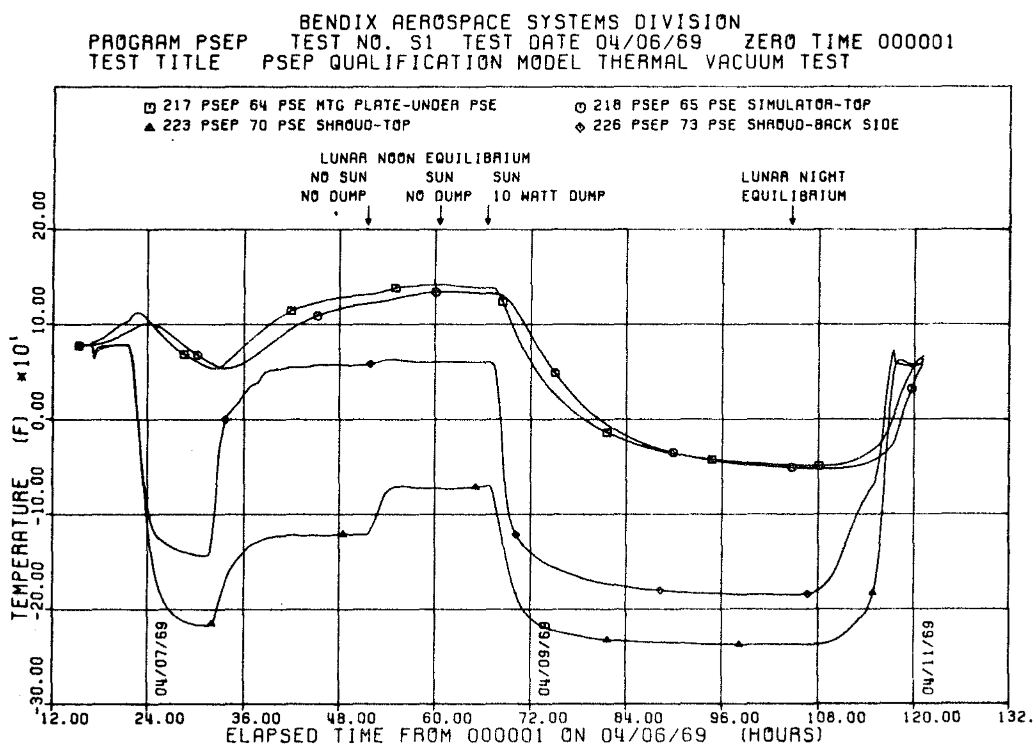


Figure 5-6. Qual Test PSE Simulator/ Shroud Temperatures

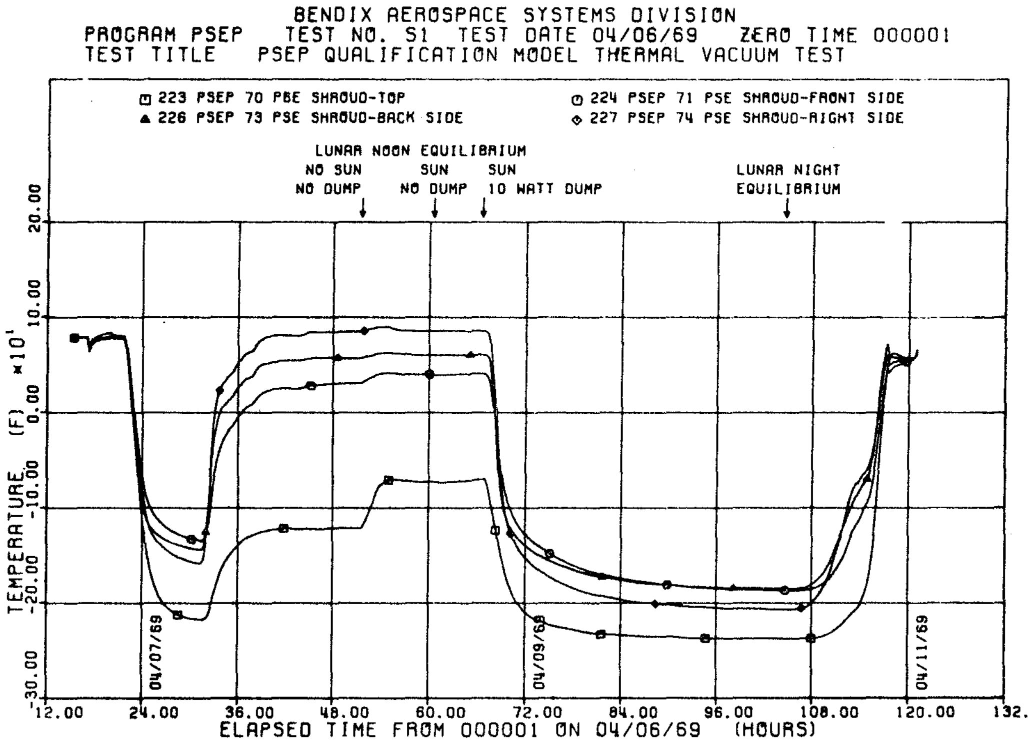


Figure 5-7. Qual Test PSE Shroud Temperatures

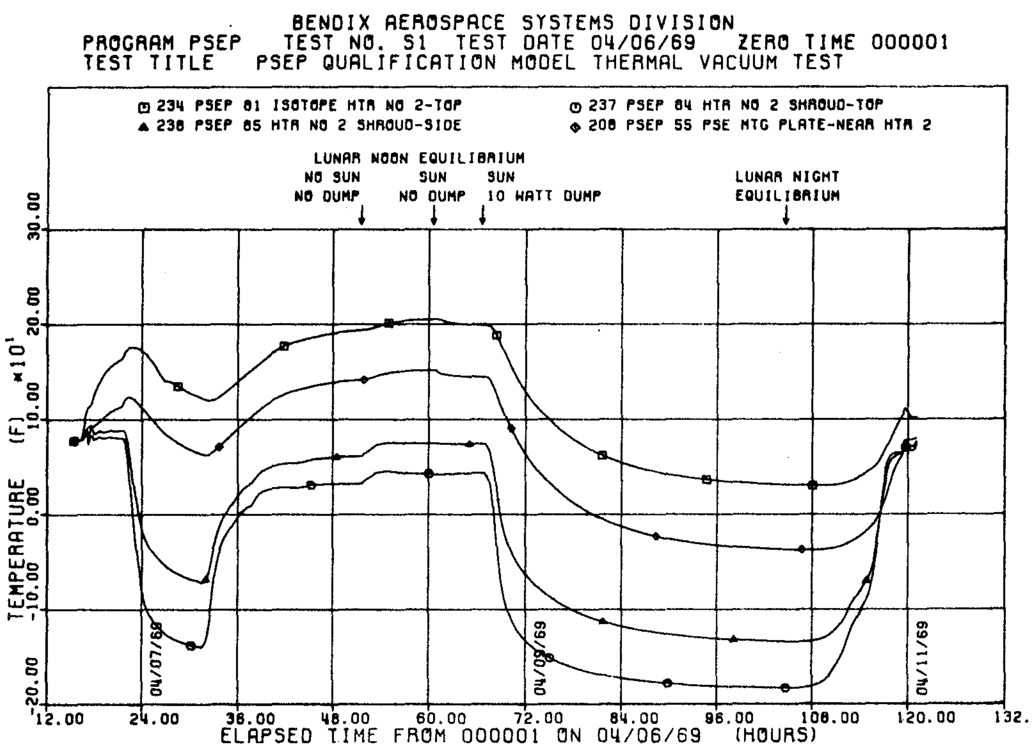


Figure 5-8. Qual Test Heater/Shroud Temperatures

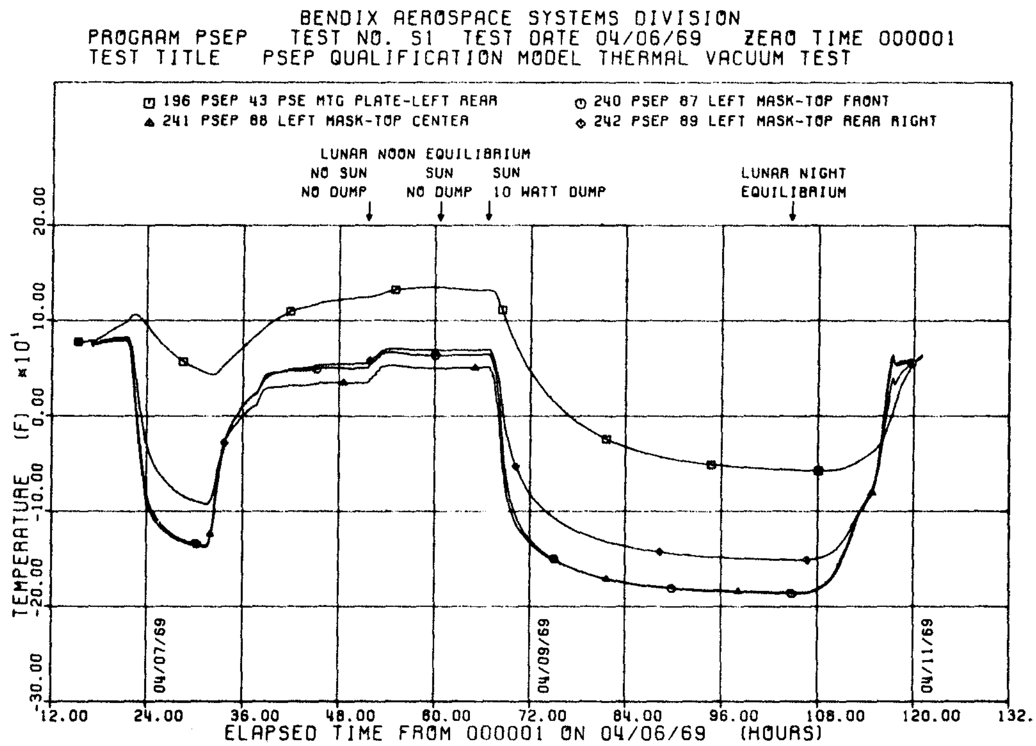


Figure 5-9. Qual Test Left Insulation Mask Temperatures

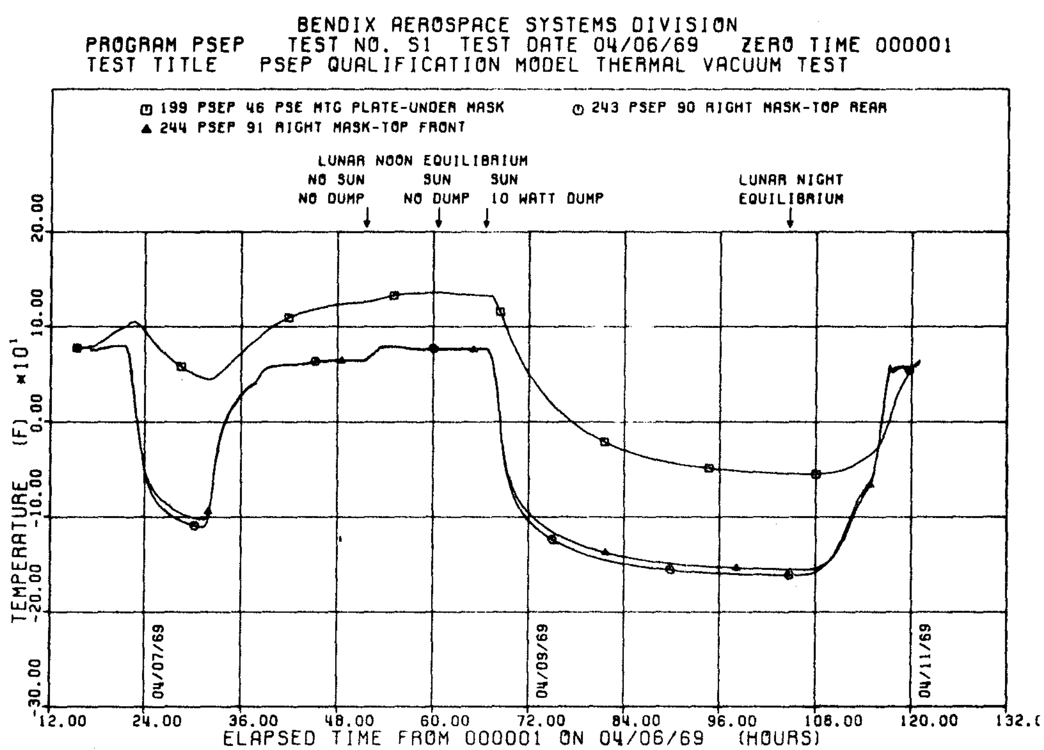


Figure 5-10. Qual Test Right Insulation Mask Temperatures

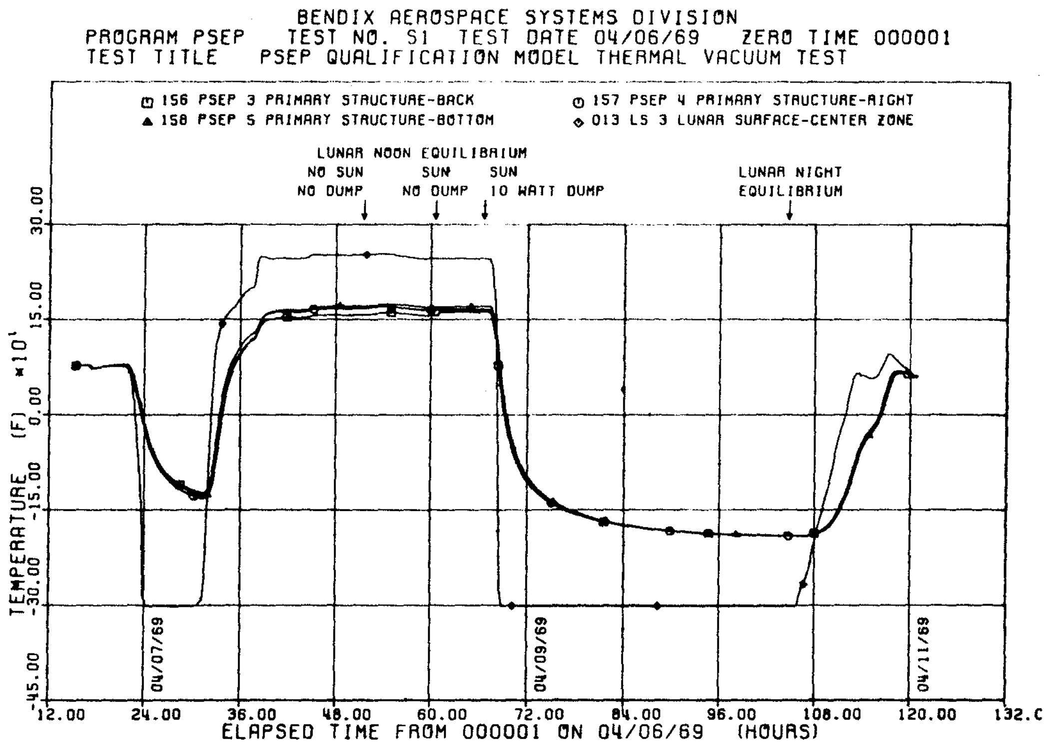


Figure 5-11. Qual Test Primary Structure Temperatures

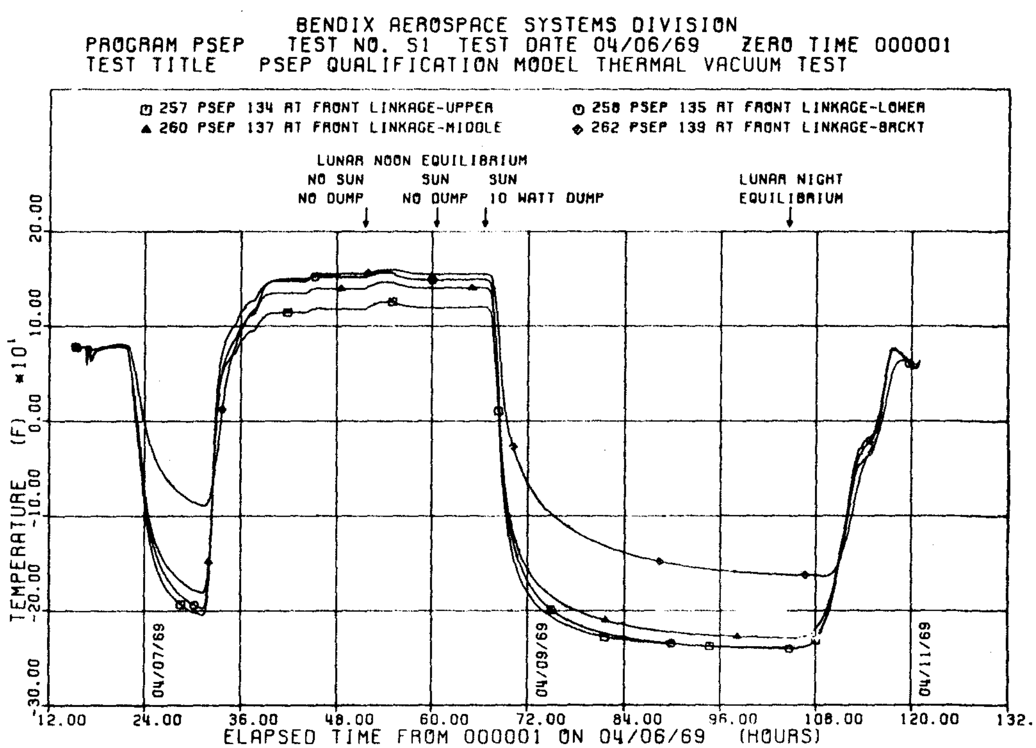


Figure 5-12. Qual Test Solar Panel Linkage Temperatures

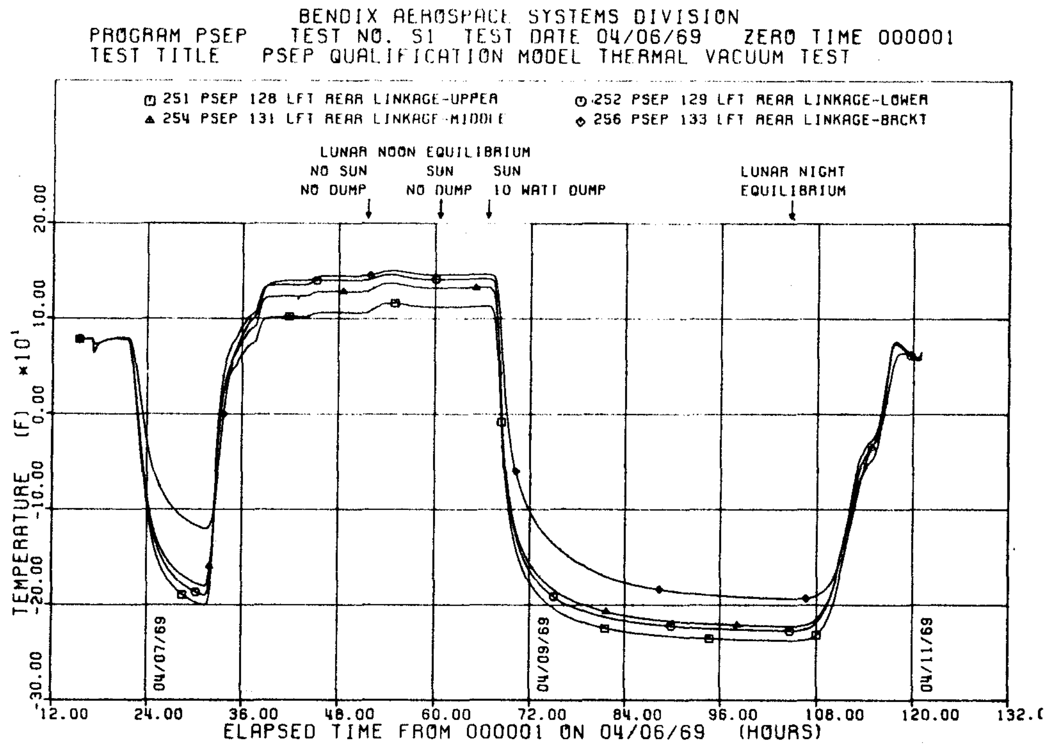


Figure 5-13. Qual Test Solar Panel Linkage Temperatures

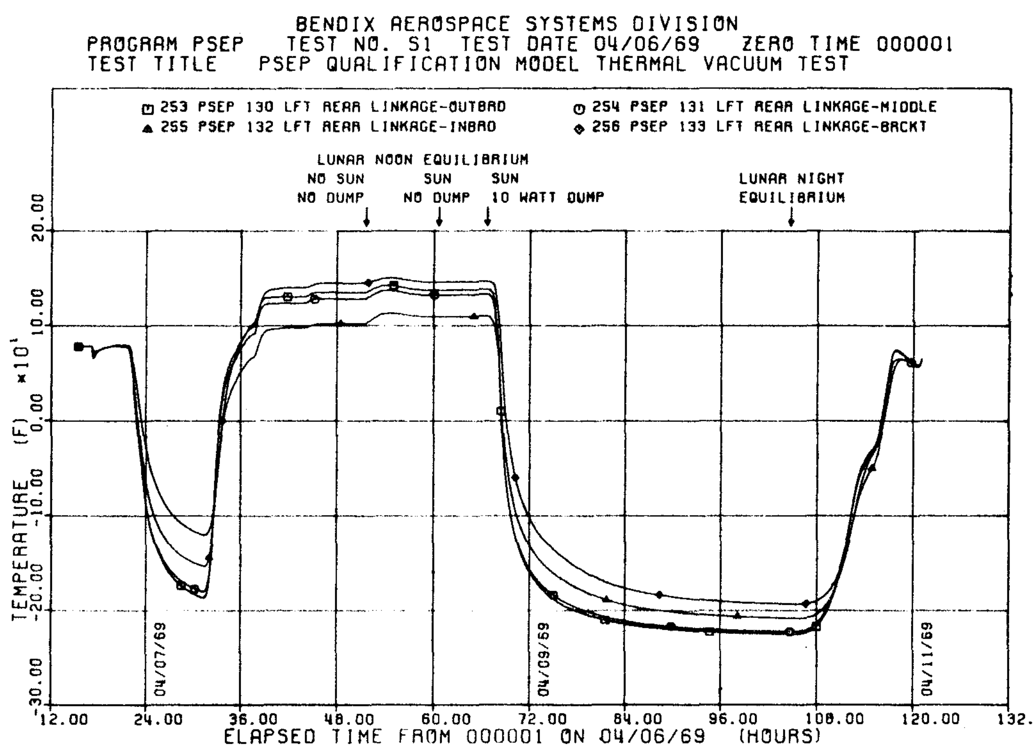


Figure 5-14. Qual Test Solar Panel Linkage Temperatures

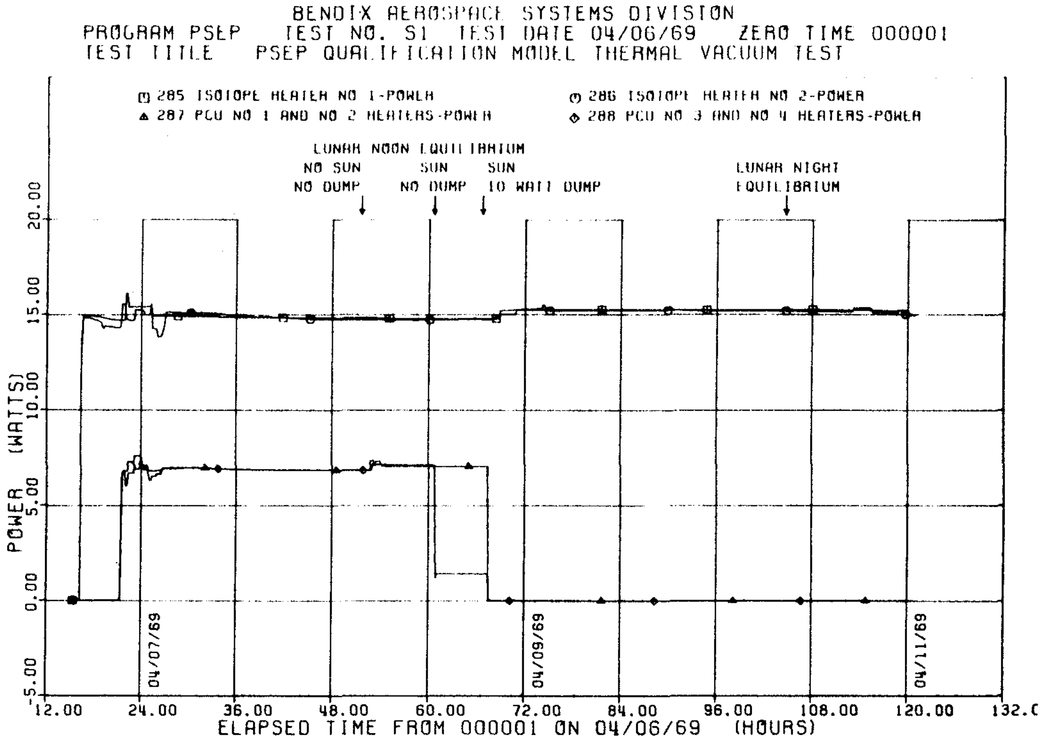


Figure 5-15. Qual Test Electric Heater Powers

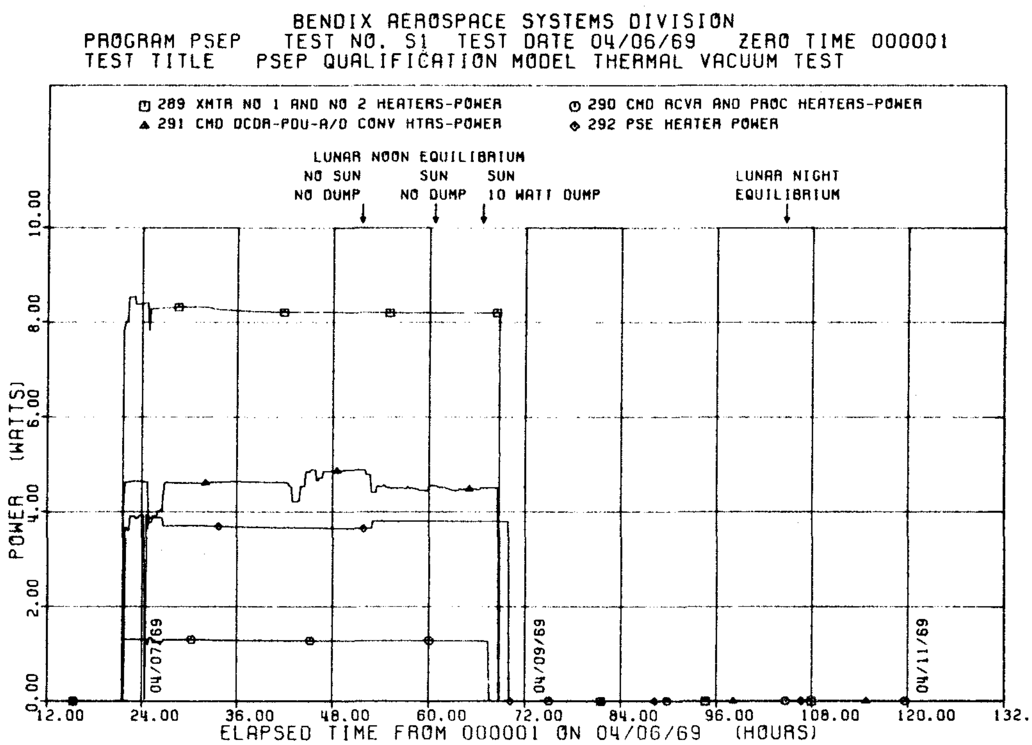


Figure 5-16. Qual Test Electric Heater Powers

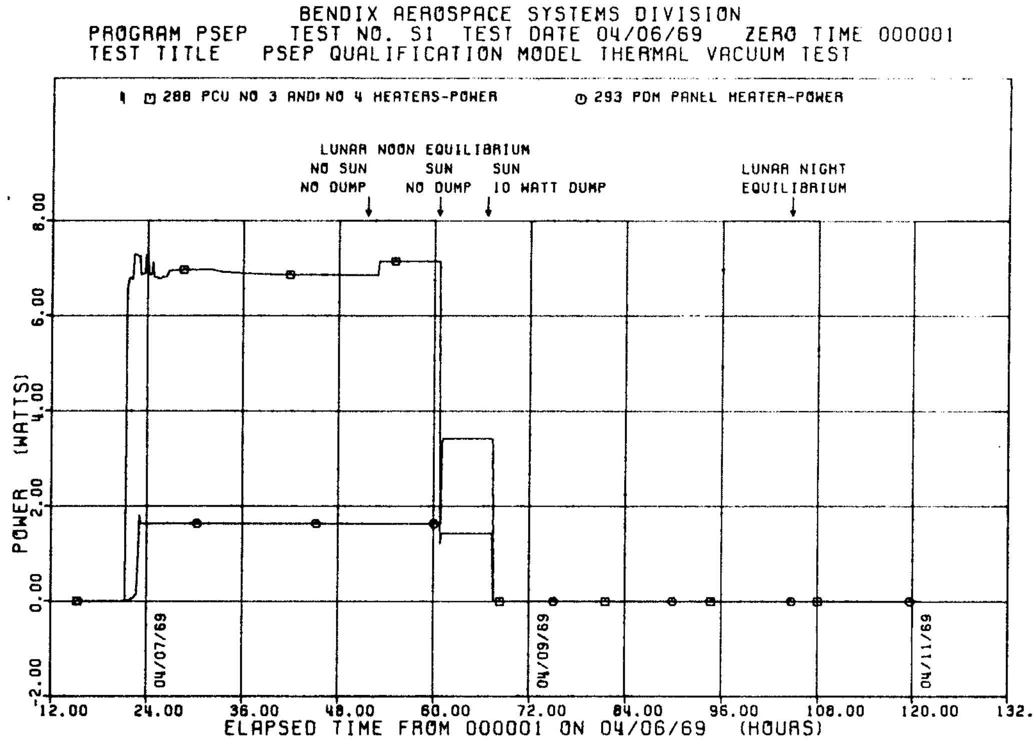


Figure 5-17. Qual Test Electric Heater Powers

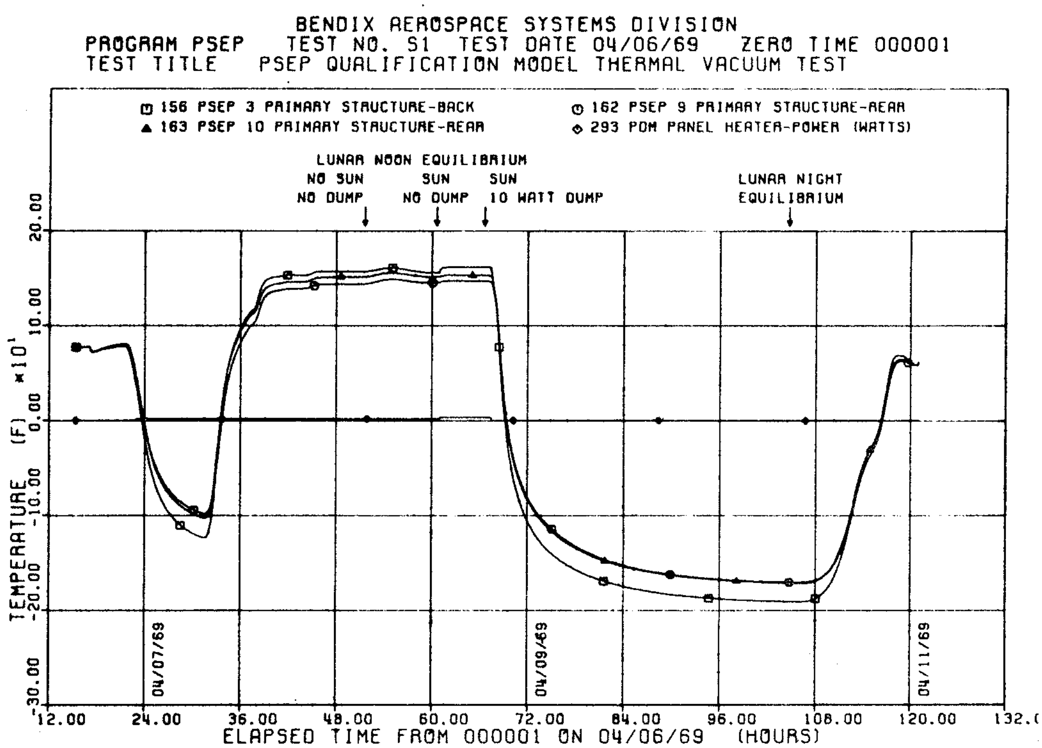


Figure 5-18. Qual Test Effect of PDM Dump on Structure Temperatures

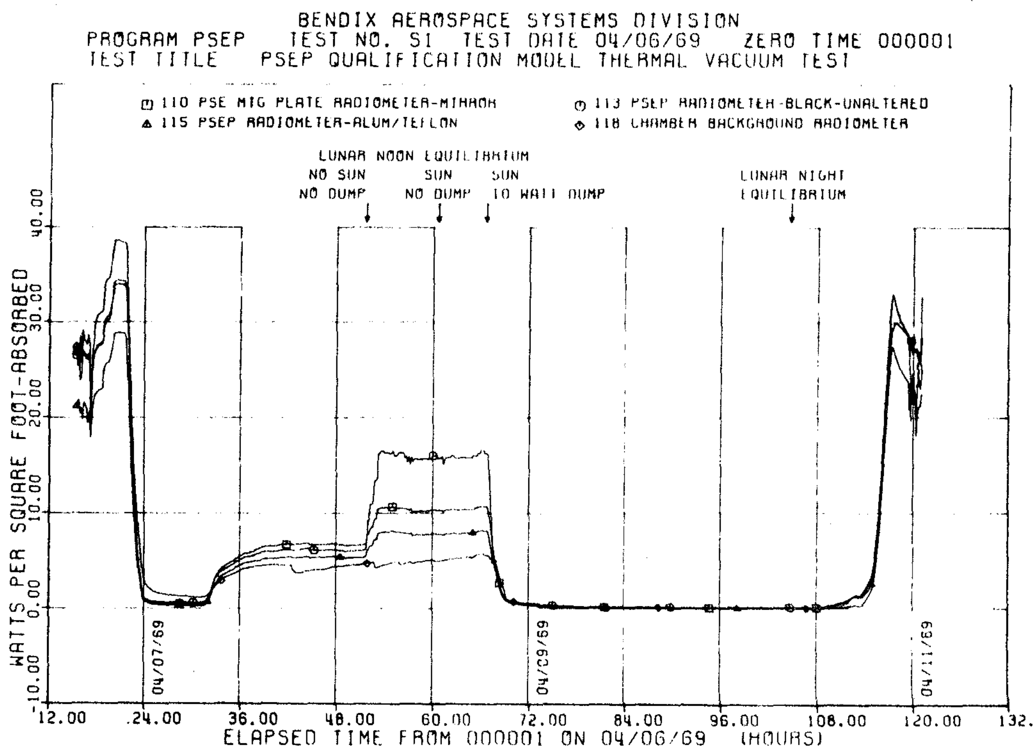


Figure 5-19. Qual Test Radiometer Measurements

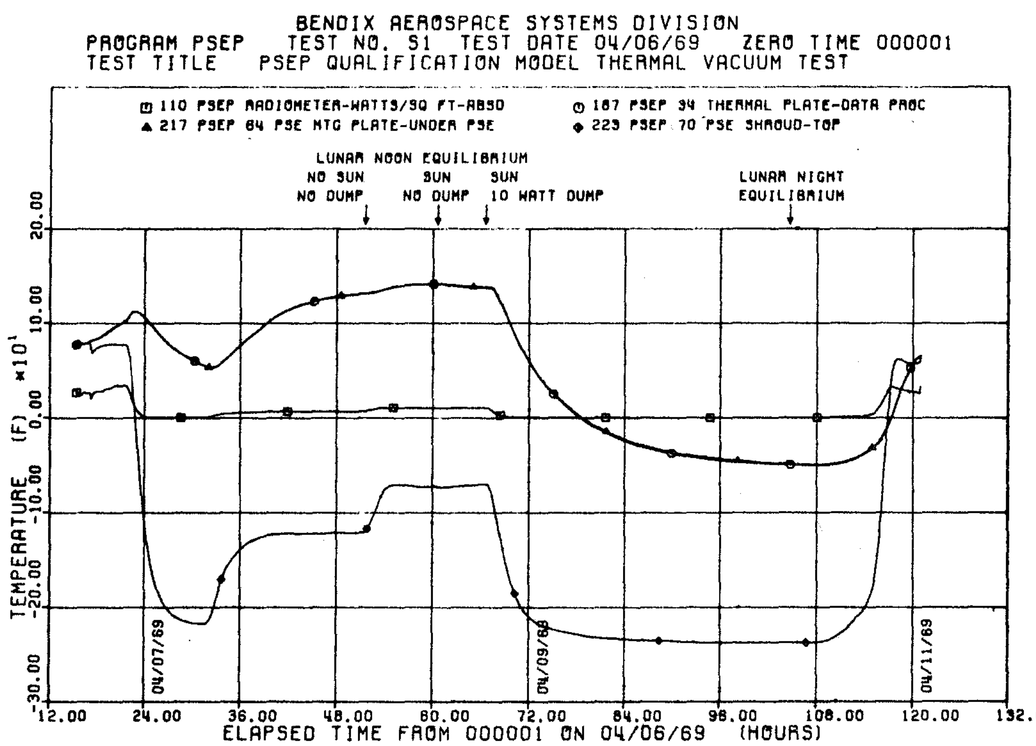


Figure 5-20. Qual Test Thermal Effect of Solar Heating

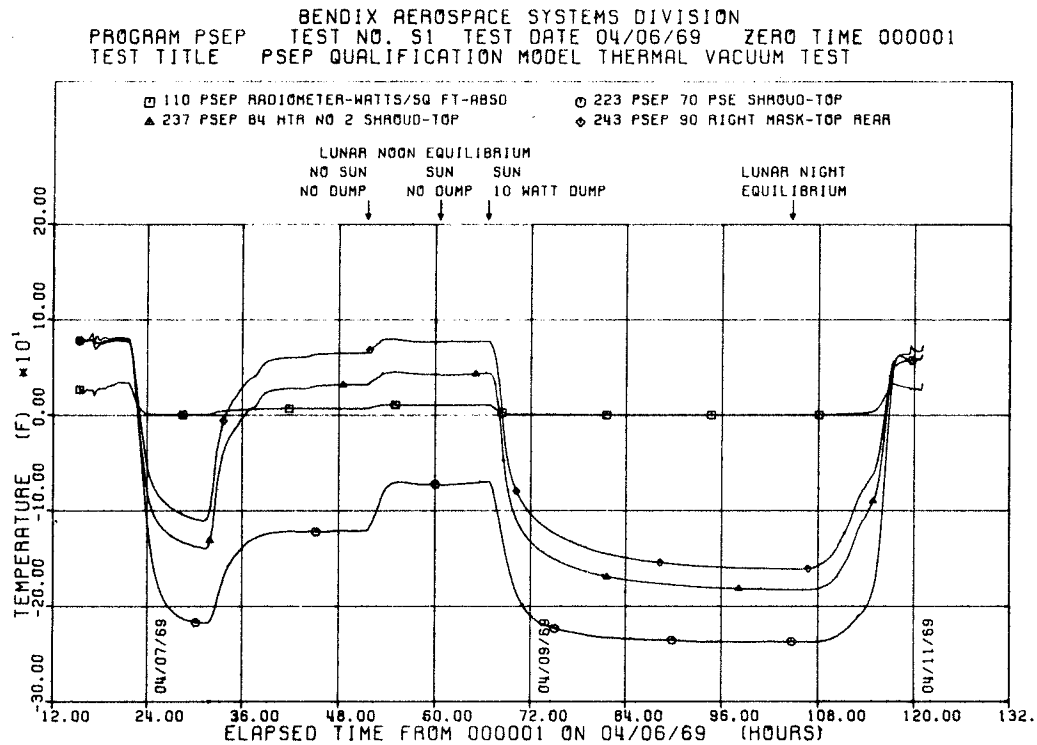


Figure 5-21. Qual Test Thermal Effect of Solar Heating

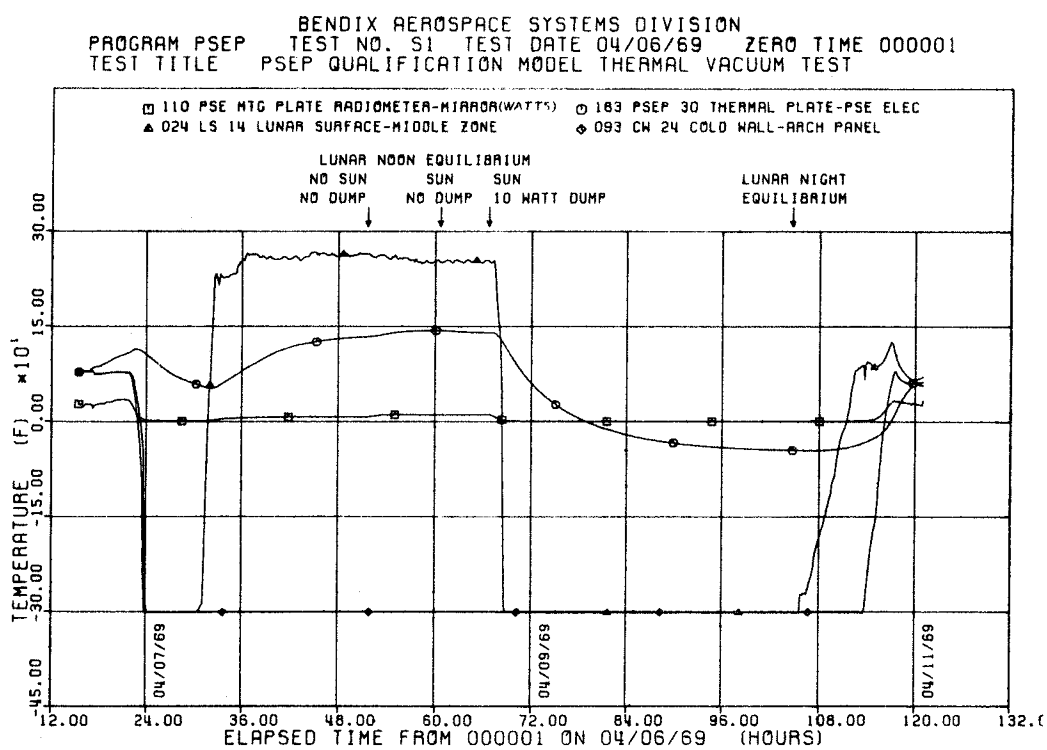


Figure 5-22. Effect of Lunar Environment Simulation Parameters on Thermal Plate Temperature

TABLE 5-1
DAS TEMPERATURE MEASUREMENTS FOR PSEP QUAL TEST
AT LUNAR NOON AND LUNAR NIGHT EQUILIBRIUM

DAS Chan.	PSEP T/C Ident.	Description	Temperatures - °F Lunar Noon No Dump	Temperatures - °F Lunar Noon 10 W. Dump	Temperatures - °F Lunar Night
154	1	Primary Structure Front	152	153	-191
155	2	Primary Structure Left Side	164	165	-194
156	3	Primary Structure Rear	156	162	-191
157	4	Primary Structure Right Side	164	165	-191
158	5	Primary Structure Bottom	169	170	-192
159	6	Structure Left Flange	157	156	-176
160	7	Structure Left Rear Flange	150	150	-174
161	8	Structure Left Rear Flange	146	147	-174
162	9	Structure Rear Flange	145	147	-170
163	10	Structure Rear Flange	152	153	-172
164	11	Structure Right Flange	154	154	-170
165	12	Structure Right Flange	158	158	-161
166	13	Structure Front Flange	158	159	-185
167	14	Structure Front Flange	155	155	-191
168	15	Thermal Plate - near Bolt #1	148	139	- 97
169	16	Thermal Plate - near Bolt #2	138	133	- --
170	17	Thermal Plate - near Bolt #3	138	135	- 66
171	18	Thermal Plate - near Bolt #4	138	136	- 66
172	19	Thermal Plate - near Bolt #5	138	135	- 68
173	20	Thermal Plate - near Bolt #6	140	137	- 66
174	21	Thermal Plate - near Bolt #7	148	145	- 58
175	22	Thermal Plate - near Bolt #8	150	148	- 56
176	23	Thermal Plate - near Bolt #9	148	141	- 54
177	24	Thermal Plate - over PCU	146	138	- 49
178	25	Thermal Plate - near PCU	148	140	- --
179	26	Thermal Plate - over PDU	146	141	- --
180	27	Thermal Plate - near PDU	150	143	- --
181	28	Thermal Plate - over A/D Conv.	146	142	- --
182	29	Thermal Plate - near A/D Conv.	148	143	- --
183	30	Thermal Plate - over PSE	144	140	- 45
184	31	Thermal Plate - near PSE	146	142	- --
185	32	Thermal Plate - near PSE	151	148	- 38
186	33	Thermal Plate - over CMD Rec.	140	134	- 51
187	34	Thermal Plate - over Data Proc.	141	138	- 50
188	35	Thermal Plate - over CMD Dec.	142	139	- 48
189	36	Thermal Plate - over CMD Dec.	139	136	- --
190	37	Thermal Plate - over Switch	137	133	- 54
191	38	Thermal Plate - near XMTR B	137	134	- 56
192	39	Thermal Plate - near XMTR B	136	133	- 55
193	40	Thermal Plate - near XMTR A	138	135	- 52
194	41	Mounting Plate - Left Edge	143	137	- 48
195	42	Mounting Plate - Left Edge	137	132	- 52
196	43	Mounting Plate - Left Rear	135	131	- 56
197	44	Mounting Plate - Back Edge	132	129	- --
198	45	Mounting Plate - Right Rear	136	133	- --
199	46	Mounting Plate - under Rt. Mask	136	133	- 54
200	47	Mounting Plate - Right Edge	138	135	- 51
201	48	Mounting Plate - Right Edge	142	139	- 47
202	49	Mounting Plate - Front Edge	150	145	- 37
203	50	Mounting Plate - Left Front	145	137	- 47
204	51	Mounting Plate - under Lt. Mask	---	---	- --
205	52	Mounting Plate - under Lt. Mask	---	---	- --
206	53	Mounting Plate - Right Front	143	140	- 44
207	54	Mounting Plate - near Heater 1	156	152	- 31
208	55	Mounting Plate - near Heater 2	152	144	- 37
209	56	Mounting Plate - under PSE	147	142	- 40
210	57	Mounting Plate - under PSE	140	136	- 50
211	58	Mounting Plate - under PSE	137	134	- 54
212	59	Mounting Plate - under PSE	138	134	- 53
213	60	Mounting Plate - under PSE	136	133	- --
214	61	Mounting Plate - under PSE	139	136	- 50
215	62	Mounting Plate - under PSE	145	142	- 41
216	63	Mounting Plate - under PSE	147	143	- 42
217	64	Mounting Plate - under PSE	142	138	- 49
218	65	PSE Simulator - Top	134	132	- 51
219	66	PSE Simulator - Front Side	---	---	- --
220	67	PSE Simulator - Left Side	133	132	- 53
221	68	PSE Simulator - Back Side	133	132	- 53
222	69	PSE Simulator - Right Side	133	132	- 52

Lunar Noon - No Dump (12:30 on 4/8/69-60.5 hrs elapsed time)
Lunar Noon - 10 W. Dump (18:30 on 4/8/69-66.5 hrs elapsed time)
Lunar Night (08:30 on 4/10/69 - 104.5 hrs elapsed time)

TABLE 5-1 (CONT.)

DAS Chan.	PSEP T/C Ident.	Description	Temperature - °F		
			Lunar Noon		Lunar Night
			No Dump	10 W. Dump	
223	70	PSE Shroud - Top	-73	-71	-238
224	71	PSE Shroud - Front Side	40	41	-187
225	72	PSE Shroud - Left Side	46	47	-191
226	73	PSE Shroud - Back Side	60	60	-185
227	74	PSE Shroud - Right Side	85	85	-207
228	75	Heater #1 - Top	199	196	21
229	76	Heater #1 - near Leads	189	186	10
230	77	Heater #1 - Side	198	195	20
231	78	Heater #1 Shroud - Top	7	9	-199
232	79	Heater #1 Shroud - Side	81	81	-137
233	80	Heater #1 Shroud - Base	69	69	-131
234	81	Heater #2 - Top	205	199	31
235	82	Heater #2 - near Leads	191	185	15
236	83	Heater #2 - Side	204	197	29
237	84	Heater #2 Shroud - Top	42	44	-183
238	85	Heater #2 Shroud - Side	75	74	-134
239	86	Heater #2 Shroud - Base	72	71	-119
240	87	Left Mask - Top Front	63	64	-186
241	88	Left Mask - Top Center	50	51	-186
242	89	Left Mask - Top Rear	69	69	-151
243	90	Right Mask - Top Rear	77	77	-161
244	91	Right Mask - Top Front	75	76	-155
124	92	Solar Cell Panel - Left Center	182	183	-260
125	93	Solar Cell Panel - Left Center	210	211	-256
126	94	Solar Cell Panel - Left Center	222	222	-256
127	95	Solar Cell Panel - Left Center	224	224	-257
128	96	Solar Cell Penel - Left Center	---	---	----
129	97	Solar Cell Panel - Left Front	195	196	-268
130	98	" " " " " "	199	200	-266
131	99	" " " " " "	211	212	-267
132	100	" " " " " "	201	202	-267
133	101	" " " " " "	208	208	-266
134	102	Solar Cell Panel - Left Rear	201	201	-266
135	103	" " " " " "	202	202	-267
136	104	" " " " " "	215	215	-266
137	105	" " " " " "	209	209	-266
138	106	" " " " " "	206	207	-267
139	107	Solar Cell Panel - Right Center	186	186	-258
140	108	Solar Cell Panel - Right Center	217	217	-256
141	109	Solar Cell Panel - Right Center	223	223	-256
142	110	Solar Cell Panel - Right Center	221	221	-256
143	111	Solar Cell Panel - Right Center	195	195	-258
144	112	Solar Cell Panel - Right Front	203	203	-265
145	113	Solar Cell Panel - Right Front	202	202	-266
146	114	Solar Cell Panel - Right Front	217	217	-266
147	115	Solar Cell Panel - Right Front	---	---	----
148	116	Solar Cell Panel - Right Front	211	211	-266
149	117	Solar Cell Panel - Right Rear	195	195	-263
150	118	Solar Cell Panel - Right Rear	193	193	-262
151	119	Solar Cell Panel - Right Rear	206	206	-262
152	120	Solar Cell Panel - Right Rear	205	204	-263
153	121	Solar Cell Panel - Right Rear	203	203	-262
245	122	Solar Panel - Left Front Linkage	115	117	-241
246	123	Solar Panel - Left Front Linkage	144	145	-244
247	124	Solar Panel - Left Front Linkage	140	141	-234
248	125	Solar Panel - Left Front Linkage	134	135	-227
249	126	Solar Panel - Left Front Linkage	113	114	-208
250	127	Solar Panel - Left Front Linkage	147	147	-190
251	128	Solar Panel - Left Rear Linkage	112	113	-237
252	129	Solar Panel - Left Rear Linkage	141	142	-227
253	130	Solar Panel - Left Rear Linkage	137	138	-225
254	131	Solar Panel - Left Rear Linkage	132	133	-223
255	132	Solar Panel - Left Rear Linkage	109	110	-208
256	133	Solar Panel - Left Rear Linkage	146	146	-193
257	134	Solar Panel - Right Front Linkage	119	120	-239
258	135	Solar Panel - Right Front Linkage	149	149	-240
259	136	Solar Panel - Right Front Linkage	145	146	-236
260	137	Solar Panel - Right Front Linkage	140	140	-229
261	138	Solar Panel - Right Front Linkage	124	124	-210
262	139	Solar Panel - Right Front Linkage	155	155	-162
263	140	Solar Panel - Right Rear Linkage	117	118	-239
264	141	Solar Panel - Right Rear Linkage	---	---	----
265	142	Solar Panel - Right Rear Linkage	144	144	-235
266	143	Solar Panel - Right Rear Linkage	139	140	-231
267	144	Solar Panel - Right Rear Linkage	125	125	-216
268	145	Solar Panel - Right Rear Linkage	153	154	-193

TABLE 5-2

DAS POWER MEASUREMENTS FOR PSEP QUAL TEST AT LUNAR NOON AND LUNAR NIGHT EQUILIBRIUM

DAS Chan.	Description	Power-Watts Lunar Noon No Dump	Power-Watts Lunar Noon 10 W. Dump	Lunar Night
120 x 121	Isotope Heater #1	14.75	14.77	15.24
122 x 123	Isotope Heater #2	14.82	14.86	15.29
271 x 272	PCU Heaters #1 and #2	7.04	7.04	0
273 x 274	PCU Heaters #3 and #4	7.13	1.43	0
275 x 276	Transmitter Heaters #1 and #2	8.19	8.19	0
277 x 278	Command Receiver and Data Processor Heaters	1.27	1.27	0
279 x 280	Command Decoder, PDU, and A/D Converter Heaters	4.54	4.49	0
281 x 282	PSE Heater	3.80	3.80	0
283 x 284	PDM Panel Heat Leak Heater	1.63	3.42	0

Note: Power values shown in the last three columns of the table were obtained by multiplying data values (current times voltage) from the pairs of DAS channels listed in the first column of the table.

Figure 5-23. Flight Acceptance Test Thermal Plate Temperatures

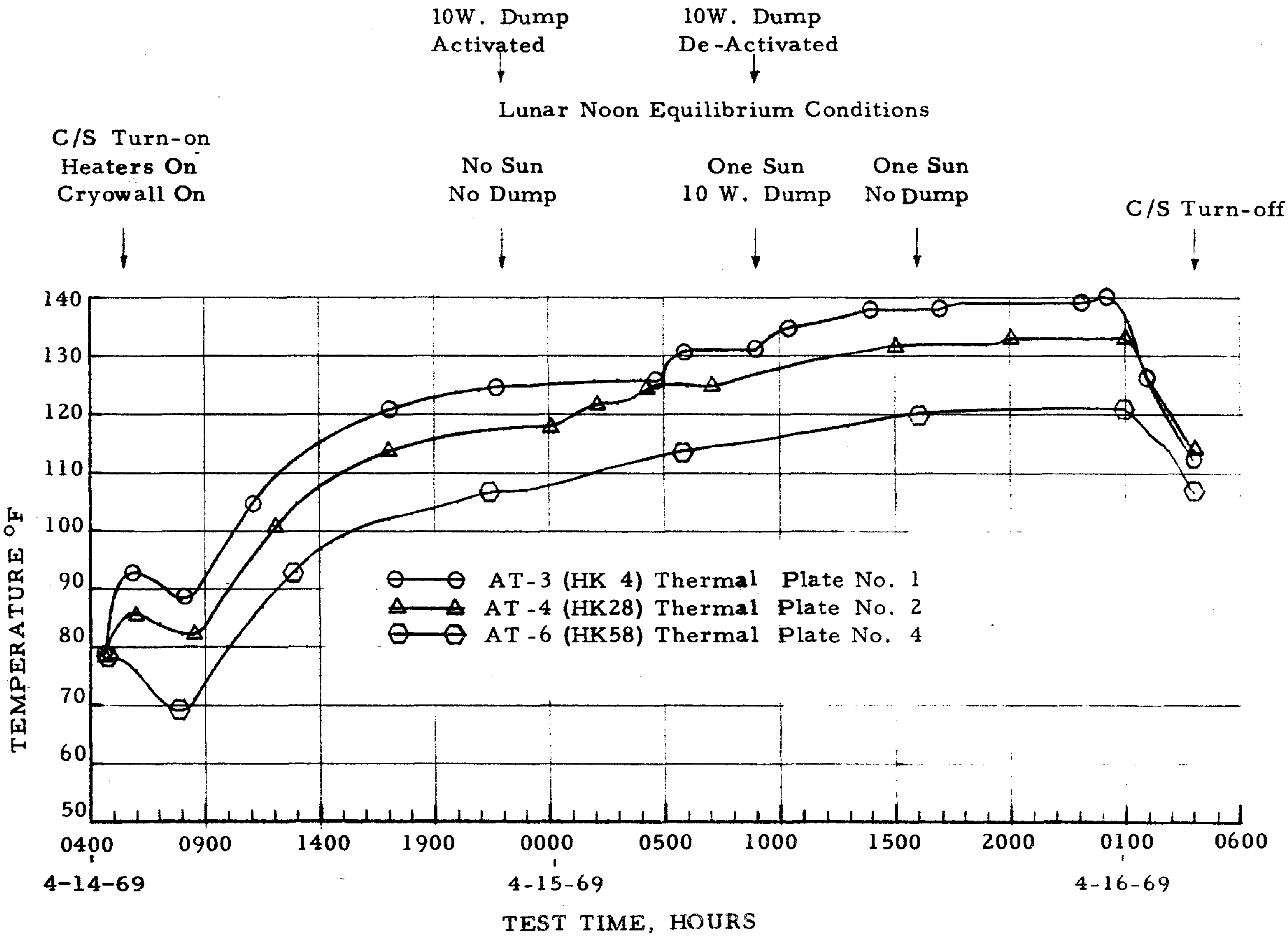


Figure 5-24. Flight Acceptance Test Electronics and Internal Thermal Bag Temperatures

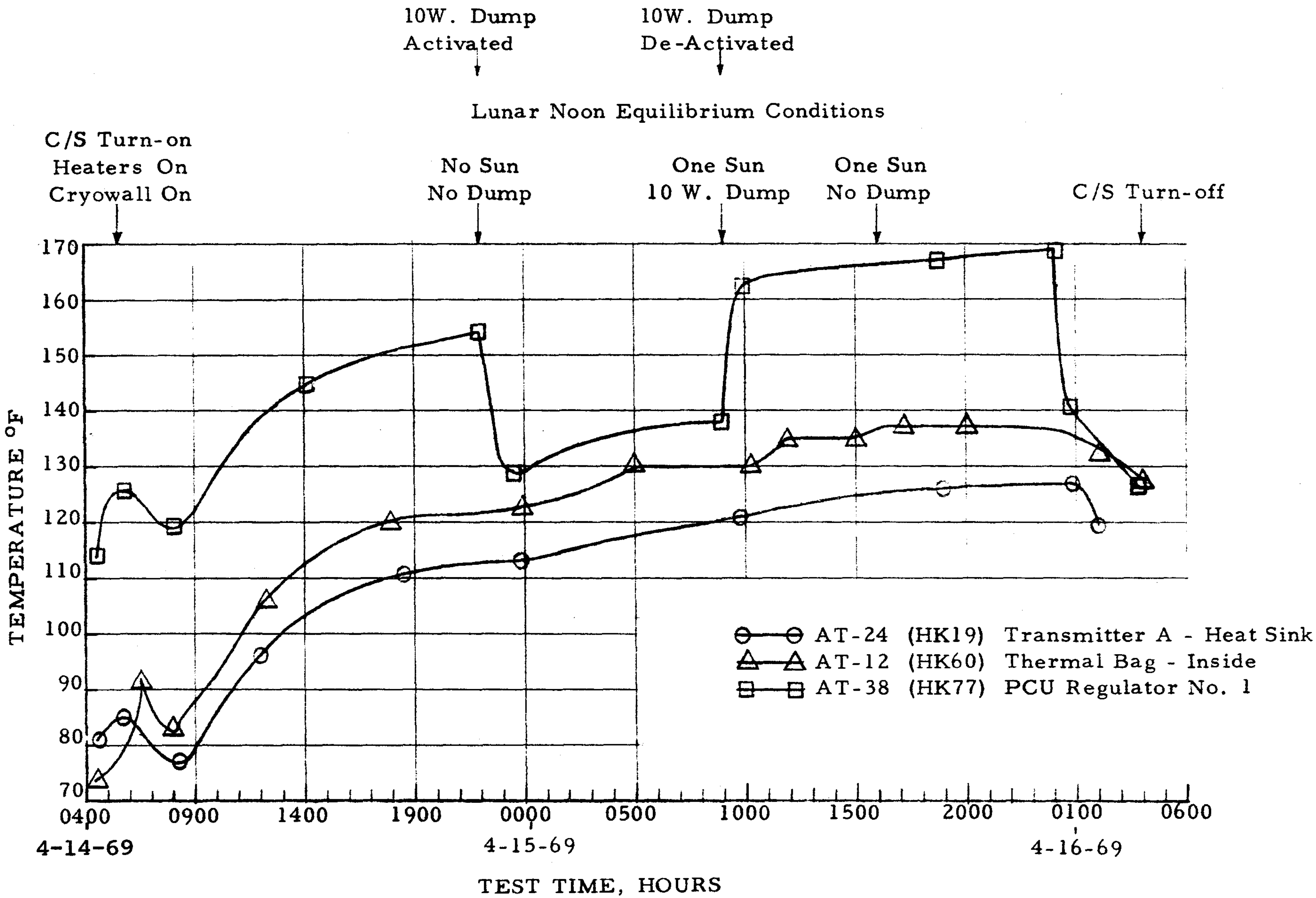


Figure 5-25. Flight Acceptance Test Structure, PDM Panel, and External Thermal Bag Temperatures and Reserve Power

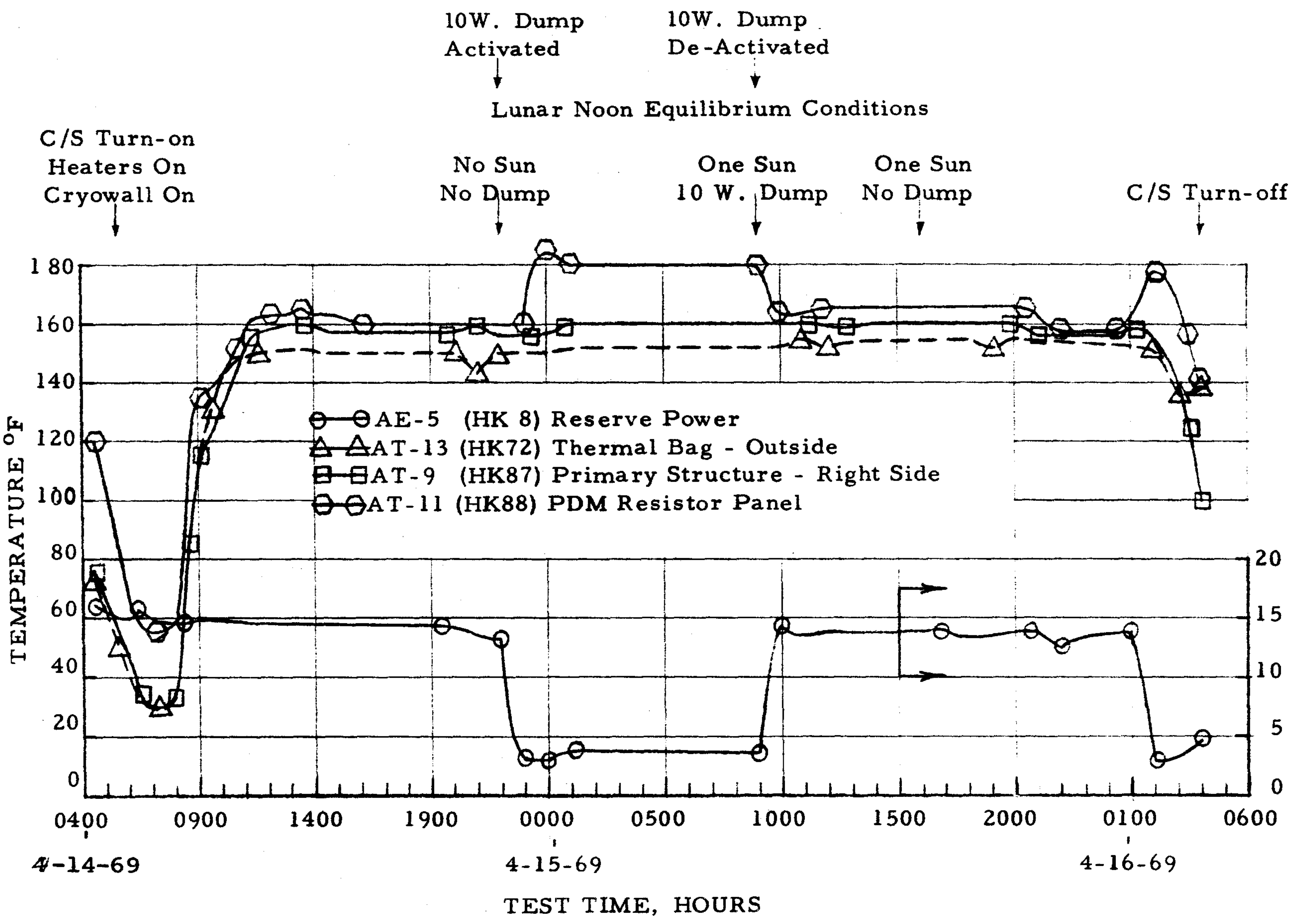


TABLE 5-3

HK TEMPERATURE MEASUREMENTS FOR PSEP FLIGHT ACCEPTANCE TEST AT LUNAR NOON EQUILIBRIUM

AT No.	HK No.	Description	Temperature - °F No Sun No Dump	One Sun 10 W. Dump	One Sun No Dump
1	27	Left Solar Cell Panel	86*	90*	91*
2	42	Right Solar Cell Panel	88*	92*	93*
3	4	Thermal Plate	125	131	138
4	28	Thermal Plate	118	126	132
5	43	Thermal Plate	120	132	137
6	58	Thermal Plate	106	115	120
7	71	Thermal Plate	111	118	125
8	59	Primary Structure-Left Side	150	156	155
9	87	Primary Structure-Right Side	156	160	160
10	15	Primary Structure-Bottom	152	156	157
11	88	PDM Resistor Panel	160	180	166
12	60	Thermal Bag-Interior	122	130	137
13	72	Thermal Bag-Exterior	150	152	155
21	16	Command Rcvr., Crystal A	113	119	125
22	17	Command Rcvr., Crystal B	---	---	---
23	18	Transmitter A-Crystal	115	122	127
24	19	Transmitter A-Heat Sink	113	119	125
25	31	Transmitter B-Crystal	---	---	---
26	32	Transmitter B-Heat Sink	---	---	---
27	33	Analog Mult. Conv.-Base	120	128	134
28	34	Analog Mult. Conv.-Internal	137	145	150
29	46	Digital Data Processor-Base	115	123	130
30	47	Digital Data Processor-Internal	127	135	141
31	48	Command Decoder-Base	116	124	129
32	49	Command Decoder-Internal	118	126	132
33	61	Command Demodulator-VCO	127	134	140
34	62	PDU-Base	121	128	134
35	63	PDU-Internal	142	148	155
36	64	PCU Power Oscillator No. 1	129	134	144
37	76	PCU Power Oscillator No. 2	124	130	138
38	77	PCU Regulator No. 1	153	137	167
39	78	PCU Regulator No. 2	124	127	138

*Solar heating of solar panel was not simulated during testing.

No Sun/No Dump (22:00 on 4/14/69)
One Sun/10 Watt Dump (09:00 on 4/15/69)
One Sun/No Dump (16:05 on 4/15/69)

5.3 Qual Retest Measurements

5.3.1 Cal Comp Plots of PSEP Temperatures

Presented are nineteen plots of some of the temperatures, absorbed solar simulation intensities, and powers recorded during the PSEP Qualification Model Thermal-Vacuum Retest. Table 5-4 lists the plot number, the measurements plotted on that plot, and the data acquisition system channel number of that measurement.

5.3.2 Temperatures and Power Levels at the Four Equilibirum Conditions

Table 5-5 lists the temperature of each PSEP location at the four thermal equilibrium conditions. Table 5-6 lists the power supplied to the electrical heaters that simulated the thermal dissipations of the PSEP components. Table 5-7 is a summary of the contents of Table 5-6. In both tables (5-6 and 5-7) comparison is made to the original qualification test.

5.3.3 Thermocouple Locations

Of the 145 PSEP thermocouples that were used during the Qual testing, (see Table 5-1) only the following T/C's were retained for the Qual Retest:

T/C No.	Location
1-14	Primary Structure
15-23, 27, 30, 34, 37, 40	Thermal Plate
65, 70, 71, 73	PSE
75	Heater 1 Top
78	Heater 1 Shroud Top
81	Heater 2 Top
84	Heater 2 Shroud Top
87	Mask, Left Front
88	Mask, Left Center
92, 94, 97, 99, 102, 104	Left Solar Panel
107, 109, 112, 114, 117, 119	Right Solar Panel

TABLE 5-4

PASSIVE SEISMIC LUNAR SIMULATION THERMAL-VACUUM TEST

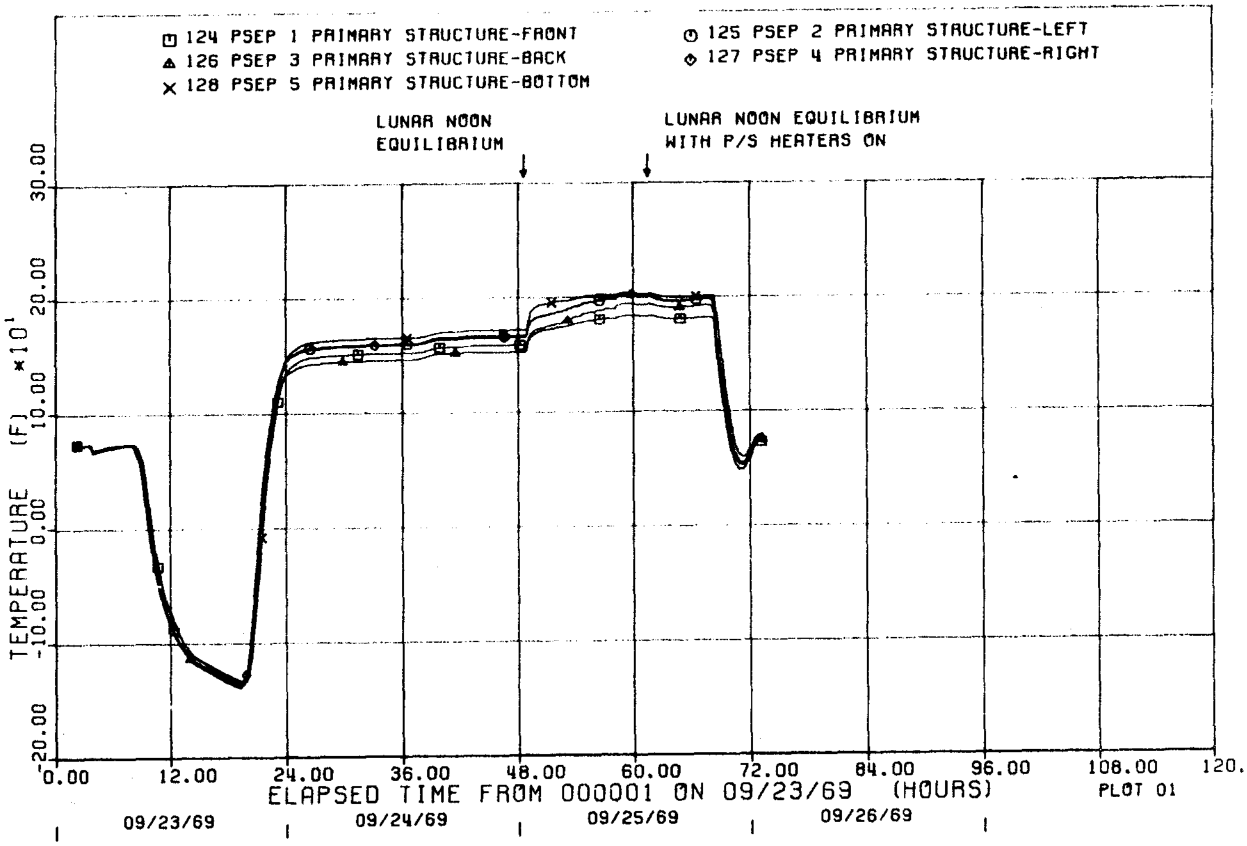
Graph	Channel	Description
1	124	PSEP 1 Primary Structure-Front
	125	PSEP 2 Primary Structure-Left
	126	PSEP 3 Primary Structure-Back
	127	PSEP 4 Primary Structure-Right
	128	PSEP 5 Primary Structure-Bottom
2	110	PSE MTG Plate Radiometer-Mirror
	113	PSEP Reference Radiometer-Black
	116	PSE Radiometer-Kapton
	198	Coupon Radiometer-Black
	199	Coupon Radiometer-Mirror
3	138	PSEP 65 PSE Simulator-Top
	139	PSEP 70 PSE Shroud-Top
	140	PSEP 71 PSE Shroud-Front Side
	141	PSEP 73 PSE Shroud-Back Side
4	142	PSEP 75 Right Isotope Heater-Top
	143	PSEP 78 Right Heater Shroud-Top
	144	PSEP 81 Left Isotope Heater-Top
	145	PSEP 84 Left Heater Shroud-Top
5	146	PSEP 87 Left Mask-Top Front
	147	PSEP 88 Left Mask-Top Center
6	148	PSEP 92 L Center Panel-Top
	149	PSEP 94 L Center Panel-Center
	150	PSEP 97 L Front Panel-Top
	151	PSEP 99 L Front Panel-Center
	152	PSEP 192 L Rear Panel-Top
	153	PSEP 104 L Rear Panel-Center
7	154	PSEP 107 R Center Panel-Top
	155	PSEP 109 R Center Panel-Center
	156	PSEP 112 R Front Panel-Top
	157	PSEP 114 R Front Panel-Center
	158	PSEP 117 R Rear Panel-Top
	159	PSEP 119 R Rear Panel-Center
8	160	PSEP 15 Thermal Plate-NR Bolt 1
	161	PSEP 16 Thermal Plate-NR Bolt 2
	163	PSEP 18 Thermal Plate-NR Bolt 4
9	164	PSEP 19 Thermal Plate-NR Bolt 5
	166	PSEP 21 Thermal Plate-NR Bolt 7
	167	PSEP 22 Thermal Plate-NR Bolt 8
	168	PSEP 23 Thermal Plate-NR Bolt 9

TABLE 5-4 (CONT.)

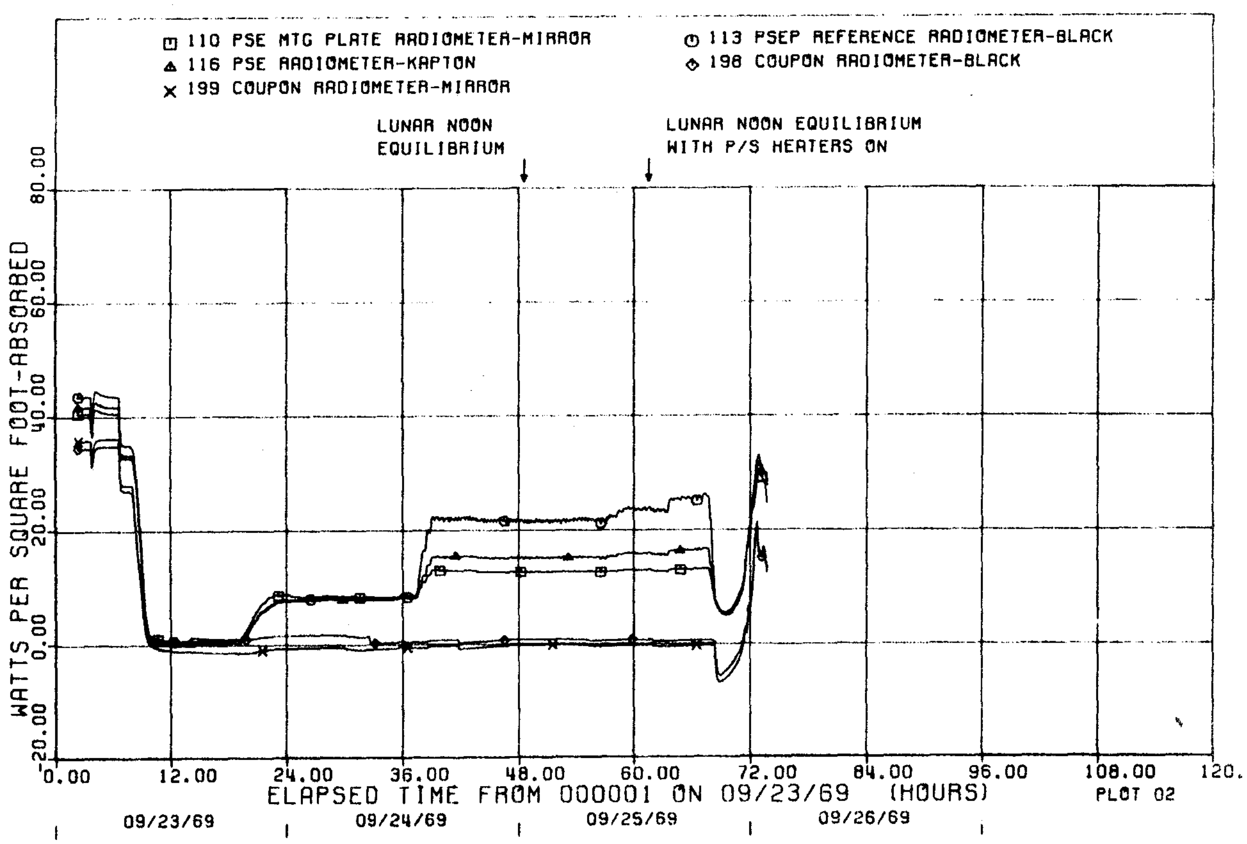
PASSIVE SEISMIC LUNAR SIMULATION THERMAL-VACUUM TEST

ιph	Channel	Description
10	169	PSEP 27 Thermal Plate-NR PDU
	170	PSEP 39 Thermal Plate-NR PSE
	171	PSEP 34 Thermal Plate-Data PROC
11	172	PSEP 37 Thermal Plate-Diplexer
	173	PSEP 40 Thermal Plate-NR Xmitter
	174	PSEP 59 PSE MTG Plate-Under PSE
	175	PSEP 64 PSE MTG Plate-Under PSE
12	218	Primary Structure-Bottom-Heater
	219	Primary Structure-Sides-Heater
13	210	Isotope Heater Number 1
	211	Isotope Heater Number 2
	212	PCU 1 And PCU 2 Heaters
	213	PCU 3 And PCU 4 Heaters
14	214	Transmitter 1 And 2 Heaters
	215	CMD RCVR And Data Proc Heaters
	216	CMD DCDR, PDU, And A/D Conv Heater
	217	PSE Heater
15	129	PSEP 06 Primary Structure-Left
	160	PSEP 15 Thermal Plate-NR Bolt 1
	166	PSEP 21 Thermal Plate-NR Bolt 7
	167	PSEP 22 Thermal Plate-NR Bolt 8
16	132	PSEP 09 Primary Structure-Rear
	133	PSEP 10 Primary Structure-Rear
	163	PSEP 18 Thermal Plate-NR Bolt 4
	164	PSEP 19 Thermal Plate-NR Bolt 5
17	005	T/C Reference Box Number 8
	007	T/C Reference Box Number 3
	010	T/C Reference Box Number 7
	176	T/C Reference Box Number 4
	177	T/C Reference Box Number 5
18	111	PSE MTG Plate Radiometer-Temp
	114	PSEP Reference Radiometer-Temp
	117	PSE Radiometer-Temperature
	200	Coupon-Black-Radiometer-Temp
	203	Coupon-Mirror-Radiometer-Temp
19	110	PSEP-Watts Per Sq Ft Absorbed
	024	LS 14 Lunar Surface-Middle Zone
	093	CW 24 Cold Wall-Arch Panel
	172	PSEP 27 Thermal Plate-Diplexer

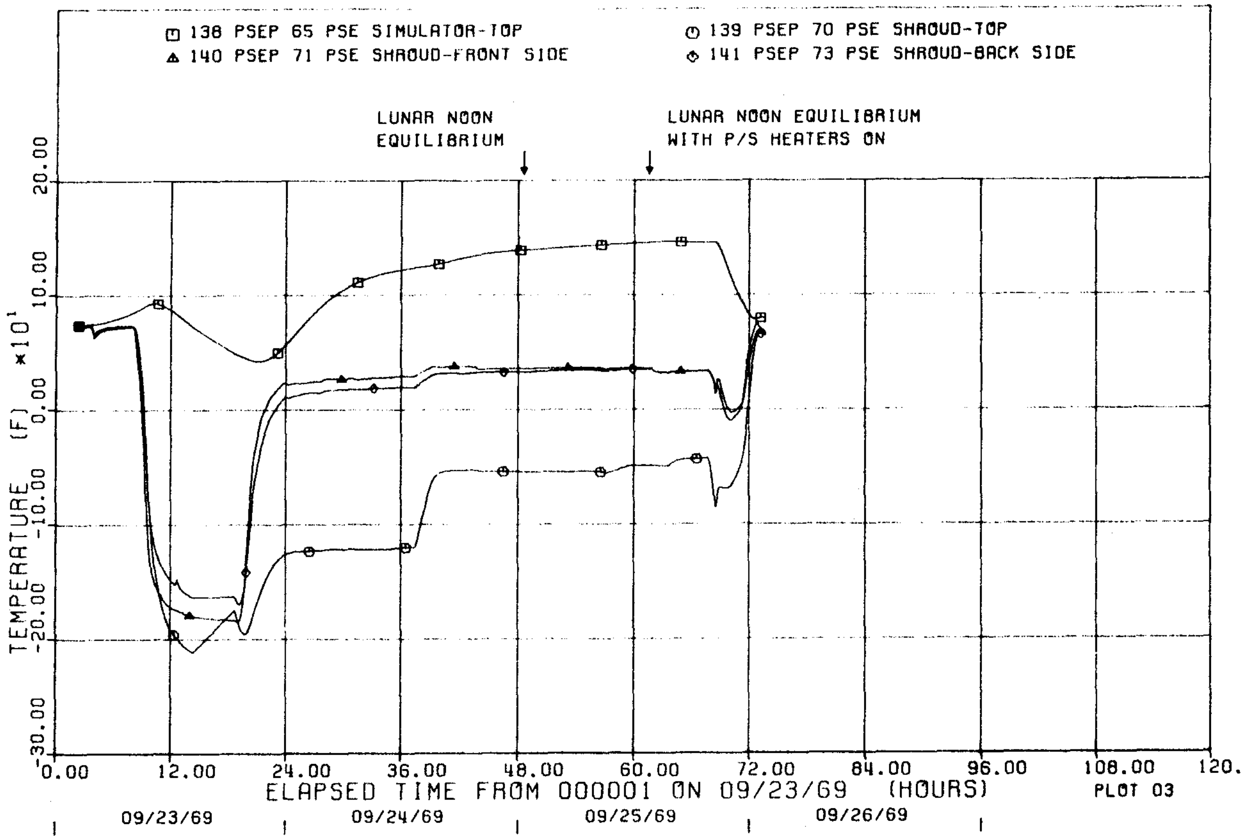
BENDIX AEROSPACE SYSTEMS DIVISION
PROGRAM PSEP TEST NO. S2 TEST DATE 09/23/69 ZERO TIME 000001
TEST TITLE PSEP LUNAR SIMULATION THERMAL VACUUM TEST



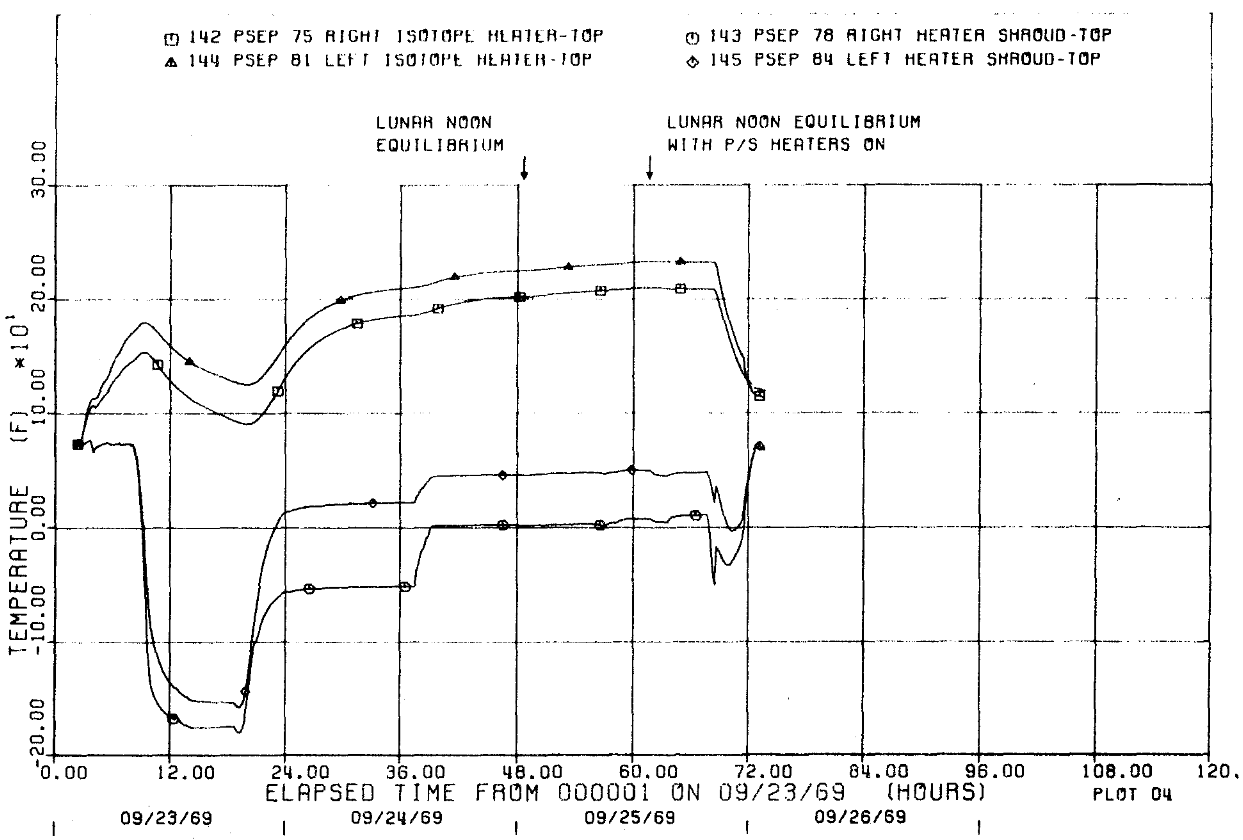
BENDIX AEROSPACE SYSTEMS DIVISION
PROGRAM PSEP TEST NO. S2 TEST DATE 09/23/69 ZERO TIME 000001
TEST TITLE PSEP LUNAR SIMULATION THERMAL VACUUM TEST



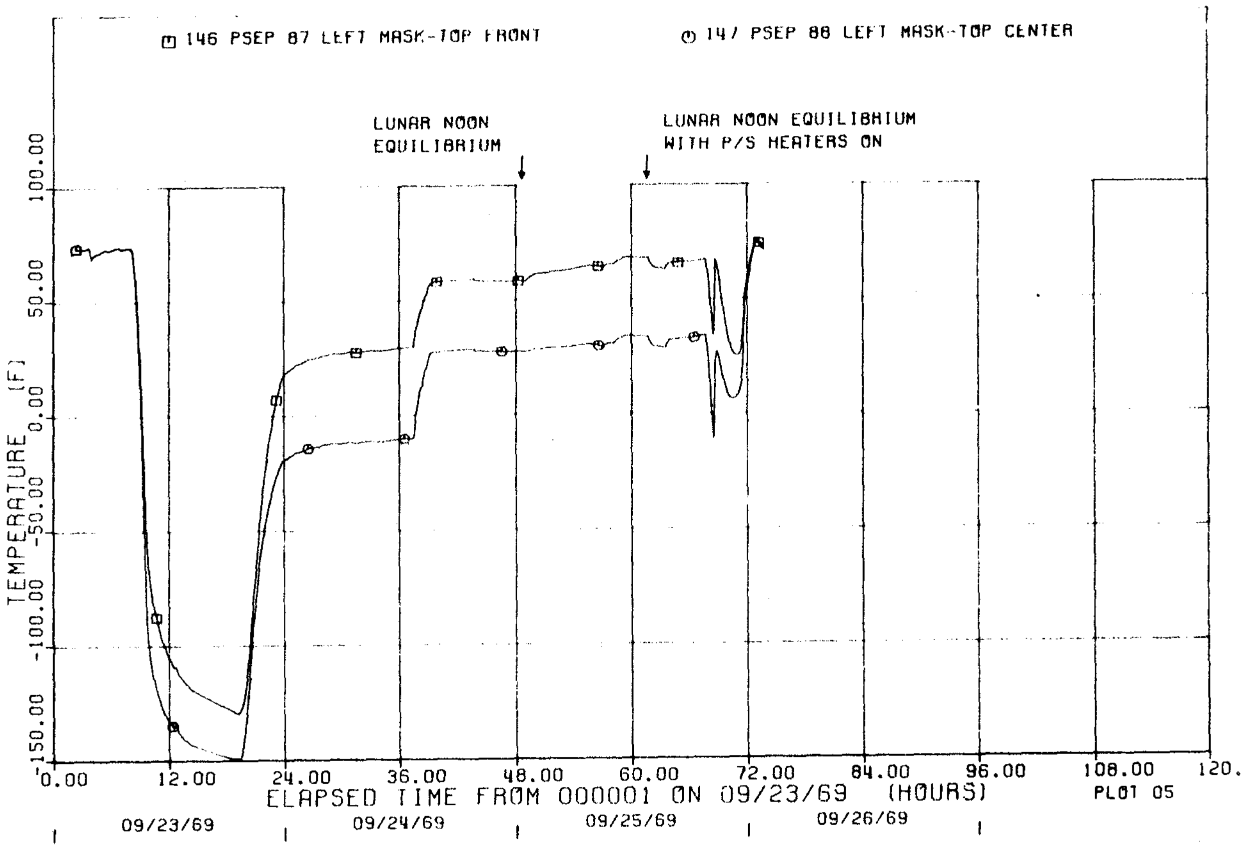
BENDIX AEROSPACE SYSTEMS DIVISION
PROGRAM PSEP TEST NO. S2 TEST DATE 09/23/69 ZERO TIME 000001
TEST TITLE PSEP LUNAR SIMULATION THERMAL VACUUM TEST



BENDIX AEROSPACE SYSTEMS DIVISION
PROGRAM PSEP TEST NO. S2 TEST DATE 09/23/69 ZERO TIME 000001
TEST TITLE PSEP LUNAR SIMULATION THERMAL VACUUM TEST

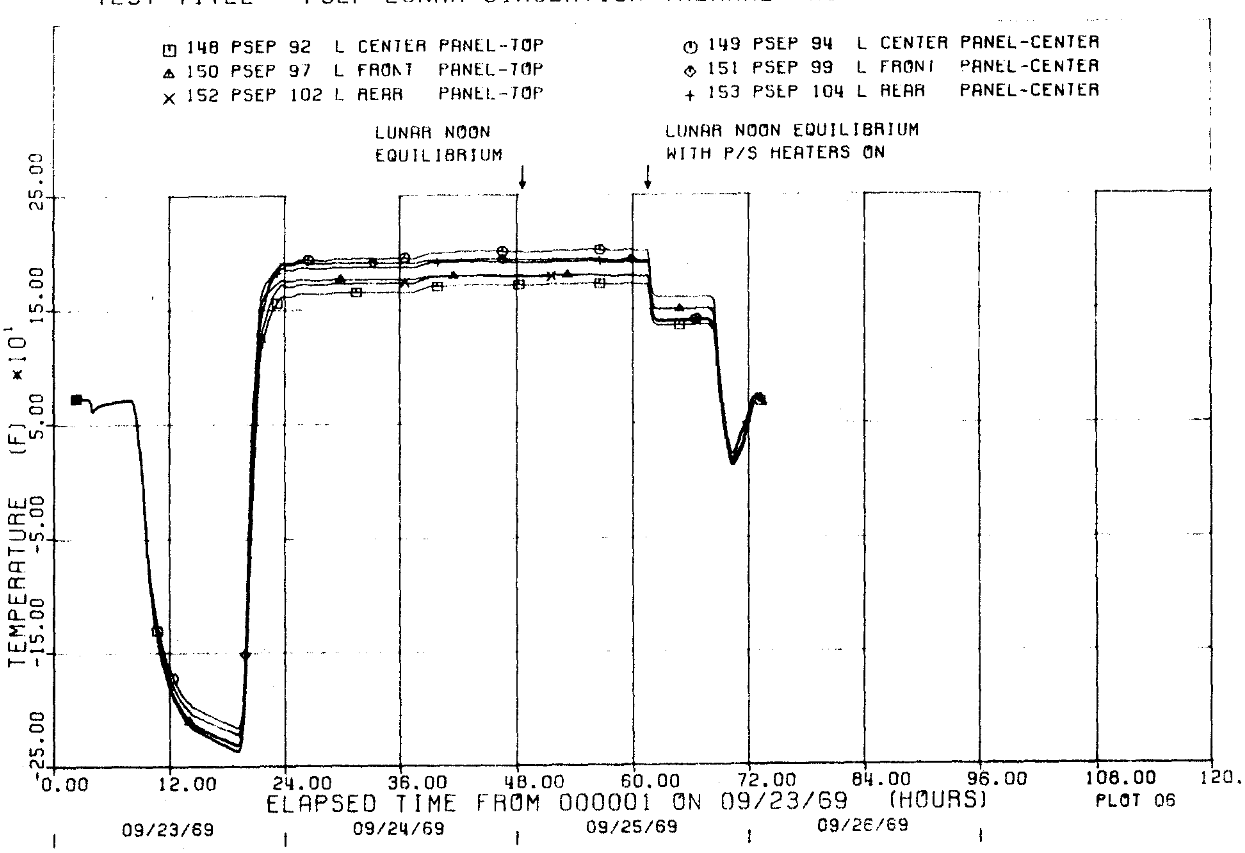


BENDIX AEROSPACE SYSTEMS DIVISION
PROGRAM PSEP TEST NO. S2 TEST DATE 09/23/69 ZERO TIME 000001
TEST TITLE PSEP LUNAR SIMULATION THERMAL VACUUM TEST



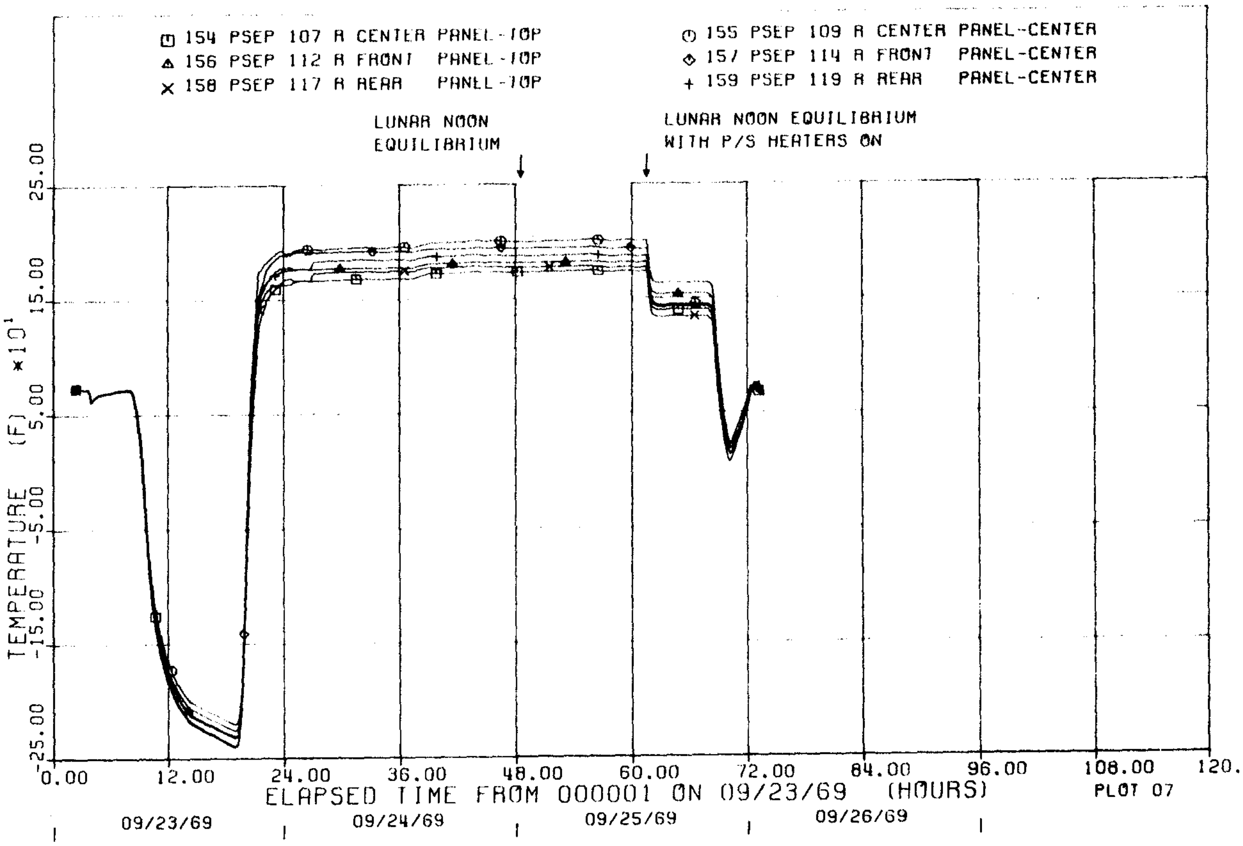
PLOT 05

BENDIX AEROSPACE SYSTEMS DIVISION
PROGRAM PSEP TEST NO. S2 TEST DATE 09/23/69 ZERO TIME 000001
TEST TITLE PSEP LUNAR SIMULATION THERMAL VACUUM TEST

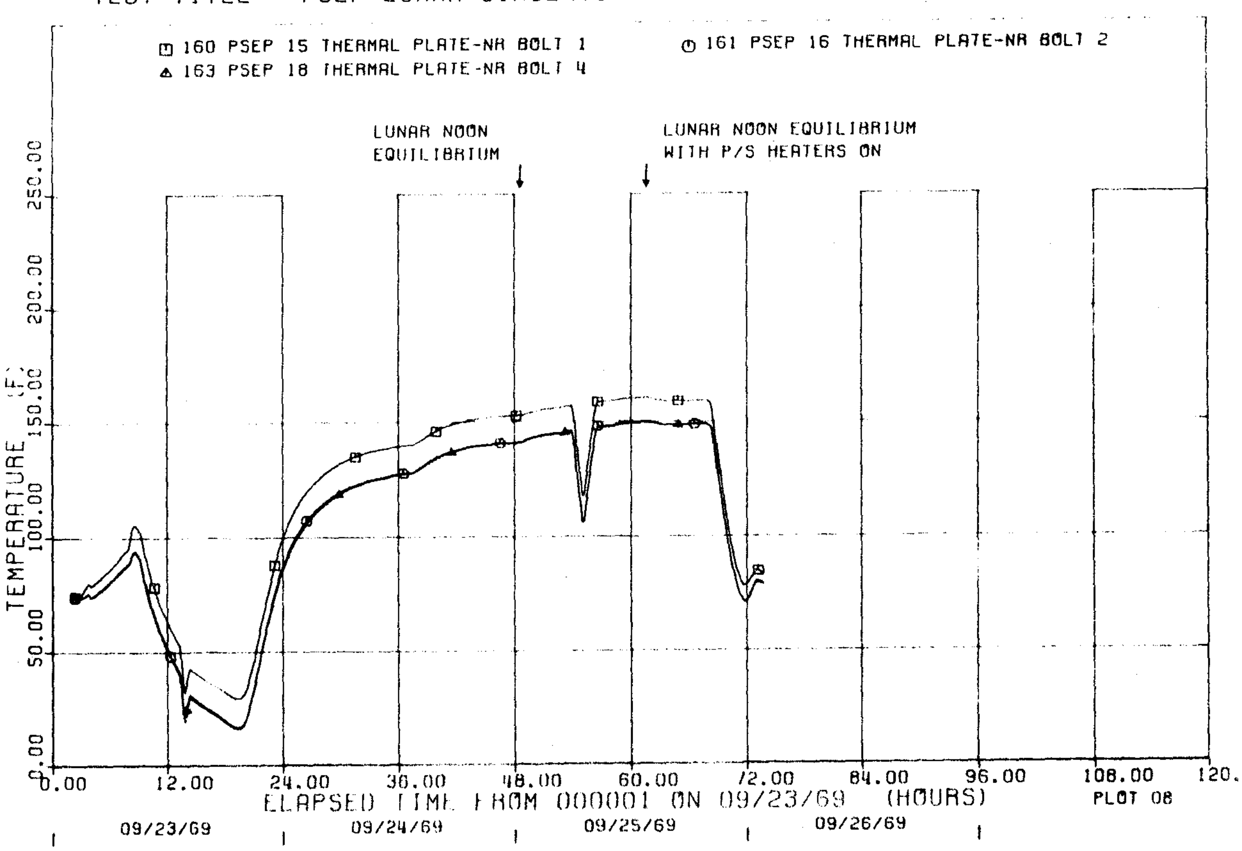


PLOT 06

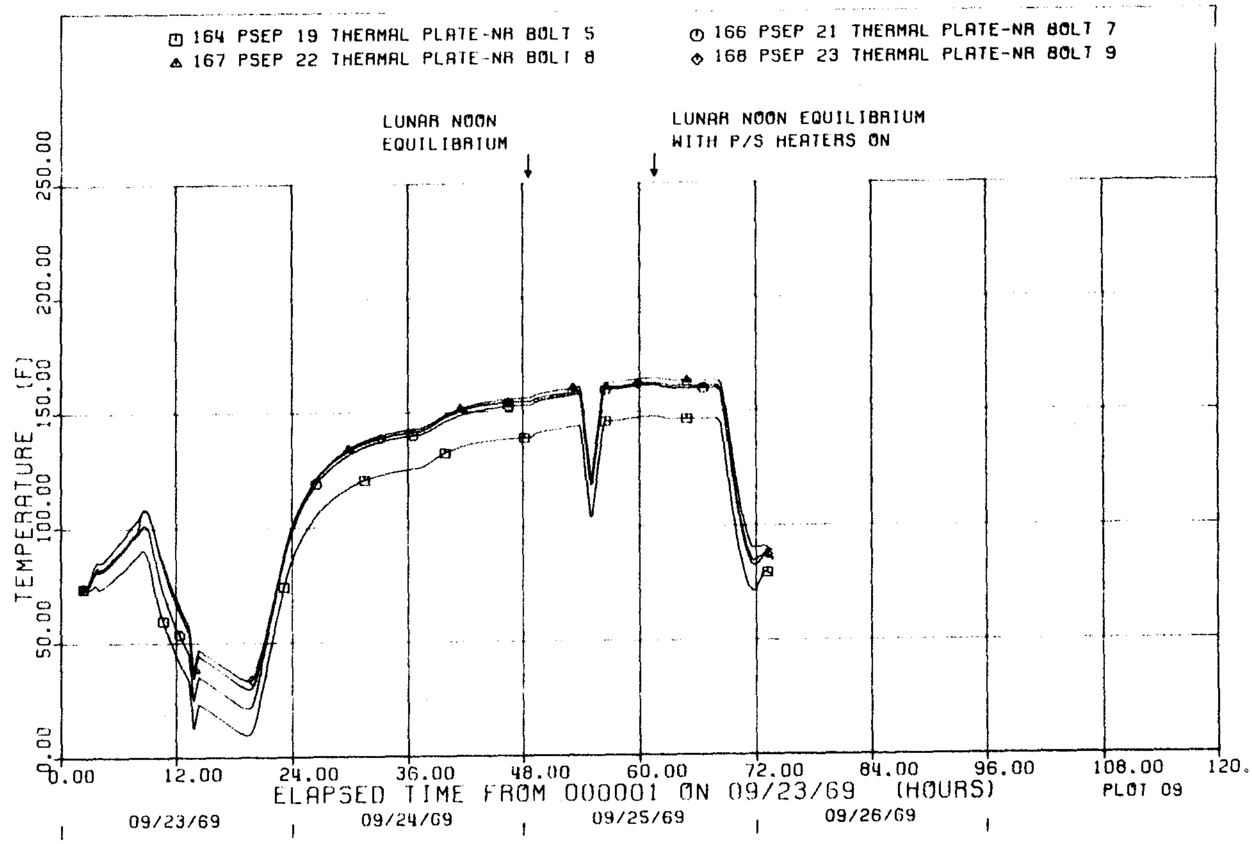
BENDIX AEROSPACE SYSTEMS DIVISION
PROGRAM PSEP TEST NO. S2 TEST DATE 09/23/69 ZERO TIME 000001
TEST TITLE PSEP LUNAR SIMULATION THERMAL VACUUM TEST



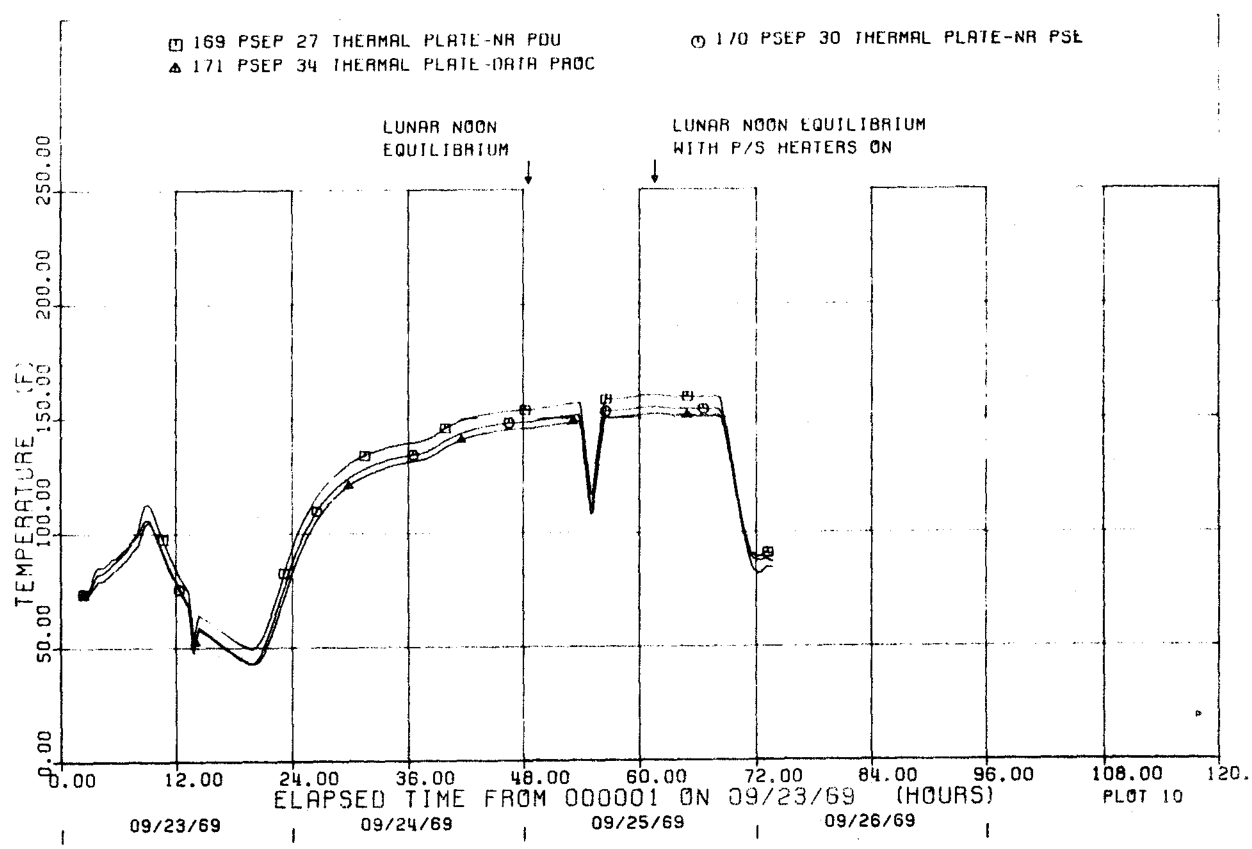
BENDIX AEROSPACE SYSTEMS DIVISION
PROGRAM PSEP TEST NO. S2 TEST DATE 09/23/69 ZERO TIME 000001
TEST TITLE PSEP LUNAR SIMULATION THERMAL VACUUM TEST



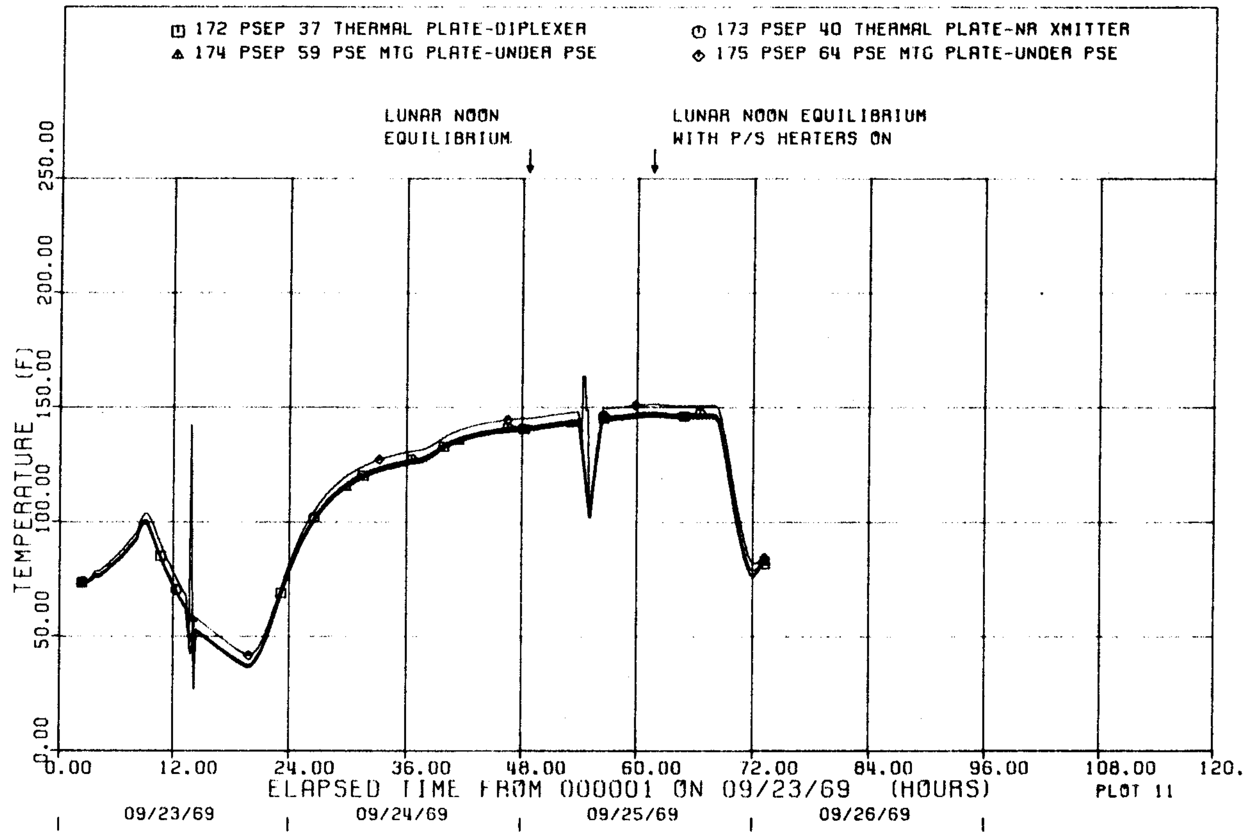
BENDIX AEROSPACE SYSTEMS DIVISION
PROGRAM PSEP TEST NO. S2 TEST DATE 09/23/69 ZERO TIME 000001
TEST TITLE PSEP LUNAR SIMULATION THERMAL VACUUM TEST



BENDIX AEROSPACE SYSTEMS DIVISION
PROGRAM PSEP TEST NO. S2 TEST DATE 09/23/69 ZERO TIME 000001
TEST TITLE PSEP LUNAR SIMULATION THERMAL VACUUM TEST

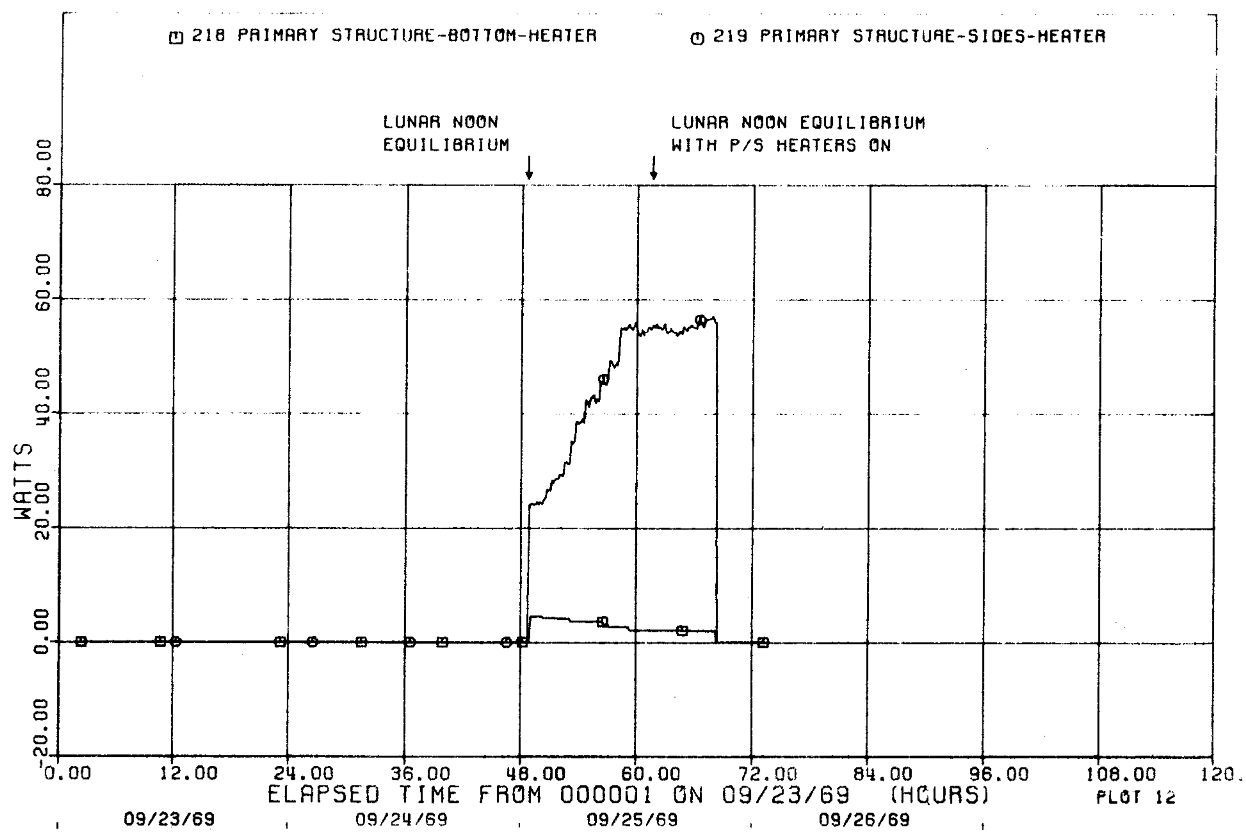


BENDIX AEROSPACE SYSTEMS DIVISION
PROGRAM PSEP TEST NO. S2 TEST DATE 09/23/69 ZERO TIME 000001
TEST TITLE PSEP LUNAR SIMULATION THERMAL VACUUM TEST



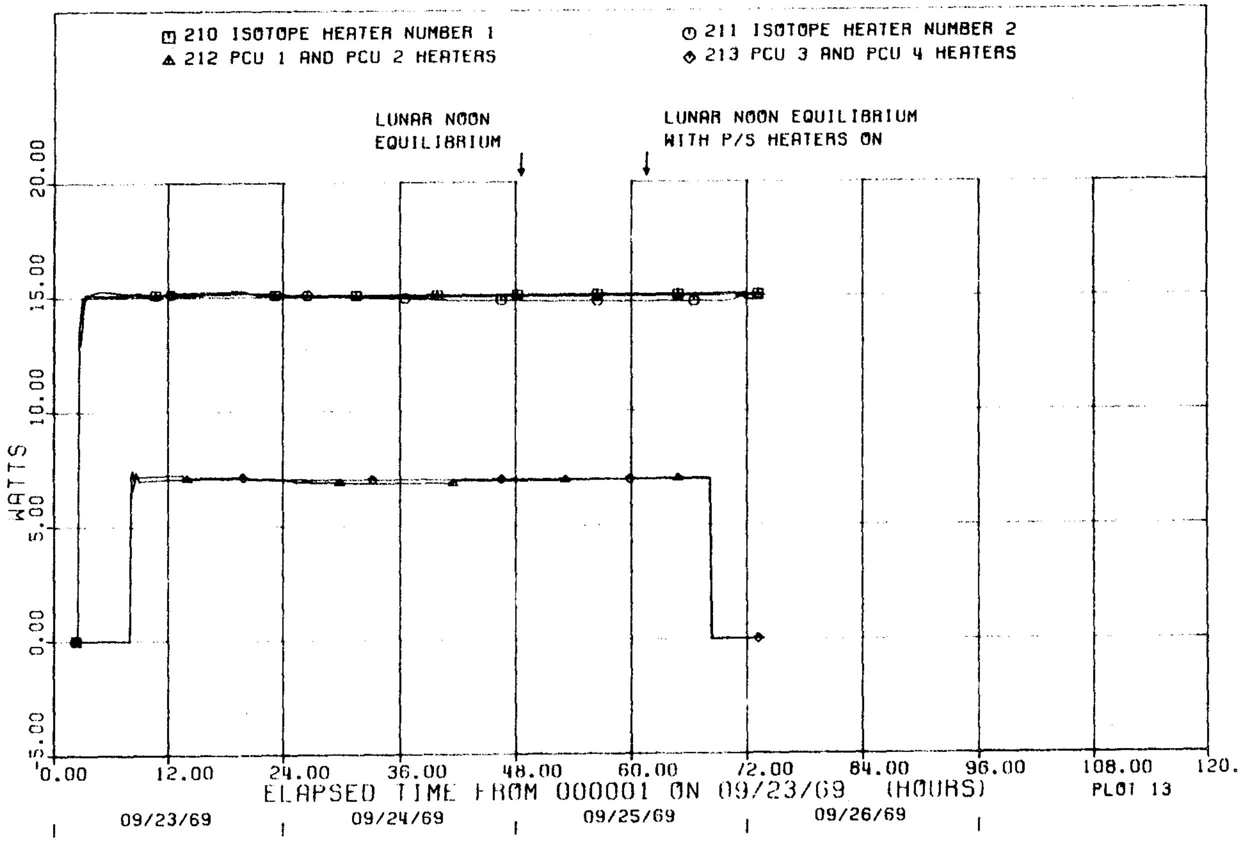
PLOT 11

BENDIX AEROSPACE SYSTEMS DIVISION
PROGRAM PSEP TEST NO. S2 TEST DATE 09/23/69 ZERO TIME 000001
TEST TITLE PSEP LUNAR SIMULATION THERMAL VACUUM TEST

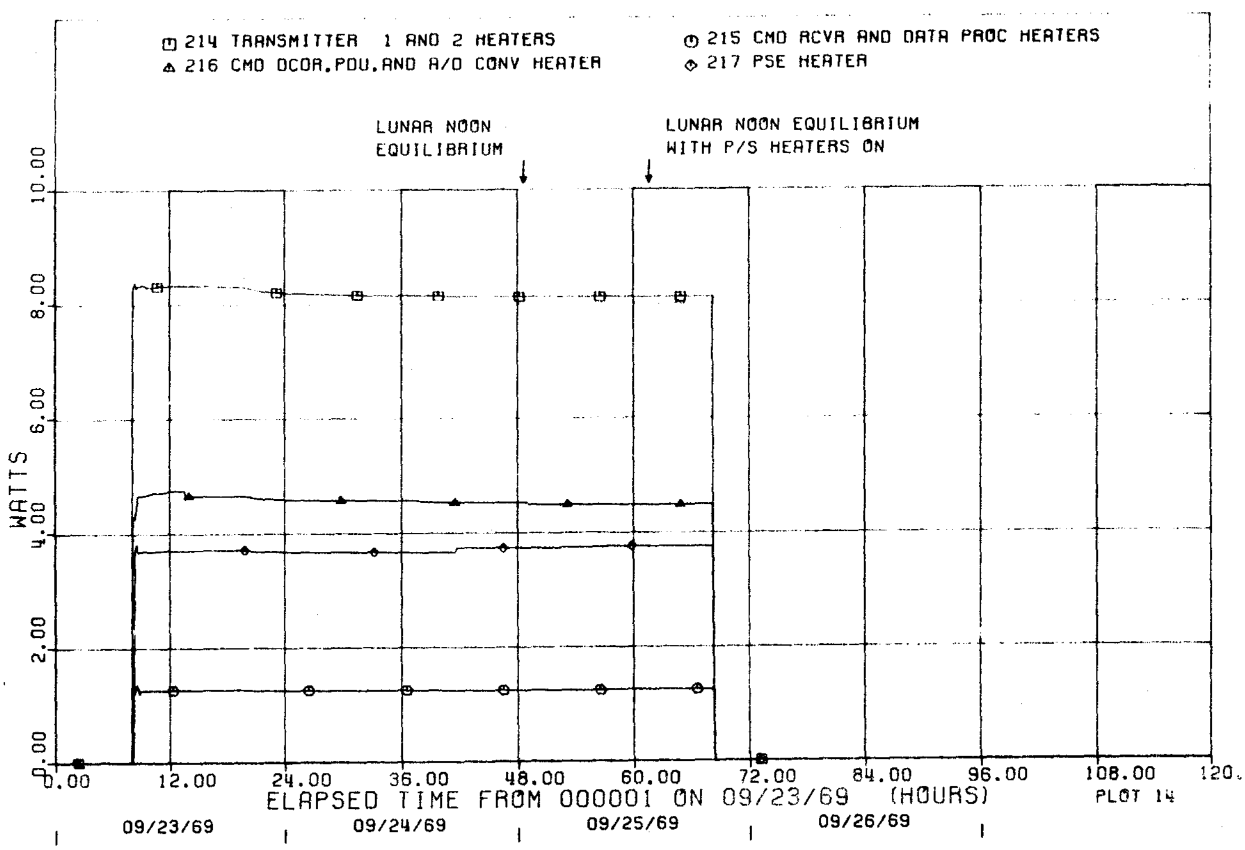


PLOT 12

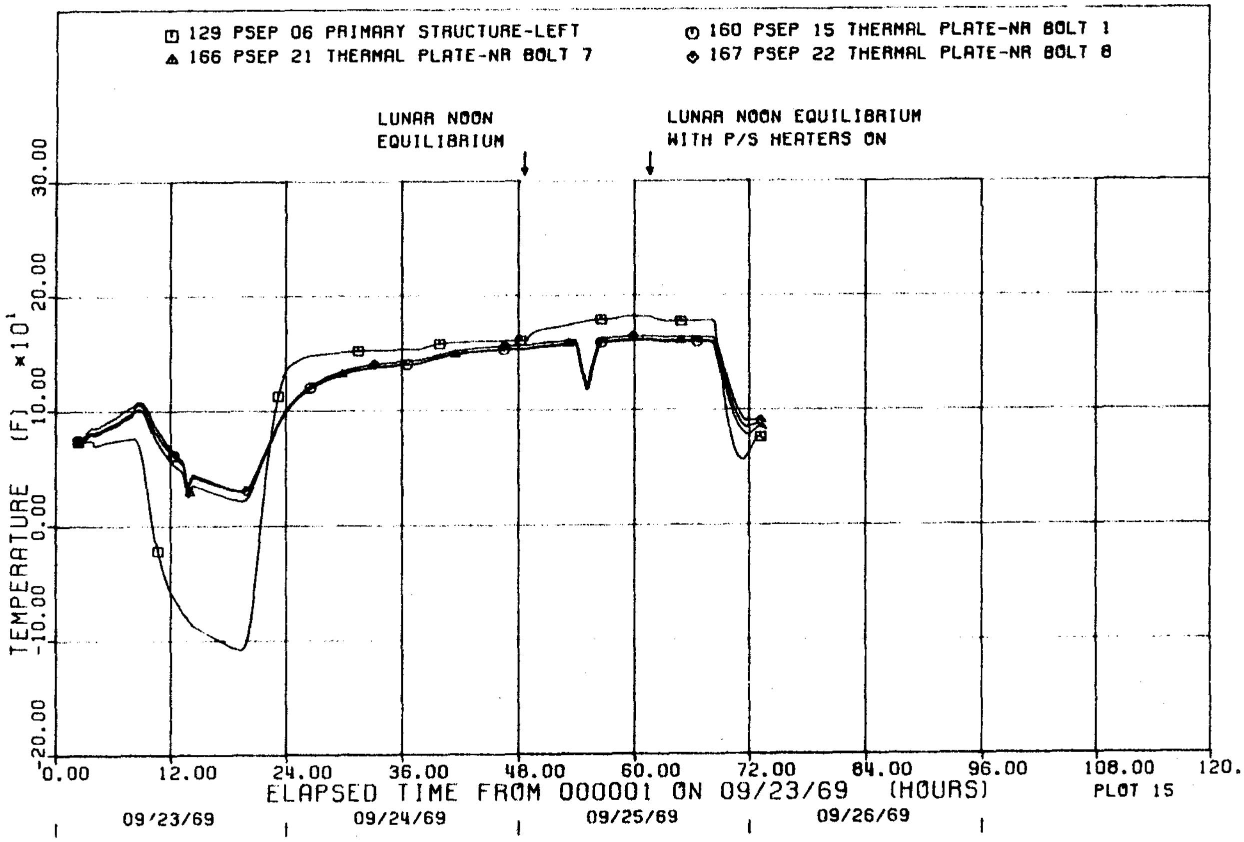
BENDIX AEROSPACE SYSTEMS DIVISION
PROGRAM PSEP TEST NO. S2 TEST DATE 09/23/69 ZERO TIME 000001
TEST TITLE PSEP LUNAR SIMULATION THERMAL VACUUM TEST



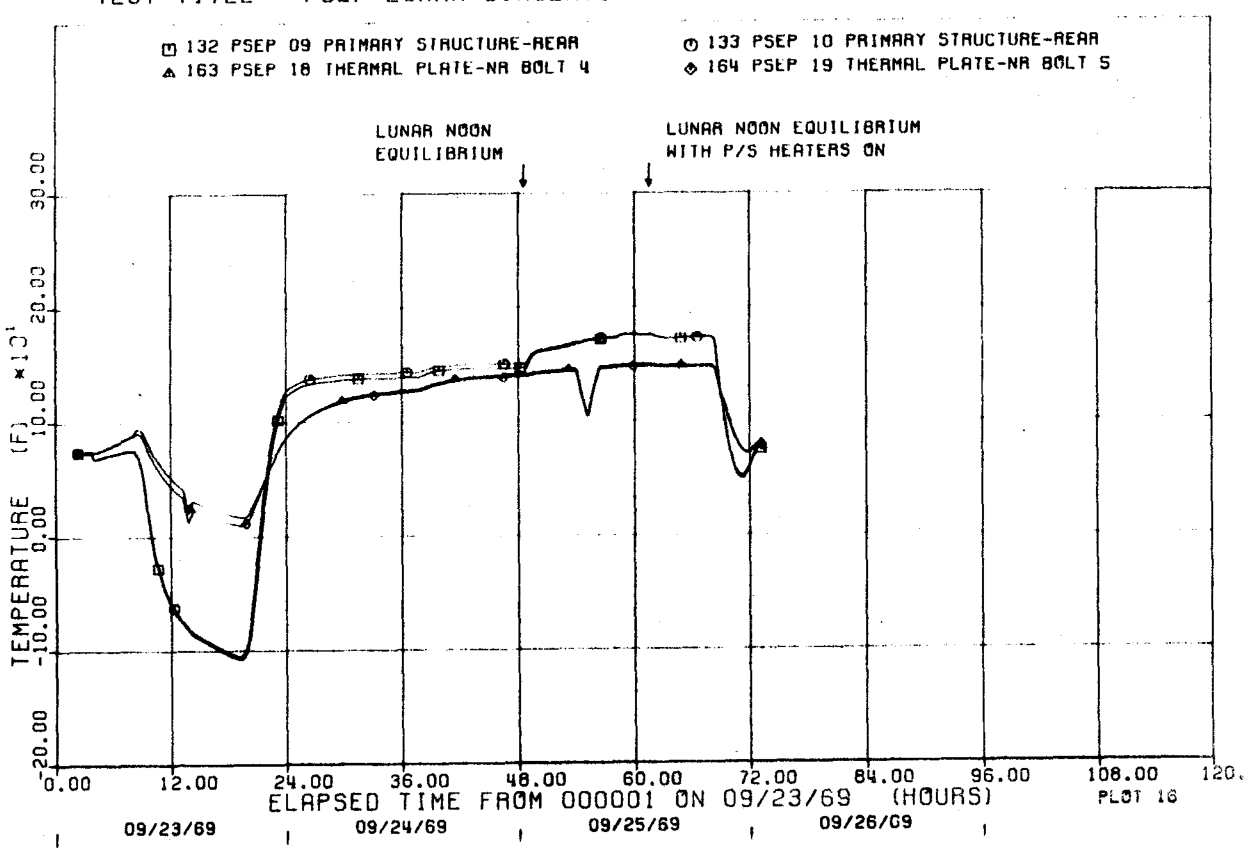
BENDIX AEROSPACE SYSTEMS DIVISION
PROGRAM PSEP TEST NO. S2 TEST DATE 09/23/69 ZERO TIME 000001
TEST TITLE PSEP LUNAR SIMULATION THERMAL VACUUM TEST



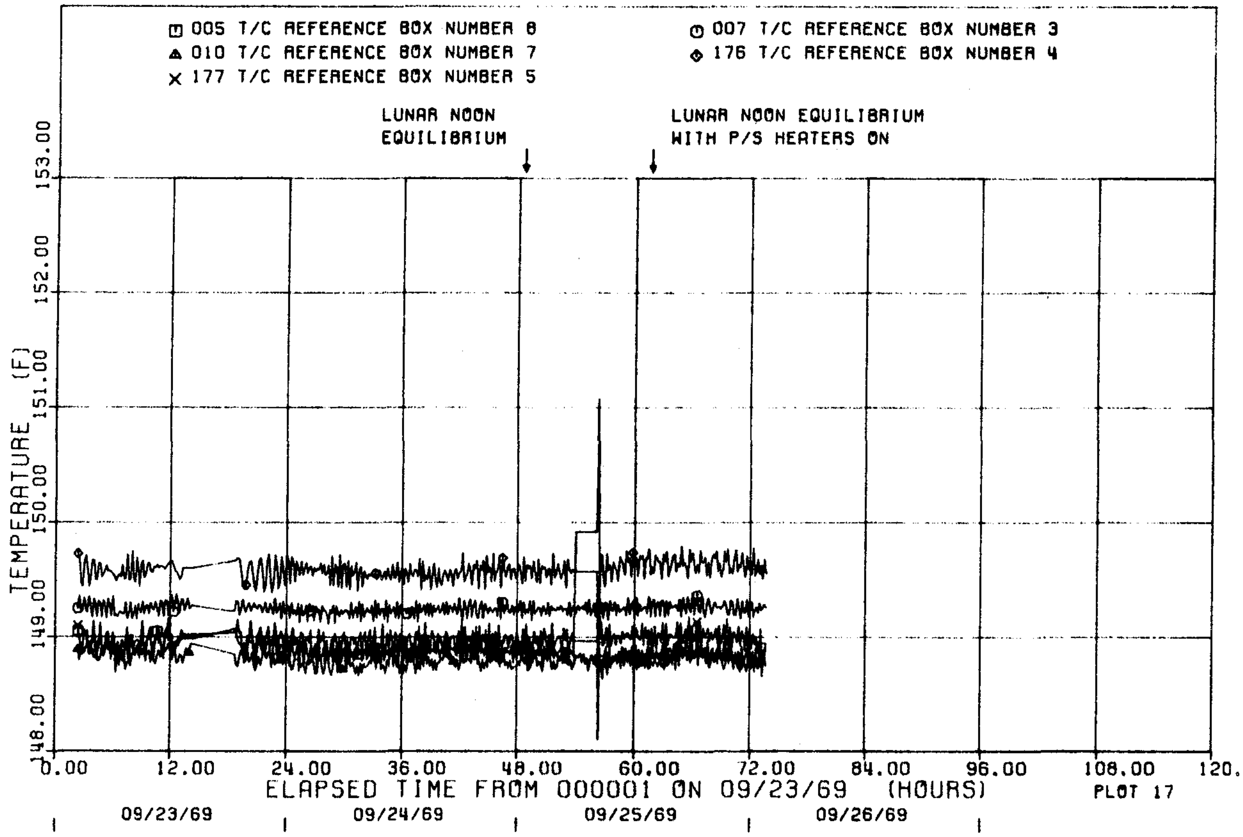
BENDIX AEROSPACE SYSTEMS DIVISION
PROGRAM PSEP TEST NO. S2 TEST DATE 09/23/69 ZERO TIME 000001
TEST TITLE PSEP LUNAR SIMULATION THERMAL VACUUM TEST



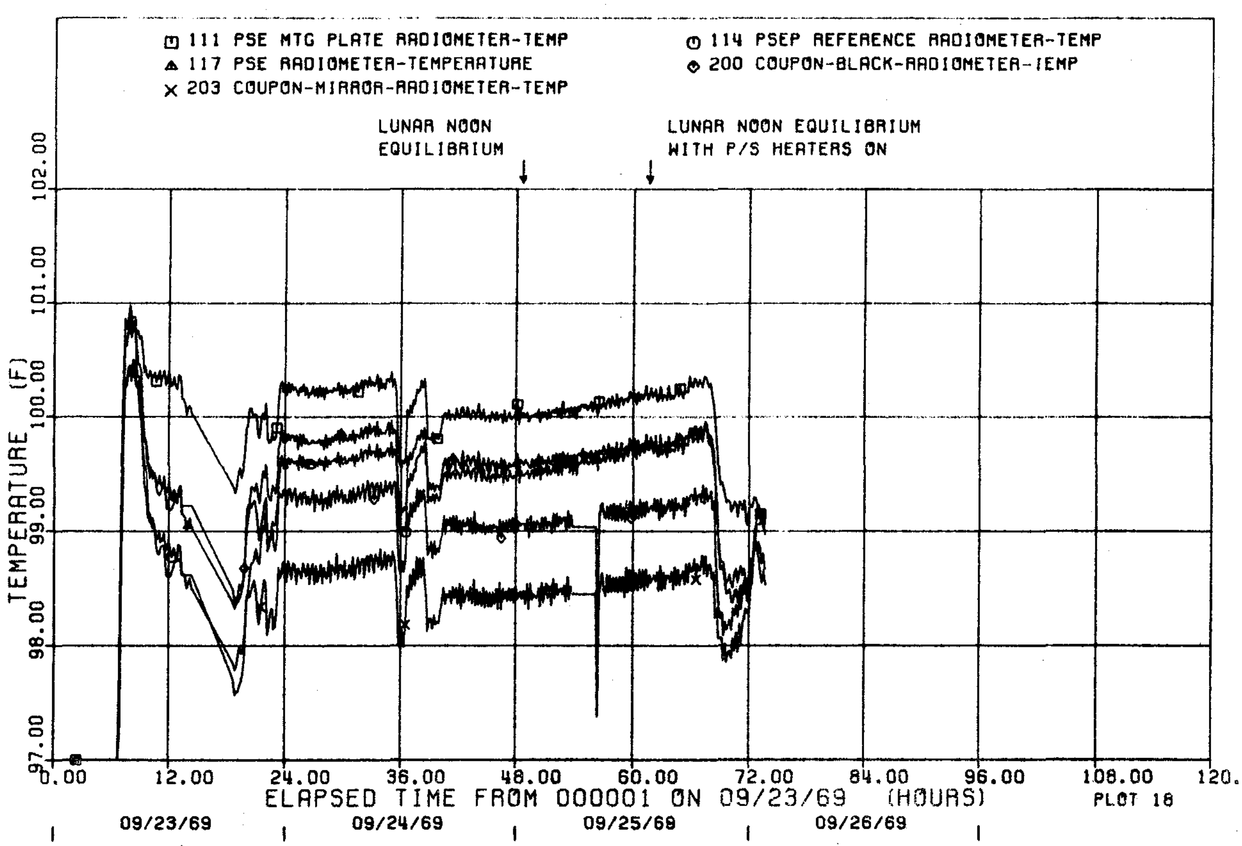
BENDIX AEROSPACE SYSTEMS DIVISION
PROGRAM PSEP TEST NO. S2 TEST DATE 09/23/69 ZERO TIME 000001
TEST TITLE PSEP LUNAR SIMULATION THERMAL VACUUM TEST



BENDIX AEROSPACE SYSTEMS DIVISION
PROGRAM PSEP TEST NO. S2 TEST DATE 09/23/69 ZERO TIME 000001
TEST TITLE PSEP LUNAR SIMULATION THERMAL VACUUM TEST



BENDIX AEROSPACE SYSTEMS DIVISION
PROGRAM PSEP TEST NO. S2 TEST DATE 09/23/69 ZERO TIME 000001
TEST TITLE PSEP LUNAR SIMULATION THERMAL VACUUM TEST



BENDIX AEROSPACE SYSTEMS DIVISION
PROGRAM PSEP TEST NO. S2 TEST DATE 09/23/69 ZERO TIME 000001
TEST TITLE PSEP LUNAR SIMULATION THERMAL VACUUM TEST

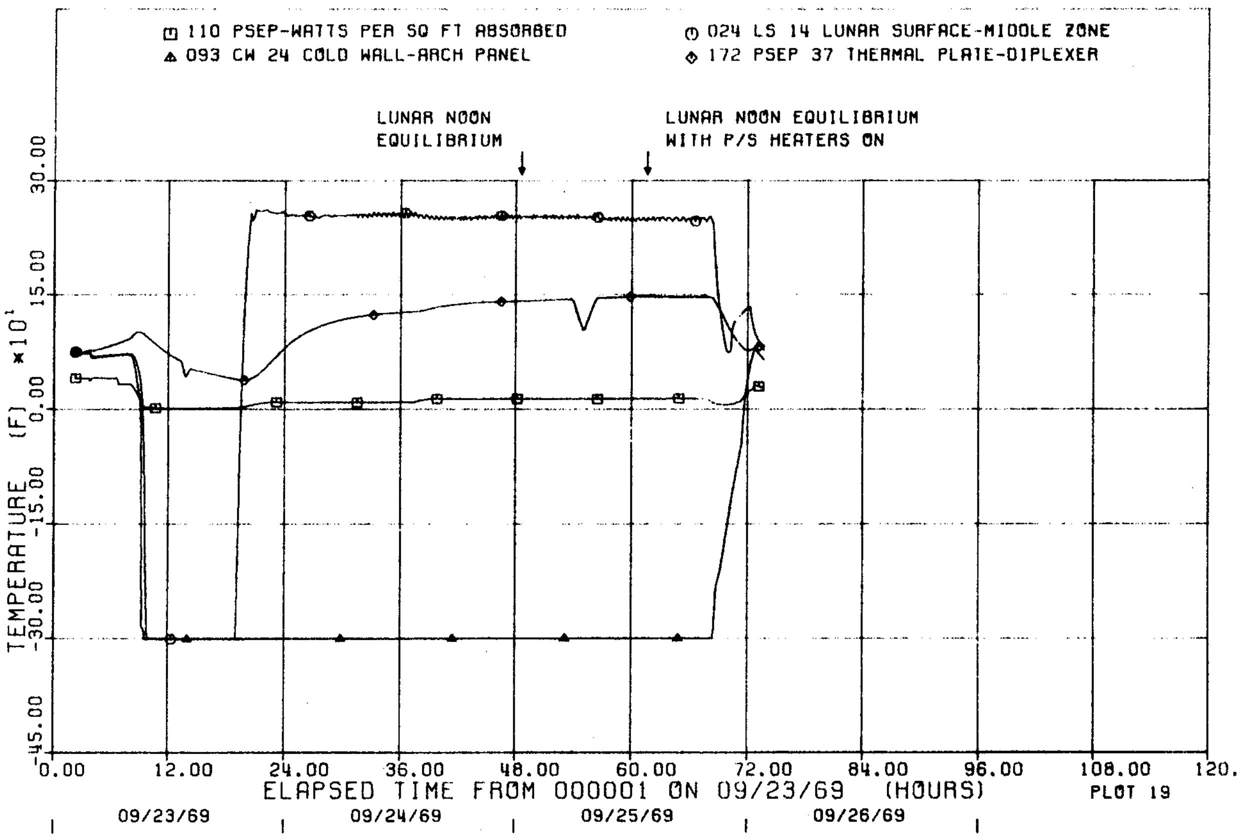


TABLE 5-5

TEMPERATURES OF COMPONENTS

Data Acquisition System Channel	Temperature Sensor Location	Temperatures - °F			
		No Solar Heating	One Sun With Normal Structure Temperature	One Sun With Structure at Temp. Recorded on Moon	One Sun With Solar Panels at 150° ± 10°F
124	Primary Structure, Front Side	152	158	183	182
125	Primary Structure, Left Side	159	166	201	198
126	Primary Structure, Back Side	146	152	194	192
127	Primary Structure, Right Side	159	164	202	198
128	Primary Structure, Bottom	165	171	202	200
129	Primary Structure, Near Bolt #1	153	160	182	178
130	Primary Structure, Near Bolt #2	144	152	179	176
131	Primary Structure, Near Bolt #3	139	147	174	172
132	Primary Structure, Near Bolt #4	138	146	175	174
133	Primary Structure, Near Bolt #5	143	150	176	173
134	Primary Structure, Near Bolt #6	146	153	178	175
135	Primary Structure, Near Bolt #7	-*	-	-	-
136	Primary Structure, Near Bolt #8	153	160	184	182
137	Primary Structure, Near Bolt #9	152	159	179	177
138	PSE Sensor Simulator - Top	123	139	145	145
139	PSE Sensor Shroud - Top	-120	-55	-50	-43
140	PSE Sensor Shroud - Front	28	35	36	33
141	PSE Sensor Shroud - Back	19	32	34	33
142	Right Isotope Heater Simulator - Top	186	202	210	209
143	Right Isotope Heater Shroud - Top	-52	2	7	11
144	Left Isotope Heater Simulator - Top	210	224	233	232
145	Left Isotope Heater Shroud - Top	22	46	50	48

*Open Thermocouple

TABLE 5-5 (CONT.)

Data Acquisition System Channel	Temperature Sensor Location	Temperatures - °F			
		No Solar Heating	One Sun With Normal Structure Temperature	One Sun With Structure at Temp. Recorded on Moon	One Sun With Solar Panels at 150° ± 10°F
146	Mounting Plate Mask - Front	29	58	68	67
147	Mounting Plate Mask - Center	-10	27	34	34
148	Left Center Solar Cell Panel Location 1	165	171	172	136
149	Left Center Solar Cell Panel Location 2	194	200	201	141
150	Left Front Solar Cell Panel Location 1	176	179	178	150
151	Left Front Solar Cell Panel Location 2	190	193	192	160
152	Left Rear Solar Cell Panel Location 1	172	178	179	139
153	Left Rear Solar Cell Panel Location 2	186	191	191	150
154	Right Center Solar Cell Panel Location 1	167	173	173	140
155	Right Center Solar Cell Panel Location 2	194	199	200	144
156	Right Front Solar Cell Panel Location 1	177	181	181	154
157	Right Front Solar Cell Panel Location 2	191	194	193	163
158	Right Rear Solar Cell Panel Location 1	174	177	177	134
159	Right Rear Solar Cell Panel Location 2	184	187	187	142
160	Thermal Plate, Near Bolt 1	140	153	160	159
161	Thermal Plate, Near Bolt 2	128	141	150	149
162	Thermal Plate, Near Bolt 3	-	-	-	-
163	Thermal Plate, Near Bolt 4	128	141	149	149
164	Thermal Plate, Near Bolt 5	126	138	148	147
165	Thermal Plate, Near Bolt 6	-	-	-	-
166	Thermal Plate, Near Bolt 7	140	153	161	160
167	Thermal Plate, Near Bolt 8	143	156	164	163
168	Thermal Plate, Near Bolt 9	142	154	162	161
169	Thermal Plate, Near PDU Electronics	140	154	160	159
170	Thermal Plate, PSE Electronics	135	148	155	154
171	Thermal Plate, Data Processor	132	145	152	151
172	Thermal Plate, Diplexer Switch	127	140	147	146
173	Thermal Plate, Near Transmitter	128	141	148	147
174	PSE Mounting Plate, Under PSE, Rear Center	126	140	146	145
175	PSE Mounting Plate, Under PSE, Center	131	145	151	151
207	Left Isotope Heater Shroud, Side	58	76	81	81
208	PSE Sensor Shroud, Lower Section, Back Side	49	59	61	60
209	PSE Sensor Shroud, Lower Section, Left Side	36	56	60	53

TABLE 5-6

DAS POWER MEASUREMENTS OF SIMULATED THERMAL DISSIPATION FOR PSEP QUAL TEST AND RETEST AT LUNAR NOON WITH ONE SUN

Description	Power - Watts		
	Test	Retest	
	No Power Dump	Normal Structure Temperature	Structure at 195°F
Isotope Heater No. 1	14.75	15.05	15.04
Isotope Heater No. 2	14.82	14.79	14.75
PCU Heaters No. 1 and No. 2	7.04	6.93	7.00
PCU Heaters No. 3 and No. 4	7.13	6.98	6.98
Transmitter Heaters No. 1 and No. 2	8.19	8.12	8.11
Command Receiver and Data Processor Heaters	1.27	1.24	1.24
Command Decoder, PDU, and A/D Converter Heaters	4.54	4.51	4.47
PSE Heaters	3.80	3.73	3.76
PDM Panel Heat Leak Heater	1.63	---	---
Primary Structure - Bottom Heaters	---	0.00	2.07
Primary Structure - Side Heaters	---	0.00	54.56

TABLE 5-7

SUMMARY OF SIMULATED THERMAL DISSIPATION FOR PSEP QUAL TEST AND RETEST AT LUNAR NOON WITH ONE SUN

	Power - Watts		
	Test	Retest	
Description	No Power Dump	Normal Structure Temperature	Structure at 195°F
1. Internal Dissipation	31.97	31.51	31.56
2. Isotope Heaters	29.57	29.84	29.79
3. Primary Structure	- - -	0.00	56.63
Total c/s Dissipation (1&2)	61.54	61.35	61.35

Although the primary change in instrumentation between the Qual and the Qual retest models resulted in thermocouple deletions, there were three thermocouple additions for the Qual retest model. One T/C (No. 85) was added to the heater 2 shroud and two T/C's (No. 145, 147) were added to the PSE shroud.

6.0 DISCUSSION

6.1 Analytical and Test Results

This section presents temperatures predicted with the PSEP thermal models as a function of model node numbers. Test measurements which correspond to the node locations are compared with the predicted values. Thermal dissipations by the electronics, isotope heaters, and PDM resistors for the Qual and Flight models are listed in Table 6-1. Tables 6-2 to 6-4 present temperatures for the Qual model, while temperatures for the Flight model (with and without plume heating protection) are shown in Tables 6-5 through 6-7. Temperature and power levels for the Qual Retest were presented in Section 5.3.2.

The following information is presented in Tables 6-2 through 6-7.

1. Thermal model node numbers
2. Description of each node
3. Predicted temperatures of all nodes at lunar noon and night equilibrium for T/V chamber test conditions.
4. Predicted temperatures of all nodes at lunar noon and night equilibrium for operation in a real lunar environment. Values are given for Flight models with and without plume heating protection.
5. Test temperatures for those nodes where applicable measurements were taken.

Correlation between test and predicted figures was excellent as discrepancies were generally less than 10°F. Correlation of average radiator plate temperatures was within 4°F.

Reflected solar energy was considered in the analytical models during the lunar day and was assumed to be diffuse. However, preliminary investigations indicate that the second-surface mirrors and Kapton are highly specular, and as a result predicted temperatures for the electronics, thermal plate, and mounting plate should be about 6°F lower than the values listed in Tables 6-2 through 6-8.

TABLE 6-1

PSEP POWER/THERMAL DISSIPATIONS FOR QUAL AND FLIGHT MODELS

	Power/Thermal Dissipation - Watts				
Thermal Model	Electronics plus PSE Sensor	Isotope Heaters	PDM Panel Dump	Total on Thermal & Mounting Plates	Total on PDM Panel
Qual Chamber Model - Noon, No Dump	31.97	29.57	5.0	61.54	5.0
Qual Chamber Model - Noon, 10 Watt Dump	26.22	29.63	10.5	55.85	10.5
Qual Chamber Model - Night	0	30.53	0	30.53	0
Qual Real Moon Model - Noon, No Dump	31.9	30.00	5.0	61.90	5.0
Qual Real Moon Model - Noon, 10 Watt Dump	26.30	30.00	10.5	56.30	10.5
Qual Real Moon Model - Night	0	30.00	0	30.00	0
Flight Chamber and Real Moon Models - Noon, No Dump	31.90	30.00	5.0	61.90	5.0
Flight Chamber and Real Moon Models - Noon, 10 Watt Dump	26.30	30.00	10.5	56.30	10.5
Flight Chamber and Real Moon Models - Night	0	30.00	0	30.00	0

TABLE 6-2

COMPARISON OF QUAL TEST TEMPERATURES TO TEMPERATURES PREDICTED WITH QUAL THERMAL MODEL FOR NO-DUMP CONDITION AT LUNAR NOON EQUILIBRIUM

Thermal Model Node No.	Node Description	Temperature -°F		
		Chamber Test	Pred. Chamber	Pred. Moon
1	PSE Insulation Shroud	-73/85	84	108
2	Heater #1 Insulation Shroud	7/81	100	129
3	Heater #2 Insulation Shroud	42/75	102	130
4	Second-Surface Mirrors		132	133
5	Left Insulation Mask	50/69	82	82
6	Second-Surface Mirrors		131	128
7	Right Insulation Mask	75/77	90	92
8	Second-Surface Mirrors		139	143
9	Second-Surface Mirrors		137	140
10	Left Solar Panel Back	182/224	200	195
11	Right Solar Panel Back	186/223	200	195
12	Left Solar Panel Front		158	197
13	Right Solar Panel Front		158	197
14	Isotope Heater #1	189/199	170	173
15	Isotope Heater #2	191/205	155	160
16	PSE Mounting Plate	145	134	136
17	↓	152	157	159
18			138	141
19		143	142	145
20		145	139	143
21		147	137	140
22			133	134
23			133	134
24		137	133	134
25		138	136	137
26		136	139	143
27		134	132	140
28		135	132	130
29	↓	136	133	134
30	PSE Sensor	133	134	141

Thermal Model Node No.	Node Description	Temperature - F		
		Chamber Test	Pred. Chamber	Pred. Moon
50	Lunar Subsurface Model	NA	NA	-25
51	↓	↓	↓	-22
52				-4
53				22
54				54
55				84
56				114
57				144
58				174
59				204
60				234
61				157
62				-23
63				-1
64				27
65				60
66				90
67				115
68				136
69				152
70				160
71	↓	↓	↓	162
96	Lunar Simulator Lip	247	247	NA
99	Lunar Simulator or Moon	248	248	250
100	Chamber Cryowall or Space	-270	-270	-460
116	Thermal Plate	146	143	144
117	↓	148	147	149
118		147	142	145
119		144	142	146
120	↓	146	141	145

Thermal Model Node No.	Node Description	Temperature -°F		
		Chamber Test	Pred. Chamber	Pred. Moon
121	Thermal Plate	144	140	142
122	↓	143	140	142
123		143	143	144
124		140	139	140
125		141	138	140
126		140	139	143
127		138	134	140
128		137	135	136
129	↓	137	140	141
130	P.C.U.		176	176
131	P.D.U.		162	165
132	Analog Multiplex Conv.		155	157
133	P.S.E.		159	162
134	Command Decoder		147	149
135	Data Processor		152	152
136	Command Receiver		142	144
137	Transmitter A		135	136
138	Transmitter B		145	146
139	Timer		139	141
140	Diplexer Filter		136	138
141	Diplexer Switch		139	141
143	Primary Structure Front	152	147	153
144	Primary Structure Rt. Side	164	161	168
145	Primary Structure Back	156	149	158
146	Primary Structure Lt. Side	164	160	168
147	Primary Structure Bottom	169	158	156
148	Thermal Bag Interior		140	143
149	Thermal Bag Exterior		152	155
160	PDM Panel Insulation	NA	NA	164
161	PDM Panel Front	NA	NA	169
164	PDM Panel Rear	NA	NA	169

Notes: 1) Second-Surface mirror α/ϵ = .06/.80
2) No plume heating protection
3) xxx/xxx represents a range of values.

TABLE 6-3

COMPARISON OF QUAL TEST TEMPERATURES TO TEMPERATURES PREDICTED WITH QUAL THERMAL MODEL FOR 10 WATT DUMP ACTIVATED AT LUNAR NOON EQUILIBRIUM

Thermal Model Node No.	Node Description	Temperature -°F		
		Chamber Test	Pred. Chamber	Pred. Moon
1	PSE Insulation Shroud	-71/85	84	107
2	Heater #1 Insulation Shroud	9/81	100	127
3	Heater #2 Insulation Shroud	44/74	101	129
4	Second-Surface Mirrors		124	125
5	Left Insulation Mask	51/69	84	82
6	Second-Surface Mirrors		124	122
7	Right Insulation Mask	76/77	92	92
8	Second-Surface Mirrors		133	137
9	Second-Surface Mirrors		130	134
10	Left Solar Panel Back	183/224	200	195
11	Right Solar Panel Back	186/223	200	195
12	Left Solar Panel Front		158	197
13	Right Solar Panel Front		158	197
14	Isotope Heater #1	186/196	162	165
15	Isotope Heater #2	185/199	149	153
16	PSE Mounting Plate	137	126	127
17	↓	144	148	151
18			132	135
19		140	135	139
20		142	133	137
21		143	130	133
22			124	126
23			124	126
24		134	124	126
25		134	129	130
26		133	132	137
27		131	125	134
28		131	125	123
29	↓	133	125	126
30	PSE Sensor	132	128	135

Thermal Model Node No.	Node Description	Temperatures - F		
		Chamber Test	Pred. Chamber	Pred. Moon
50	Lunar Subsurface Model	NA	NA	-25
51	↓	↓	↓	-22
52				-4
53				22
54				54
55				84
56				114
57				144
58				174
59				204
60				234
61				159
62				-23
63				-1
64				27
65				60
66				90
67				115
68				137
69				153
70				161
71	↓	↓	↓	163
96	Lunar Simulator Lip	247	247	NA
99	Lunar Simulator or Moon	248	248	250
100	Chamber Cryowall or Space	-270	-270	-460
116	Thermal Plate	138	132	134
117	↓	142	138	141
118		142	134	138
119		140	136	140
120	↓	142	135	139

Thermal Model Node No.	Node Description	Temperature - °F		
		Chamber Test	Pred. Chamber	Pred. Moon
121	Thermal Plate	140	133	135
122	↓	138	132	134
123		136	132	133
124		134	130	131
125		138	130	132
126		137	132	136
127		135	127	134
128		134	128	129
129	↓	133	132	133
130	P.C.U.		152	153
131	P.D.U.		153	156
132	Analog Multiplex Conv.		148	150
133	P.S.E.		153	156
134	Command Decoder		140	143
135	Data Processor		145	145
136	Command Receiver		133	136
137	Transmitter A		128	129
138	Transmitter B		137	138
139	Timer		131	132
140	Diplexer Filter		129	131
141	Diplexer Switch		131	132
143	Primary Structure Front	153	147	153
144	Primary Structure Rt. Side	165	161	168
145	Primary Structure Back	162	153	166
146	Primary Structure Lt. Side	165	161	169
147	Primary Structure Bottom	170	159	158
148	Thermal Bag Interior		133	136
149	Thermal Bag Exterior		151	154
160	PDM Panel Insulation	NA	NA	180
161	PDM Panel Front	NA	NA	193
164	PDM Panel Rear	NA	NA	192

Notes: 1) Second-surface mirror α/ϵ = .06/.08
2) No plume heating protection
3) xxx/xxx represents a range of values.

TABLE 6-4

COMPARISON OF QUAL TEST TEMPERATURES TO TEMPERATURES PREDICTED WITH QUAL THERMAL MODEL AT LUNAR NIGHT EQUILIBRIUM

Thermal Model Node No.	Node Description	Temperature-°F		
		Chamber Test	Pred. Chamber	Pred. Moon
1	PSE Insulation Shroud	-238/-185	-223	-232
2	Heater #1 Insulation Shroud	-199/-131	-174	-180
3	Heater #2 Insulation Shroud	-183/-119	-174	-179
4	Second-Surface Mirrors		-55	-60
5	Left Insulation Mask	-186/-151	-187	-194
6	Second-Surface Mirrors		-52	-59
7	Right Insulation Mask	-155/-161	-185	-191
8	Second-Surface Mirrors		-43	-46
9	Second-Surface Mirrors		-46	-50
10	Left Solar Panel Back	-268/-256	-298	-323
11	Right Solar Panel Back	-266/-256	-299	-325
12	Left Solar Panel Front		-298	-324
13	Right Solar Panel Front		-299	-325
14	Isotope Heater #1	10/21	-17	-22
15	Isotope Heater #2	15/31	-27	-30
16	PSE Mounting Plate	-47	-54	-59
17		-37	-31	-36
18			-45	-49
19		-44	-41	-44
20		-41	-43	-46
21		-42	-49	-53
22			-54	-59
23			-55	-59
24		-54	-55	-59
25		-53	-50	-55
26			-43	-47
27			-51	-52
28		-53	-52	-58
29		-55	-55	-60
30	PSE Sensor	-52	-51	-54
50	Lunar Subsurface Model	NA	NA	-25
51				-28
52				-46
53				-72
54				-104
55				-134
56				-164
57				-194
58				-224
59				-254
60				-284
61				-206
62				-27
63				-49
64				-77
65				-110
66				-140
67				-165
68				-186
69				-202
70				-210
71				-211
96	Lunar Simulator Lip	-317	-317	NA
99	Lunar Simulator or Moon	-317	-317	-300
100	Chamber Cryowall or Space	-300	-300	-460
116	Thermal Plate	-49	-52	-57
117			-44	-48
118		-38	-45	-49
119		-45	-43	-46
120		-45	-45	-48
121		-50	-48	-52
122		-51	-51	-56
123		-50	-54	-58
124		-51	-54	-58
125		-50	-50	-54
126	Thermal Plate	-48	-46	-49
127		-55	-51	-53
128		-56	-52	-57
129		-54	-55	-59
130	P. C. U.		-56	-60
131	P. D. U.		-52	-56
132	Analog Multiplex Conv.		-47	-51
133	P. S. E.		-46	-49
134	Command Decoder		-46	-49
135	Data Processor		-51	-56
136	Command Receiver		-54	-58
137	Transmitter A		-52	-57
138	Transmitter B		-55	-59
139	Timer		-54	-59
140	Diplexer Filter		-51	-56
141	Diplexer Switch		-54	-59
143	Primary Structure Front	-191	-190	-198
144	Primary Structure Rt. Side	-191	-197	-205
145	Primary Structure Back	-191	-196	-204
146	Primary Structure Lt. Side	-194	-195	-204
147	Primary Structure Bottom	-192	-195	-205
148	Thermal Bag Interior		-53	-57
149	Thermal Bag Exterior		-139	-144
160	PDM Panel Insulation	NA	NA	-205
161	PDM Panel Front	NA	NA	-211
164	PDM Panel Rear	NA	NA	-211

Note: 1) Second-Surface mirror $\epsilon = 0.80$
2) No plume heating protection
3) xxx/xxx represents a range of values

TABLE 6-5

COMPARISON OF FLIGHT TEST TEMPERATURES TO TEMPERATURES PREDICTED WITH FLIGHT THERMAL MODEL FOR NO-DUMP CONDITION AT LUNAR NOON EQUILIBRIUM

Thermal Model Node No.	Node Description	Temperatures - °F			
		Chamber Test	Pred. Chamber	Pred. Moon No Prot.	Pred. Moon Prot.
1	PSE Insulation Shroud		80	112	155
2	Heater #1 Insulation Shroud		97	133	186
3	Heater #2 Insulation Shroud		99	135	189
4	Second-Surface Mirrors		128	131	140
5	Left Insulation Mask		81	57	188
6	Second-Surface Mirrors		123	121	130
7	Right Insulation Mask		86	66	196
8	Second Surface Mirrors		132	138	148
9	Second Surface Mirrors		132	137	149
10	Left Solar Panel Back	91	80	195	196
11	Right Solar Panel Back	90	80	195	196
12	Left Solar Panel Front		70	197	197
13	Right Solar Panel Front		70	197	197
14	Isotope Heater #1		166	170	181
15	Isotope Heater #2		148	155	165
16	PSE Mounting Plate		130	133	143
17			152	156	167
18			133	138	150
19			134	141	151
20			132	138	148
21			132	136	146
22			128	131	141
23			128	131	141
24			128	131	141
25			129	132	142
26			131	138	148
27			124	135	145
28			124	123	132
29			128	131	141
30	PSE Sensor		130	136	146
50	Lunar Subsurface Model	NA	NA	-25	-25
51				-22	-22
52				-4	-4
53				22	22
54				54	54
55				84	84
56				114	114
57				144	144
58				174	174
59				204	204
60				234	234
61				157	157
62				-23	-23
63				-1	-1
64				27	27
65				60	60
66				90	90
67				115	115
68				136	136
69				152	152
70				160	161
71				161	162
96	Lunar Simulator Lip	251	251	NA	NA
99	Lunar Simulator or Moon	251	251	250	250
100	Chamber Cryowall or Space	-261	-261	-460	-460
116	Thermal Plate	138	138	142	151
117			142	146	156
118		137	136	141	152
119		137	136	141	152
120			134	140	150
121	Thermal Plate	132	134	138	149
122			135	139	149
123			138	141	151
124		125	133	137	147
125			131	135	145
126			131	138	148
127		120	126	135	145
128			128	130	140
129		125	135	138	147
130	P. C. U.	167	170	173	183
131	P. D. U.	155	158	161	171
132	Analog Multiplex Conv.	150	149	153	164
133	P. S. E.		152	158	168
134	Command Decoder	140	138	145	155
135	Data Processor	141	143	147	157
136	Command Receiver	125	138	141	151
137	Transmitter A	127	128	130	140
138	Transmitter B		140	143	152
139	Timer		134	137	147
140	Diplexer Filter		129	132	142
141	Diplexer Switch		134	137	147
143	Primary Structure Front		146	153	154
144	Primary Structure Rt. Side	160	156	168	168
145	Primary Structure Back		151	158	158
146	Primary Structure Lt. Side	155	156	168	169
147	Primary Structure Bottom	157	157	156	157
148	Thermal Bag Interior		135	139	149
149	Thermal Bag Exterior		150	153	156
160	PDM Panel Insulation		147	163	163
161	PDM Panel Front	166	156	169	169
164	PDM Panel Rear	166	156	169	169

Note: Second-Surface Mirror α/ϵ = .06/.80

TABLE 6-6

COMPARISON OF FLIGHT TEST TEMPERATURES TO TEMPERATURES PREDICTED WITH FLIGHT THERMAL MODEL FOR 10 WATT DUMP ACTIVATED AT LUNAR NOON EQUILIBRIUM

Thermal Model Node No.	Node Description	Temperature - °F Chamber Test	Pred. Chamber	Pred. No Prot.	Moon Prot.
1	PSE Insulation Shroud		79	112	154
2	Heater #1 Insulation Shroud		96	132	186
3	Heater #2 Insulation Shroud		98	134	188
4	Second-Surface Mirrors		119	123	133
5	Left Insulation Mask		80	56	188
6	Second-Surface Mirrors		116	115	125
7	Right Insulation Mask		86	66	196
8	Second-Surface Mirrors		126	132	143
9	Second-Surface Mirrors		126	130	143
10	Left Solar Panel Back		80	195	196
11	Right Solar Panel Back		80	195	196
12	Left Solar Panel Front		70	197	197
13	Right Solar Panel Front		70	197	197
14	Isotope Heater #1		158	162	174
15	Isotope Heater #2		142	149	159
16	PSE Mounting Plate		121	124	135
17	↓		144	148	159
18	↓		127	132	144
19	↓		128	135	145
20	↓		126	132	143
21	↓		125	129	140
22	↓		120	123	133
23	↓		120	123	133
24	↓		120	123	133
25	↓		122	125	136
26	↓		125	132	142
27	↓		117	128	139
28	↓		117	116	127
29	↓		120	123	133
30	PSE Sensor		124	129	140
50	Lunar Subsurface Model	NA	NA	-25	-25
51	↓			-22	-22
52	↓			-4	-4
53	↓			22	22
54	↓			54	54
55	↓			84	84
56	↓			114	114
57	↓			144	144
58	↓			174	174
59	↓			204	204
60	↓			234	234
61	↓			158	159
62	↓			-23	-23
63	↓			-1	-1
64	↓			27	27
65	↓			60	60
66	↓			90	90
67	↓			115	116
68	↓			157	157
69	↓			153	153
70	↓			161	162
71	↓			163	163
96	Lunar Simulator Lip	251	251	NA	NA
99	Lunar Simulator or Moon	251	251	250	250
100	Chamber Cryowall or Space	-261	-261	-460	-460
116	Thermal Plate	131	128	131	141
117	↓		133	137	148
118	↓	132	129	134	145
119	↓	132	129	135	146
120	↓		128	134	145
121	↓	120	127	131	142
122	↓		127	130	141
123	↓		127	130	141
124	↓	118	125	128	138
125	↓		124	128	138
126	Thermal Plate		125	132	142
127	↓	115	120	129	139
128	↓		121	123	133
129	↓	118	127	130	140
130	P. C. U.	137	147	150	160
131	P. D. U.	148	149	155	164
132	Analog Multiplex Conv.	145	142	146	158
133	P. S. E.		145	152	162
134	Command Decoder	134	132	138	149
135	Data Processor	135	136	140	151
136	Command Receiver	119	129	132	143
137	Transmitter A	122	121	123	133
138	Transmitter B		132	135	145
139	Timer		126	129	139
140	Diplexer Filter		123	125	136
141	Diplexer Switch		126	129	139
143	Primary Structure Front		146	153	154
144	Primary Structure Rt Side	160	157	168	169
145	Primary Structure Back		158	166	166
146	Primary Structure Lt Side	156	157	169	169
147	Primary Structure Bottom	156	159	158	159
148	Thermal Bag Interior		127	132	142
149	Thermal Bag Exterior		149	153	156
160	PDM Panel Insulation		163	177	178
161	PDM Panel Front	180	178	193	193
164	PDM Panel Rear	180	178	193	193

Note: Second-Surface mirror $\alpha/\epsilon = .06/.80$

TABLE 6-7

TEMPERATURES PREDICTED WITH FLIGHT MODEL AT LUNAR NIGHT EQUILIBRIUM

Thermal Model Node No.	Node Description	Temperature - °F Pred. Chamber	Pred. No Prot.	Moon Prot.
1	PSE Insulation Shroud	-223	-231	-233
2	Heater #1 Insulation Shroud	-178	-182	-188
3	Heater #2 Insulation Shroud	-176	-180	-185
4	Second-Surface Mirrors	-61	-62	-61
5	Left Insulation Mask	-189	-206	-206
6	Second-Surface Mirrors	-59	-62	-62
7	Right Insulation Mask	-186	-203	-203
8	Second-Surface Mirrors	-50	-49	-48
9	Second Surface Mirrors	-51	-52	-51
10	Left Solar Panel Back	-294	-323	-323
11	Right Solar Panel Back	-294	-325	-325
12	Left Solar Panel Front	-294	-323	-323
13	Right Solar Panel Front	-294	-325	-325
14	Isotope Heater #1	-23	-24	-23
15	Isotope Heater #2	-34	-33	-32
16	PSE Mounting Plate	-60	-61	-60
17	↓	-37	-38	-37
18	↓	-51	-51	-51
19	↓	-48	-47	-46
20	↓	-50	-49	-48
21	↓	-55	-55	-55
22	↓	-60	-61	-60
23	↓	-60	-61	-61
24	↓	-60	-61	-60
25	↓	-56	-57	-57
26	↓	-51	-49	-49
27	↓	-58	-55	-54
28	↓	-59	-62	-61
29	↓	-61	-62	-61
30	PSE Sensor	-57	-57	-57
50	Lunar Subsurface Model	NA	-25	-25
51	↓		-28	-28
52	↓		-46	-46
53	↓		-72	-72
54	↓		-104	-104
55	↓		-134	-134
56	↓		-164	-164
57	↓		-194	-194
58	↓		-224	-224
59	↓		-254	-254
60	↓		-284	-284
61	↓		-206	-206
62	↓		-27	-27
63	↓		-49	-49
64	↓		-77	-77
65	↓		-110	-110
66	↓		-140	-140
67	↓		-165	-165
68	↓		-186	-186
69	↓		-202	-202
70	↓		-210	-210
71	↓		-211	-211
96	Lunar Simulator Lip	-300	NA	NA
99	Lunar Simulator or Moon	-300	-300	-300
100	Chamber Cryowall or Space	-300	-460	-460
116	Thermal Plate	-58	-59	-58
117	↓	-50	-50	-50
118	↓	-51	-52	-51
119	↓	-50	-49	-49
120	↓	-52	-51	-50
121	↓	-54	-55	-54
122	↓	-57	-58	-57
123	↓	-59	-60	-59
124	↓	-59	-60	-60
125	Thermal Plate	-56	-57	-56
126	↓	-53	-52	-52
127	↓	-57	-55	-55
128	↓	-58	-60	-59
129	↓	-61	-62	-61
130	P. C. U.	-61	-62	-61
131	P. D. U.	-57	-58	-58
132	Analog Multiplex Conv.	-53	-54	-53
133	P. S. E.	-52	-52	-51
134	Command Decoder	-52	-52	-51
135	Data Processor	-57	-58	-57
136	Command Receiver	-59	-60	-60
137	Transmitter A	-58	-60	-59
138	Transmitter B	-61	-62	-61
139	Timer	-60	-61	-60
140	Diplexer Filter	-57	-58	-58
141	Diplexer Switch	-60	-61	-60
143	Primary Structure Front	-185	-199	-198
144	Primary Structure Rt. Side	-192	-205	-205
145	Primary Structure Back	-191	-204	-204
146	Primary Structure Lt. Side	-190	-204	-203
147	Primary Structure Bottom	-190	-206	-205
148	Thermal Bag Interior	-63	-59	-58
149	Thermal Bag Exterior	-99	-145	-144
160	PDM Panel Insulation	-219	-205	-204
161	PDM Panel Front	-200	-211	-209
164	PDM Panel Rear	-200	-211	-209

Note: Second-Surface Mirror $\alpha/\epsilon = .06/.80$

TABLE 6-8

PREDICTED TEMPERATURES FOR FLIGHT MODEL WITH A MIRROR SOLAR ABSORPTIVITY OF 0.08 IN A REAL LUNAR NOON ENVIRONMENT

Thermal Model Node No.	Node Description	Temperatures - °F			
		No Dump		10 Watt Dump	
		No Prot.	Prot.	No Prot.	Prot.
1	PSE Insulation Shroud	109	150	108	150
2	Heater #1 Insulation Shroud	128	176	127	175
3	Heater #2 Insulation Shroud	130	180	129	179
4	Second-Surface Mirrors	138	146	130	139
5	Left Insulation Mask	57	187	56	187
6	Second-Surface Mirrors	128	137	122	131
7	Right Insulation Mask	66	196	66	195
8	Second-Surface Mirrors	145	154	139	149
9	Second-Surface Mirrors	144	155	138	149
10	Left Solar Panel Back	195	196	195	196
11	Right Solar Panel Back	195	196	195	196
12	Left Solar Panel Front	197	197	197	197
13	Right Solar Panel Front	197	197	197	197
14	Isotope Heater #1	177	187	170	179
15	Isotope Heater #2	162	171	156	165
16	PSE Mounting Plate	140	149	132	141
17	↓	163	173	156	165
18		145	156	139	150
19		148	157	142	151
20		145	154	140	149
21		143	152	136	146
22		138	147	131	139
23		138	147	130	139
24		138	147	131	139
25		139	148	133	142
26		145	154	139	148
27		142	150	136	145
28		130	139	124	133
29		138	147	131	139
30	PSE Sensor	143	152	137	146
50	Lunar Subsurface Model	-25	-25	-25	-25
51	↓	-22	-22	-22	-22
52		-4	-4	-4	-4
53		22	22	22	22
54		54	54	54	54
55		84	84	84	84
56		114	114	114	114
57		144	144	144	114
58		174	174	174	174
59		204	204	204	204
60		234	234	234	234
61		157	158	159	159
62		-23	-23	-23	-23
63		-1	-1	-1	-1
64		27	27	27	27
65		60	60	60	60
66		90	90	90	90
67		115	115	116	116
68		136	137	137	137
69		152	152	153	153
70		161	161	162	162
71		162	162	163	164
99	Lunar Simulator or Moon	250	250	250	250
100	Chamber Cryowall or Space	-460	-460	-460	-460
116	Thermal Plate	149	157	138	147
117	↓	153	162	145	154
118		148	158	141	151
119		148	157	143	152
120		147	156	141	151
121		145	154	139	148
122		146	155	138	147
123		148	157	138	147
124		144	152	136	144
125		142	151	135	144
126	Thermal Plate	145	154	139	148
127	↓	142	151	136	145
128		137	146	130	139
129		145	153	137	146
130	P. C. U.	180	189	157	166
131	P. D. U.	168	177	160	169
132	Analog Multiplex Conv.	161	170	154	163
133	P. S. E.	165	174	159	168
134	Command Decoder	152	160	146	155
135	Data Processor	154	163	147	156
136	Command Receiver	148	157	140	149
137	Transmitter A	137	146	130	139
138	Transmitter B	150	158	142	151
139	Timer	144	153	136	145
140	Diplexer Filter	139	148	133	142
141	Diplexer Switch	144	153	136	145
143	Primary Structure Front	153	154	154	154
144	Primary Structure Rt. Side	168	168	168	169
145	Primary Structure Back	158	159	166	166
146	Primary Structure Lt. Side	169	169	169	170
147	Primary Structure Bottom	157	157	158	159
148	Thermal Bag Interior	146	154	139	148
149	Thermal Bag Exterior	155	158	155	158
160	PDM Panel Insulation	163	164	178	178
161	PDM Panel Front	169	169	193	193
164	PDM Panel Rear	169	169	193	193

All values in Tables 6-2 through 6-7 are based on a second-surface mirror α/ϵ of 0.06/0.80. The effective mirror solar absorptivity (α) is expected to degrade to 0.08 over the life of the PSEP/mission in the absence of contamination from the LM ascent. Predicted operating temperatures for the Flight model with a mirror α of 0.08 in a real lunar environment are presented in Table 6-8. As discussed in Section 2, this degradation of mirror solar absorptivity will cause an increase of about 6 to 8°F in lunar noon thermal plate temperatures.

6.2 Thermal Effects of LM on PSEP

6.2.1 Heating of PSEP by LM Ascent Stage Exhaust Gas Plume

Heating effects of the LM ascent stage exhaust gas plume on various PSEP components were studied for deployment distances between 50 and 100 feet from LM. Based on the study results, a plume heating protection system was installed which consisted of two layers of 5 mil Kapton over all PSEP exterior insulation surfaces oriented normal to the exhaust gas flow and one 5 mil layer on exterior insulation surfaces parallel to the flow. The insulation which had exposed surfaces covered with Kapton are 1) the aluminized mylar around the mounting plate edge, 2) the isotope heater shrouds and masks, 3) the PSE shroud, and 4) the mounting plate masks.

References 6, 7 and 8 (published in May, 1969) contain details on the results from this study. The following highlights from the referenced documents are presented in Figures 6-1 to 6-3.

1. Figure 6-1. Maximum plume heating rates versus time after LM ascent stage liftoff at PSEP deployment distances of 50 ft and 100 ft from LM.

2. Figure 6-2. Predicted temperatures of insulation materials subjected to plume heating at 50 ft and 100 ft deployment distances from LM.

3. Figure 6-3. Predicted temperatures of various PSEP materials subjected to plume heating at a 100 ft deployment distance from LM.

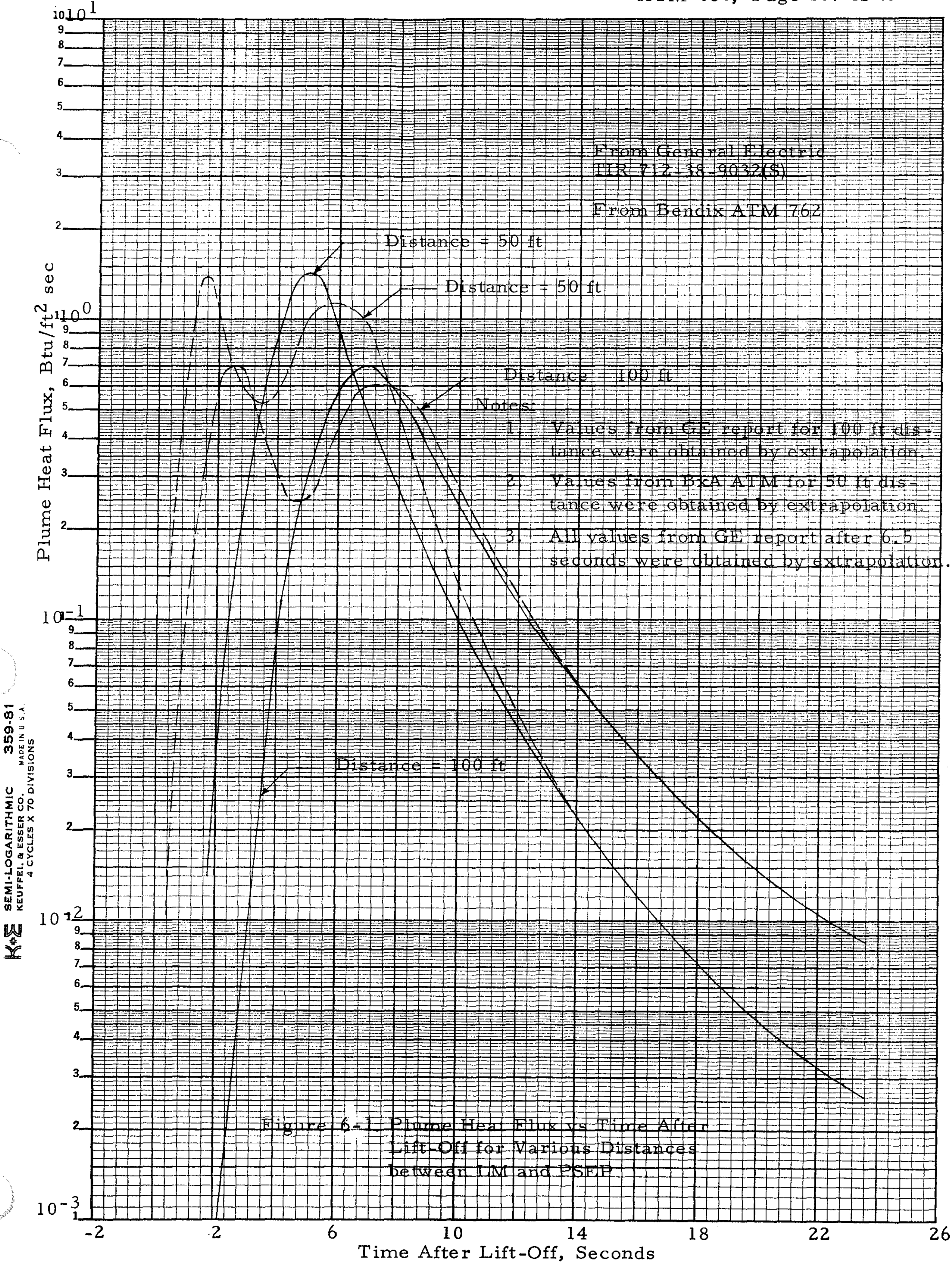


Figure 6-1. Plume Heat Flux vs Time After Lift-Off for Various Distances between LM and PSEP

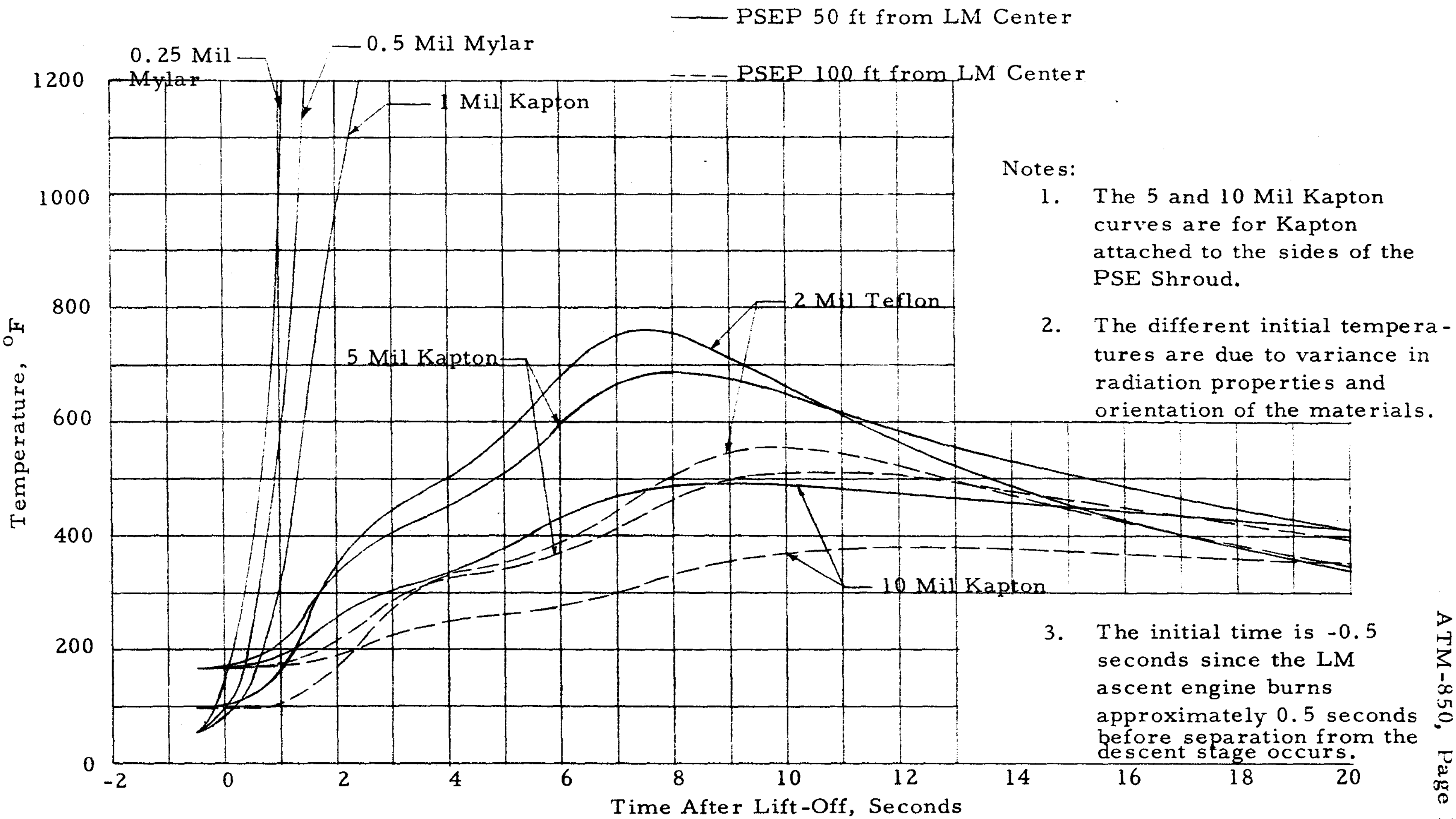


Figure 6-2. Temperature versus Time After Lift-Off for PSEP Insulation Mask and Shroud Materials

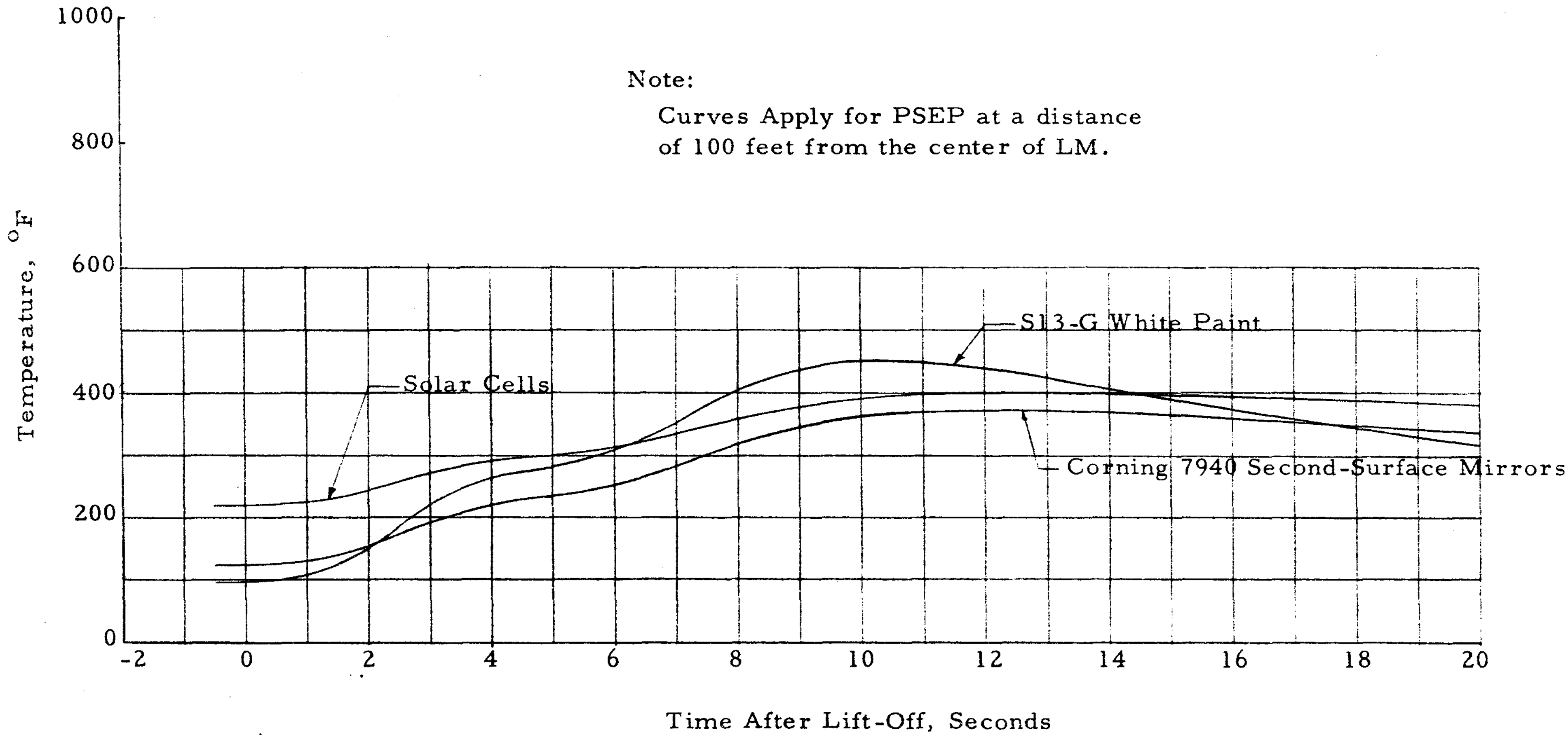


Figure 6-3. Temperatures of Various PSEP Components versus Time After LM Lift-Off

6.2.2 Thermal Radiation Effect of LM Descent Stage on Deployed PSEP

The effect of thermal radiation from the LM descent stage on PSEP temperatures were studied. The purpose of the study was to establish how far PSEP should be deployed from LM in order to minimize the heating effects. The study results, which are presented in Figures 6-4 and 6-5, indicate that the LM descent stage has little effect on PSEP at deployment distances greater than 25 feet.

The analysis was performed with a simplified version of the PSEP Flight thermal model with no plume heating protection, and the figures are intended to illustrate temperature differences only. Results are conservative since it was assumed that the LM surface facing PSEP was also facing the sun.

6.2.3 Temperature of PSEP in LM SEQ Bay

The following two studies were conducted to determine the effect of the LM SEQ bay on PSEP temperatures.

1. Determine the steady-state average temperature of the PSEP thermal plate at the time of withdrawal from the SEQ bay for a range of bay thermal emissitivities from 0.3 to 0.9. Reference 9 presents the details of this study.

2. Determine the PSEP transient thermal response during LM launch, flight, and lunar touchdown in order to establish a maximum predicted thermal plate temperature during storage of PSEP in the SEQ bay. This study was also done for a 0.3 to 0.9 range of SEQ bay emissivities, and the results are contained in Reference 10.

Results from both studies dictated that the internal SEQ bay compartment walls be coated with a high emissivity black thermal coating.

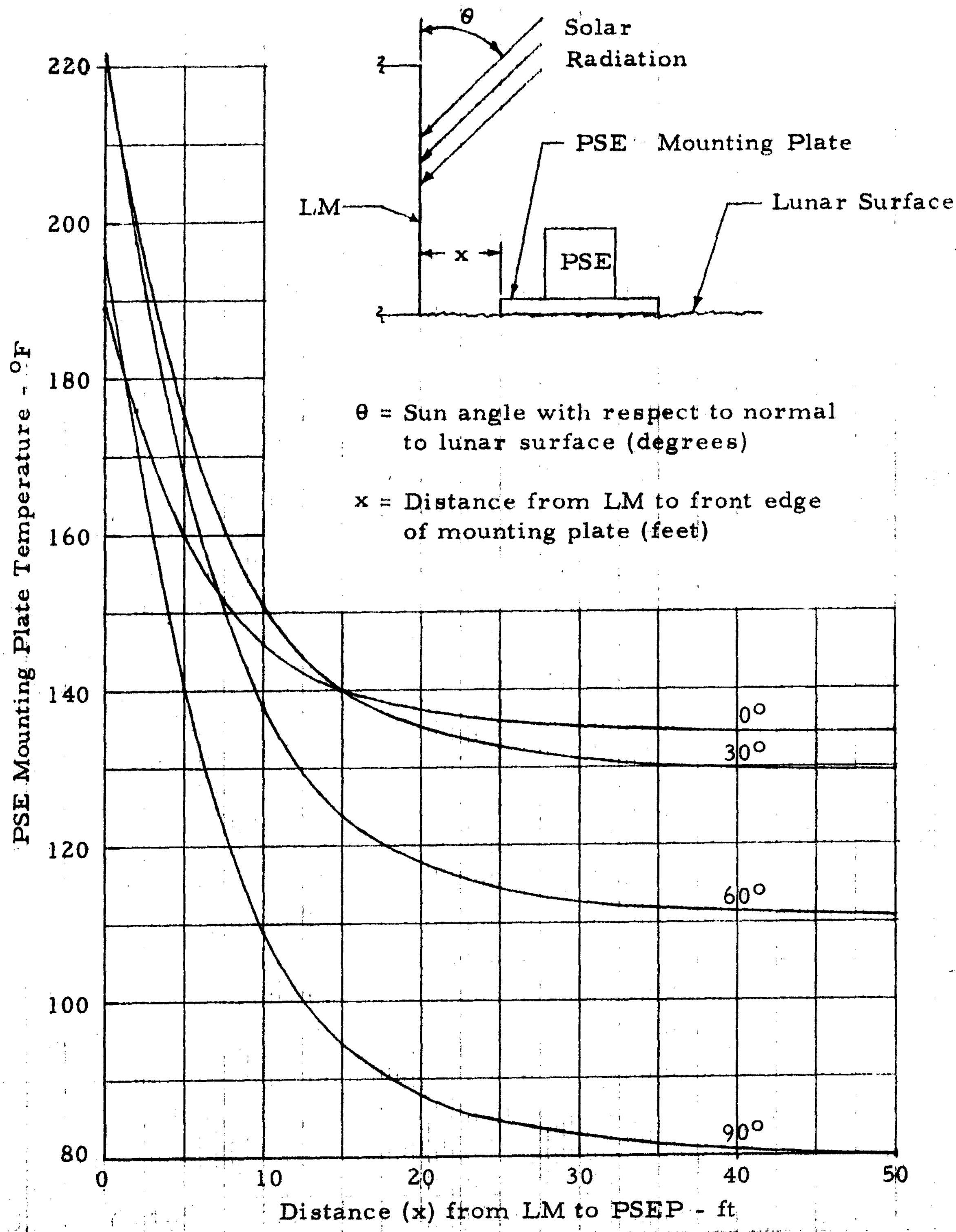


Figure 6-4. PSE Mounting Plate Temperature vs Distance between LM and PSEP for Various Sun Angles

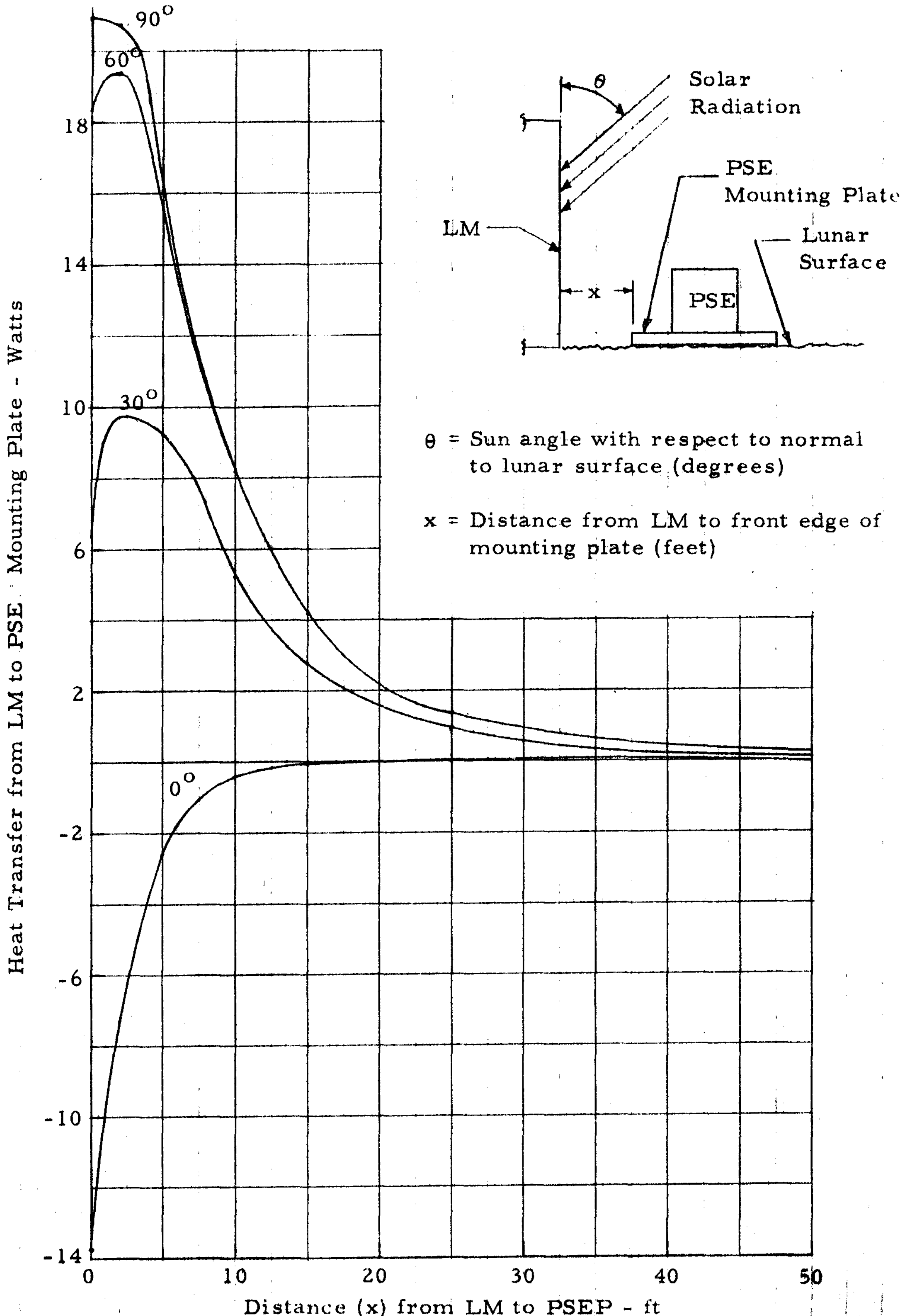


Figure 6-5. Heat Transfer from LM to PSE Mounting Plate vs Distance between LM and PSEP for Various Sun Angles

6.3 PSEP Thermal Design Studies

The Passive Seismic Experiment Package (PSEP) was thermally designed to maintain thermal plate temperatures below 140°F during the lunar day and above -65°F during the lunar night. The thermal control system is passive, with radioisotope heaters supplying lunar night survival power when the electronics are not operating. Solar cell panels, which are positioned at a distance from the control station, provide power to the electronics during the lunar day while exerting minimal influence on the thermal control system. Some of the studies which contributed to the final thermal control system design are discussed in the following paragraphs.

6.3.1 Thermal Control Configuration

At the beginning of the PSEP program a number of parametric studies were performed to establish a thermal control configuration. Areas investigated were:

1. Exterior surface coating of PSE mounting plate (white paint and second-surface mirrors were primary candidates).
2. Insulation masking required on top of mounting plate for control of day-to-night temperature swing.
3. Amount of isotope heater power required for lunar night survival.
4. Active versus passive thermal control systems.
5. Orientation of solar cell panels with respect to the Central Station.

The results from these studies were preliminary but formed the following guidelines for the final thermal control configuration.

1. Second-surface mirrors maintain required component temperatures and provide the best day-to-night thermal plate temperature swing.

2. Central Station components should have the smallest possible "views" of the solar panels.

3. Required isotope heater power would be about 30 ± 10 watts.

4. Optimum radiating area of mounting plate exterior coating would be 2.0 ± 0.5 ft^2.

5. A passive control system would probably be adequate.

Reference 11 presents details on the study.

6.3.2 Thermal Isolator Design and Selection

An analysis was conducted to design and select the fasteners which would join the thermal and mounting plates and which would satisfy structural and thermal requirements. The thermal goal was a design which would thermally isolate the thermal plate from the primary structure. Unfortunately, in order to satisfy structural requirements a nine-bolt fastener design was selected which barely met minimum thermal requirements. Analytical predictions and T/V chamber test results showed the resulting total heat leak through the fasteners at lunar night to be about 4 watts. This heat leak virtually erased any margin of safety in the overall thermal design for lunar night operation. Details on the selected fasteners and on alternate designs which were considered are presented in Reference 12.

6.3.3 PSE Mounting Plate Skin Thickness Study

A parametric thermal study was performed to determine the effect of PSE mounting plate skin thickness upon temperature gradients and average temperatures of the mounting and thermal plates. Results showed that increasing the ALSEP design skin thickness of 0.016 inch to 0.032 inch would produce an effective reduction in temperature gradients with a small weight penalty. A corresponding slight decrease in average mounting and thermal plate temperatures would also occur for both day and night conditions. Consequently, a 0.032 inch mounting plate skin thickness was incorporated into the PSEP design. Results from the parametric study are contained in Reference 13.

6.3.4 Isotope Heater Locations and Masking Pattern

A series of parametric studies were conducted to determine the optimum locations for the two isotope heaters and the mounting plate insulation masks. The results from these studies are presented in References 14 and 15 and established the locations of the heaters and masks in the final PSEP design.

6.4 Heat Leak Summary

Table 6-9 compares test and predicted heat leaks across the Qual model insulation masks, shrouds, isolation bolts, and cables while Figure 6-6 depicts the predicted heat flow distribution at the thermal plate for the lunar noon and night equilibrium conditions. "Test" heat leaks were determined by dividing test temperature differences by calculated resistances. Consequently, some error may be involved in these values. However, errors are expected to be small since predicted and test temperatures generally agreed very well. The exception to this was the temperatures on the exterior surfaces of the insulation masks and shrouds during lunar noon. Predicted values were higher than test values since the analytical thermal model assumed a solar radiation level of one sun on the masks and shrouds whereas the level during testing was less than one sun on these components. The reason for this low level is as follows:

Solar radiation during testing was simulated by tungston filament quartz lamps which do not emit energy with the same spectral distribution as the sun. Emitted energy from the lamps contained a much higher percentage of radiation in the infrared range than does solar energy. Consequently, the power level of the lamps or energy emitted by the lamps was established based on energy absorbed by the second-surface mirrors; i.e., when the amount of absorbed radiation equaled 0.06 times 442 Btu/ft^{2}hr, the lamps were assumed to be emitting at a level equivalent to one sun. Since the mirrors have an infrared emissivity of 0.8 compared to 0.6 - 0.7 for the masks and shrouds, the masks and shrouds did not absorb sufficient radiation to simulate the condition of one sun incident energy.

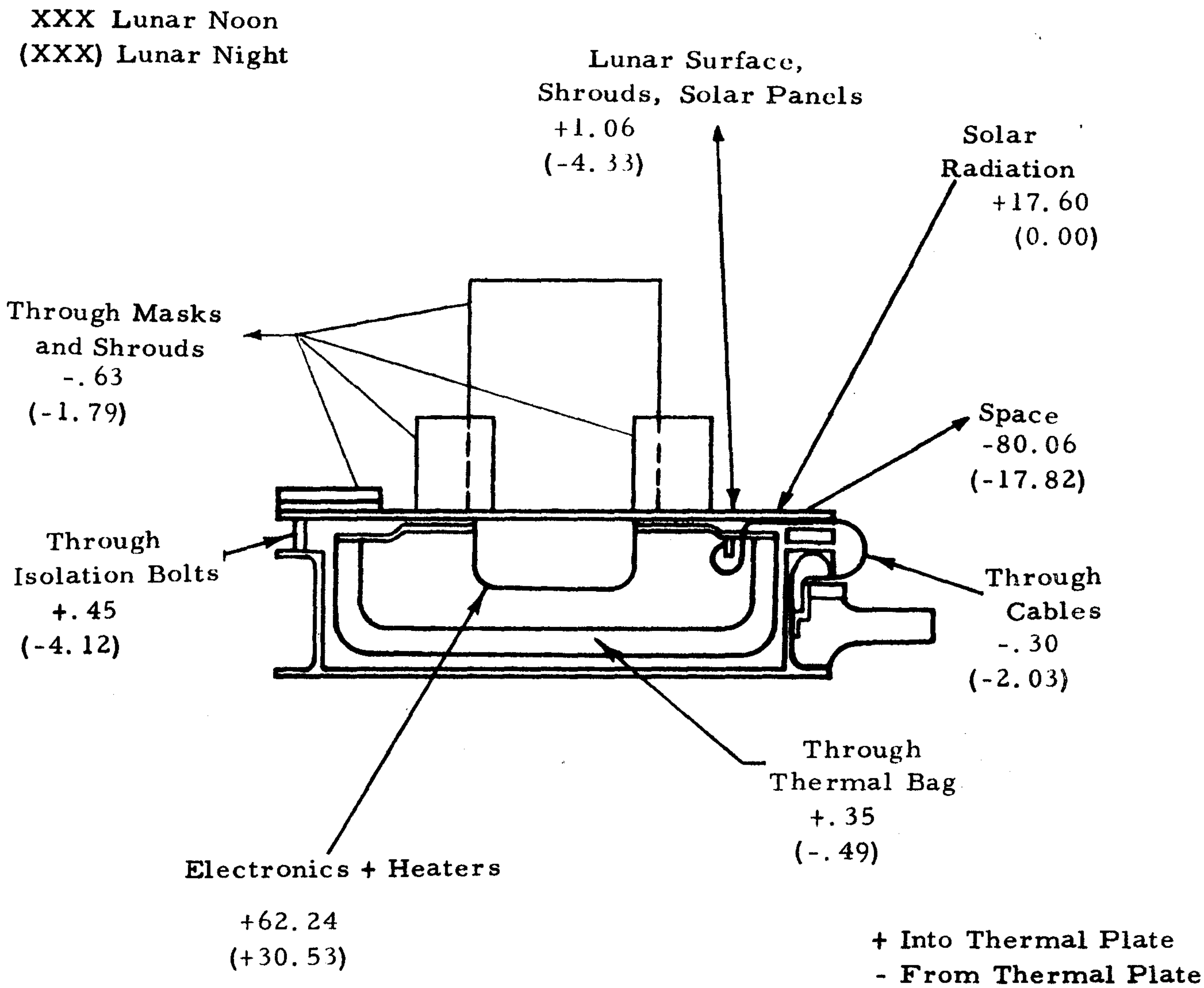
TABLE 6-9

COMPARISON OF PREDICTED AND TEST HEAT LEAKS FOR PSEP QUAL MODEL IN T/V CHAMBER

Item	Heat Leak - Watts			
	Noon (No Dump)		Night	
	Predicted	Test	Predicted	Test
PSE Shroud	-0.13	-0.62	-0.45	-0.49
Heater #1 Shroud	-0.14	-0.34	-0.33	-0.43
Heater #2 Shroud	-0.11	-0.35	-0.31	-0.43
Left Insulation Mask	-0.16	-0.23	-0.41	-0.37
Right Insulation Mask	-0.09	-0.13	-0.30	-0.22
Isolation Bolts	+0.45	+0.37	-4.12	-4.13
Thermal Bag	+0.35	+0.35*	-0.49	-0.49*
Electronic Cables	-0.27	-0.27*	-1.65	-1.65*
PSE Sensor Cables	-0.03	-0.03*	-0.38	-0.38*
Total	-0.13	-1.25	-8.44	-8.59

*Not measured.

Note: A minus sign designates heat flow away from the Central Station components.



Notes:

1. All values are in watts

2. No PDM dump at lunar noon

Figure 6-6. Thermal Balances on PSEP Qual Model Thermal Plate in T/V Chamber Test Environment

This situation is reflected in the shroud and mask heat leaks in Table 6-9. Note that for lunar noon the test heat leaks are considerably higher than predicted values. The explanation is that a greater temperature differential existed between the surface adjacent to the insulation interior and the exterior insulation surface during the test than for the predictions. The exterior insulation surfaces were cooler at noon during the test than the predicted values because they received less than one sun of incident solar radiation.

Conversely, since no solar heating was simulated at lunar night, test and predicted temperatures for exterior surfaces of the masks and shrouds agreed quite well, with a resultant excellent correlation between predicted and test heat leaks for this condition.

The analytical thermal model was never corrected to reflect the test level of solar heating on the masks and shrouds since the heat leak discrepancy causes no significant alteration in thermal plate temperatures at lunar noon. The critical large heat leaks occur for the lunar night condition where test and predicted values compared very favorably.

Table 6-10 presents predicted heat leaks for the Flight model on the lunar surface with the plume heating protection system installed, and Figure 6-7 depicts the predicted heat flow distribution at the thermal plate for the lunar noon and night equilibrium conditions.

6.5 Lunar Environment Simulation

6.5.1 Parametric Study of Lunar Environment Simulation

A number of aspects of lunar environment simulation in the T/V chamber which can cause model test temperatures to vary from anticipated temperatures for real lunar operation are listed below:

1. Size, emissivity, and temperature of the lunar surface simulator

2. Size, emissivity, and temperature of the space simulator (cryowall).

3. Simulation of solar radiation with tungsten - filament quartz lamps.

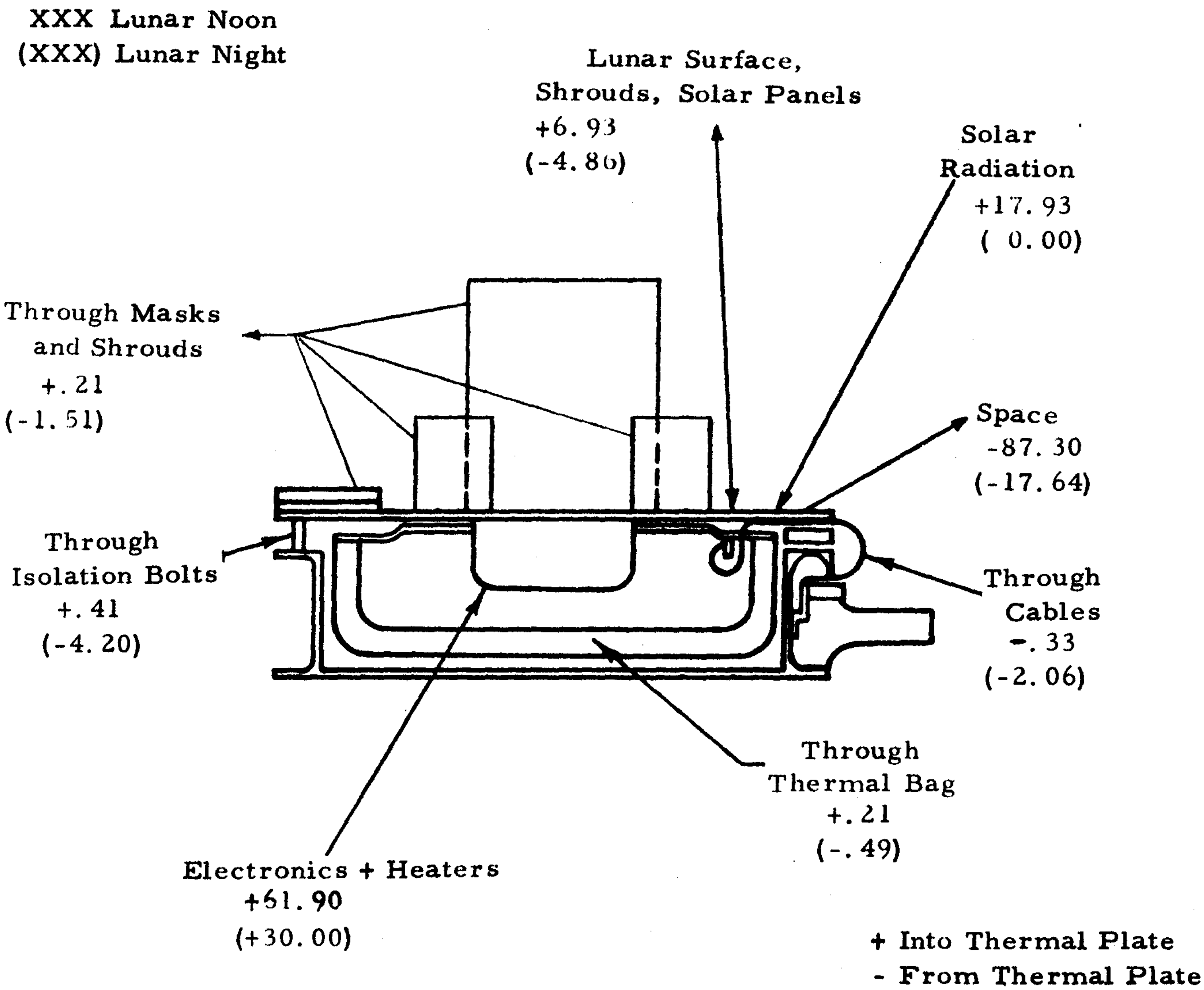
TABLE 6-10

PREDICTED HEAT LEAKS FOR PSEP FLIGHT MODEL WITH PLUME HEATING PROTECTION IN A REAL LUNAR ENVIRONMENT

Item	Heat Leak — Watts				
	Lunar Noon				Lunar Night
	No Dump $\alpha = 0.06$	No Dump $\alpha = 0.08$	10 W. Dump $\alpha = 0.06$	10 W. Dump $\alpha = 0.08$	
PSE Shroud	+0.02	0	+0.04	+0.01	-0.46
Heater #1 Shroud	+0.01	-0.02	+0.02	-0.01	-0.34
Heater #2 Shroud	+0.05	+0.02	+0.06	+0.03	-0.32
Left Insulation Mask	+0.11	+0.10	+0.13	+0.11	-0.35
Right Insulation Mask	+0.02	+0.01	+0.02	+0.02	-0.04
solation Bolts	+0.41	+0.25	+0.68	+0.51	-4.20
Thermal Bag	+0.21	+0.10	+0.39	+0.27	-0.49
Electronics Cables	-0.29	-0.35	-0.07	-0.14	-1.68
PSE Sensor Cables	-0.04	-0.05	-0.02	-0.04	-0.38
Total	+0.50	+0.06	+1.25	+0.76	-8.26

Notes: 1) α refers to mirror solar absorptivity.

2) A minus sign designates heat flow away from the Central Station components.



Notes:

1. All values are in watts
2. Kapton plume heating protection system is installed
3. No PDM dump at lunar noon

Figure 6-7. Thermal Balances on PSEP Flight Model Thermal Plate in Real Lunar Envrionment

Several parametric studies were conducted to determine the variation of thermal plate average temperature with the average temperatures and thermal emissivities of the lunar simulator and cryowall. An additional study showed the effect of solar radiation simulation on thermal plate temperature. The study results cover a 15 to 40 watt range of electronics thermal dissipation and are based on the T/V chamber lunar simulator and cryowall dimensions.

Figures 6-8 to 6-12 show thermal plate average temperature as a function of cryowall and lunar simulator average temperatures. Since there is no electronics power dissipation at night and since the lunar simulator average temperature had always met the test goal of -300°F at night, only thermal plate temperature versus cryowall temperature was plotted for lunar night (see Figure 6-10). Variation of thermal plate temperature with cryowall and lunar simulator emissivity is shown in Figures 6-13 and 6-14. No curves are shown for lunar night since cryowall and lunar simulator emissivities have negligible effect on temperatures for this environmental condition. Plots of thermal plate temperature versus the level of simulated incident solar radiation are illustrated in Figures 6-15 and 6-16.

Results from the studies generally show a 1.3°F change in thermal plate temperature for each one watt change in energy absorbed by the plate. Reference 3 contains additional discussion on the effects of environmental simulation.

6.5.2 Lunar Environment Simulation Results

6.5.2.1 Lunar Simulator and Cryowall

Measurements taken during Qual and Flight testing revealed the following average temperatures over the lunar simulator and cryowall surfaces:

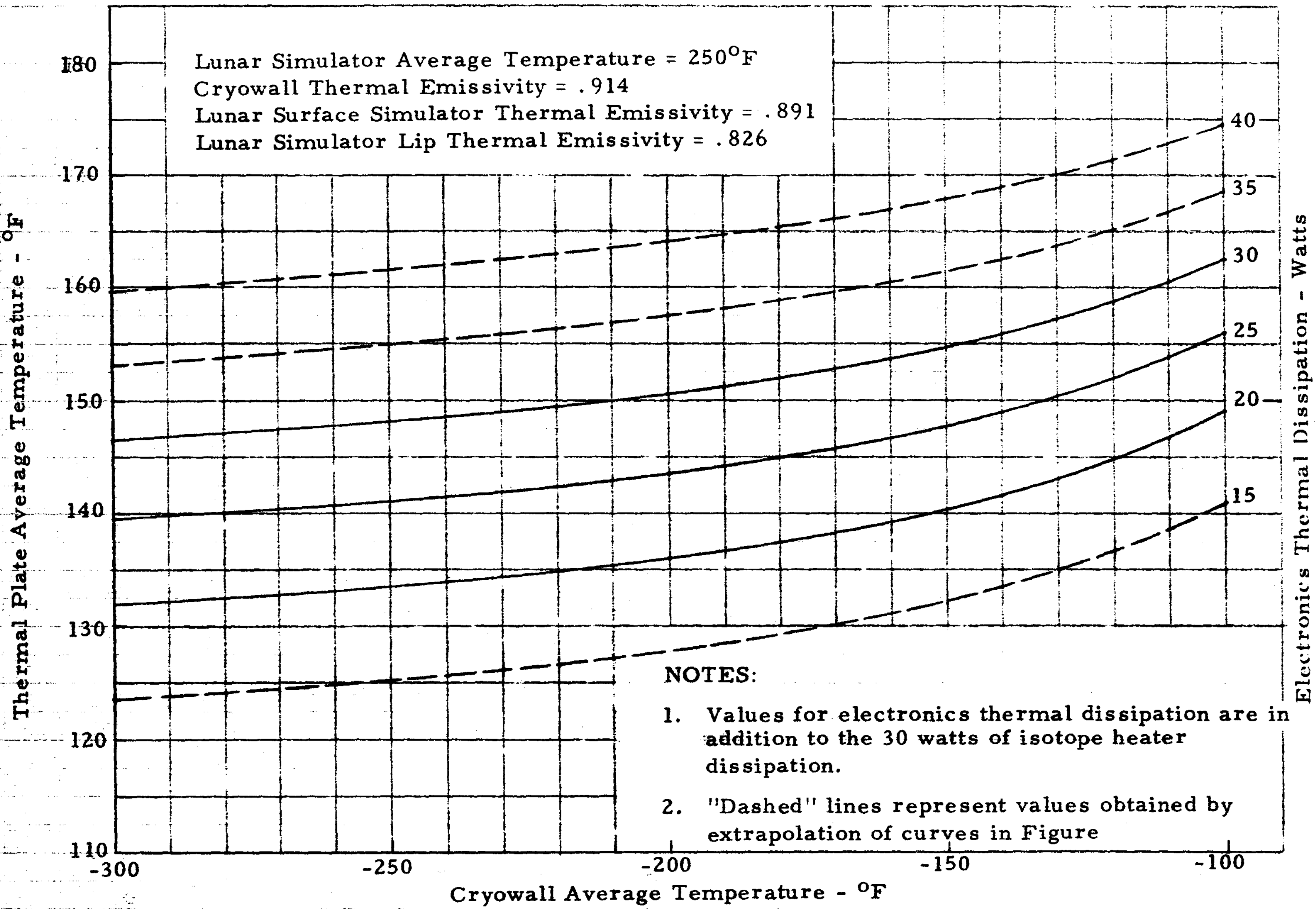


Figure 6-8. Thermal Plate Average Temperature vs Cryowall Average Temperature for Various Levels of Electronics Thermal Dissipation at Lunar Noon in T/V Chamber

Lunar Simulator Average Temperature = 250°F
Cryowall Thermal Emissivity = .914
Lunar Surface Simulator Thermal Emissivity = .891
Lunar Simulator Lip Thermal Emissivity = .826

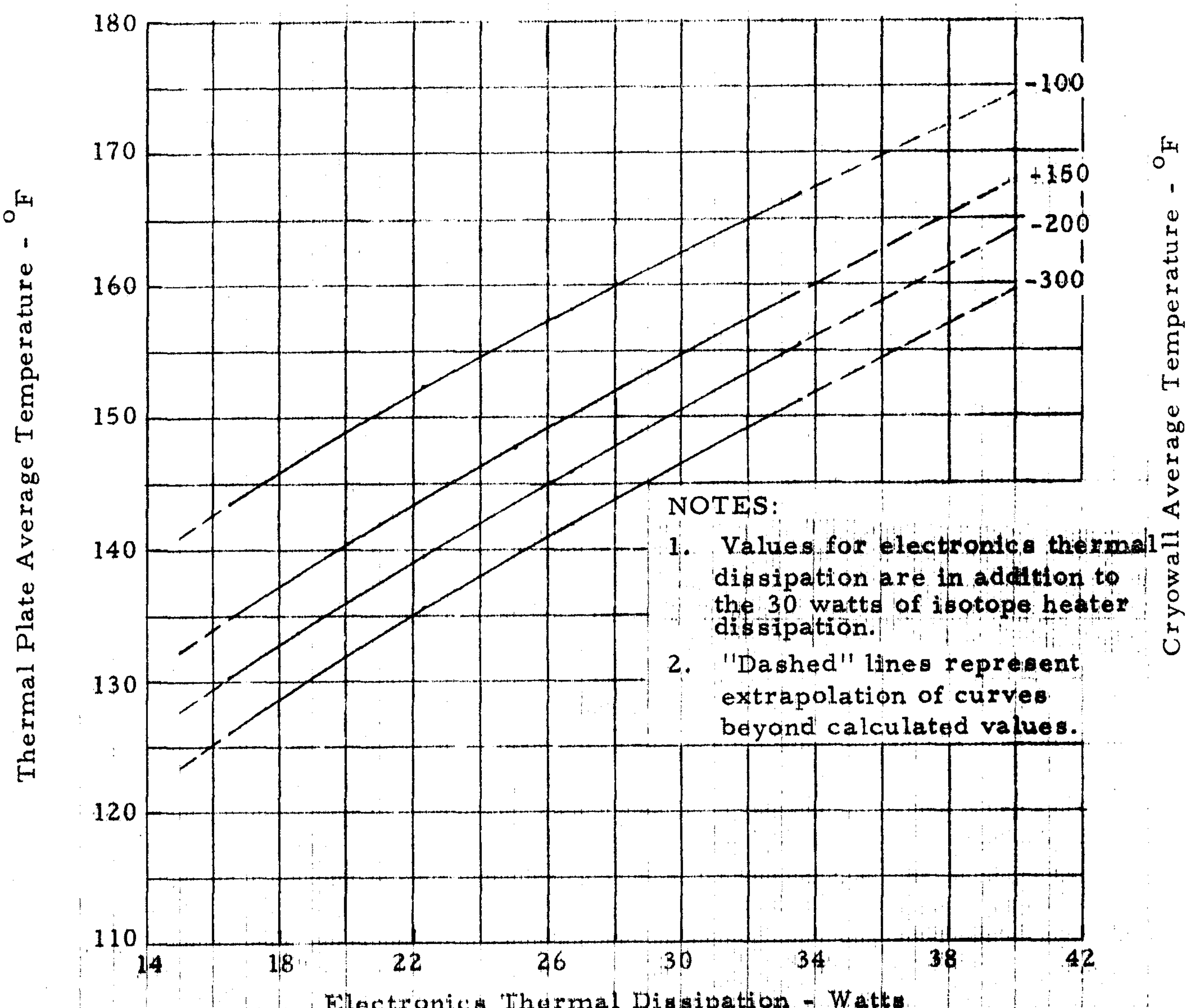


Figure 6-9. Thermal Plate Average Temperature vs Electronics Thermal Dissipation for Various Cryowall Average Temperatures at Lunar Noon in T/V Chamber

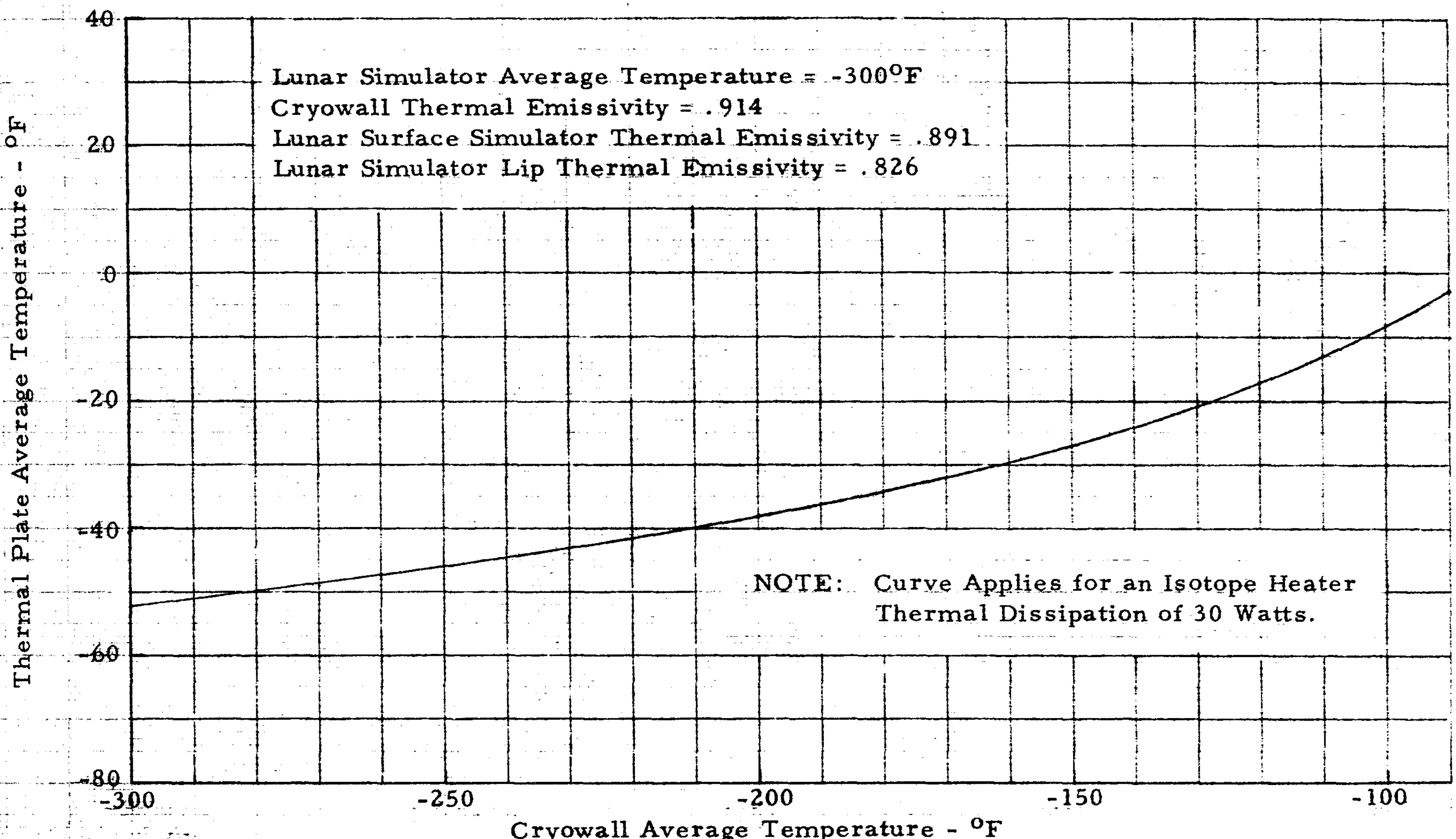


Figure 6-10. Thermal Plate Average Temperature vs Cryowall Average Temperature at Lunar Night in T/V Chamber

Cryowall Average Temperature = -300°F
Cryowall Thermal Emissivity = .914
Lunar Surface Simulator Thermal Emissivity = .891
Lunar Simulator Lip Thermal Emissivity = .826

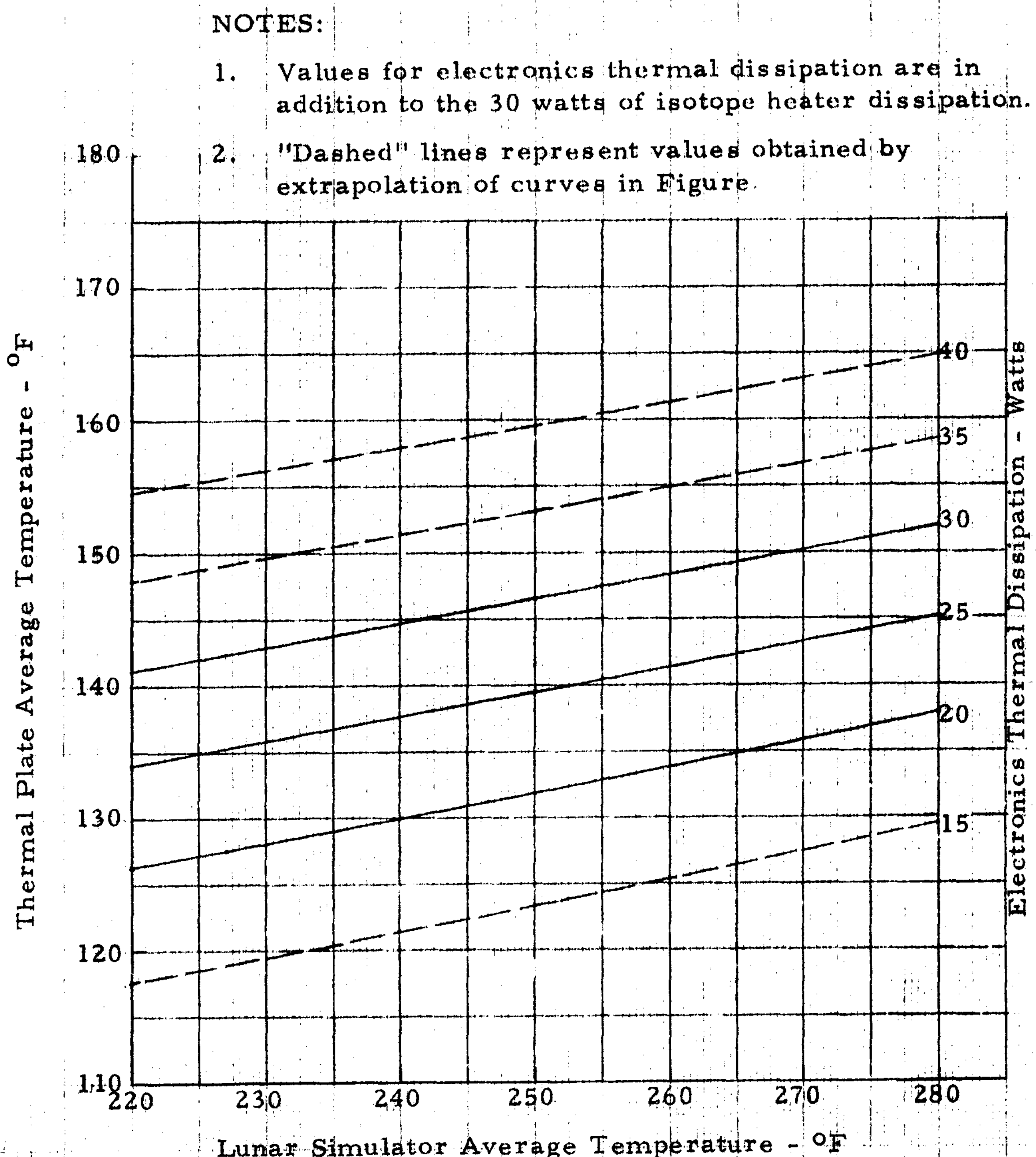


Figure 6-11. Thermal Plate Average Temperature vs Lunar Simulator Average Temperature for Various Levels of Electronics Thermal Dissipation at Lunar Noon in T/V Chamber

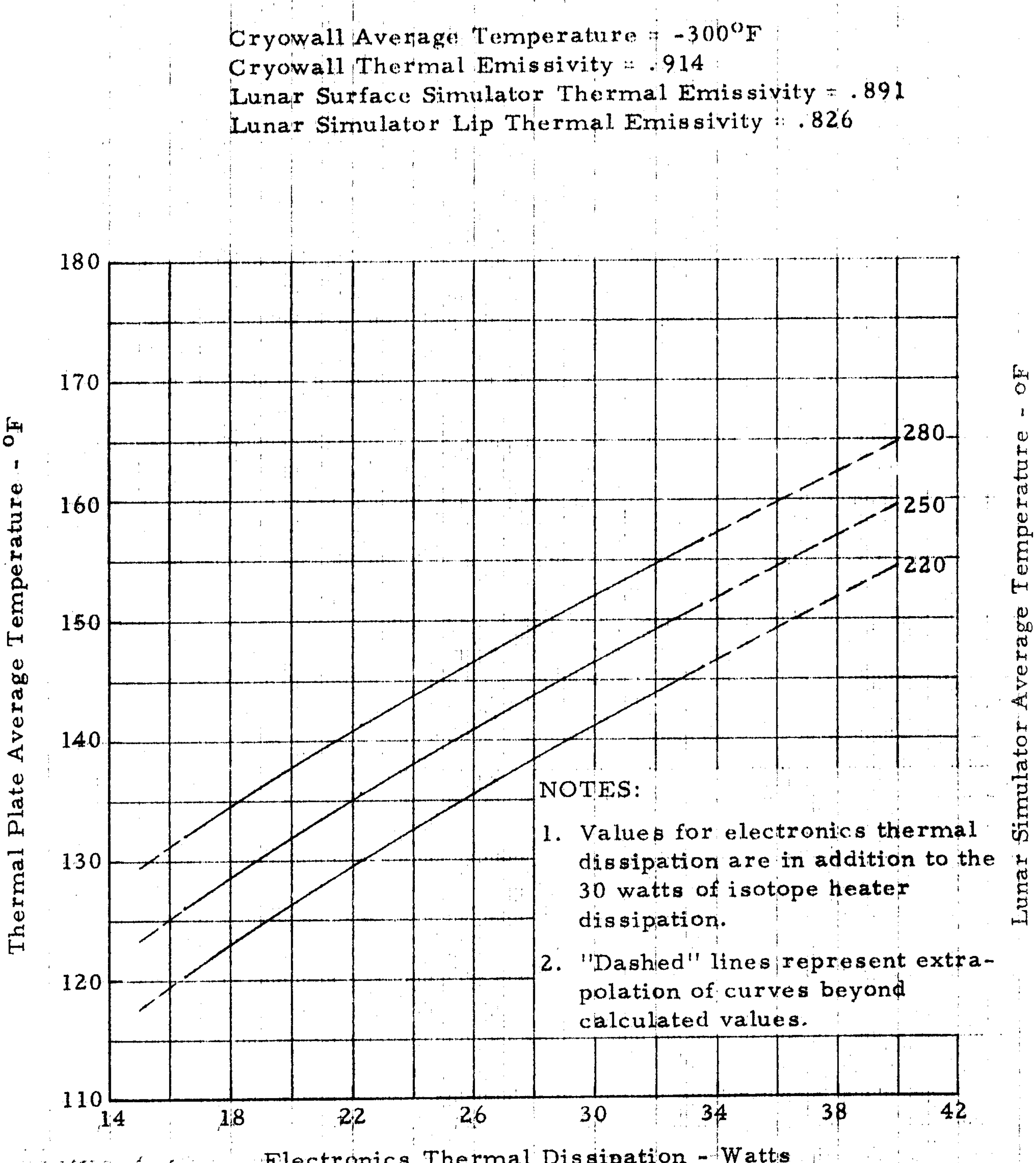


Figure 6-12. Thermal Plate Average Temperature vs Electronics Thermal Dissipation for Various Lunar Simulator Temperatures at Lunar Noon in T/V Chamber

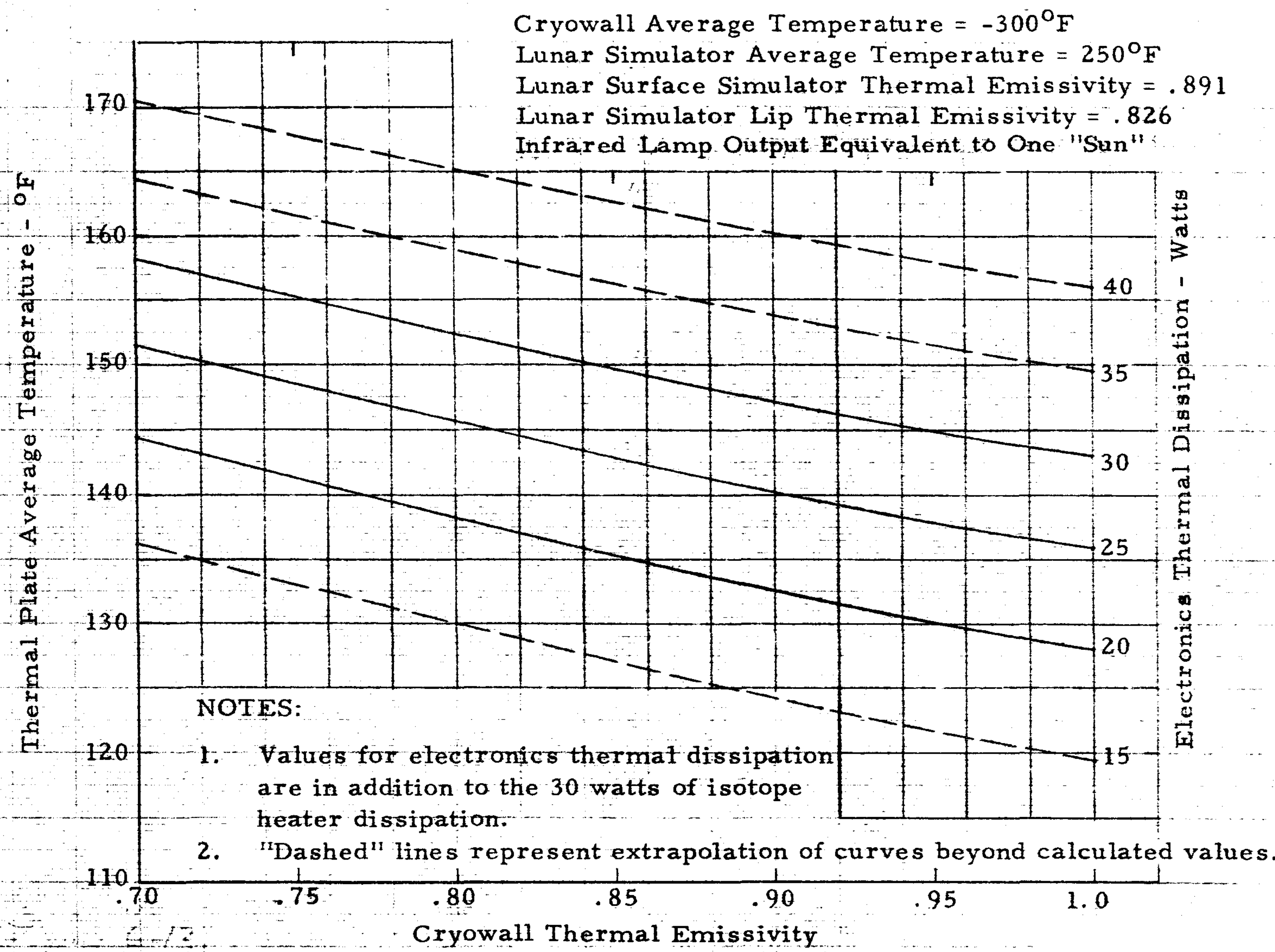


Figure 6-13. Thermal Plate Average Temperature vs Cryowall Thermal Emissivity for Various Levels of Electronics Thermal Dissipation at Lunar Noon in T/V Chamber

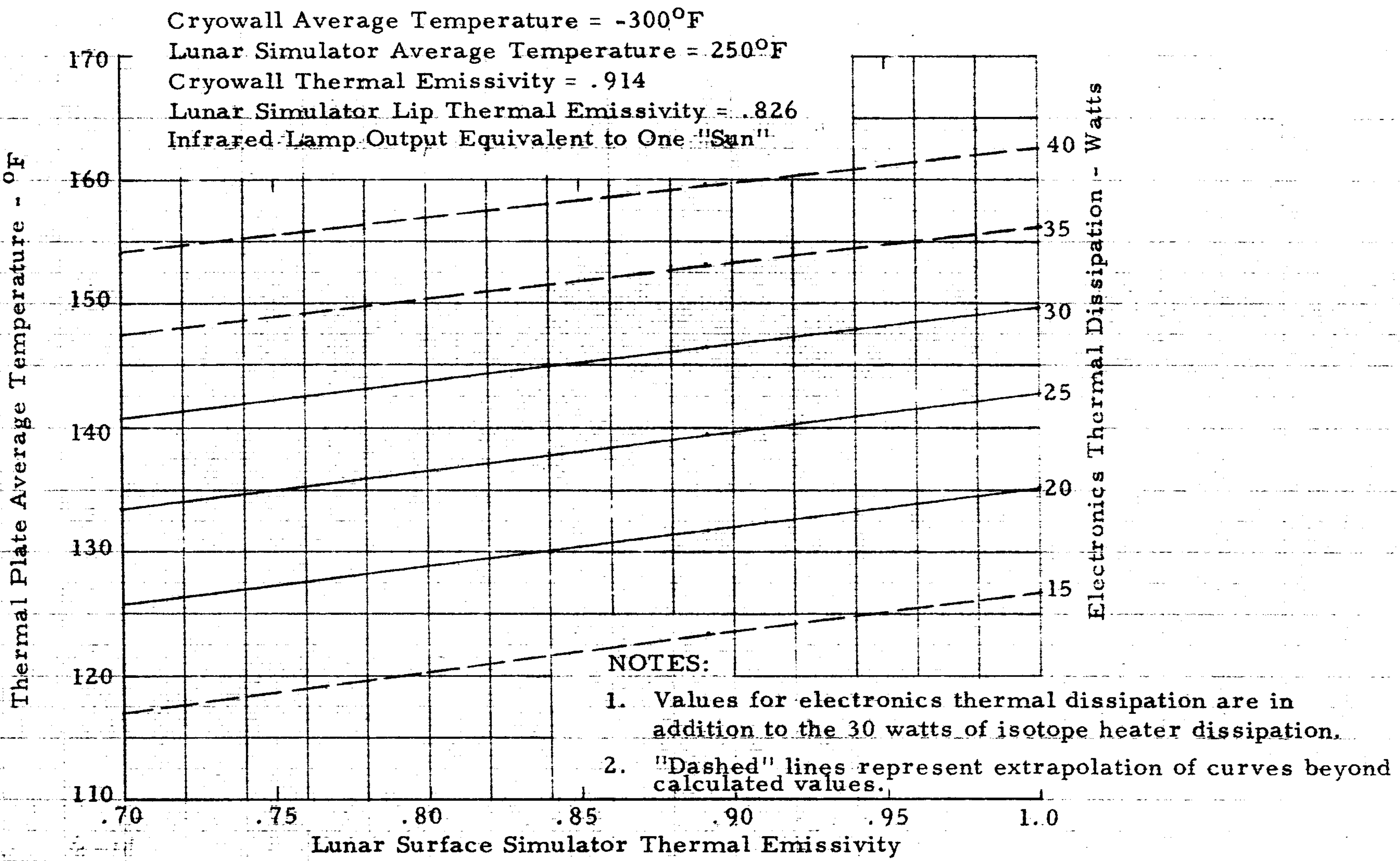


Figure 6-14. Thermal Plate Average Temperature vs Lunar Surface Simulator Thermal Emissivity for Various Levels of Electronics Thermal Dissipation at Lunar Noon in T/V Chamber

Cryowall Average Temperature = -300°F
Lunar Simulator Average Temperature = 250°F
Cryowall Thermal Emissivity = .914
Lunar Surface Simulator Thermal Emissivity = .891
Lunar Simulator Lip Thermal Emissivity = .826

NOTES:

1. One "Sun" corresponds to the lunar noon condition of 130 watts/ft² of incident solar radiation normal to PSEP surfaces.

2. Values for electronics thermal dissipation are in addition to the 30 watts of isotope heater dissipation.

3. "Dashed" lines represent values obtained by extrapolation of curves in Figure.

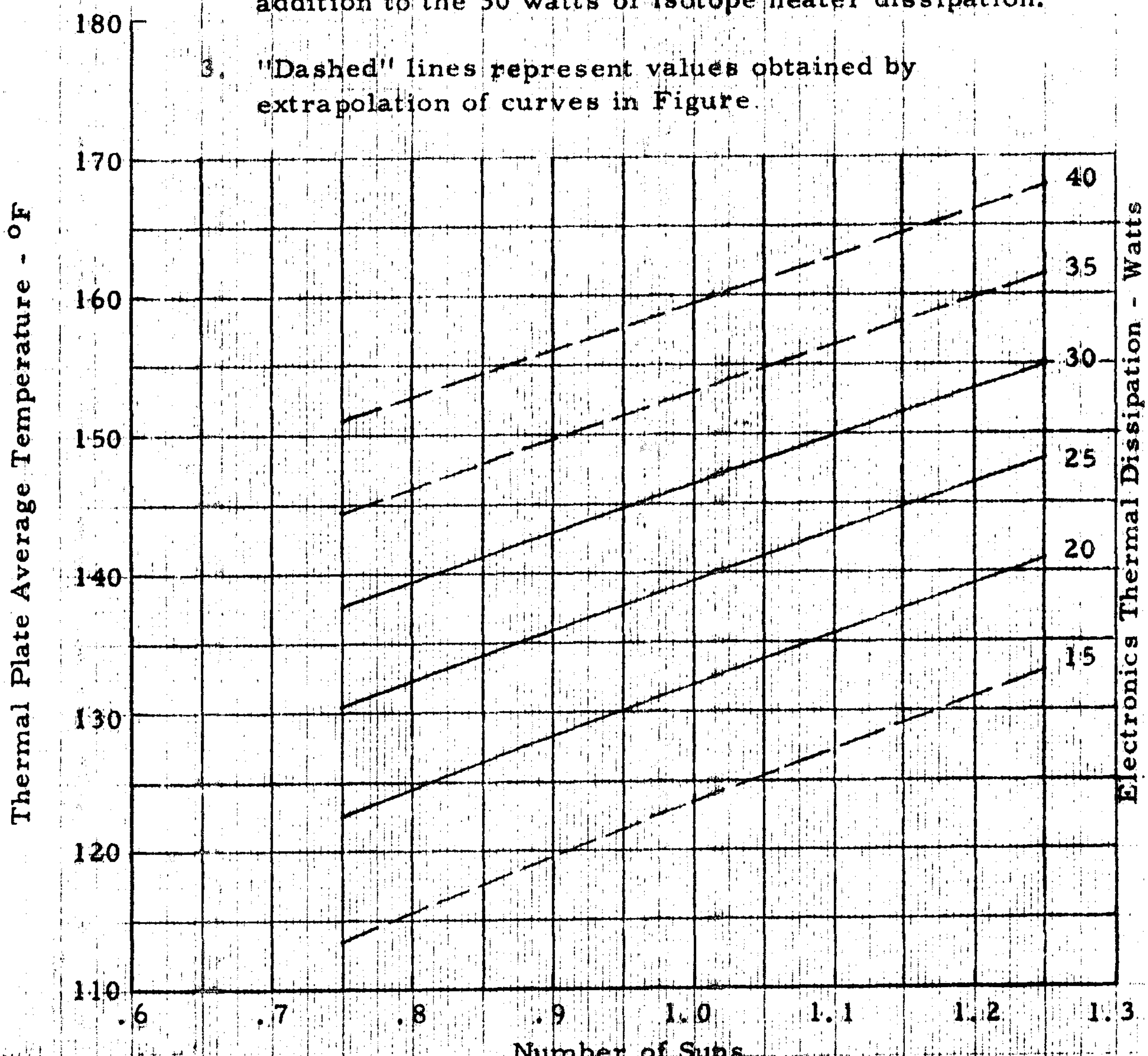


Figure 6-15. Thermal Plate Average Temperature vs Solar Radiation Heating Rate for Various Levels of Electronics Thermal Dissipation at Lunar Noon in T/V Chamber

Cryowall Average Temperature = -300°F
Lunar Simulator Average Temperature = 250°F
Cryowall Thermal Emissivity = .914
Lunar Surface Simulator Thermal Emissivity = .891
Lunar Simulator Lip Thermal Emissivity = .826

NOTES:

1. One "Sun" corresponds to the lunar noon condition of 130 watts/ft^2 of incident solar radiation normal to PSEP surfaces.
2. Values for electronics thermal dissipation are in addition to the 30 watts of isotope heater dissipation.
3. "Dashed" lines represent extrapolation of curves beyond calculated values.

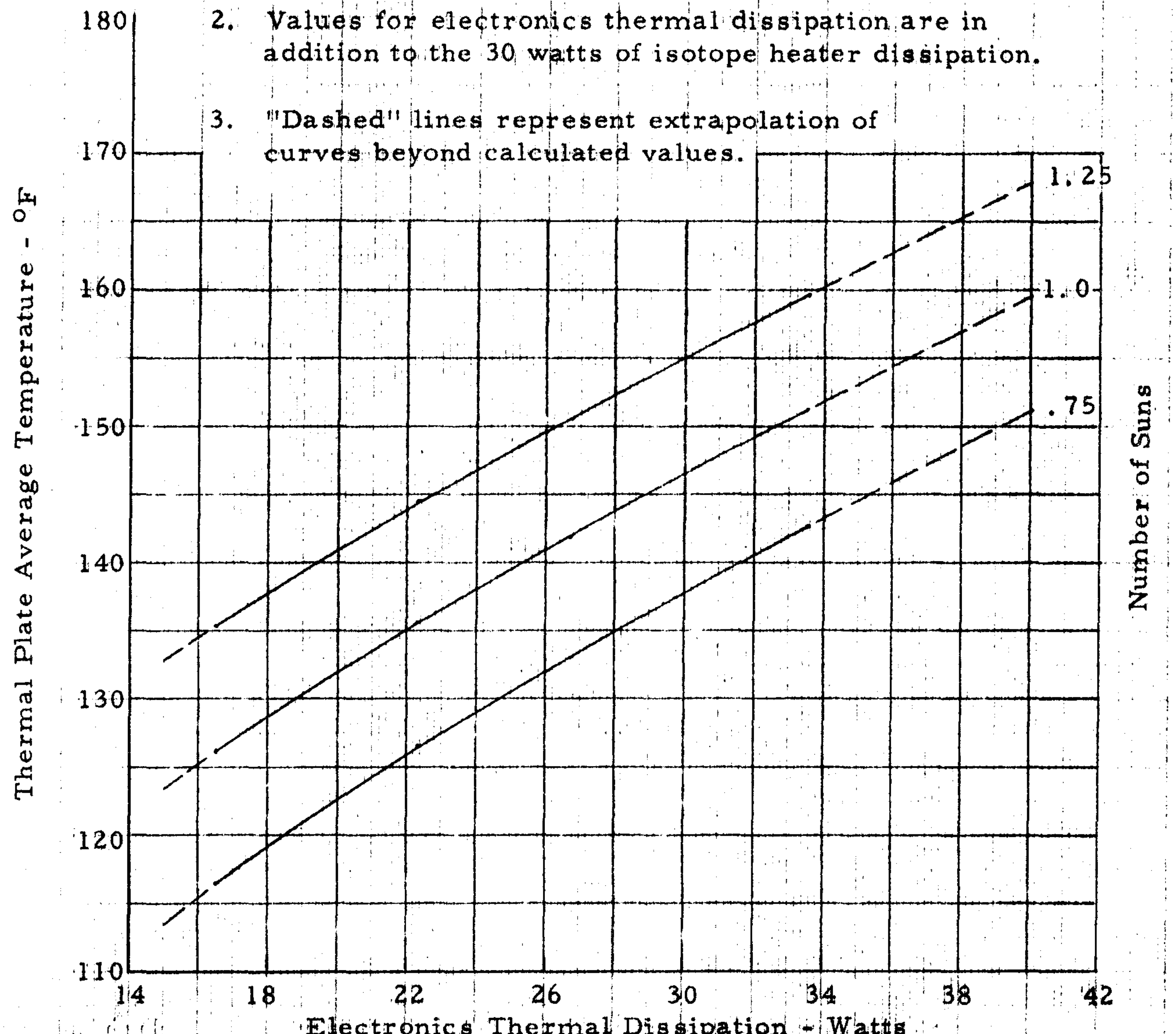


Figure 6-16. Thermal Plate Average Temperature vs Electronics Thermal Dissipation for Various Levels of Solar Radiation at Lunar Noon in T/V Chamber

Component	Average Temperature - °F		
	Qual		Flight
	Noon	Night	Noon
Lunar Surface Simulator	248	-317	251
Lunar Simulator Lip	247	-317	251
Cryowall	-270	-300	-261

Thermal emissivity measurements, which were taken over the lunar simulator and cryowall surfaces prior to testing, revealed average emissivities of 0.891, 0.826, and 0.914 over the lunar surface simulator, lunar simulator lip, and cryowall, respectively.

6.5.2.2 Solar Radiation Simulation

During PSEP Qual testing, a series of readings were taken with four radiometers in order to establish the operating power level of the tungsten filament lamps which would simulate one sun (130 watts/ft^2) of incident energy to the second-surface mirrors. Three of the radiometers, described below, were located adjacent to each other next to PSEP with their upper surfaces parallel to and at the same height as the PSE mounting plate top surface.

1. A Second-surface mirror was attached to a radiometer to obtain a direct measurement of absorbed energy by the PSEP mirrors.

2. A standard black-coated radiometer was used as a reference.

3. Aluminized teflon was fastened to a radiometer to obtain a direct measurement of energy absorbed by the PSE shroud top.

The fourth radiometer was positioned in a corner of the chamber away from PSEP to obtain background readings which involved no direct absorption of energy from the lamps.

Significant Qual test events for which radiometer readings were obtained are described below:

1. Lunar night at the beginning of testing with the Qual model electronics turned on (05:00 on 4/7/69).

2. Lunar noon with the lamps turned-off (03:30 on 4/8/69).

3. Lunar noon with the lamps activated (12:30 on 4/8/69).

4. Lunar night at the end of testing with only the isotope heaters activated.

Since the radiometers have a good view of the PSE shroud, their readings are affected by this component. Thus, when establishing a reference reading corresponding to no energy absorbed by the radiometers, the second lunar night reading (test event #4) was used since the shroud temperature was much lower during this phase than during the radiometer background test.

Also, it was necessary to determine what portion of the lunar noon readings were due to radiation from the PSE shroud. This was achieved with results from a reference test which was conducted prior to the Qual test with no model in the chamber. For example, with the lamps turned-off the mirror radiometer had a reading of -3.14 millivolts (mv) without the model in the chamber versus a reading of -2.94 mv with the model. The difference of 0.02 mv corresponded to 2.3 watts/ft^2 of absorbed energy which had to be subtracted from radiometer measurements when adjusting the lamp power level to simulate a one sun condition. Second-surface mirrors will absorb about (.06) (130) = 7.8 watts/ft^2 of direct solar energy at lunar noon on the moon. This means the mirror radiometer should have absorbed 7.8 + 2.3 = 10.1 watts/ft^2 for the mirror radiometer, which indicates that the lamps were at the correct power level.

The radiometer readings, sensitivities, and calculated absorbed energy are listed in Tables 6-11 and 6-12 at lunar night and at various lunar noon conditions.

TABLE 6-11
RADIOMETER READINGS AND SENSITIVITIES FOR PSEP QUALIFICATION TEST

T/V Chamber Condition	Radiometer Reading - Millivolts			
	Mirror	Reference Black	Aluminized Teflon	Background
Lunar Night	-3.53	-3.64	-3.17	-4.22
Lunar Noon w/o Model w/o Lamps	-3.14	-3.29	-2.89	-3.81
Lunar Noon w/Model w/o Lamps	-2.94	-3.09	-2.67	-3.80
Lunar Noon w/Model w/Lamps	-2.64	-2.24	-2.45	-3.77

Radiometer	Radiometer Sensitivity (Absorbed Energy in Watts/ft^2/mv)
Mirror (#34454)	11.57
Reference Black (#33172)	11.00
Aluminized Teflon (#33166)	10.82
Background (#33168)	10.96

TABLE 6-12
ENERGY ABSORBED BY RADIOMETERS
FOR PSEP QUALIFICATION TEST

	Energy Absorbed by Radiometer - Watts/ft^2			
T/V Chamber Condition	Mirror	Reference Black	Aluminized Teflon	Background
Lunar Night	0	0	0	0
Lunar Noon w/o Model w/o Lamps	4.46	3.85	3.03	4.49
Lunar Noon w/Model w/o Lamps	6.75	6.05	5.41	4.60
Lunar Noon w/Model w/Lamps	10.19	15.40	7.79	4.93

Since testing was conducted in a chamber enclosure which had surface emissivities less than 1.0, some of the energy emitted from the hot lunar surface simulator at lunar noon was reflected about the chamber and impinged on PSEP. This situation does not occur on the moon since space reflects no energy. Consequently, the lunar noon readings were composed of absorbed radiation directly from the lamps and PSE shroud and indirectly from the lunar simulator. Of the 10.19 watts/ft^2 total for the mirror radiometer, 4.46 watts/ft^2 is attributable to the reflected lunar simulator radiation.

Since a significant portion of the simulated solar radiation consisted of reflected lunar simulator energy, the lamps were operated at a fairly low power level and therefore emitted a high percentage of infrared radiation. The result was that the shrouds and masks received less than one sun equivalent incident solar radiation since these components have a lower infrared emissivity than the mirrors. This situation had negligible effect on thermal plate temperatures and is discussed further in Section 6.4.

The effect of infrared energy on simulation of solar radiation is illustrated by the results in Table 6-12. Before the lamps were turned-on, all radiation in the chamber was essentially in the infrared regime. The surface of the black radiometer has a nominal absorptivity of 0.89 in the solar regime, which is considerably higher than the 0.06 value for the mirrors. However, the black value falls off rapidly for wavelengths greater than 10 microns whereas the mirror increases. Consequently, prior to activating the lamps, the mirror radiometer absorbed more energy than the black radiometer. However, after the lamps were turned-on a significant percentage of the energy is in the solar range, and the black radiometer absorbed the greater amount.

Solar radiation simulation for the PSEP Flight Acceptance Test was identical to that which was used for the PSEP Qualification Test.

Solar radiation was simulated during the PSEP Qualification Model Retest by the same I. R. lamp array that was used in the PSEP Qualification Test. The array consisted of sixteen 1000 watt tungsten filament lamps mounted 95 inches above the PSEP mirrored radiator plate.

To measure the radiation flux density from the I. R. lamps, three radiometers (described below) were mounted on the same plane with and two inches away from the radiator plate. The radiometers, in the order listed below, were mounted 2. 5, 4. 5, and 6. 5 inches right of the fore-aft center line of PSEP. These three radiometers were:

1. A second-surface mirror covered radiometer (S/N 34454) used to measure the flux density absorbed by the PSEP mirrored radiator plate.

2. An unaltered black radiometer (S/N 34455) used as a reference.

3. A Kapton covered radiometer (S/N 34453) used to measure the flux density absorbed by the PSE shroud top.

The mirrored radiometer (number "1" above) was used to establish the "one-sun" condition in the chamber. Thermal equilibrium conditions and the mirrored radiometer readings are listed in Table 6-13. The difference in the mirrored radiometer readings (Table 6-13 conditions "2" and "3") is 2. 94 watts per square foot absorbed and represents that energy reflected by the cold wall that originated at the hot lunar surface simulator. The difference in the mirrored radiometer readings between conditions "4" and "5" is 4. 14 watts per square foot absorbed and is due to the IR array only. The total of the above two items (the indirect reflected radiation and the IR lamp array direct radiation) is 7. 08 watts per square foot absorbed.

Since the radiometers have a good view of PSEP, the radiometer readings are affected by PSEP. In condition "3" of Table 6-13, PSEP is warm and is radiating to the radiometers. This amount of energy (0. 56 watts per square foot absorbed) is the "night model effect." The difference between conditions "4" and "2" (4. 93 watts per square foot

TABLE 6-13
MIRRORED RADIOMETER READINGS
AT THERMAL EQUILIBRIUM CONDITIONS
FOR PSEP QUALIFICATION RETEST

Condition	Chamber Thermal Condition	Solar Simulation Condition	PSEP in Chamber	Mirrored Radiometer Readings ~ mv	Energy Absorbed By PSEP watts/ft^2
1	Lunar Night	------	No	-3.50	0.00
2	Lunar Noon	No Sun	No	-3.20	3.50
3	Lunar Night	------	Yes	-3.45	0.56
4	Lunar Noon	No Sun	Yes	-2.77	8.43
5	Lunar Noon	One Sun	Yes	-2.41	12.57

Note: Condition 1 was used to determine the "zero energy" level for all three radiometers.

absorbed) is the "noon model effect." These two model effects are background radiation and do not affect the thermal balance of PSEP. The total of the two model effects (5.49) and the solar simulation (7.08) is 12.57 watts per square foot absorbed.

The radiometer background (zero flux level) readings, sensitivities, and absorbed energies are listed in Tables 6-14 and 6-15. Note that the energy absorbed by the mirrored radiometer is 2.38 watts higher in the retest. This difference is due to the higher emissivity of the Kapton shrouds and appears in the model effect only.

6.5.3 Effect of Lunar Environment Simulation on PSEP Performance

Thermal effects of various T/V chamber test parameters on temperature predictions related to PSEP operation in a real lunar environment were evaluated. Discrepancies between test and predicted real lunar thermal plate temperatures caused by individual parameters are listed in Table 6-16 for the Flight model with no plume heating protection. However, the values should also apply to the other Flight and Qual models, except for the effect resulting from the simulated solar heating of the solar panels. A negative value indicates that the chamber test measurement was lower than the predicted temperature for actual lunar operation.

As indicated by the table, thermal plate temperatures for the Flight model on the moon will be 4°F higher at noon and 3°F lower at night than values obtained during T/V chamber testing.

6.5.4 Solar Panel Temperature Effect

At the conclusion of the PSEP Qualification Thermal-Vacuum Retest, the solar panel simulators were allowed to cool from 194°F to 150°F. The primary structure was maintained at 195°F. At thermal equilibrium the average thermal plate temperature was 151°F. This 1°F decrease in average thermal plate temperature for a 44°F decrease in solar panel simulator temperature, shows that the thermal isolation of the solar panels from the thermal plate is very good.

TABLE 6-14

RADIOMETER BACKGROUNDS AND SENSITIVITIES FOR PSEP QUAL TEST AND RETEST

Radiometer		Sensitivity Watts/ft^2 mv (absorbed)	Background (Lunar Night)
Mirrored	34454 (Test)	11.57	-3.53
Reference Black	33172 (Test)	11.00	-3.64
Aluminized Teflon	33166 (Test)	10.82	-3.17
Chamber background	33168 (Test)	10.96	-4.22
Mirrored	34454 (Retest)	11.57	-3.50
Reference Black	34455 (Retest)	11.40	-3.80
Kapton	34453 (Retest)	10.76	-3.86

TABLE 6-15

ENERGY ABSORBED BY RADIOMETERS IN THE PSEP QUAL TEST AND RETEST AT LUNAR NOON-ONE SUN-EQUILIBRIUM

Thermal-Vacuum Chamber Condition	Energy Absorbed - Watts/ft^2		
	Mirrored PSEP	Reference Black	PSE*
Test - Lunar Night	0	0	0
Test - No Power Dump	10.19	15.40	7.79
Retest - Normal Structure and Solar Panel Temperatures	12.57	21.27	14.97

*The PSE radiometer was aluminized teflon coated in the PSEP Qual Test, and was Kapton coated in the retest.

TABLE 6-16

EFFECT OF LUNAR ENVIRONMENT SIMULATION ON PSEP FLIGHT THERMAL PERFORMANCE

	Effect on Thermal Plate Temperature - °F	
Test Parameter	Noon	Night
Average temperature of chamber cryowall	+2	+3
Infrared emissivity of chamber cryowall	+3	0
Average temperature of lunar simulator	0	0
Infrared emissivity of lunar simulator	-3	0
Finite size of lunar simulator	-3	0
Simulation of solar radiation	0	0
Simulation of solar panel heating	-3	0
Total	-4	+3

6.6 Effect of Primary Structure Emissivity on PSEP Performance

Since the isolator bolts allow significant heat transfer between the primary structure and thermal plate during lunar night, structure temperature influences the thermal plate temperature. Consequently, the effect of structure surface finish (or emissivity) on PSEP thermal performance was studied. Results are illustrated in figures 6-17 and 6-18 and are based on the Qual model in the T/V chamber.

Results showed that a sizeable increase in thermal plate temperature could be attained at lunar night with an accompanying small increase in noon temperature by decreasing the structure external emissivity. For example, if the structure external surface had been changed from S13G white paint to bare aluminum (ϵ = 0.1), the noon-to-night temperature swing in the chamber would have been reduced by about 10°F. Further decrease in structure emissivity showed little improvement in temperature swing.

The study was extended to the real moon condition, and predicted improvements in temperature swing decreased due to the strong influence of the lunar surface on structure temperatures (The structure rests on the real lunar surface whereas it is supported on insulation blocks above the chamber lunar simulator). For example, only a 7°F temperature swing improvement was predicted for a polished aluminum finish (ϵ = .01) on the structure.

Due to uncertainties in the real moon thermal model predictions and due to the relatively small anticipated improvement in thermal performance, no action was initiated to alter the structure external surface finish.

6.7 Specular vs. Diffuse Solar Reflection

As part of the analysis on the PSEP Flight thermal performance, a study was conducted to compare the thermal effects of specular and diffuse reflection of solar radiation off the second surface mirrors and Kapton shrouds.

Prior to the installation of Kapton over-all insulation masks and shrouds, thermal analyses were based on the assumption that reflected solar radiation was diffuse in nature. This assumption provided conservatism in the analysis since at the critical lunar noon condition, some radiation reflected from the mirrors would reach the shrouds and masks. If the mirrors are assumed specular, all radiation reflected from them goes to space at the lunar noon condition.

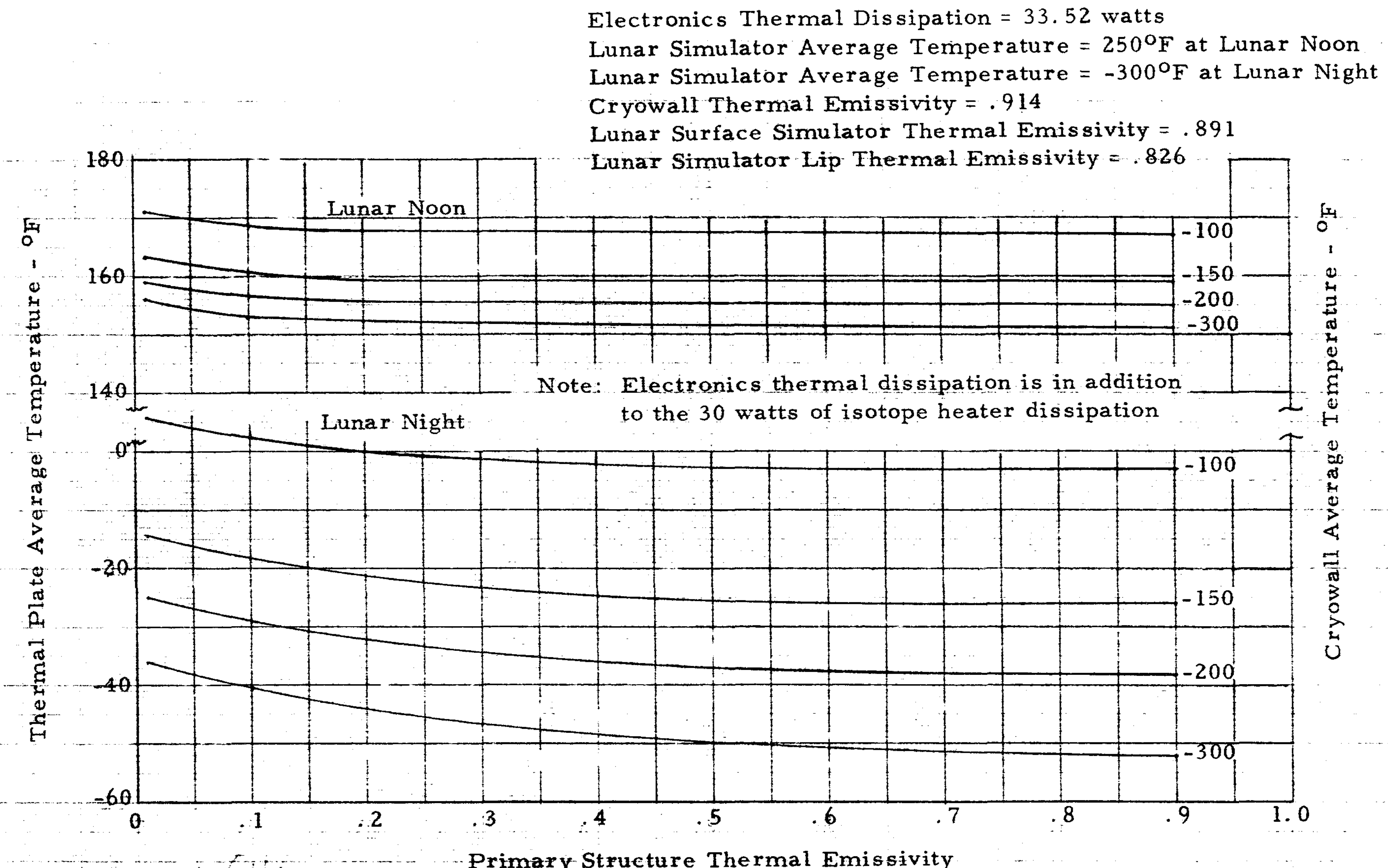


Figure 6-17. Thermal Plate Average Temperature vs Primary Structure Thermal Emissivity for Various Cryowall Temperatures in the T/V Chamber

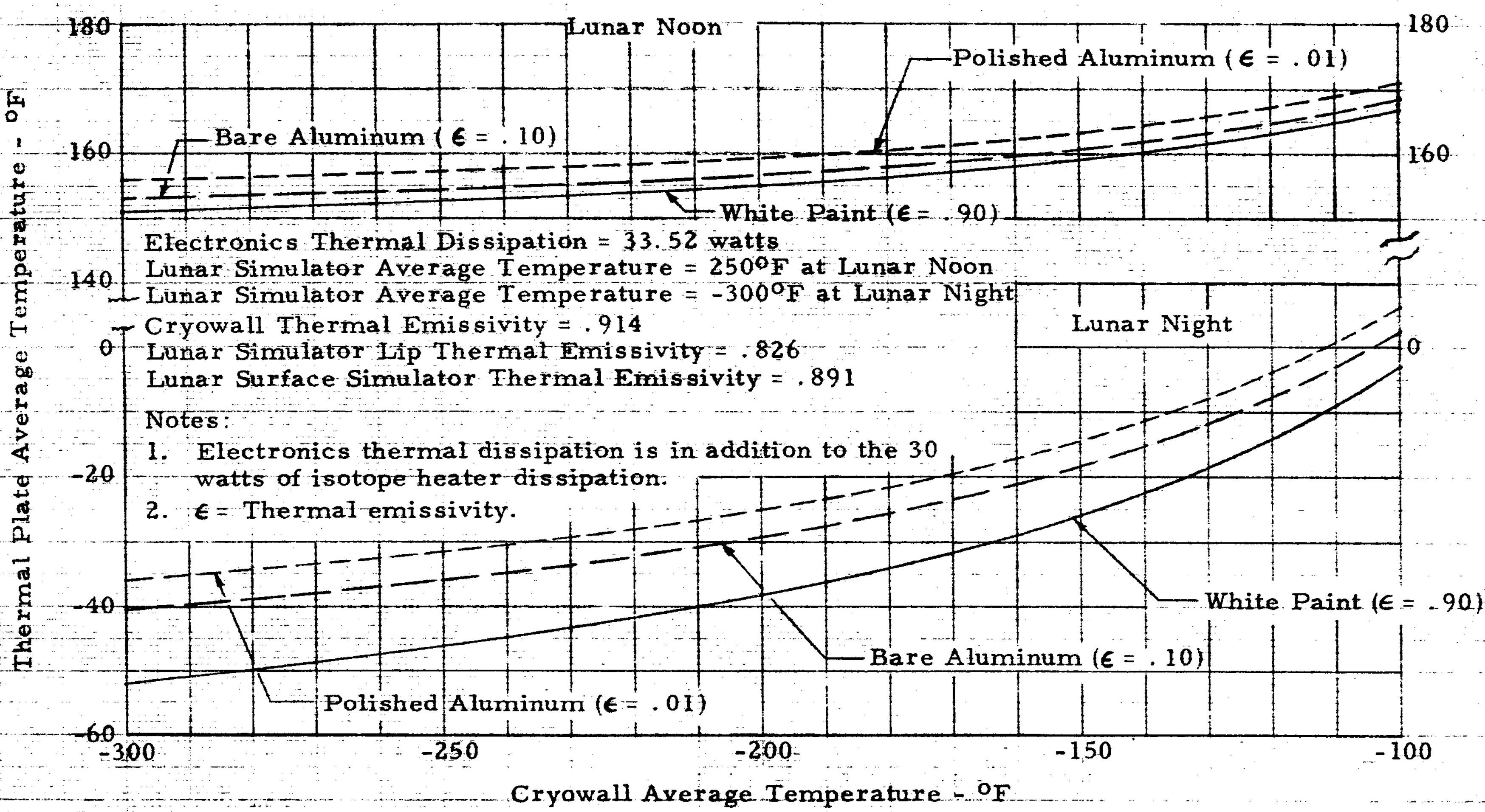


Figure 6-18. Thermal Plate Average Temperature vs Cryowall Average Temperature for Various Primary Structure External Finishes in T/V Chamber

After the decision to install the plume heating protection system, a study was conducted to determine what effect specular solar reflection from the Kapton and mirror surfaces would have on predicted PSEP thermal performance. Problem areas considered in the study were as follows:

1. The effect of specular reflection on thermal plate temperatures.

2. The possibility of specular reflection causing maximum temperatures to occur at a lunar day condition other than noon.

3. The accuracy of the one-node representation of the irregularly-shaped PSE shroud in the PSEP thermal models.

Study results were based on two very simple thermal models which consisted of the mirrors, PSE shroud, lunar surface, and space. One model used a single node to represent the PSE shroud, while 3 nodes defined the shroud in the second model. The insulation masks and heater shrouds were neglected since their effect on temperatures is small compared to the mirrors and to the PSE shroud. Also, electronics thermal dissipation was input directly to the mirrors as very little temperature gradient exists across the thermal and PSE mounting plates. Heat leaks were neglected since they are relatively unimportant during the day.

Results from the study are presented in Figure 6-19 where thermal plate average temperature is plotted versus lunar sun angle. The temperatures should be used only for comparison purposes since the magnitudes of the values are shifted somewhat from the more exact predictions due to the simplifications in the models.

The following conclusions were drawn from the study results:

1. Lunar day temperature predictions based on a one-node PSE shroud model with 100% diffuse mirror and Kapton surfaces were the highest.

2. The maximum lunar day temperature predictions occur at the lunar noon, except for the 3-node PSE shroud model with 100% specular surfaces which predicts maximum temperature at a 60 degree sun angle.

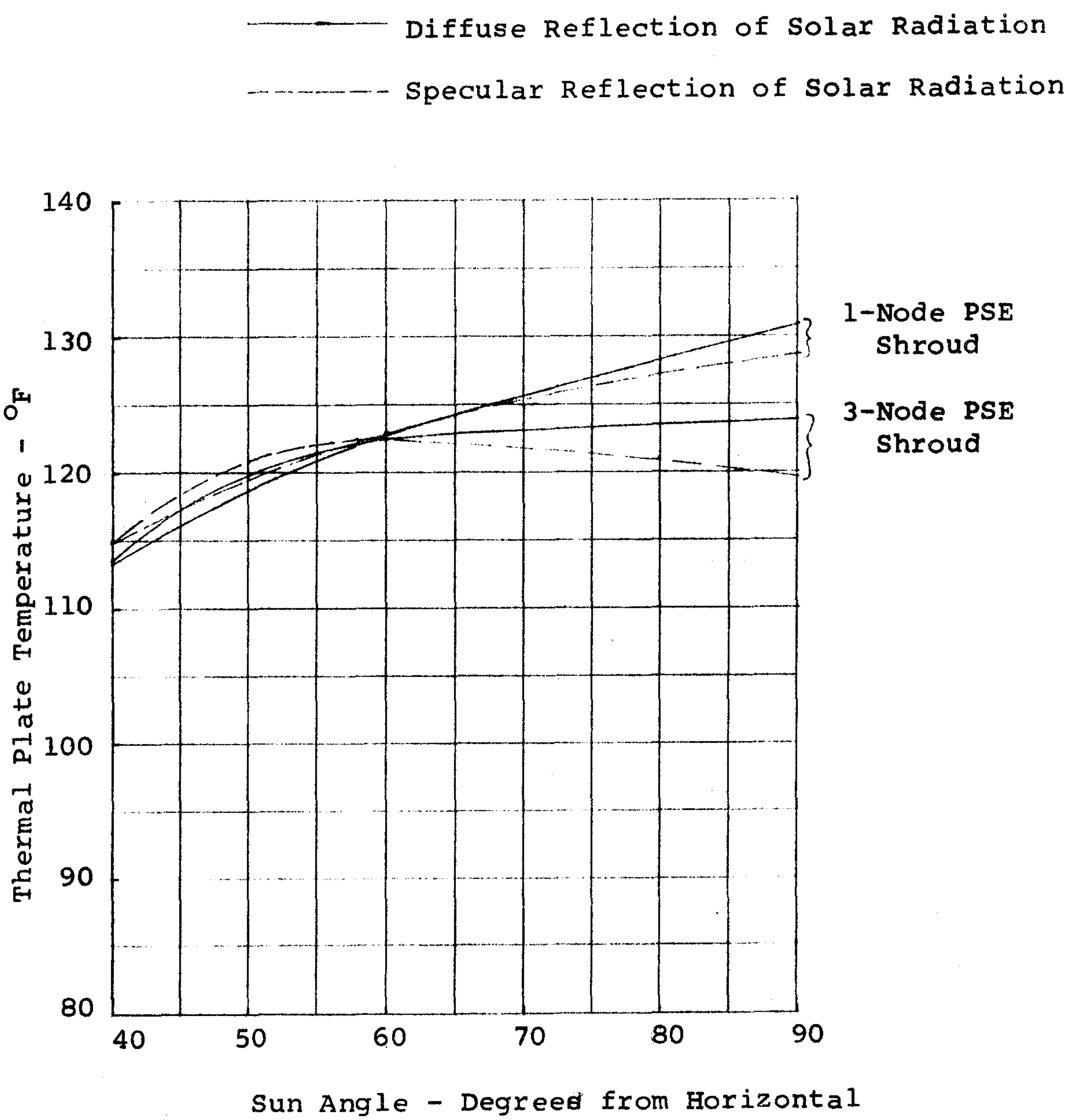


Figure 6-19. Comparison of Flight Model Thermal Plate Temperature Predictions Based on Diffuse and Specular Reflection of Solar Radiation

3. The one-node model predicts higher temperatures than the 3-node model. Little difference (1 to 2°F) existed between temperature predictions from the two models for diffuse reflection, while there was nearly a 4°F spread for specular reflection.

4. About 6°F higher maximum temperatures were predicted with the assumption of 100% diffuse reflection of solar energy than with the assumption of 100% specular reflection. For conservatism, the temperature predictions presented in this report are based on the study results for diffuse surfaces.

6.8 PSEP Thermal Design Features

The PSEP lunar performance requirements, which were outlined in Section 1, were achieved through application of the following thermal design features:

1. Radioisotope heaters for lunar night survival.

   A total of thirty watts of thermal energy was supplied by two radioisotope heaters, fastened to the PSE mounting plate, to maintain the average thermal plate temperature above -65°F during the lunar night.

2. Thermal isolation from the lunar surface.

   The central station electronics, PSE, and isotope heaters were effectively isolated from lunar environmental effects by multilayer insulation (i.e., the thermal bag, PSE shroud, and heater shrouds), low thermal conductance attachments, and low emittance vacuum deposited aluminum.

3. Thermal dissipation by radiation to space.

   Thermal energy dissipated by the electronics and PSE sensor is conducted through the mounting plate to the second surface mirrors and then rejected to space.

4. Low absorption of solar energy.

   Central station materials exposed to solar radiation (i.e. white paint, mirrors and shrouds) were selected for low solar absorptivity and high infrared emissivity to keep lunar day temperatures at minimum levels.

5. Protection against exhaust plume heating.

Layers of high temperature aluminized Kapton were placed over the insulation shrouds and masks to eliminate material failure due to LM exhaust plume heating.

7.0 REFERENCES

1. Hearin, L., "Thermal Analysis of ALSEP Prototype "A" Central Station with Comparison to Test Results", Bendix ATM-751.

2. Johnson, P., "ALSEP Prototype "A" Central Station Final Thermal Analysis and Test Results", Bendix ATM-796, October 1968.

3. Johnson, P., "ALSEP Qual SA Thermal Vacuum Chamber Test Report", Bendix ATM-824, January 1969.

4. Bendix Thermal Analyzer Computer Program.

5. Simms, R., "Lunar Subsurface Model", Bendix IM 9712-767, April 1968.

6. Johnson, P. and McNaughton, J. "PSEP Plume Heating Study", Bendix IM 9712-1123, May 1969.

7. McNaughton, J., "Plume Heating Study Summary", Bendix IM 9712-1121, May 1969.

8. Johnson, P., "FEP Teflon Properties", Bendix Contact Report 9712-1122, May 1969.

9. Simms, R., "Partial Response to EASEP QTRR RFC No. EQT-P-5", Bendix IM 981-155, February 1969.

10. McNaughton, J., "Elevated EASEP Temperatures During Lunar Withdrawal", Bendix IM 981-165, March 1969.

11. Johnson, P. and Simms, R., "Thermal Control Configuration Parametric Studies", October 1968.

12. Simms, R. and Owens, J., "Thermal Isolator Design and Selection - PSEP Central Station", Bendix EATM-23, January 1969.

13. Burns, R., "PSE Mounting Plate Skin Thickness Study", Bendix EATM-39, January 1969.

14. Simms, R., "Preliminary Isotope Heater Locations and Masking Pattern - PSEP Central Station", Bendix EATM-10, December 1968.

15. Simms, R., "Final Isotope Heater Locations and Masking Pattern - PSEP Central Station", Bendix EATM-48, January 1969.

16. Simms, R., "Changes to the Qual C/S Heater Power Profile", Bendix IM 981-177, March 1969.

17. Courtois, D., "PSEP Power Management", Bendix EATM-44, February 1969.