Bendix

Aerospace Systems Division

R. MILEY

ALSEP Qual SA Thermal
Vacuum Chamber Test Report

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This ATM presents test data for the ALSEP Qual SA Central Station and Pallet 2/RTG packages and compares these data with analytical predictions, with the primary purpose being to accurately predict steady-state temperatures for operation in a real lunar environment.

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PAGE 25 - PREDICTED LUNAR NOON TEMP
PREDICTED LUNAR NIGHT TEMP

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1.0 INTRODUCTION

This document presents the results from the Acceptance, Mission Simulation, and Design Limit thermal vacuum (T/V) chamber tests on the ALSEP Qual SA Central Station and Pallet 2/RTG and compares these results with analytical predictions for the test and the real lunar environments. The three tests, conducted during the T/V Qualification Test Program, are briefly described below:

1. Acceptance Test - The Qual SA model was subjected to an accelerated lunar day-to-night cycle with the objective of verifying the system thermal/electrical performance for operation in lunar morning, lunar noon, and lunar night environments.

2. Mission Simulation Test - A simulated real lunar day-to-night cycle was imposed on the model with the purpose of qualifying system performance over a 28 day cycle.

3. Design Limit Test - The Central Station (C/S) was operated with the radiator plate at the highest temperatures predicted for the actual lunar environment to verify performances of the C/S and Pallet 2/RTG for this condition.

Pictures which illustrate the Central Station and Pallet 2/RTG deployed in the BxA 20 x 27 ft T/V Chamber are presented in Figures 1.1 to 1.3.

Based on Proto A test program results and on increased electronics loads for the Qualification and Flight C/S configurations, several thermal design improvements, which are outlined below, were required and incorporated into the Qual SA and subsequent Flight models.

1. Sunshield awnings and side curtain extensions were removed to reduce lunar day operating temperatures of the radiator plate.

2. The width of the radiator masks was increased from 6 to 7 inches to reduce radiator lunar noon-to-night temperature swing.

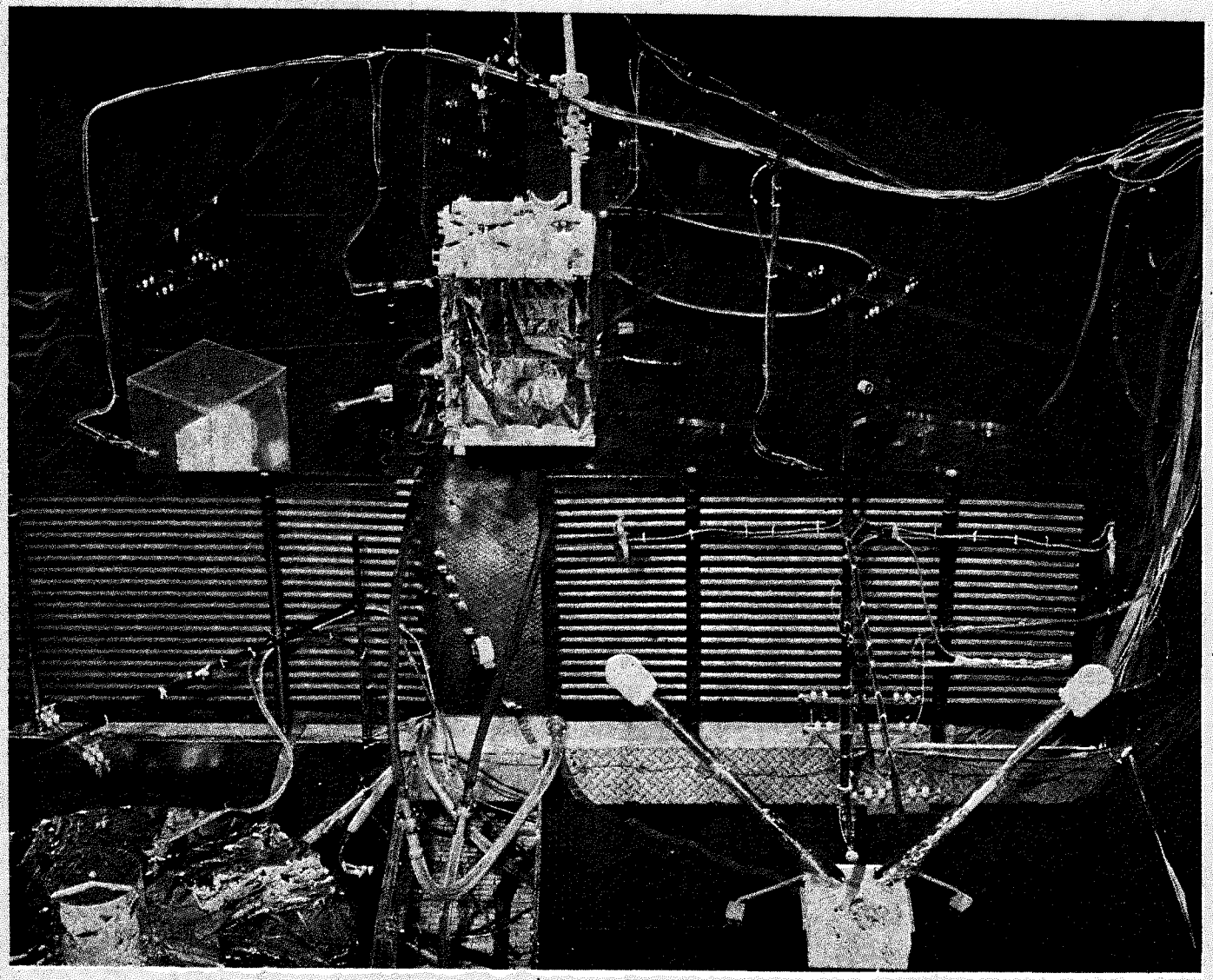


Figure 1.1 Qual SA ALSEP Deployed in Lunar Simulation Chamber for Thermal Vacuum Test

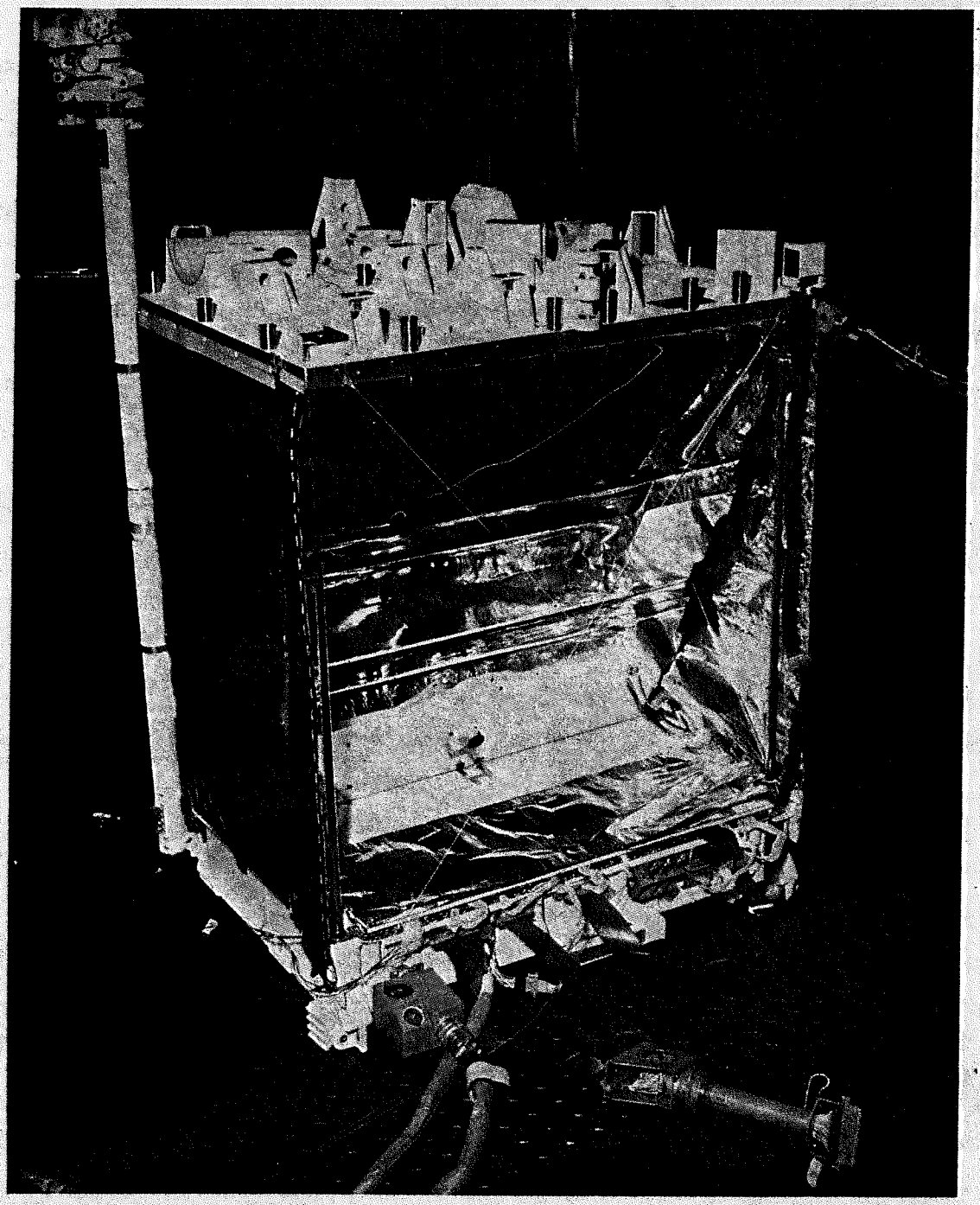


Figure 1.2 Qual SA Central Station Deployed in Lunar Simulation Chamber for Thermal Vacuum Test

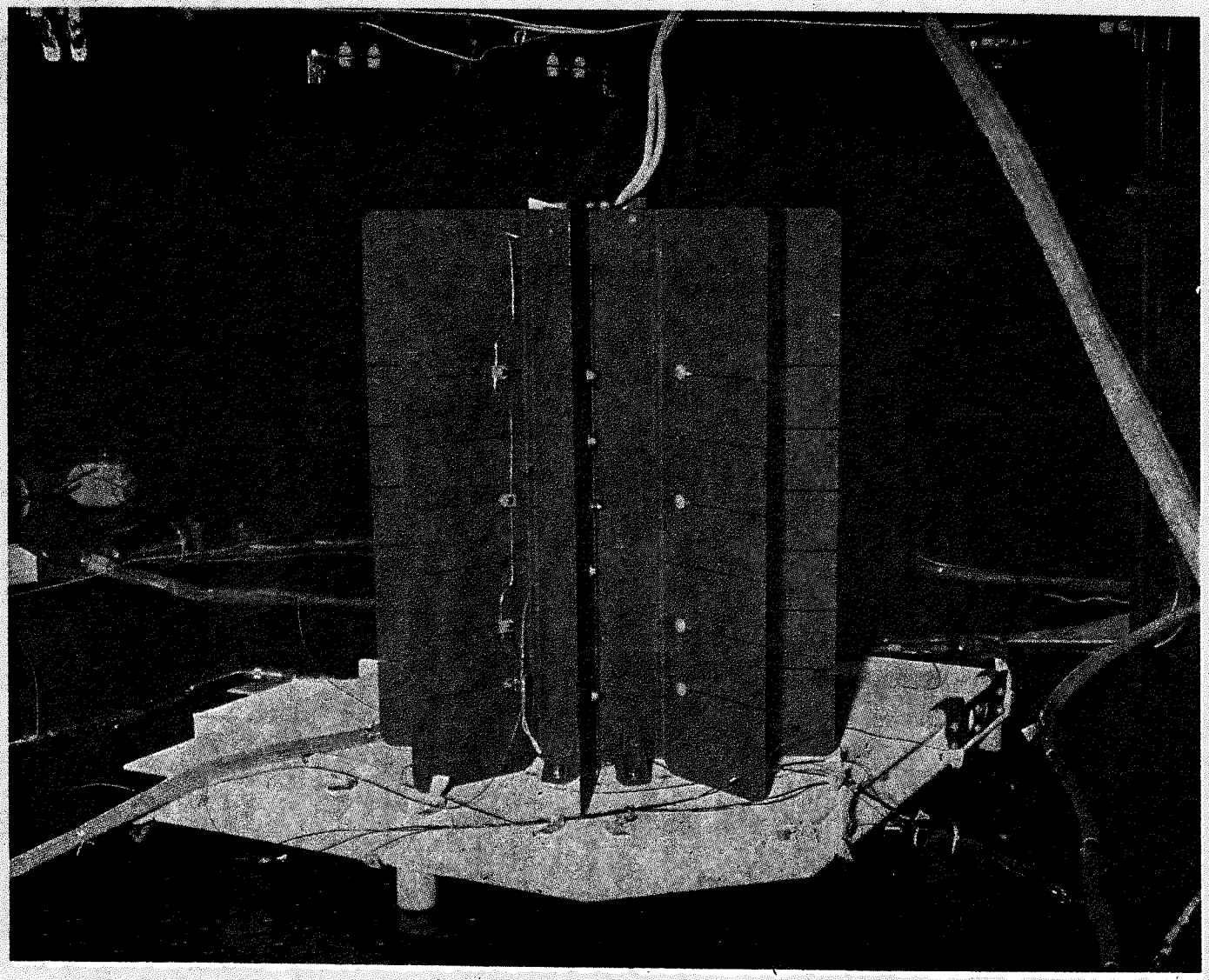


Figure 1.3 Qual SA Pallet 2/RTG Deployed in Lunar Simulation Chamber for Thermal Vacuum Test

3. Additional "backup" heaters were attached to the radiator plate to provide contingency power at lunar night to optimize temperature swing.

To illustrate the effect of the design improvements, predicted thermal performances of the Qual SA Acceptance and Proto A Central Station models in a real lunar environment are compared below.

C/S Model	Radiator Average Temperature (°F) Lunar Noon	Lunar Night	Temperature Swing
Proto A	133	-22	155
Qual SA	127	3	124
Specification	125	0	125

Thus, the above design modifications produced the following thermal improvements in C/S operation:

1. Lunar noon radiator average temperature decreased 6°F.

2. Lunar night radiator average temperature increased 25°F.

3. Noon-to-night radiator temperature swing decreased 31°F.

Further details on the Qual SA design improvements are presented in Section 7.4.

Studies were conducted to determine thermal effects of various T/V chamber test parameters and conditions (listed below) on temperature predictions related to the operation of the Qual SA C/S in a real lunar environment. Results from these studies are presented in Sections 3 and 7. Discrepancies between test and predicted real lunar radiator and structure temperatures caused by individual parameters are summarized below for the Acceptance Test configuration. A negative value indicates the chamber test measurement was lower than the predicted value for actual lunar operation.

The finite size of the lunar surface simulator obviously causes most of the difference between T/V chamber test and real lunar performances during the lunar day.

Test Parameter or Condition	Effect on Temperature - °F Radiator Noon	Radiator Night	Prim. Structure Noon	Prim. Structure Night
Average temperature of chamber cryowalls	+2	+2	+5	+5
Thermal emissivity of chamber cryowalls	+5	0	+1	0
Finite size of lunar surface simulator	-34	0	-14	0
Average temperature of lunar surface simulator	0	0	0	0
Temperature gradients over lunar surface simulator	0	0	+2	0
Thermal emissivity of lunar surface simulator and simulation of solar energy reflected from lunar surface	-8	0	-17	0
Thermal conduction and radiation between C/S and lunar surface simulator	0	+1	+21	+6
Power dissipations of C/S electronic components which are temperature dependent	0	0	0	0
Close proximity of RTG to C/S in chamber	0	0	+6	+29
Total	-35	+3	+4	+40

Section 7 presents thermal effects of incomplete deployment of the side curtains and of C/S misalignment on the moon. Incomplete side curtain deployment will have negligible influence on radiator temperatures at the critical lunar noon and night conditions. Worst case Central Station misalignment might cause up to a 7°F increase in radiator plate average temperature at lunar noon.

Sections 4, 5 and 6 contain general descriptions of test methods, of test results, and of the C/S thermal model used for analytical predictions.

2.0 SUMMARY OF RESULTS AND CONCLUSIONS

2.1 Analytical and Test Results

Predicted and test temperatures for 1) Acceptance, 2) Mission Simulation, and 3) Design Limit Qual SA vacuum chamber test phases are presented. Analytical predictions and subsequent post-test correlation with chamber test results were performed for equilibrium conditions at lunar noon, lunar night, and the design limit. Overall test results revealed favorable temperature distributions on all Central Station and Pallet 2/RTG components, and excellent temperature correlation was obtained with the pre-test predicted values as shown in following figures. All Qual SA component temperatures were within operating limits established prior to testing.

Temperature predictions for C/S operation in a real lunar environment are presented and compared with predictions for chamber test conditions. Unless specified otherwise, test data is from the Data Acquisition System (DAS) engineering instrumentation.

2.1.1 Acceptance Test

The Qual SA model was subjected to an accelerated lunar day-to-night test cycle, one lunation, with the lunar surface simulator average temperature ranging from 250° F at noon to -300° F at night. Included in the test program was a lunar morning ALSEP System turn-on followed by thermal stabilization at both the simulated lunar noon and night environments. Testing consisted of two phases. The first extended from 5-11-68 to 5-20-68 when a chamber failure occurred at the beginning of lunar noon, while the second section covered a complete lunation from 5-29-68 to 6-9-68.

2.1.1.1 Central Station Thermal Performance

Figure 2.1 illustrates a sample Central Station (C/S) radiator plate temperature cycle and depicts major events which occurred during testing: pre-test ambient integrated system test (IST), lunar morning, lunar noon, lunar night, and post-test ambient IST.

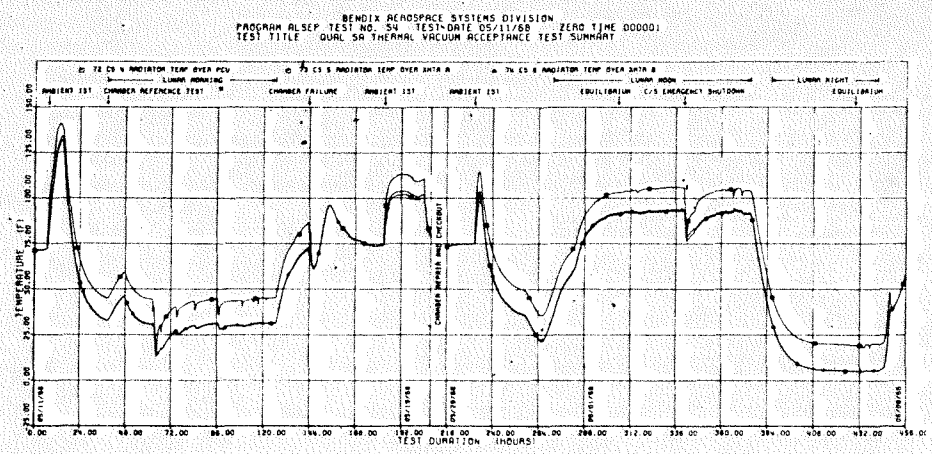
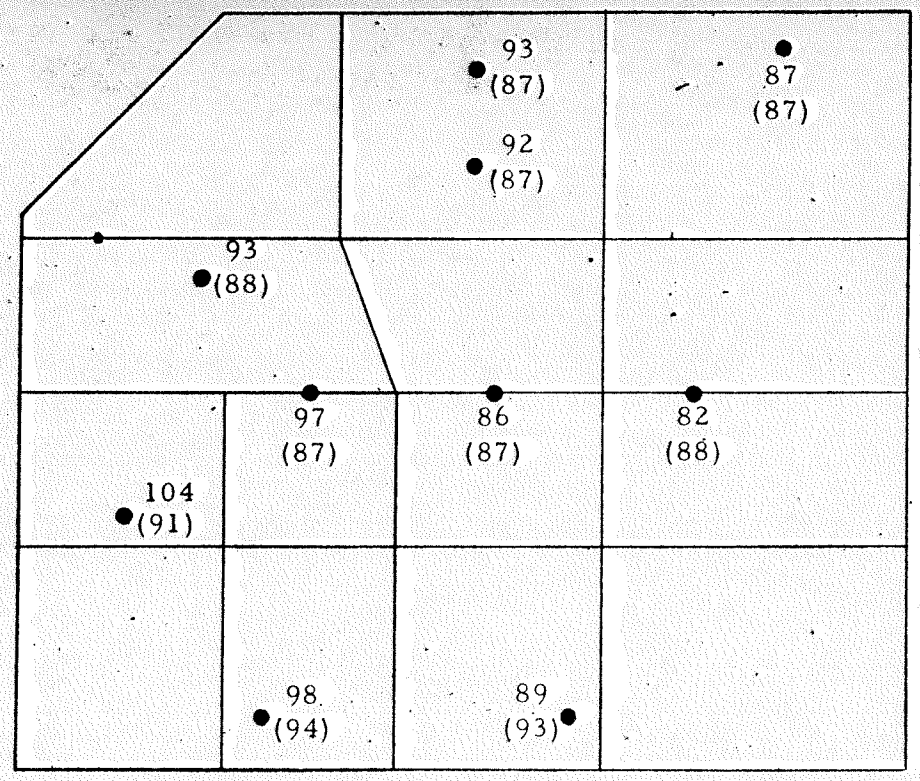


Figure 2.1 Qual SA Central Station Radiator Plate Temperature Profiles for T/V Acceptance Test

Qual SA Acceptance Test temperature distributions over the C/S are compared with predicted values in Figures 2.2 through 2.4.

Except for the sunshield, discrepancies between predicted and test values ranged from 0° F to 13° F and averaged 3° F and 0° F, respectively, for the radiator plate in the "noon" and "night" environments. An abbreviated comparison of test results to predicted temperatures for various C/S components in the chamber and real moon environments is presented below.



Lunar Noon

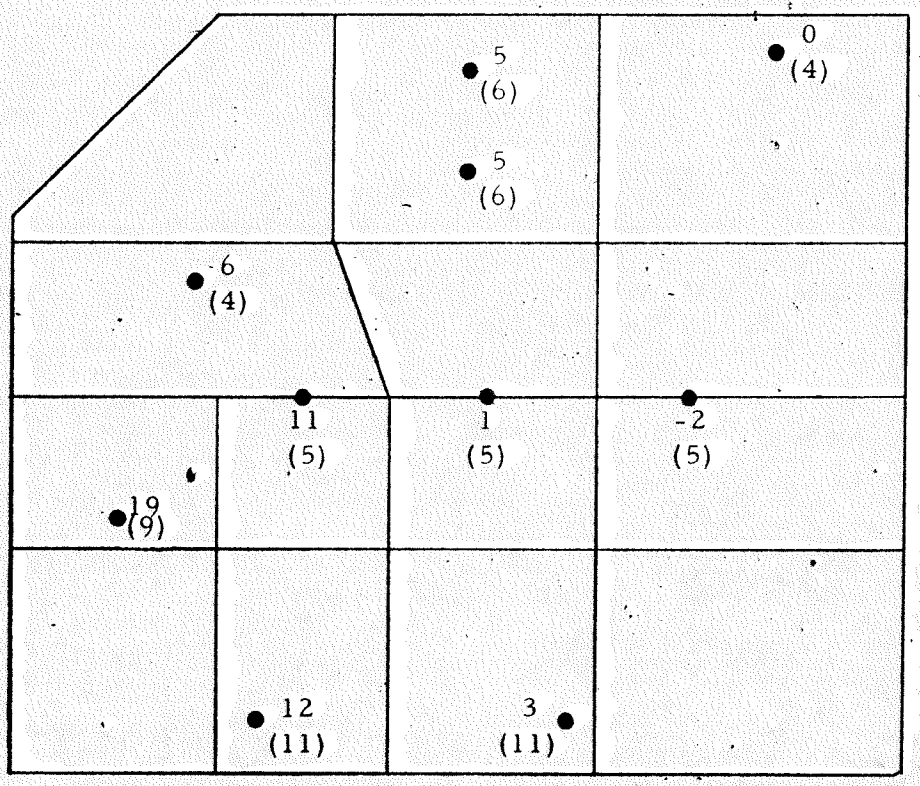
$T_{ave_{meas}} = 92^{o}F$

$T_{ave_{pred}} = 89^{o}F$

Electronics Thermal Dissipation = 37.6 Watts

xxx Measured
(xxx) Predicted

Note: Dividing Lines Outline Radiator Plate Nodes for Thermal Model



Lunar Night

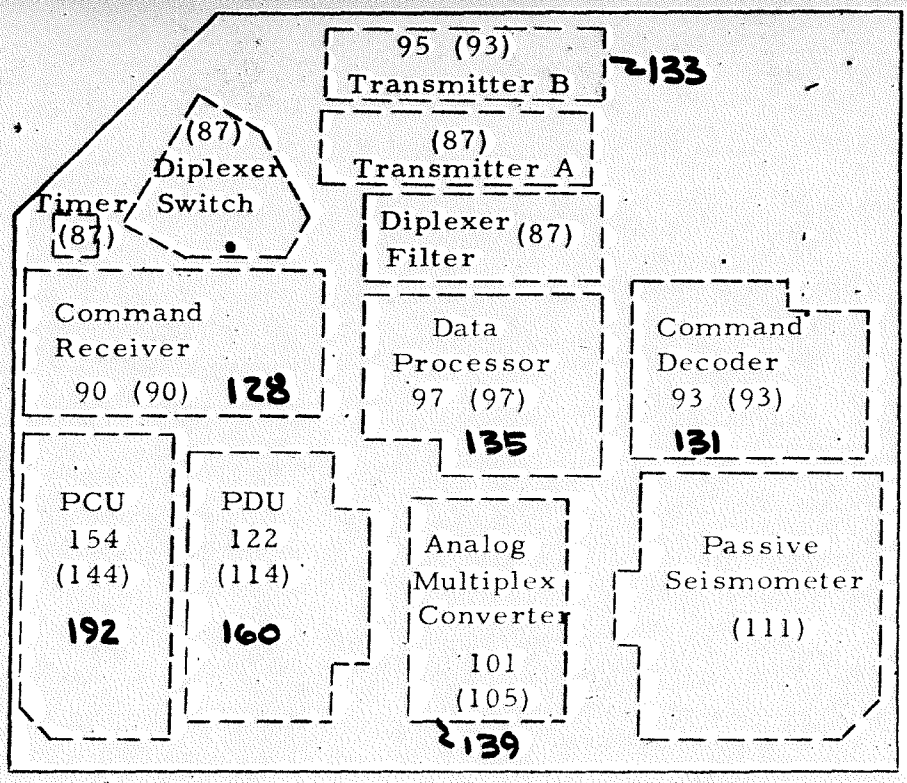
$T_{ave_{meas}} = 6^{o}F$

$T_{ave_{pred}} = 6^{o}F$

Electronics Thermal Dissipation = 37.6 Watts

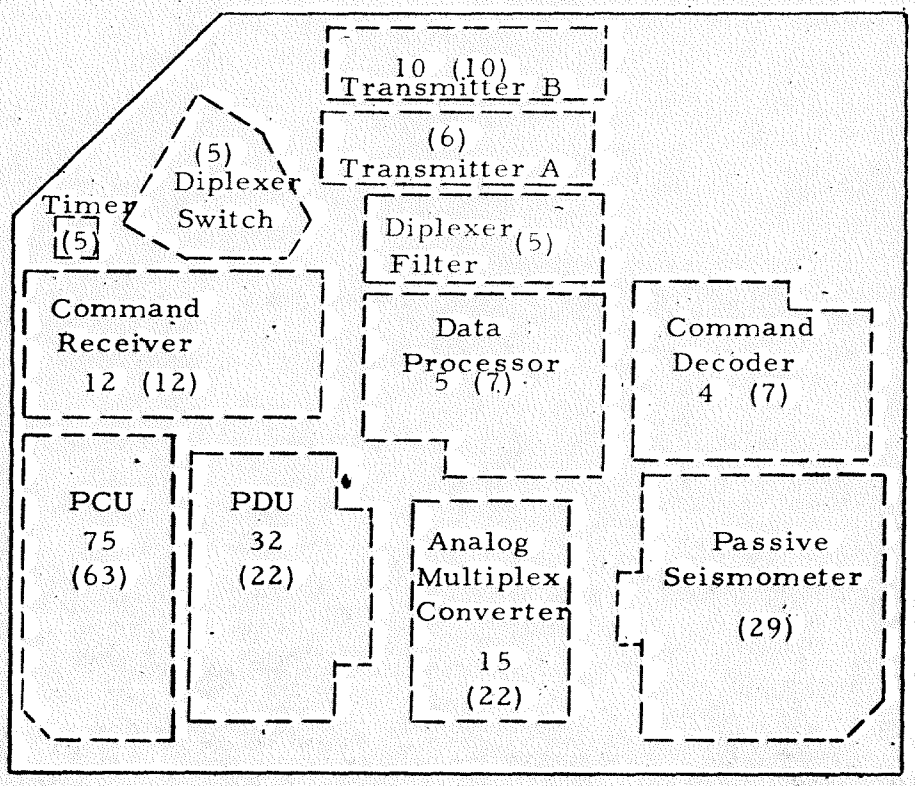
Figure 2.2 Qual SA Acceptance Test; Measured vs Predicted Radiator Temperatures for Lunar Noon and Lunar Night (^{o}F)

A = 38°F



Lunar Noon
Electronics Thermal
Dissipation = 37.6 Watts

xxx Measured
(xxx) Predicted



Lunar Night
Electronics Thermal
Dissipation = 37.6 Watts

Note: Measured values are the "hot" or internal electronics temperatures obtained with the Telemetry (Housekeeping) data system.

Figure 2.3 Qual SA Acceptance Test; Measured vs Electronics Temperatures for Lunar Noon and Lunar Night (°F)

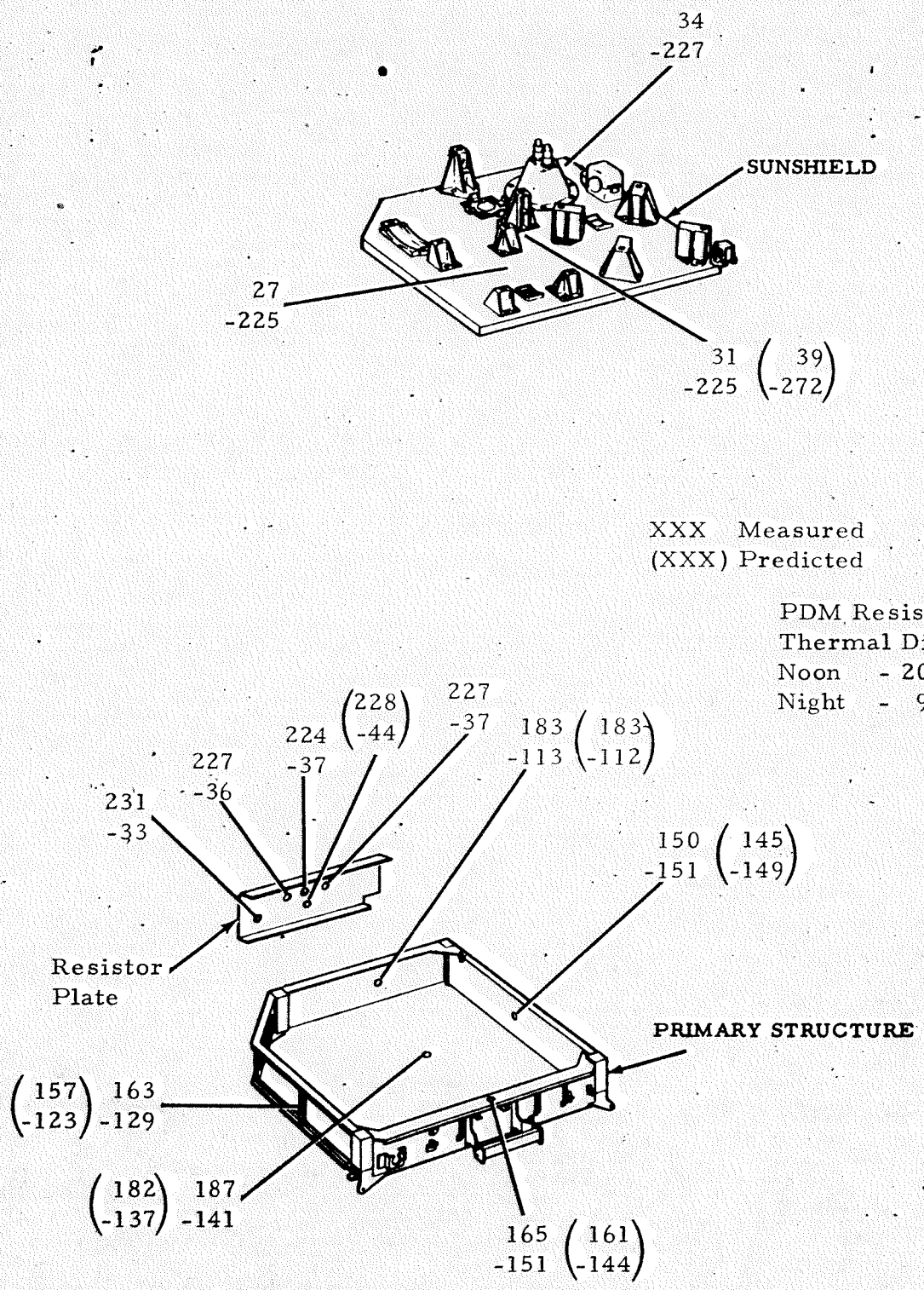


Figure 2.4 Qual SA Acceptance Test; Measured vs. Predicted Sunshield and Primary Structure Temperatures for Lunar Noon and Night (°F)

	Temperatures - °F						
	Lunar Noon				Lunar Night		
C/S Component	Chamber Test	Predicted Chamber	Predicted Real Moon*	Δ	Chamber Test	Predicted Chamber	Predicted Real Moon*
Radiator Plate, average	92	89	127	38	6	6	3
Structure Sides, average	165	162	164	2	-136	-131	-176
Structure Bottom	187	182	168	-14	-141	-137	-181
Sunshield Top	31	39	31	-8	-226	-272	-232
Resistor Plate	227	228	231	4	-36	-44	-60

*These predicted values are adjusted for discrepancies between predicted and test figures for the T/V chamber Acceptance Test configuration.

As shown by this table, radiator plate average temperature swings were 86, 83, and 124° F, respectively, for the Acceptance Test chamber performance, predicted Acceptance Test chamber performance, and predicted performance in a real lunar environment.

Tables 7.1 and 7.2 in Section 7 give detailed comparisons of analytical model temperature predictions and test data. Temperature versus time plots of various C/S test measurements are presented in Section 6.1 along with Data Acquisition System (DAS) and Housekeeping (HK) steady-state data at lunar noon and night.

2.1.1.2 Pallet 2/RTG Thermal Performance

Figures 2.5 and 2.6 illustrate temperature histories of RTG fins and pallet surfaces below the RTG. Temperature distribution over the RTG and Pallet 2 surfaces at lunar noon and night are illustrated in Figures 2.7 and 2.8 and are tabulated in Table 6.3. Pallet temperatures under the RTG ranged from 320° F at lunar noon to -30° F at night. RTG fin temperatures varied from 449° F at noon to 381° F at night.

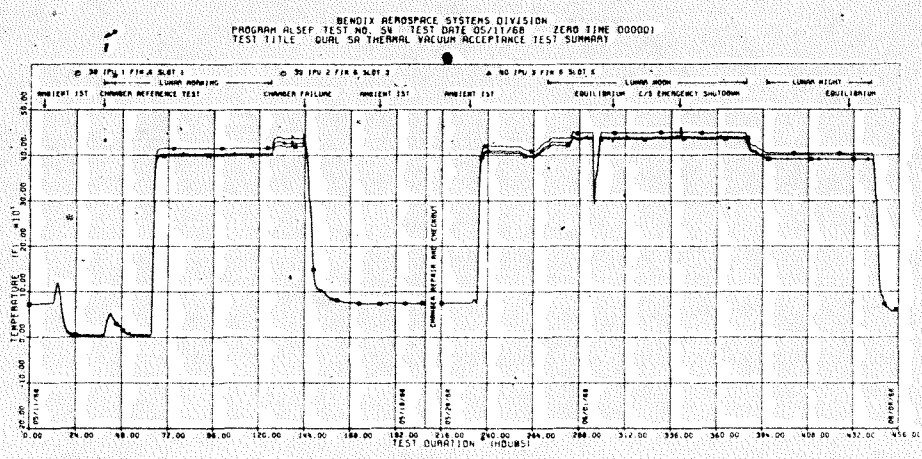


Figure 2.5 Temperature Distribution over RTG for Qual SA T/V Acceptance Test

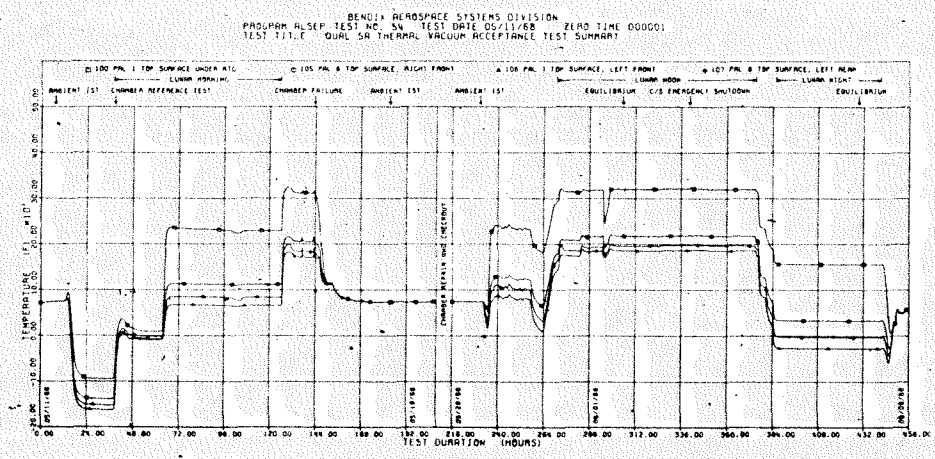


Figure 2.6 Temperature Distribution over Pallet 2 for Qual SA T/V Acceptance Test

The RTG dissipated approximately 1460 watts with 67.2 watts input to the Central Station at lunar noon and 67.4 watts input at lunar night. C/S power inputs represent a 5 to 6 watt increase over Proto A input power and produced the intended sizeable decrease in day-to-night temperature swing, as discussed in Section 7.4.

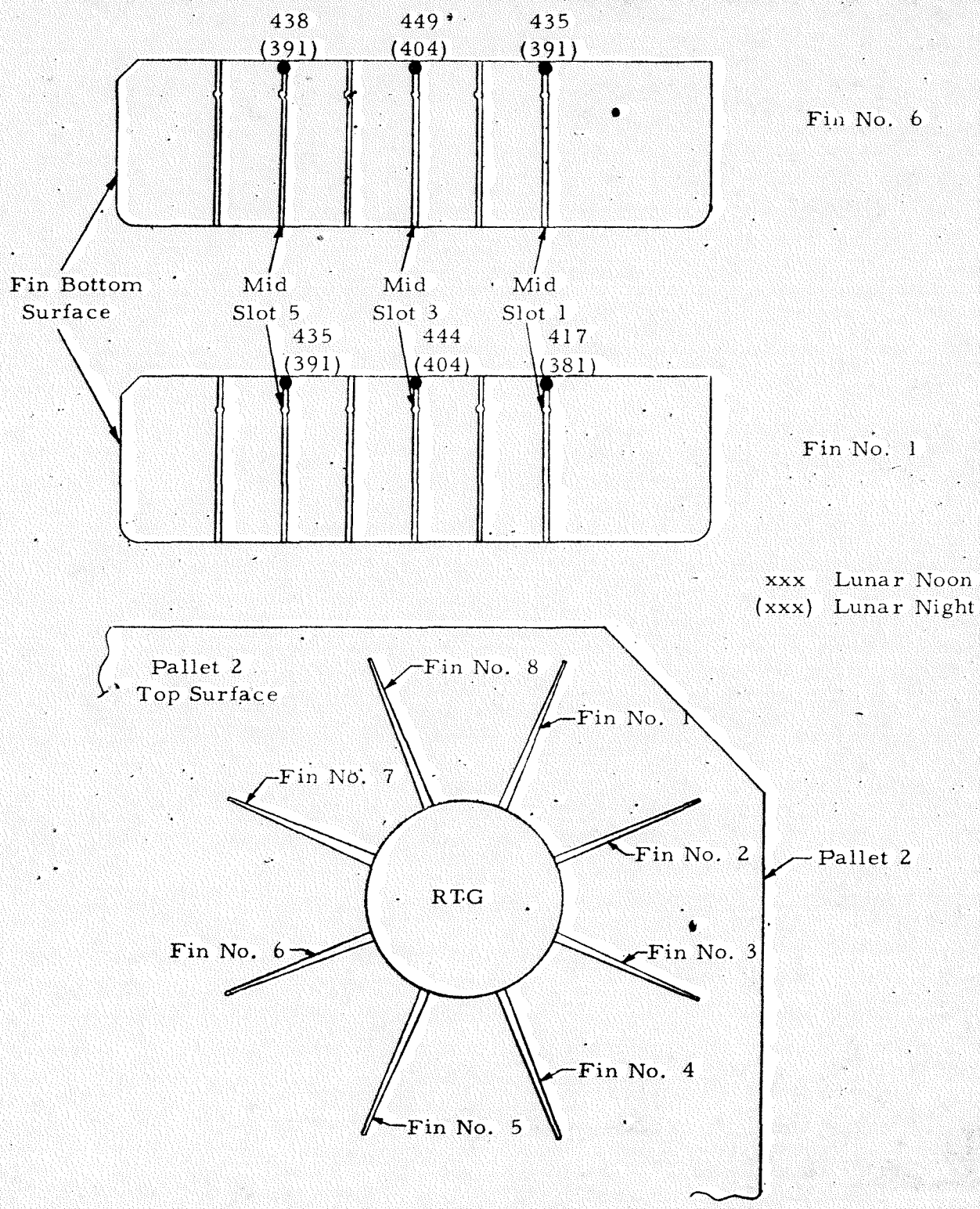


Figure 2.7 Qual SA Acceptance Test; Measured RTG Temperatures (°F) at Lunar Noon and Night

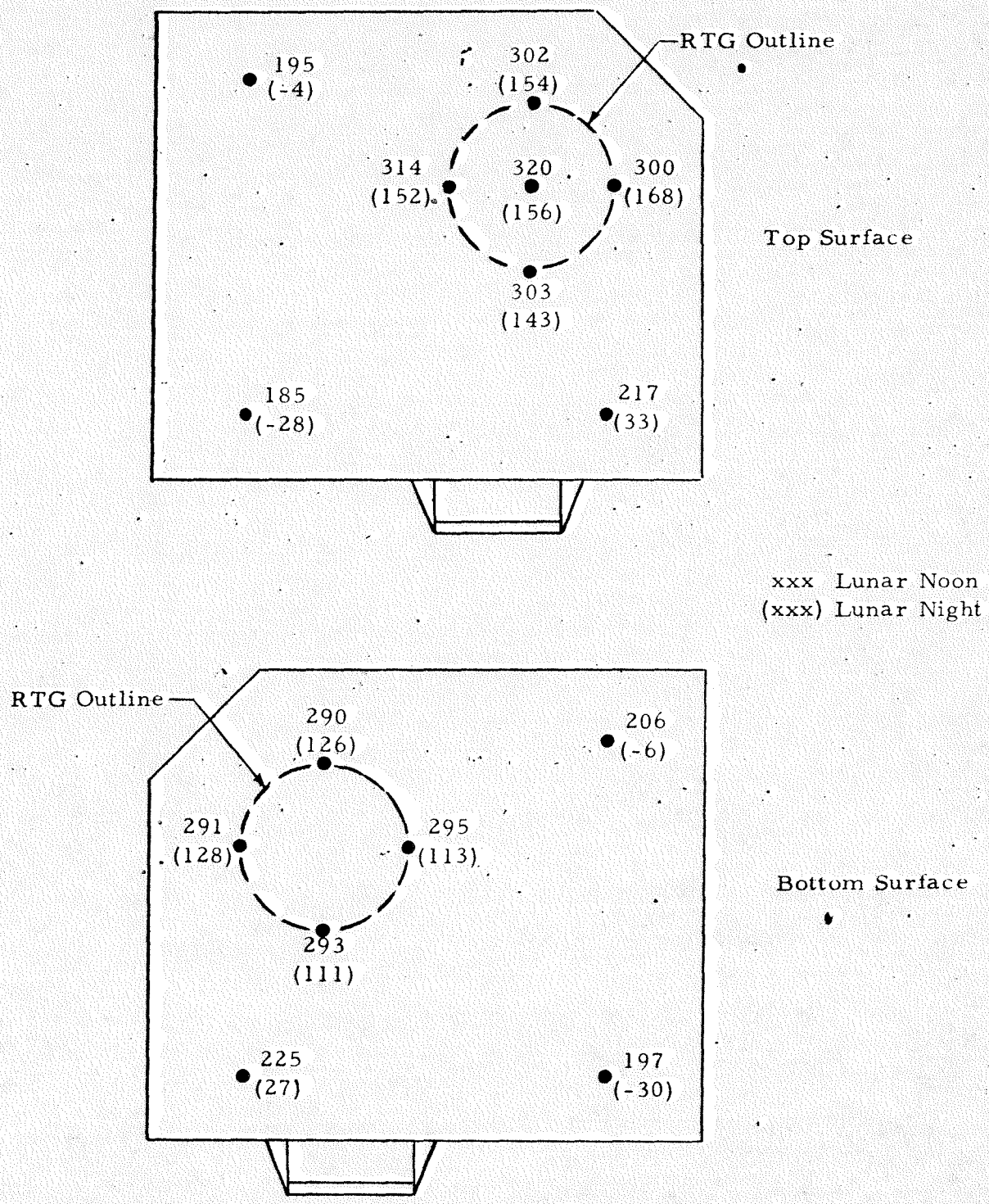


Figure 2.8 Qual SA Acceptance Test; Measured Pallet 2 Surface Temperatures (°F) at Lunar Noon and Night

2.1.2 Mission Simulation Test

The Qual SA model was subjected to an actual lunar day-to-night cycle from 7-14-68 to 8-7-68 where lunar surface temperature versus time was simulated with "step" temperature changes. Solar heating on sunshield and Pallet 2/RTG surfaces was simulated with infrared lamps to correspond to lunar surface temperature during the lunar day phase of the test.

2.1.2.1 Central Station Thermal Performance

Figure 2.9 illustrates a sample radiator plate temperature swing and depicts major events, which are similar to Acceptance Test events. The Design Limit Test, which is discussed in Section 2.1.3, is included and is represented by data after 8-7-68.

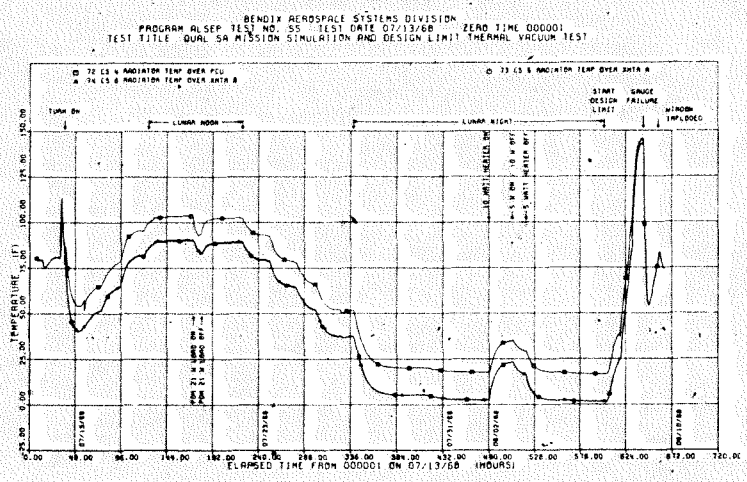


Figure 2.9 Qual SA Central Station Radiator Plate Temperature Profiles for T/V Mission Simulation and Design Limit Tests

Since Mission Simulation Test and predicted temperature distributions over the C/S at lunar noon and night are essentially equivalent to the respective Acceptance Test figures, only the following abbreviated comparison of test and predicted results is presented.

	Temperatures ~ °F					
	Lunar Noon			Lunar Night		
C/S Component	Chamber Test	Predicted Chamber	Predicted Real Moon*	Chamber Test	Predicted Chamber	Predicted Real Moon*
Radiator Plate, average	91	91	123	3	6	0
Structure Sides, average	157	157	157	-141	-135	-179
Structure Bottom	180	179	161	-146	-140	-184
Sunshield Top	40	42	37	-233	-272	-239
PDM Resistor Panel	198	199	202	-36	-51	-60

*These predicted values are adjusted for discrepancies between predicted and test figures for the T/V chamber Mission Simulation Test configuration.

On 7/20/68 during lunar noon, the 7 and 14 watt PDM dump loads were activated simultaneously for about 8.5 hours, which forced the radiator plate average temperature from 91°F down to a minimum of 83°F. On 8/2/68 during lunar night, the 10 watt reserve power heater on the radiator plate was activated for about 24 hours with a resultant rise in radiator average temperature from 3°F to a maximum of 24°F. At the beginning of 8/3/68 the 10 watt heater was turned-off while the 5 watt heater was activated for nearly 14.5 hours. A 16°F decrease in radiator average temperature was experienced before the heater was deactivated. Steady-state conditions were nearly achieved in these three tests. By activating both the PDM dump loads and the 10 watt heater, the lunar noon-to-night radiator temperature swing can be reduced from 88°F to 59°F. A discussion of these tests and comparisons of test data to predicted values are presented in Section 7.1.1.

Temperature versus time plots of various test measurements are contained in Section 6.2 along with DAS and HK steady-state data at lunar noon and night. Tables 7.3 and 7.4 in Section 7 compare predicted and test temperatures for individual thermal model nodes.

2.1.2.2 Pallet 2/RTG Thermal Performance

Figures 2.10 and 2.11 show temperature histories of RTG fins and surrounding pallet surfaces for both the Mission Simulation and Design Limit Tests. Mission Simulation thermal performances of the pallet and RTG during lunar noon and night are essentially equal to Acceptance Test results.

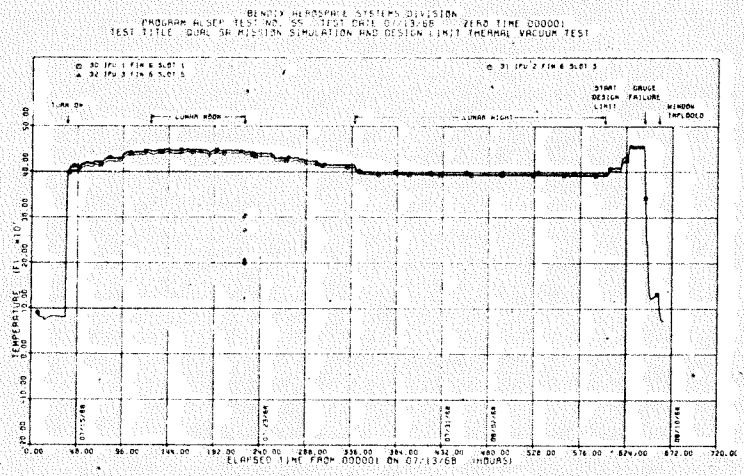


Figure 2.10 Temperature Distribution over RTG for Qual SA T/V Mission Simulation and Design Limit Tests

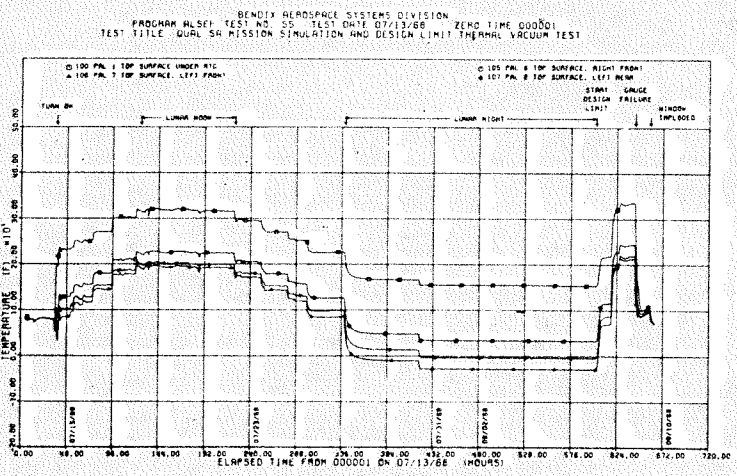


Figure 2.11 Temperature Distribution over Pallet 2 for Qual SA T/V Mission Simulation and Design Limit Tests

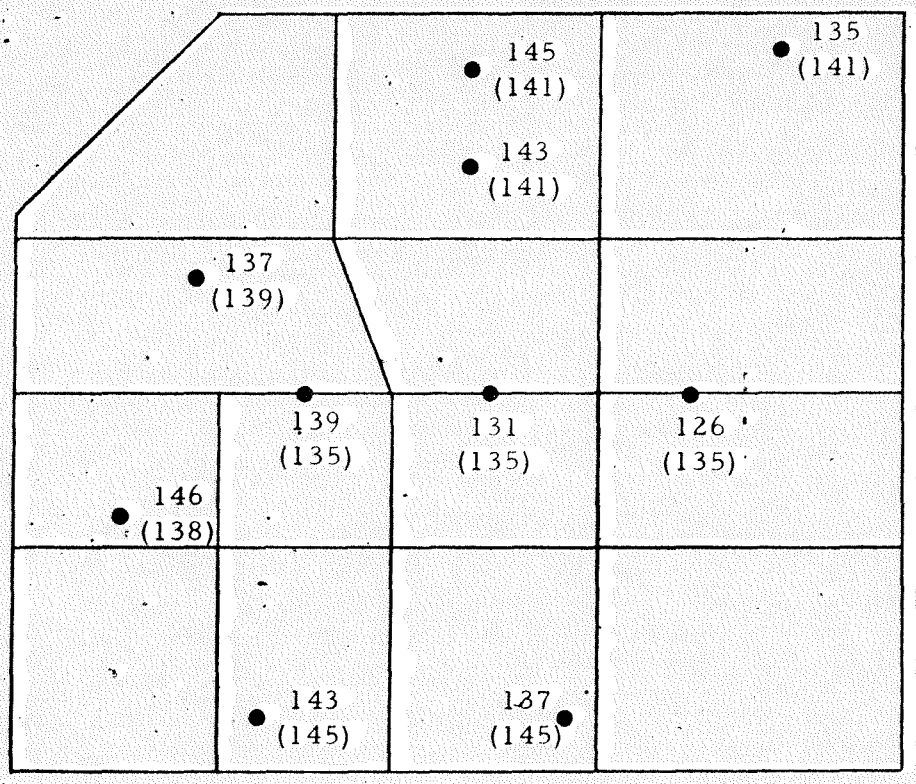
2.1.3 Design Limit Test

At the conclusion of the Mission Simulation Test (8-7-68), the Qual SA model was subjected to a Design Limit Test until 8-9-68, the objective being to operate the C/S with the radiator plate at the highest average temperature (approximately 140°F) predicted for real lunar conditions. Also, the lunar simulator was held at a 280°F average temperature to duplicate the highest anticipated lunar surface temperature which the C/S will experience. Solar heating of the sunshield was increased to 1.25 "suns" for a "margin of safety." The 140°F level was established by estimating the increase in radiator temperature above normal T/V test values due to the following effects:

Effect	Temperature Increase (°F)
Operation in a real lunar environment (lunar surface temperature at 250°)	35
Lunar surface at 280°F instead of 250°F (Assumed thermal emissivity = 0.95)	9
Direct solar heating of insulation masks due to C/S misalignment	6
Total	50

Since Acceptance and Mission Simulation average radiator temperatures were 92°F and 91°F, respectively, a value of 140°F was selected for the Design Limit Test. Two heaters were sized to contribute about 40°F of the temperature increase and were fastened to the radiator plate under the masks, while the remaining temperature increase would be produced by the 280°F lunar simulator. Figure 2.12 illustrates maximum radiator plate temperatures for this test phase, while the following table compares test and predicted values for various C/S components.

Note: Dividing Lines Outline Radiator Plate Nodes for Thermal Model



xxx Measured
(xxx) Predicted

Electronics Thermal Dissipation = 35.8 Watts

$T_{ave_{meas}} = 138^{o}F$

$T_{ave_{pred}} = 139^{o}F$

Thermal Dissipation by Radiator Heaters = 24.0 Watts

Figure 2.12 Qual SA Design Limit Test; Measured versus Predicted Maximum Radiator Temperatures (^{o}F)

C/S Component	Temperature ~ °F Chamber Test	Predicted Chamber
Radiator Plate, average	138	139
Structure Sides, average	187	185
Structure Bottom	215	215
Sunshield Top	67	66
PDM Resistor Panel	225	229

The predicted average radiator temperature was not quite achieved since the actual thermal emissivity of the lunar simulator was 0.89 instead of the estimated 0.95. Test data are presented in Section 6; while Section 7 gives a detailed comparison of predicted and test values. As shown by Table 6.3 in Section 6, Pallet 2/RTG temperatures ranged from 4°F to 28°F higher during the Design Limit Test than during the Acceptance and Mission Simulation Tests.

2.2 Capability of Analytical Qual SA Central Station Model

The Qual SA Central Station analytical model is considered capable of predicting steady-state temperatures within accuracies listed below:

C/S Component	Temperature Accuracy
Radiator Plate - average	±5°F
Primary Structure	±10°F
PDM Resistor Panel	±10°F
Sunshield	±10°F

These accuracies are applicable providing that (1) differences between analysis and actual electronics thermal dissipations are within ±5 percent; (2) heat dissipation at the resistor plate is within ±10 percent; (3) side curtains, insulation masks, and radiator thermal paint are properly installed; and (4) no significant deterioration of radiation properities for the reflector and other surfaces occurs during lunar operation.

2.3 Discrepancies Between Predicted and Test Results

From preceding results, one notes that correlation between predicted and test temperatures is quite good, except for the sunshield top during lunar night. The probable reason for this relatively large discrepancy is that the insulation on the bottom surface of the sunshield was not fastened securely at one corner. This corner "hung down" during testing and allowed the sunshield bottom to see relatively hot reflector and internal side curtain surfaces. Therefore, an increased amount of heat escaped through the sunshield and raised its temperature above the anticipated level. This mis-orientation of the insulation had no noticeable effect during lunar noon since solar heating and sunshield surface properties control sunshield temperature. A design modification has probably corrected this problem.

Since PDM resistor panel thermal dissipation fluctuated rapidly and continuously during testing, it was difficult to establish "mean" reserve power values for correlating predicted and test temperatures. Even with this problem, correlation generally was good.

2.4 Real Lunar Environment Analysis Results

Lunar noon analysis results predict a 35°F higher average radiator plate temperature for a real lunar surface environment than for the Qual SA Acceptance Test condition. This discrepancy is due primarily to higher radiation heat transfer between the radiator and lunar surface and to lower radiation from the radiator to space for actual moon operation. The corresponding discrepancy for the Mission Simulation model is 32°F, which is less than for T/V Acceptance due to higher cryowall temperatures which occurred during Mission Simulation testing. For lunar night, the thermal model predicts a 3°F lower average radiator plate temperature for the real lunar environment than for test conditions. This small difference is caused by lower primary structure temperatures and by the -459°F temperature of real space, which replaces the chamber cryowall wall test temperatures for real moon operation.

3.0 LUNAR ENVIRONMENT SIMULATION

As stated earlier, the predicted Qual SA Acceptance C/S radiator plate average temperature in the real lunar environment is 35 F higher at lunar noon and 3°F lower at lunar night than in the chamber test environment. These temperature differences are due to several aspects of lunar environment simulation which are discussed in following sections.

3.1 Lunar Surface Simulator

Physical dimensions, shape, and performance of the lunar surface simulator directly affect results from thermal-vacuum tests (see Reference 1).

3.1.1 Configuration

Because of the limited size of the lunar surface simulator, the Central Station's "view" of the moon is less than for a real lunar environment. Radiation configuration factors from various C/S surfaces to the real and simulated moons were computed (see Reference 2), and the results for "Side 1" are shown in Figure 3.1. Side 1 refers to the C/S enclosure bounded by the side curtains, sunshield awning, specular reflector, and rectangular portion of the radiator plate. An "indirect" configuration factor refers to a factor from a surface to the image of another surface in the specular reflector. As expected, configuration factors involving the lunar simulator are equal to or less than factors involving the real moon.

Small configuration factors for the T/V chamber environment cause the C/S radiator to stabilize at lower lunar day temperatures during T/V testing than during actual lunar operation, as shown by results of an analytical study presented in Figure 3.2. Chamber environmental parameters used in this study approximated actual Acceptance Test conditions, and the figure is intended only to illustrate differences between T/V chamber test and real moon radiator temperatures. The radiator plate was selected for the study because it is the one surface upon which all C/S electronic component temperatures depend. Results show that measured lunar night temperatures in the vacuum chamber should be essentially equal to real lunar values for a -300°F uniform cryowall temperature. However, at lunar noon measured temperatures were predicted to be about 34°F low at an electronics thermal dissipation level of 38 watts.

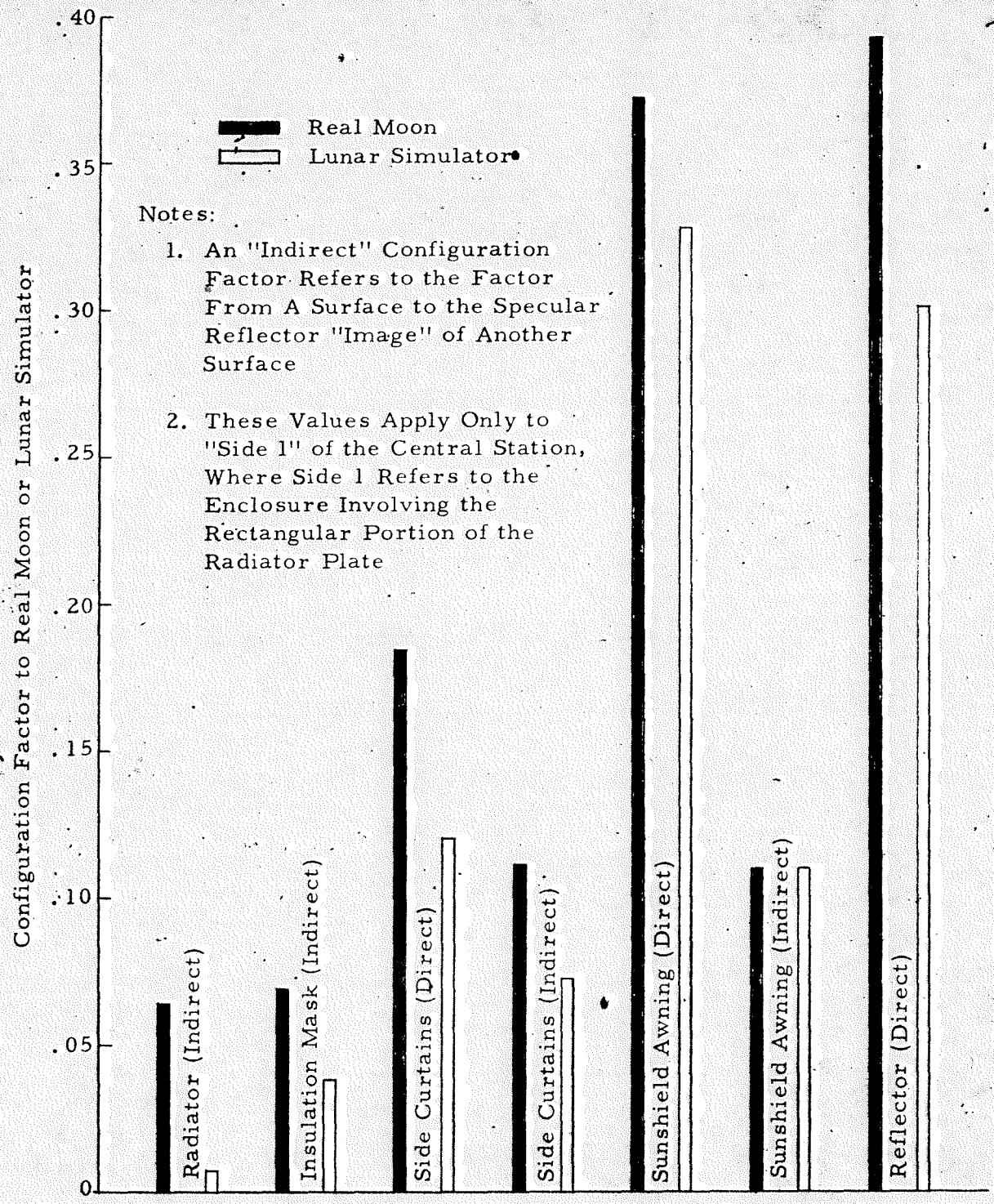
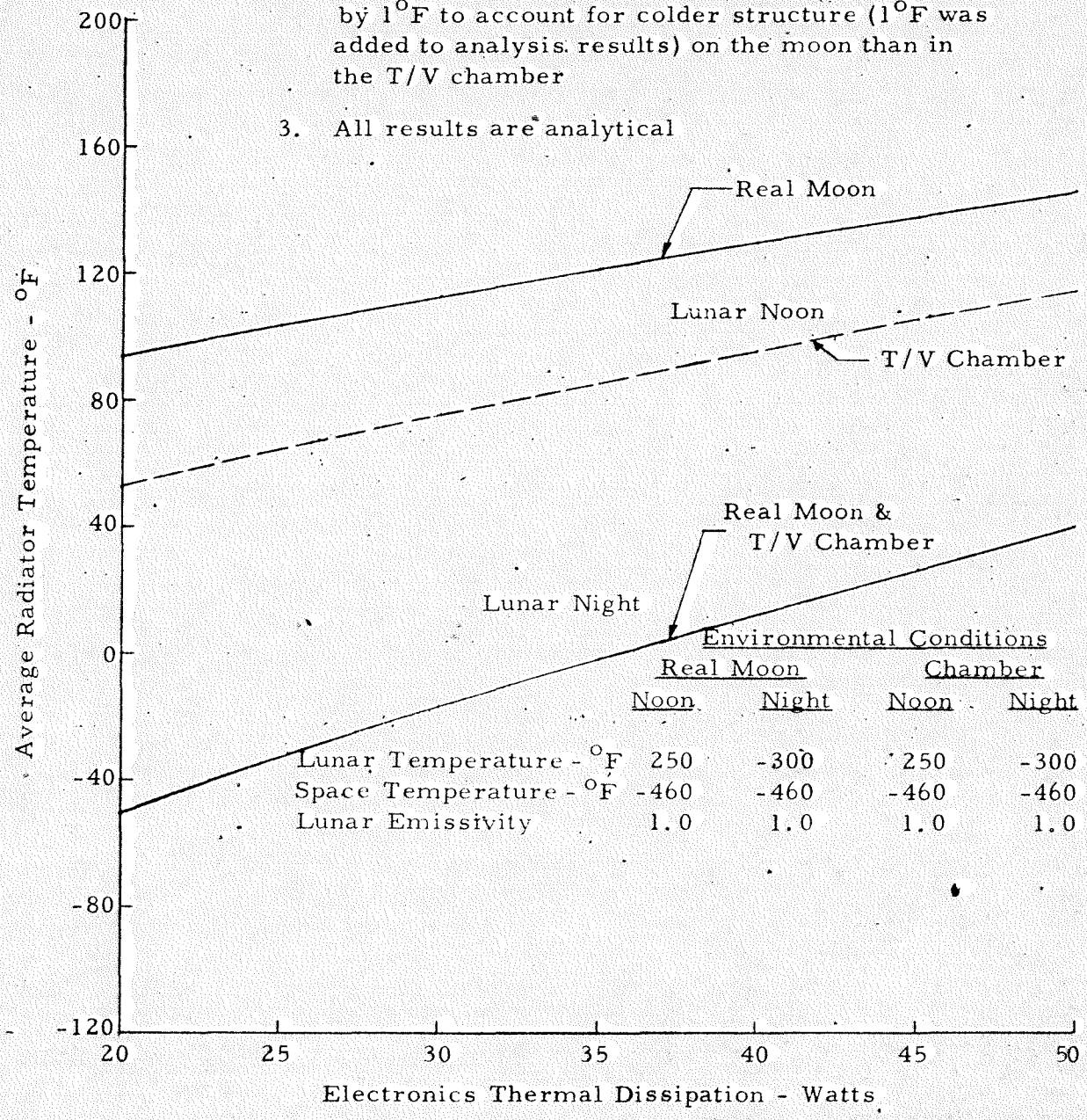


Figure 3.1 Central Station Configuration Factors to Real Moon and Lunar Simulator

Notes:

1. Results are for the Acceptance Test model
2. All real moon night values have been adjusted by 1°F to account for colder structure (1°F was added to analysis results) on the moon than in the T/V chamber
3. All results are analytical



Environmental Conditions	Real Moon		Chamber	
	Noon	Night	Noon	Night
Lunar Temperature - °F	250	-300	250	-300
Space Temperature - °F	-460	-460	-460	-460
Lunar Emissivity	1.0	1.0	1.0	1.0

Figure 3.2 Central Station Radiator Temperature versus Electronics Thermal Dissipation

Thus, a 34°F difference in radiator temperature can be attributed to the limited size of the lunar surface simulator, and measured radiator average temperatures in the chamber can be corrected to arrive at predicted lunar surface operation temperatures.

3.1.2 Temperature

Radiative energy interchange occurs between most C/S surfaces and the lunar surface simulator, and simulator temperature directly affects the temperature of each of these surfaces. Results from a study (shown in Figure 3.3) indicate that at lunar noon a change of 3°F over the entire lunar surface simulator produces nearly a 1°F change on the C/S radiator. Consequently, it is important to accurately establish lunar simulator temperatures when correlating test and predicted results.

Performance of the 14' x 14' lunar surface simulator at lunar noon during the Qual SA Acceptance Test, as developed from Reference 5, is shown in Figure 3.4. Instead of the desired uniform temperature distribution, temperature of the simulator varied from 234°F to 279°F. Similarly, Figures 3.5 and 3.6 show temperature distribution over the lunar simulator for the Mission Simulation and Design Limit Tests. To accurately evaluate radiation heat transfer from the simulator to the Central Station, configuration factors from all C/S surfaces to each isothermal area on the lunar surface simulator should be calculated. However, the required amount of engineering effort and computer time would be prohibitive.

In order to reduce correlation work to a reasonable level, a single weighted average simulator temperature was used. For example, a 250°F average was computed from data in both Figures 3.4 and 3.5. However, such a simplification can lead to inaccuracies in analytical predictions. As illustrated in Figure 3.7 for the Acceptance Test, the radiator's view of the lunar surface simulator (via the specular reflector) is restricted by the side curtains. Thus, certain areas of the simulator not "seen" by the radiator contribute to weighted averages.

A simple analysis was performed to estimate the magnitude of error introduced by the use of average simulator temperatures. Results showed little effect on C/S components by uneven temperature distribution over the lunar simulator. Specific analysis techniques and results are outlined in Reference 13 and in Section 7.3.2.

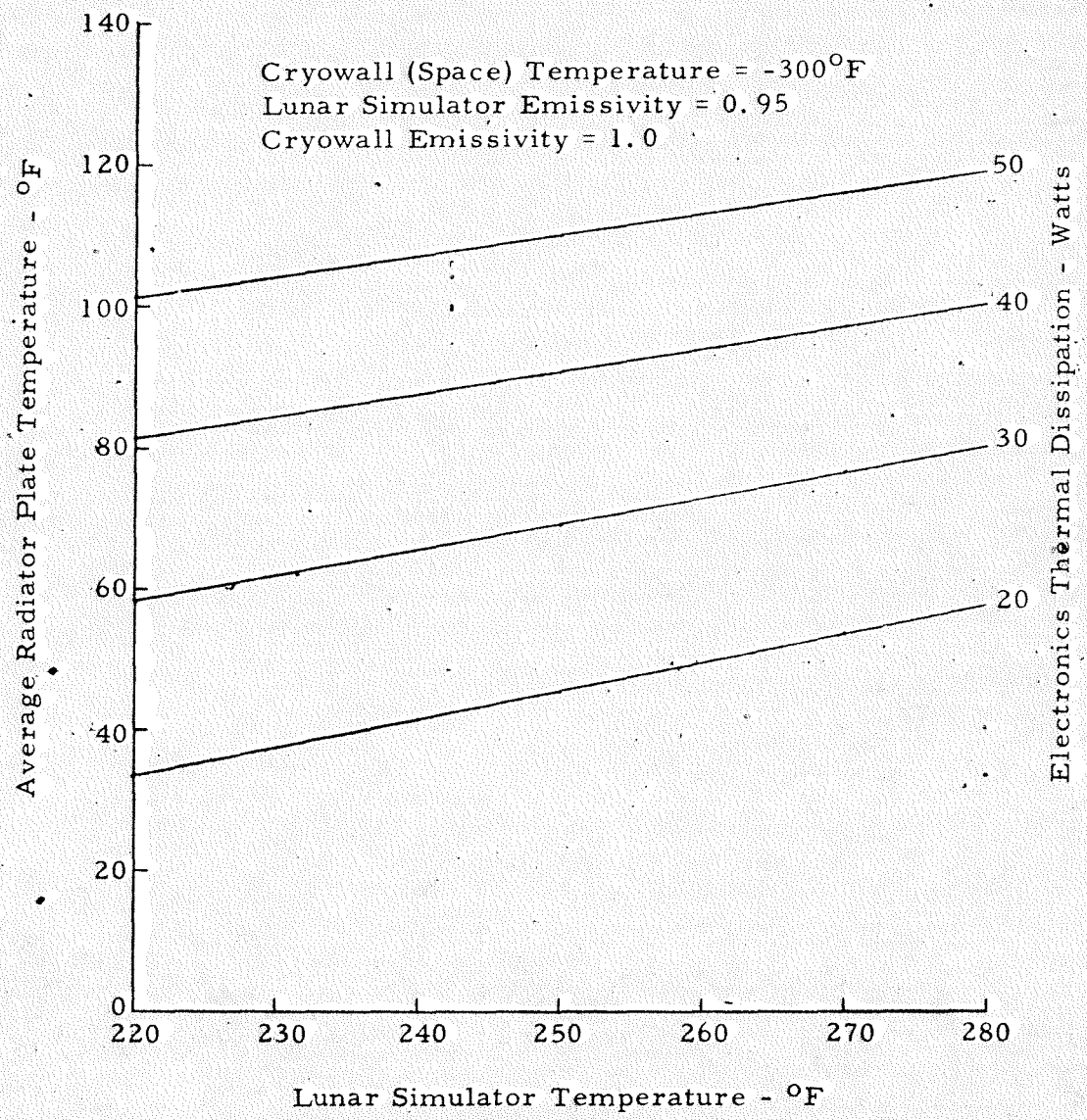


Figure 3.3 Central Station Radiator Plate Temperature vs Lunar Surface Simulator Temperature

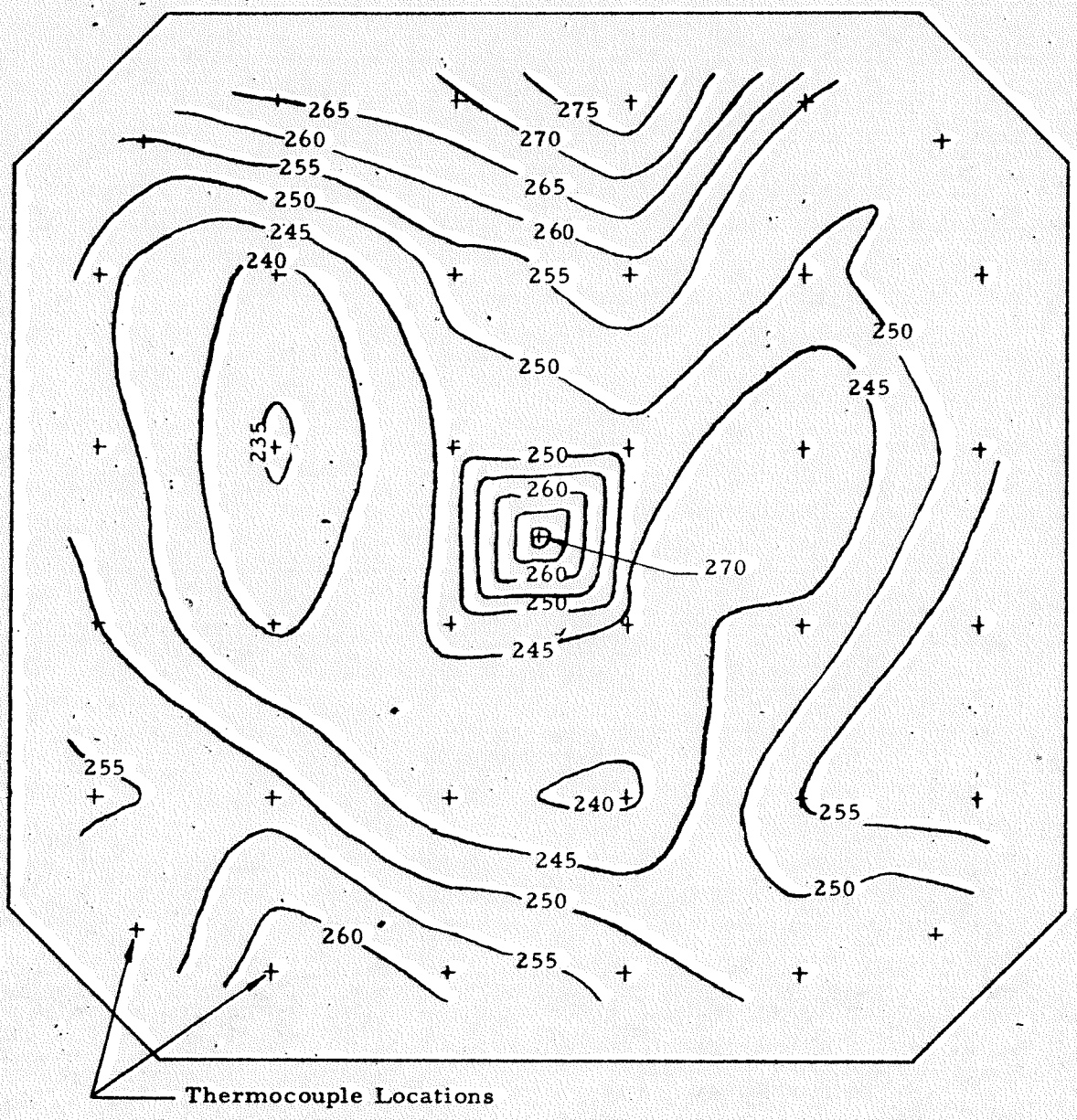


Figure 3.4 14' x 14' Lunar Surface Simulator Temperature Profile (°F); Qual SA Acceptance Test at Lunar Noon

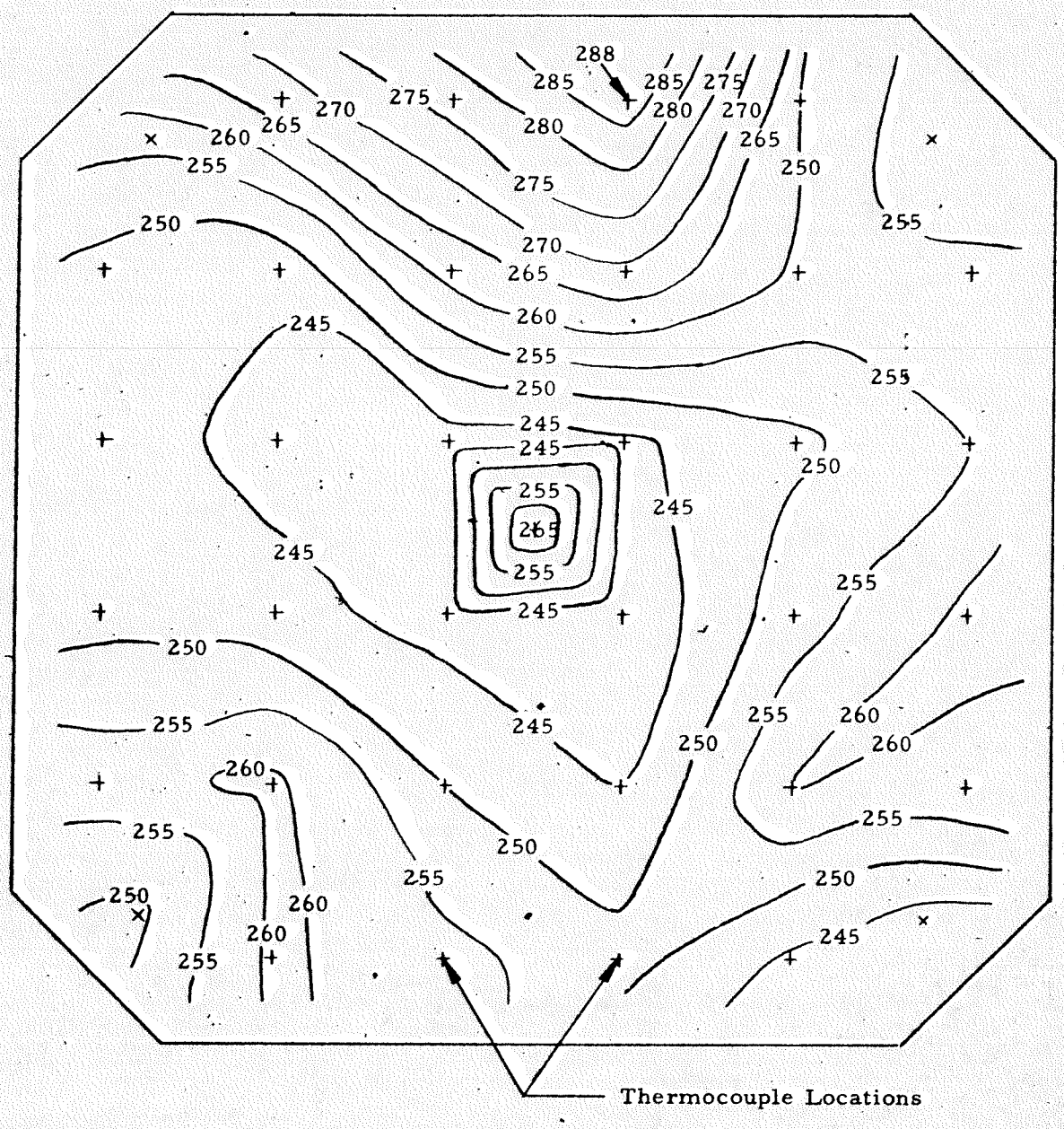


Figure 3.5 14' x 14' Lunar Surface Simulator Temperature Profile (°F); Qual SA Mission Simulation at Lunar Noon (7-19-68, 09:50 hrs)

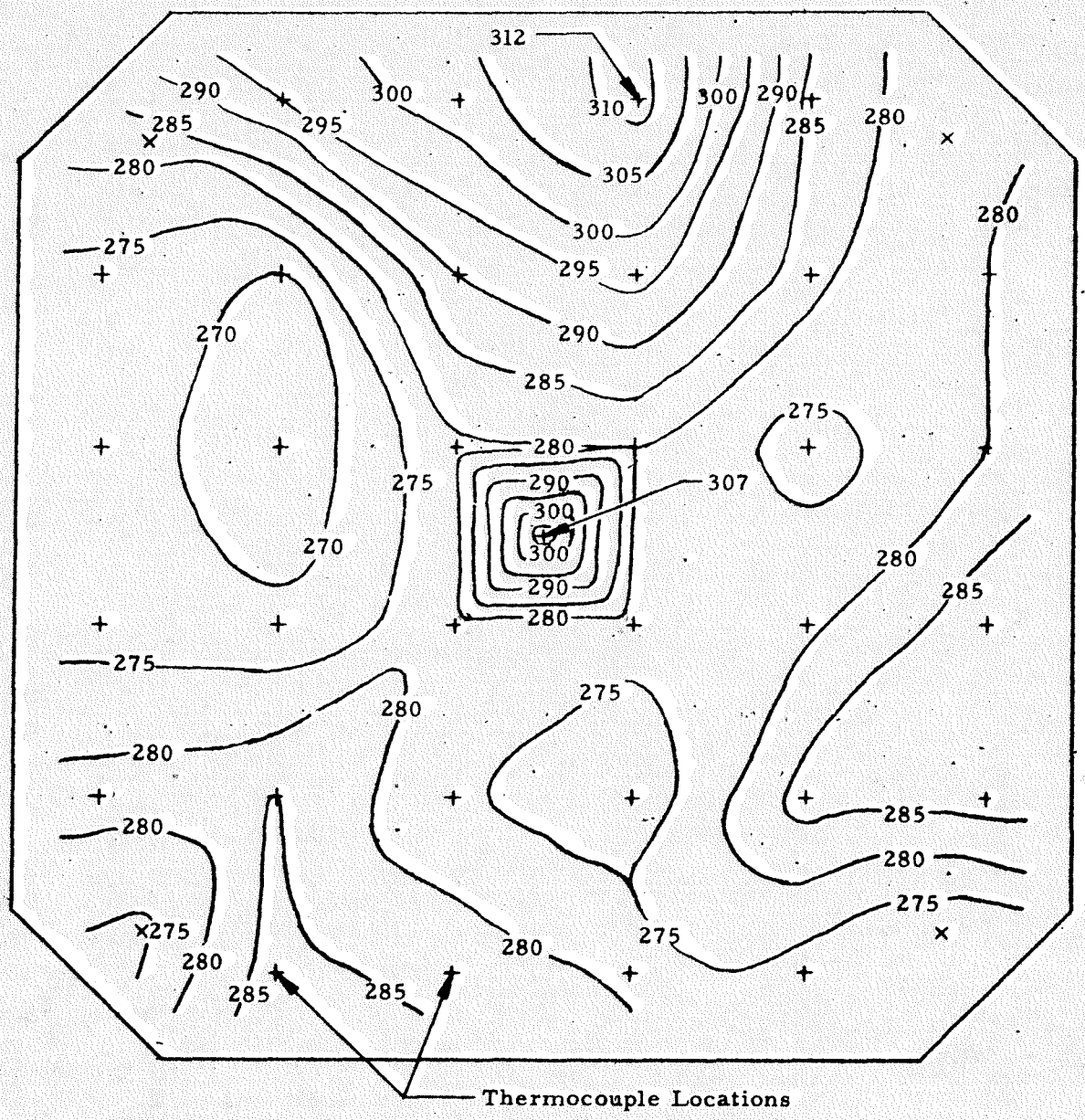


Figure 3.6 14' x 14' Lunar Surface Simulator Temperature Profile (°F); Qual SA Design Limit Test (8-8-68, 15:10 hrs)

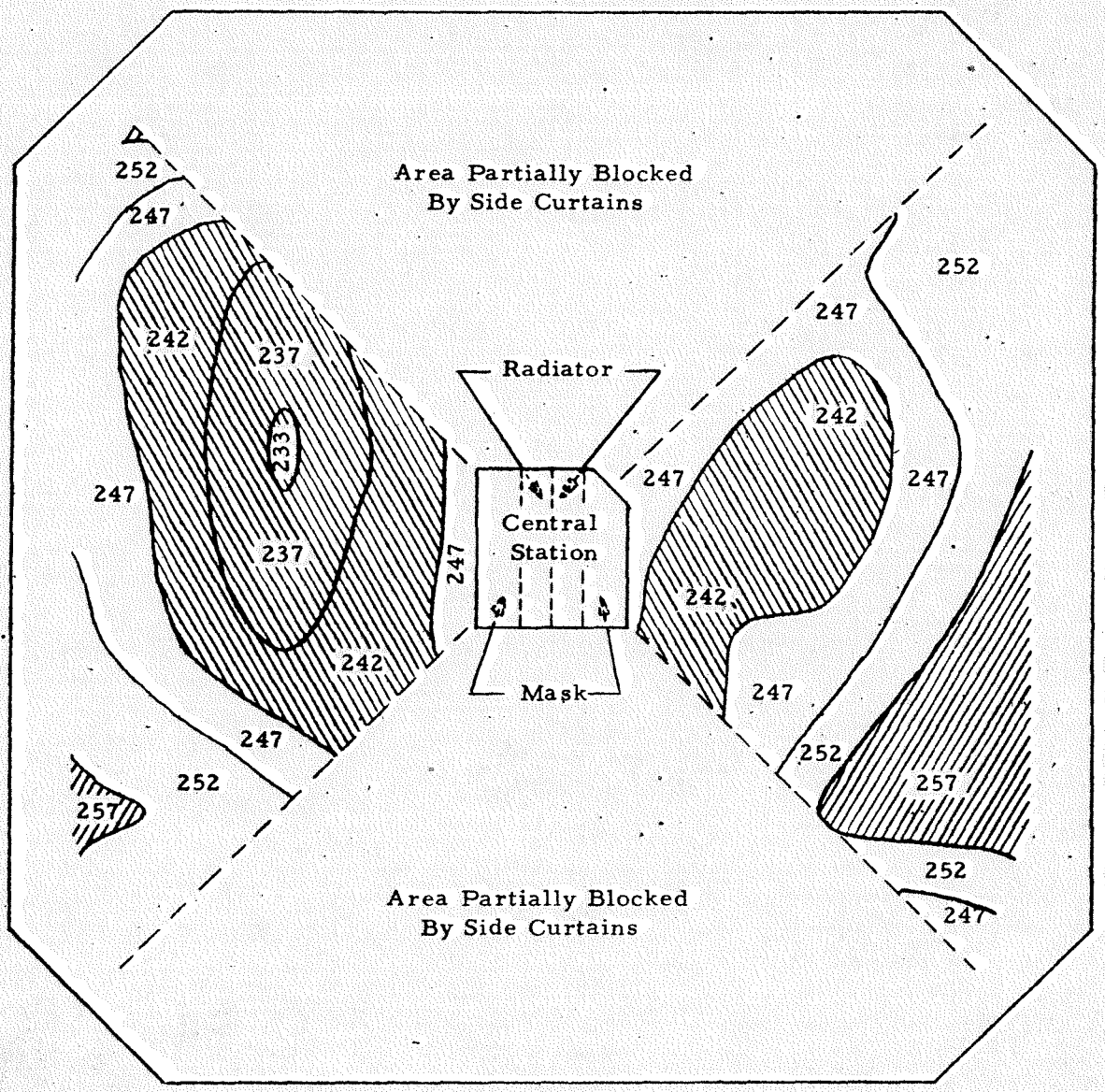


Figure 3.7 14' x 14' Lunar Surface Simulator Temperature Profile (F); Qual SA Acceptance Test at Lunar Noon

3.1.3 Lunar Radiant Energy

When evaluating radiation heat transfer between the C/S and lunar surface, lunar albedo, which is that fraction of incident solar radiation reflected at the lunar surface, must be considered since it causes an additional heat load in the C/S as shown in Figure 3.8(A). The magnitude of this albedo may vary from extremely small values up to approximately 10 percent of the incident solar energy.

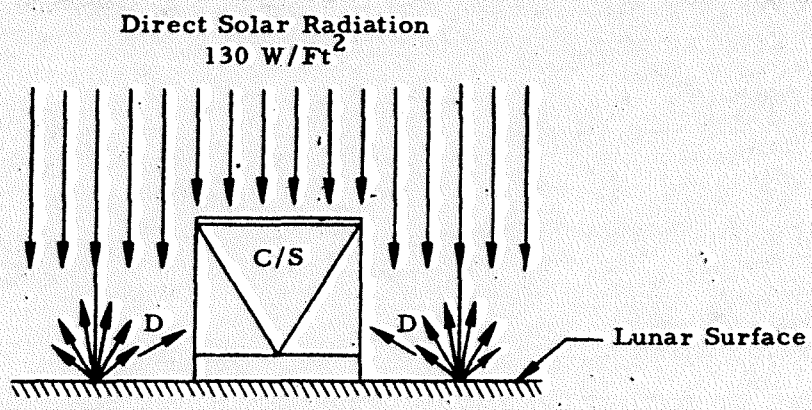
As the lunar surface temperature represents a thermal equilibrium condition for a body in space, the total radiant energy leaving the surface is equal to the incident solar radiation; that is, the sum of emitted and reflected energy will always be constant for a particular sun angle regardless of the amount of albedo, as illustrated in Figures 3.8(B) and (C). At lunar noon, incident radiation is equal to the "Solar Constant" of 130 watts/ft^2. Because radiant energy leaving the lunar surface is generally diffuse, the exact value of albedo is not critical in computing Central Station thermal performance on the moon.

Consequently, lunar radiant energy may be simulated in the vacuum chamber (in the absence of solar heating) by forcing the lunar surface simulator to emit radiation at a rate equal to the incident solar radiation encountered in the actual lunar environment. If solar absorptivity and thermal emissivity of a Central Station surface receiving radiation from the lunar simulator are different, some error exists. However, such error is not considered significant in view of the prohibitive additional time and cost required for an exact treatment of lunar emitted and reflected radiation.

As no solar heating of the lunar surface simulator is provided during testing, two methods are available to force simulator emitted radiation to equal incident solar radiation which occurs in the actual lunar environment:

1. Provide a lunar simulator with an emissivity equal to 1.0 and at the real moon temperature.

2. For an emissivity less than 1.0, raise simulator temperature sufficiently so that the simulator radiates at a rate equal to the real moon emitted plus reflected energy.



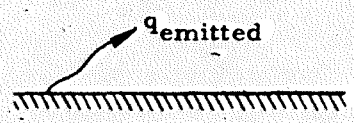
D = Diffusely Reflected Radiation = Albedo x 130 W/Ft^2

(A) Albedo Heat Load on Central Station

Moon Assumed Black

$\alpha = \epsilon = 1.0$; T = 253F

$q_{emitted} = \epsilon \sigma T^4 = 130 \frac{W}{Ft^2}$



(B) Idealized Lunar Surface

Moon Assumed Gray

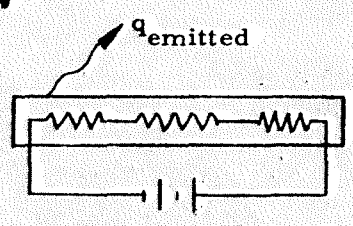
$\alpha = \epsilon = 0.9$; T = 253F

$q_{emitted} = \epsilon \sigma T^4 = 117$ W/Ft^2

$q_{reflected} = (1-\alpha) \times 130 = 13$ W/Ft^2

(C) Assumed Lunar Surface

$\epsilon = 0.89$ (measured)



$q_{emitted} = 114$ W/Ft^2 (T = 250F)

$q_{emitted} = 130$ W/Ft^2 (T = 274F)

(D) Lunar Surface Simulator

α = solar absorptivity

ϵ = thermal emissivity

Figure 3.8 Lunar Surface Radiant Energy at Lunar Noon

A 0.89 average thermal emissivity was measured for the Qual SA lunar surface simulator. Thus, a 274°F lunar simulator temperature instead of the actual Acceptance and Mission Simulation Test averages of 250°F would be required to simulate the real lunar noon thermal environment, as shown in Figure 3.8(D). Figure 3.3 shows that this temperature increase would cause an approximate temperature rise on the radiator baseplate of 8°F at lunar noon in the test chamber.

3.2 Cryowall

The cryowall uses LN_2 to simulate the space heat sink, and the temperature at which it is maintained directly affects the temperature of every surface of the Central Station. A study was made to determine the effect of cryowall temperature on C/S radiator temperature, and results are presented in Figures 3.9 and 3.10. As shown, an increase in cold wall temperature from -300°F to -100°F raises the average radiator temperature approximately 20°F at lunar noon and 30°F at lunar night, depending somewhat upon Central Station thermal dissipation.

Figure 3.11 illustrates the cryowall configuration, which is made up of four separate sections. The lunar simulator section has already been discussed, and the remaining three sections are as follows: the curtain at the south end of the chamber, the arch which encircles 270° of the cylindrical portion of the chamber, and the door at the north end of the chamber. Cryopanels, which make up each of the last three sections, are plumbed in series/parallel combinations whereas the lunar surface simulator is plumbed in a series configuration.

Performance of the cryowall during the Acceptance Test at simulated lunar noon and lunar night has been developed from Reference 5 and is shown in Figure 3.12. Lunar noon and night temperatures are given without and with parentheses, respectively. "Average" temperatures for the curtain, arch, and door sections were determined by two methods: straight numerical average and "weighted" average based on area. These averages are listed along with temperature ranges in the table below:

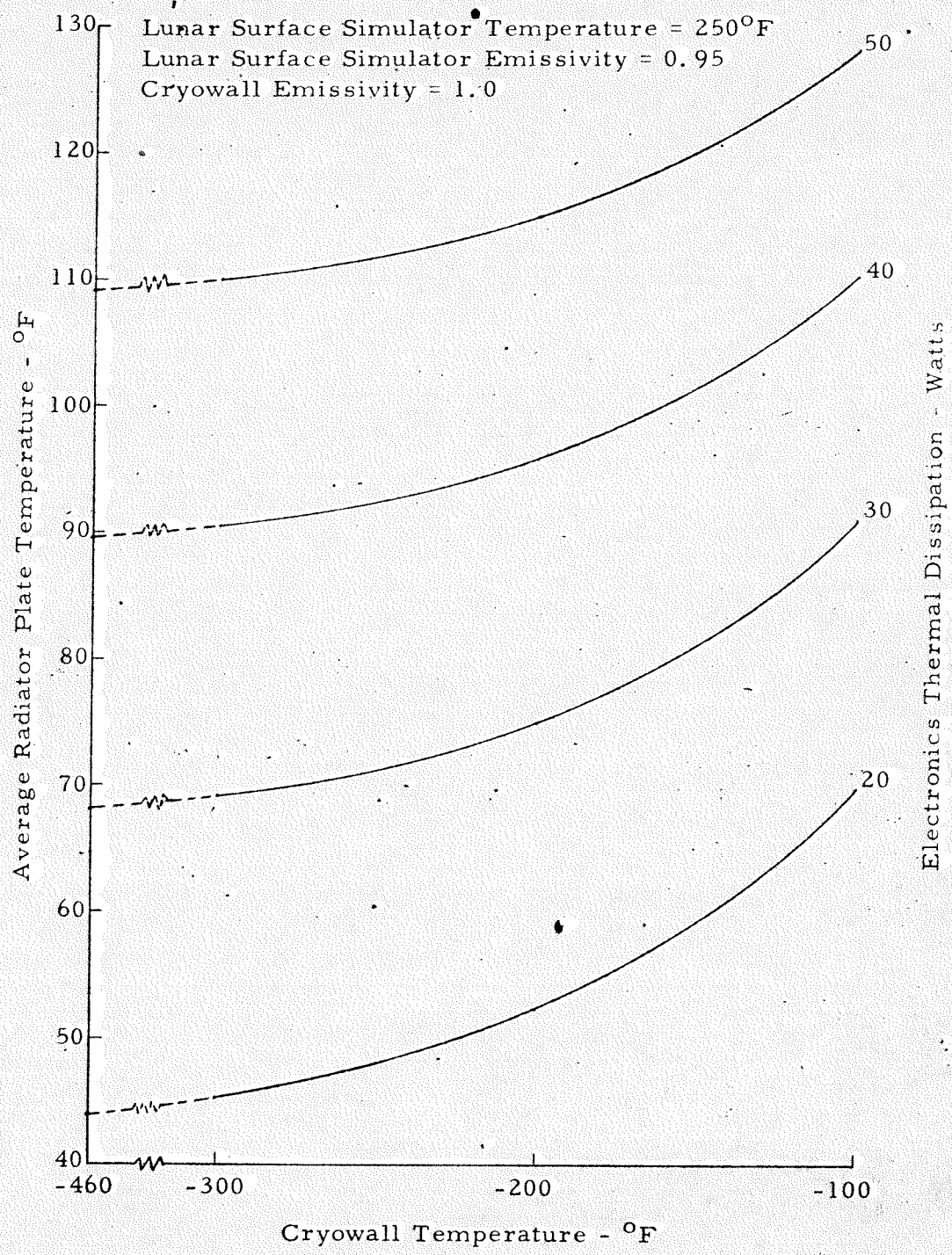


Figure 3.9 Central Station Radiator Plate Average Temperature vs Cryowall Temperature at Lunar Noon

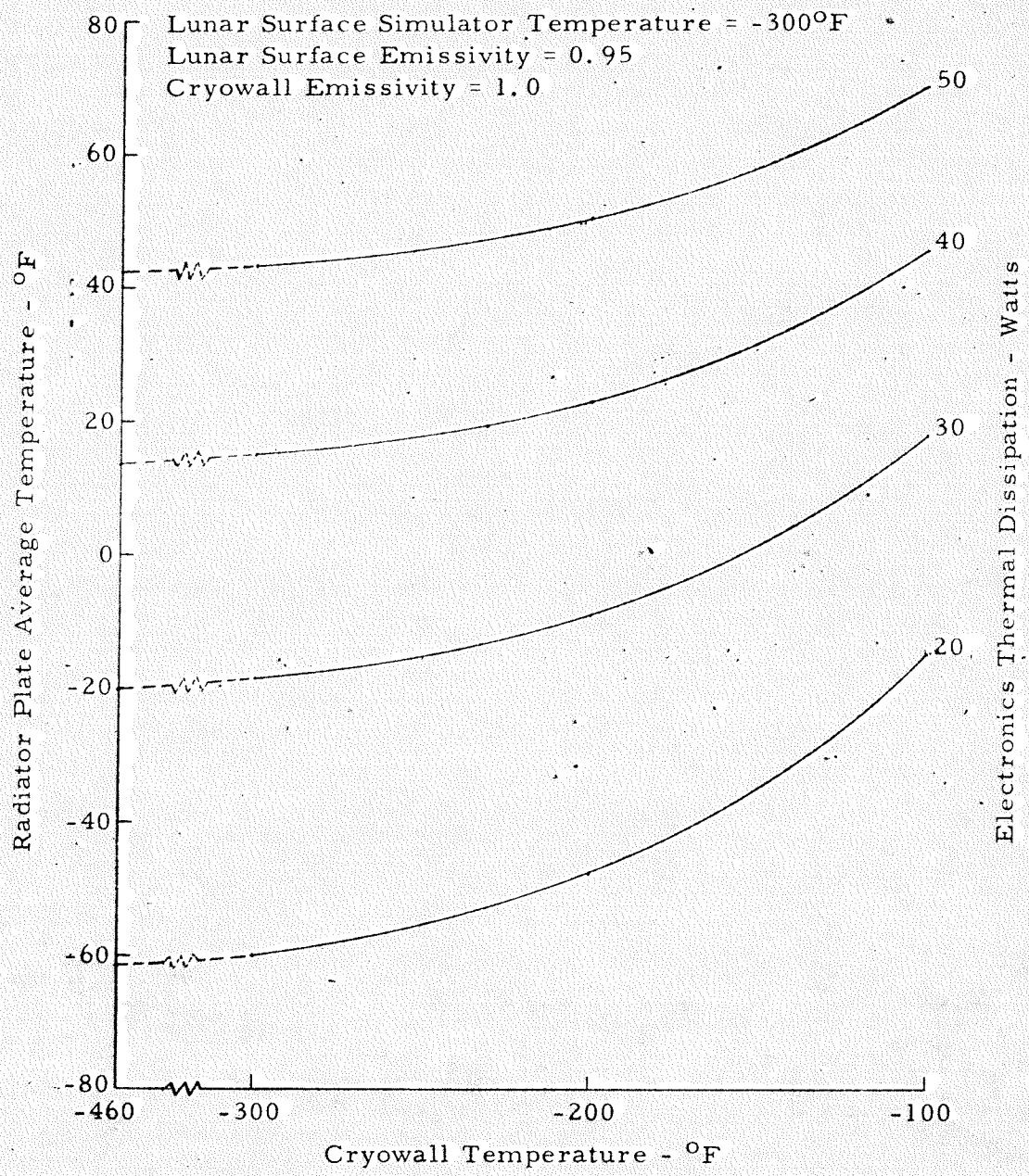
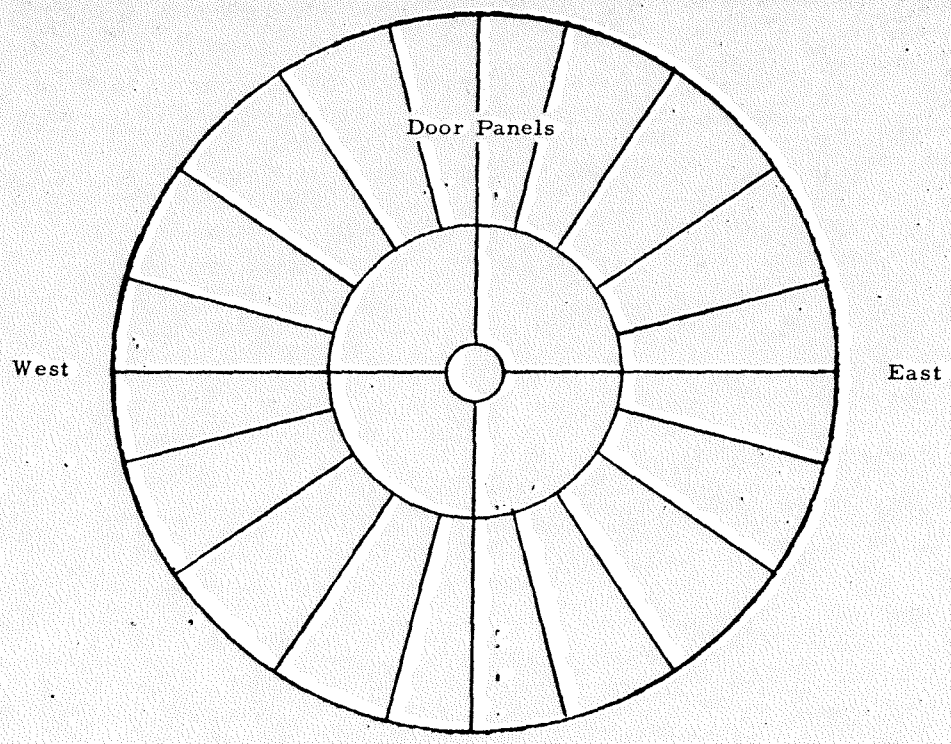
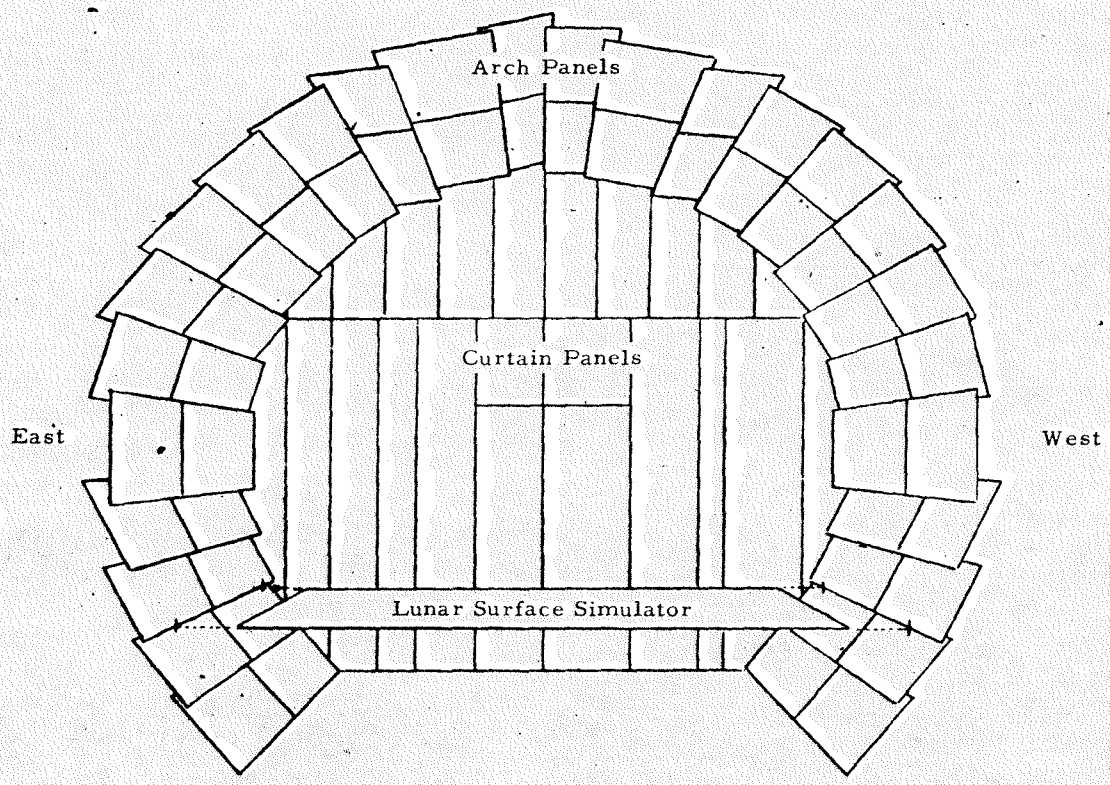


Figure 3.10 Central Station Radiator Plate Average Temperature vs Cryowall Temperature at Lunar Night

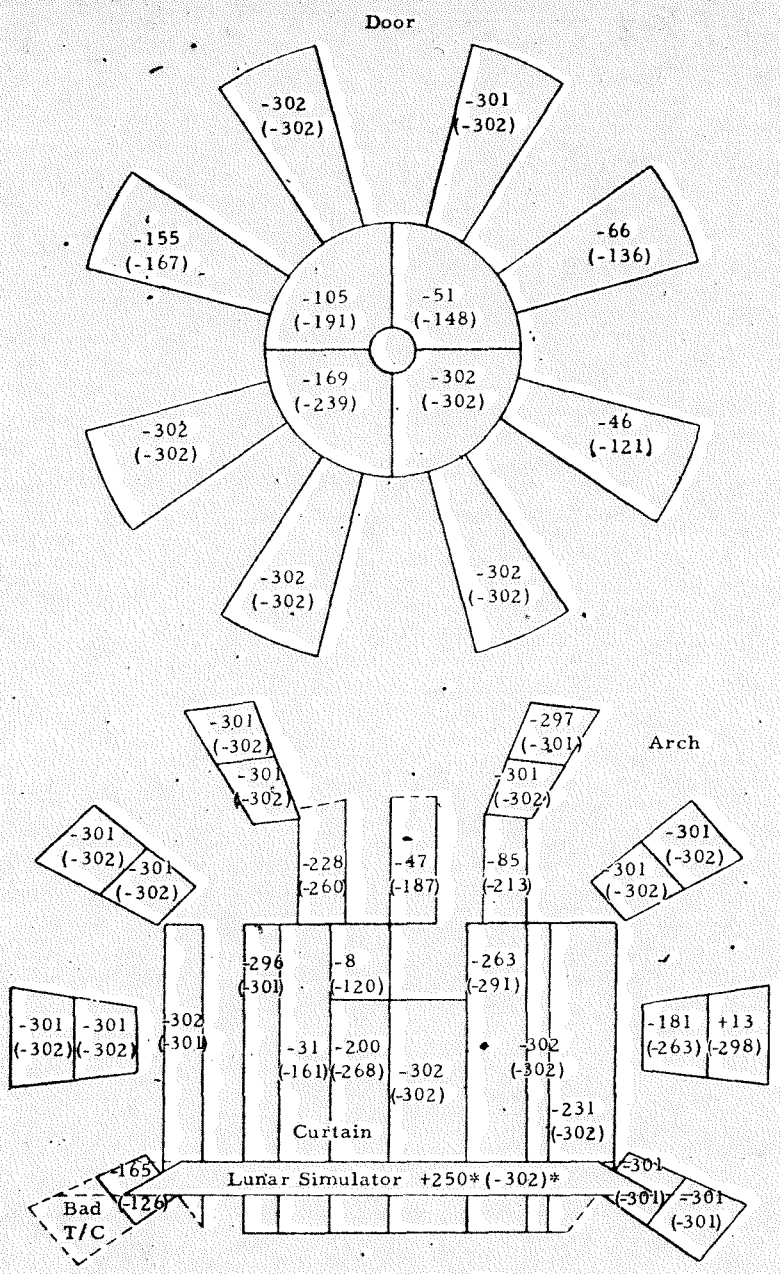


View of Cryowall Looking North



View of Cryowall Looking South

Figure 3.11 Cryowall Panel Configuration; 20' x 27' Lunar Simulation Chamber



* Numerical Average Temperature

xxx Lunar Noon 6/2/68, 7:10, ALSEP Day 154, Test Time = 308 hrs

(xxx) Lunar Night 6/7/68 21:10, ALSEP Day 159, Test Time = 432 hrs

Cryowall Section	Cryowall Average Temperatures ~ °F Numerical Noon	Numerical Night	Weighted Noon	Weighted Night
Door	-200	-235	-210	-239
Curtain	-191	-250	-202	-258
Arch	-263	-287	-263	-289

Figure 3.12 Cryowall Equilibrium Temperatures (°F) (Instrumented Panels Only); Qual SA T/V Acceptance Test

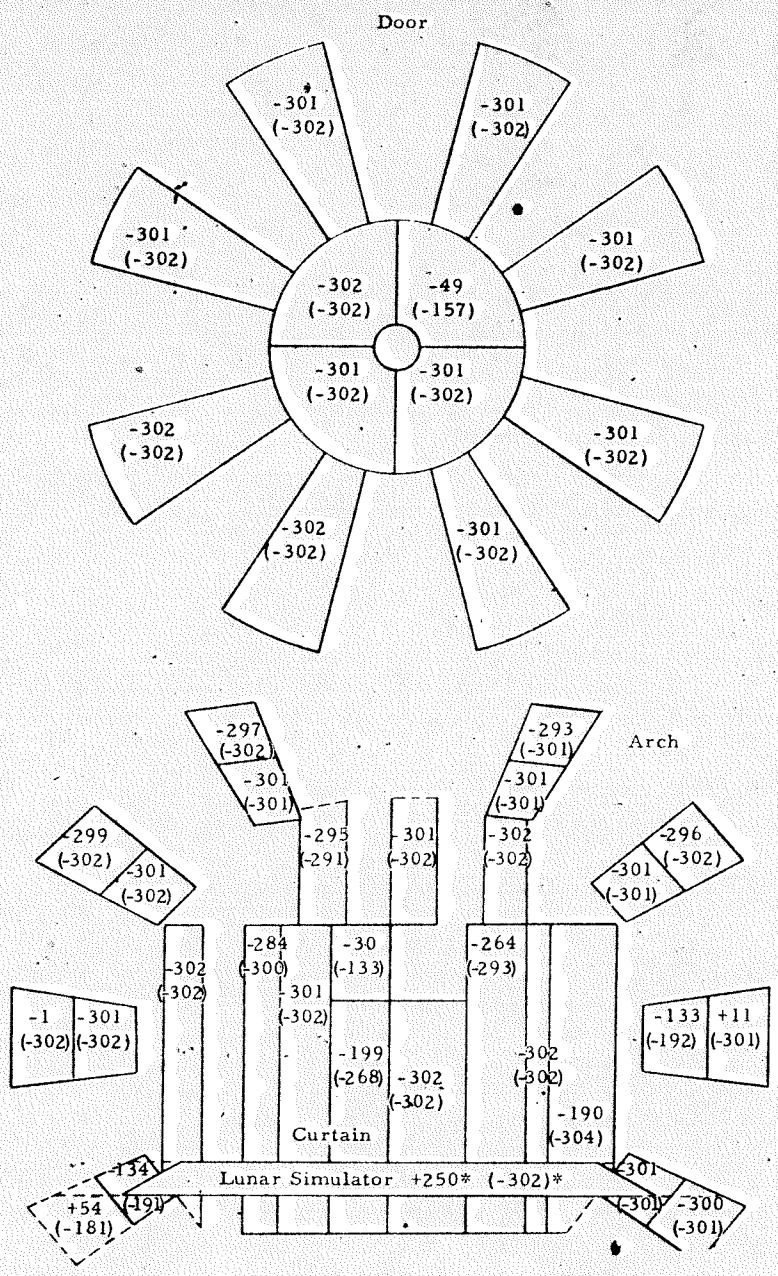
Cryowall Section	Test Condition	Temp. Range of Instrumented Panels (°F)	Numerical Average (°F)	Weighted Average (°F)
Curtain	Lunar Noon	-302 to -8	-191	-202
Curtain	Lunar Night	-302 to -124	-250	-258
Arch	Lunar Noon	-301 to +13	-263	-263
Arch	Lunar Night	-302 to -126	-287	-289
Door	Lunar Noon	-302 to -46	-200	-210
Door	Lunar Night	-302 to -121	-235	-239

Above "averages" may be in error since no method exists to estimate temperatures of noninstrumented panels (due to the series/parallel plumbing) and can lead to error in C/S temperature predictions. However, since the arch has the most influence on radiator temperature and since the two "averages" for this section were essentially equal, minimal error is anticipated. Similarly, cryowall performances during the Mission Simulation and Design Limit Tests are shown in Figures 3.13 and 3.14 and are similar to the Acceptance Test performance.

If the temperature of each cryowall panel were known and if the configuration factor between each panel and C/S surface were evaluated, the exact radiative energy interchange between the C/S and cryowall could be computed. However, as for the lunar surface simulator, this approach would be prohibitive in time and cost. Thus, the simplification of average cryowall temperature is used in correlating predicted and test temperatures. For Qual SA correlation work, "weighted averages" were used.

As shown by Figures 3.9 and 3.10, radiator plate temperatures measured during vacuum chamber testing are approximately 2°F higher for both lunar noon and lunar night than if the cryowall sections had been at the "real" space temperature of -460°F.

Post-test thermal emissivity measurements were obtained over the cryowall surfaces which revealed an average of 0.91. According to results from the thermal study presented in Section 7.3.3, this causes an additional 5°F increase in radiator temperature at lunar noon over what would be expected with the real space emissivity of 1.0.



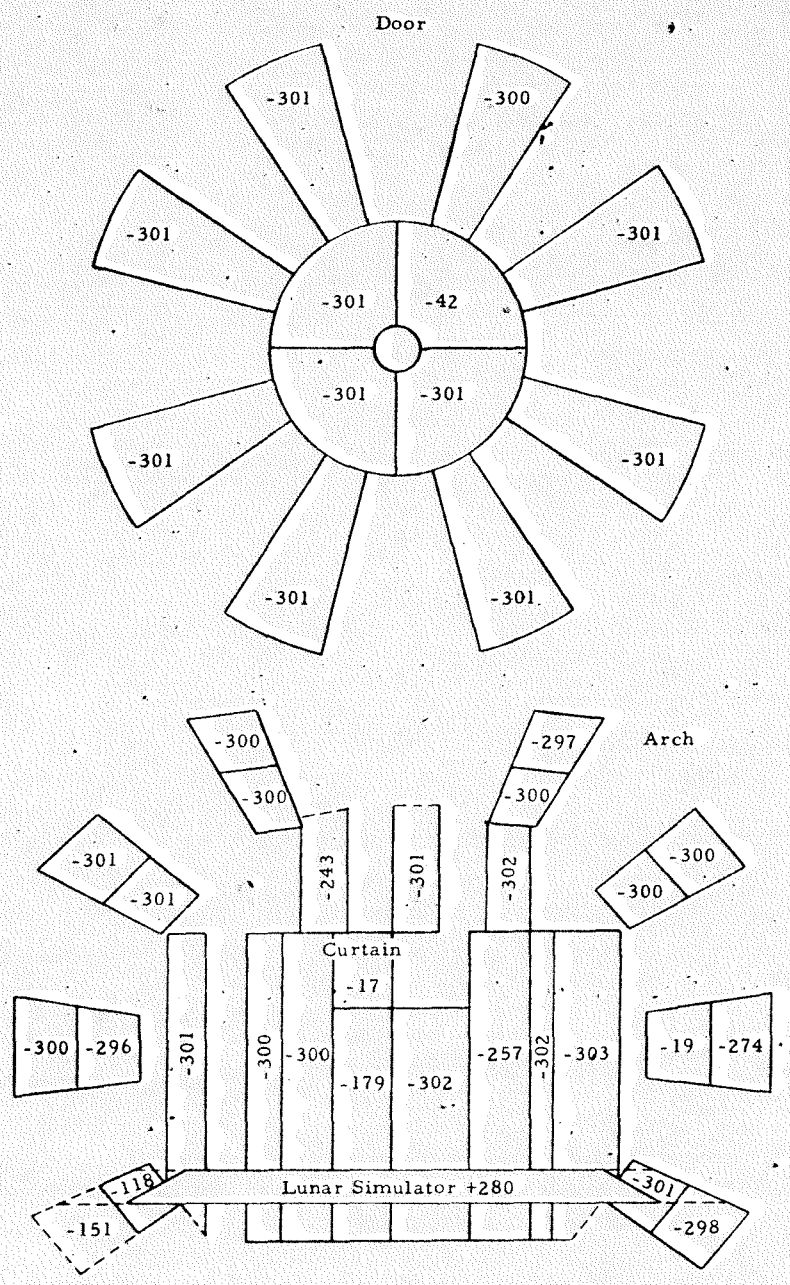
* Numerical Average Temperature

xxx Lunar Noon 7/22/68 00:00, ALSEP Day 204, Elapsed Time = 216 hrs

(xxx) Lunar Night 8/06/68 12:00, ALSEP Day 219, Elapsed Time = 588 hrs

Cryowall Section	Cryowall Average Temperatures ~ °F Numerical Noon	Numerical Night	Weighted Noon	Weighted Night
Door	-280	-290	-297	-295
Curtain	-256	-283	-271	-289
Arch	-218	-280	-219	-283

Figure 3.13 Cryowall Equilibrium Temperatures (°F) (Instrumented Panels Only); Qual SA T/V Mission Simulation Test



Cryowall Average Temperatures ~ °F

Cryowall Section	Numerical	Weighted
Door	-279	-291
Curtain	-259	-271
Arch	-260	-270

Figure 3.14 Cryowall Equilibrium Temperatures (°F) (Instrumented Panels Only); Qual SA T/V Design Limit Test (15 hrs 10 min of 8-8-68)

3.3 Support of Central Station on Lunar Surface Simulator

The bottom of the Central Station was supported 1.75 inches above the lunar simulator by insulation blocks during testing whereas it will rest on the actual lunar surface. As a result, primary structure temperatures were considerably higher during lunar night in the vacuum chamber which in turn causes the radiator plate average temperature to be roughly 1°F higher than for real moon operation. This support arrangement has little effect on structure or radiator temperatures during lunar noon.

3.4 Combined Effects of Lunar Environment Simulation

Individual effects discussed above are summarized below to determine the overall effect of the Acceptance Test lunar environment simulation on C/S radiator temperature. Negative ΔT indicates that chamber test measurements were lower than predicted values for real lunar operation.

Effect	ΔT (°F) Lunar Noon	Lunar Night
Lunar Surface Simulator Configuration	-34	0
Lunar Surface Simulator Temperature	0	0
Lunar Radiant Energy	-8	0
Chamber Cryowall Temperature	+2	+2
Chamber Cryowall Emissivity	+5	0
Central Station Support	0	+1
TOTAL	-35	+3

Thus, to obtain actual lunar operating conditions, add 35°F to the measured radiator temperatures at lunar noon and subtract 3°F at lunar night. Since measured average radiator temperatures were 92°F and 6°F, the corrected values for lunar surface operation become 127°F and 3°F. These values apply for the Acceptance Test electronics thermal dissipation of 37.6 watts at both lunar noon and lunar night.

4.0 THERMAL ANALYSIS

In preceding paragraphs, simulation of the lunar environment was studied in detail with the purpose of comparing chamber test data with actual lunar surface operation predictions. All studies were based on the Qual SA C/S thermal analysis model, which has the capability of determining variation of radiator plate temperature with critical parameters (such as electronics thermal dissipation and cryowall temperature). The model is comprised of numerous "nodes," "resistors," and heat inputs which simulate C/S components and heat transfer between them.

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

4.1 Central Station Thermal Models

Figures 4.1 to 4.3 illustrate deployed assembly and primary components of the C/S, while References 6 and 7 provide details on physical characteristics and functions of each component. Thermal models for temperature predictions at operating conditions in the vacuum chamber and on the real lunar surface are described below.

4.1.1 Thermal Model for Vacuum Chamber Conditions

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

4.1.1.1 Nodal Designation

C/S components are divided into isothermal nodes as identified in Figures 4.4 to 4.9. The T/V chamber cryowall was divided into nodes as specified in Figure 4.10 to simulate the test temperature distribution since the desired uniform temperature over this surface was not obtained during testing. For the Design Limit Test, two additional nodes (170 and 171) were required to represent radiator plate heaters. Node 170 was placed between nodes 102 and 114, while node 171 was located between nodes 108 and 115.

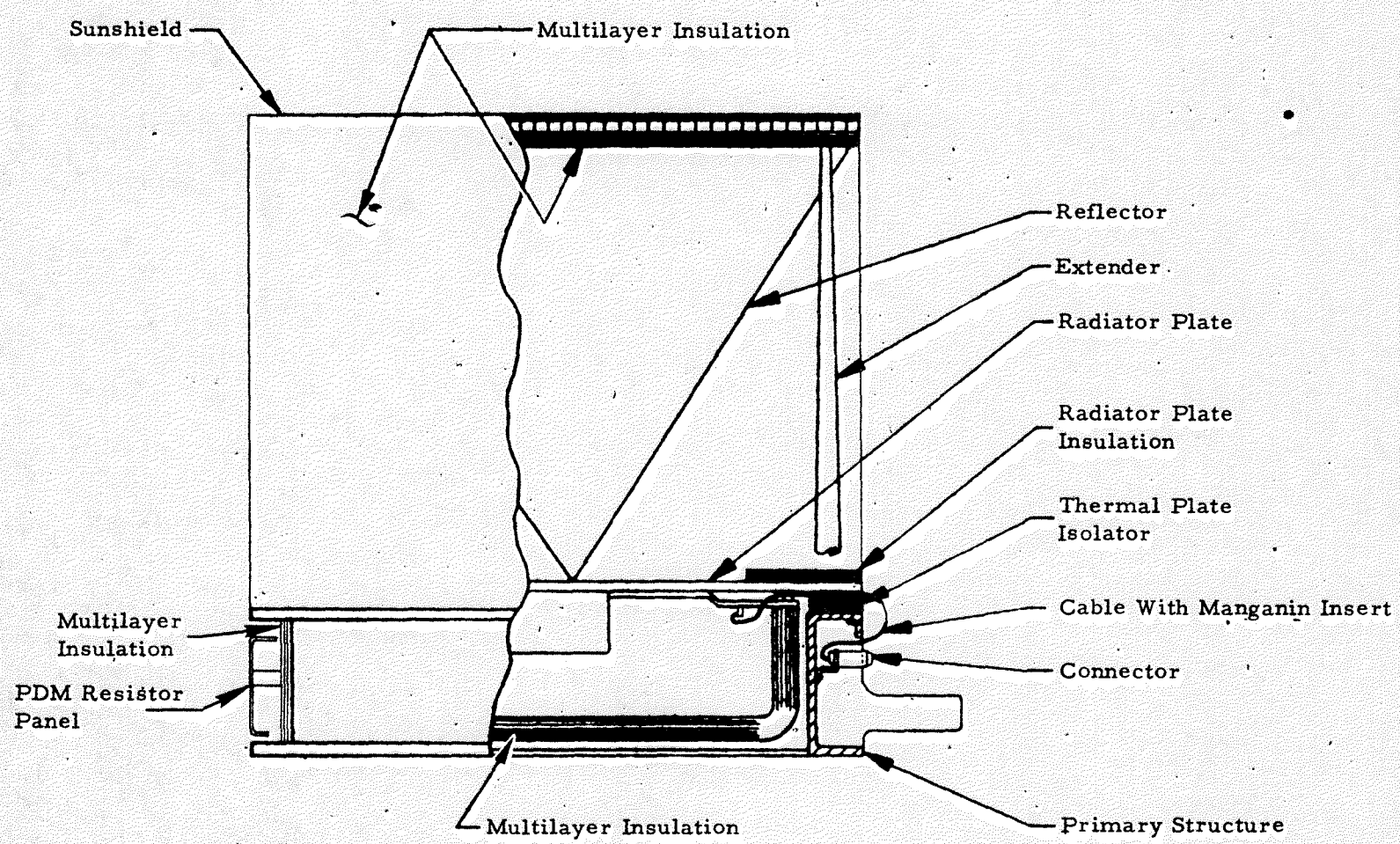


Figure 4.1 Central Station Assembly

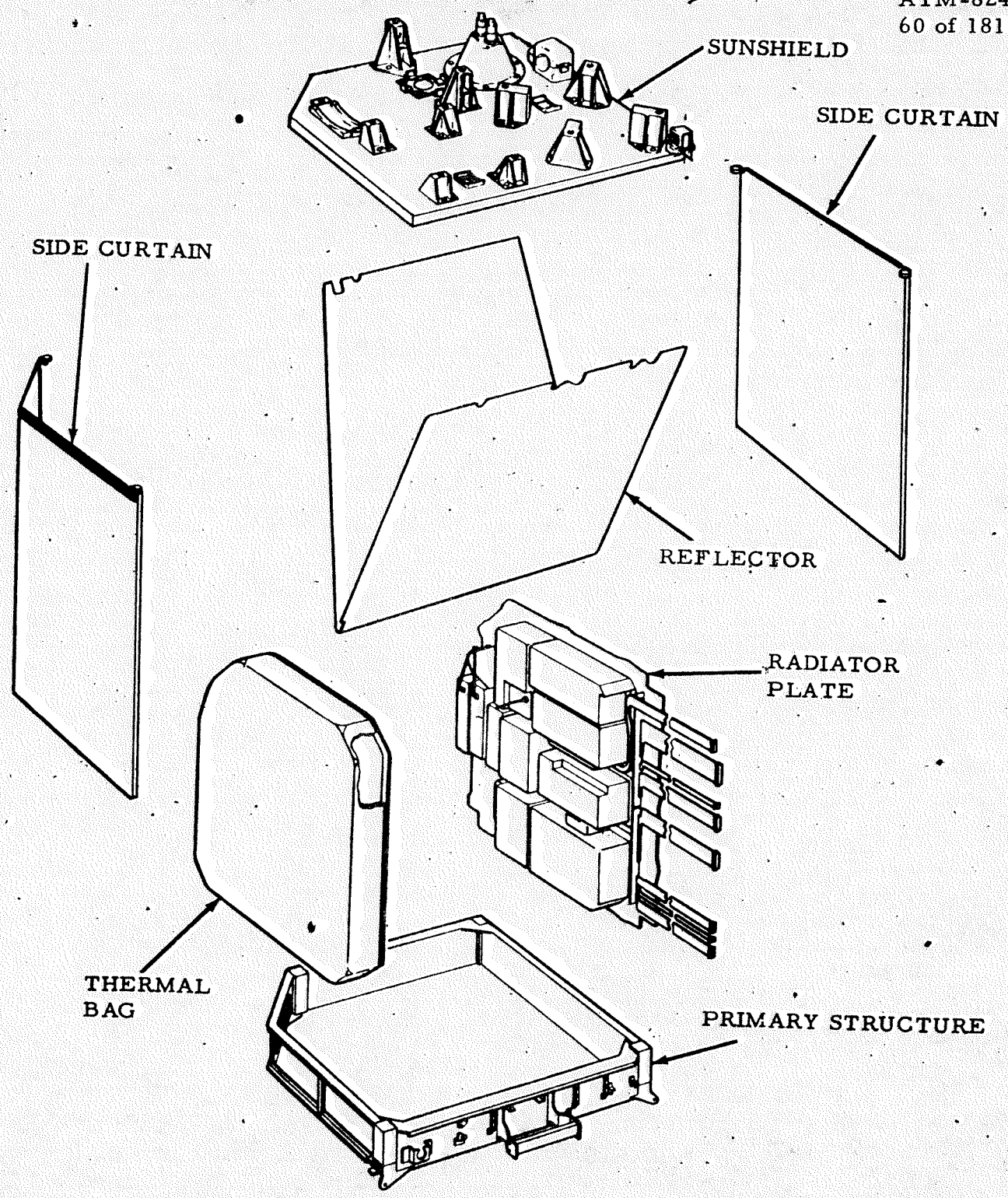


Figure 4.2 Primary Components of Central Station Thermal Control System

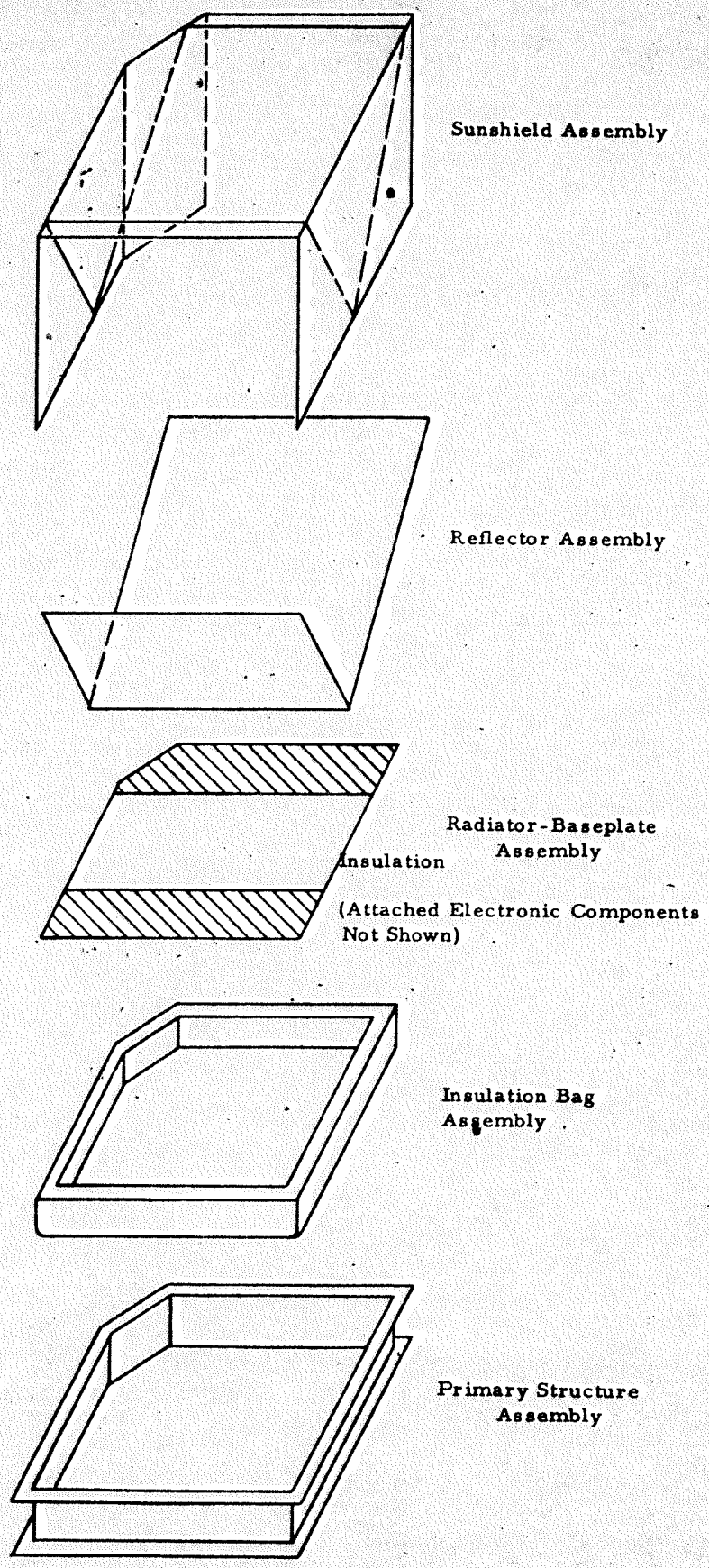


Figure 4.3 Exploded Schematic View of Central Station Thermal Control System

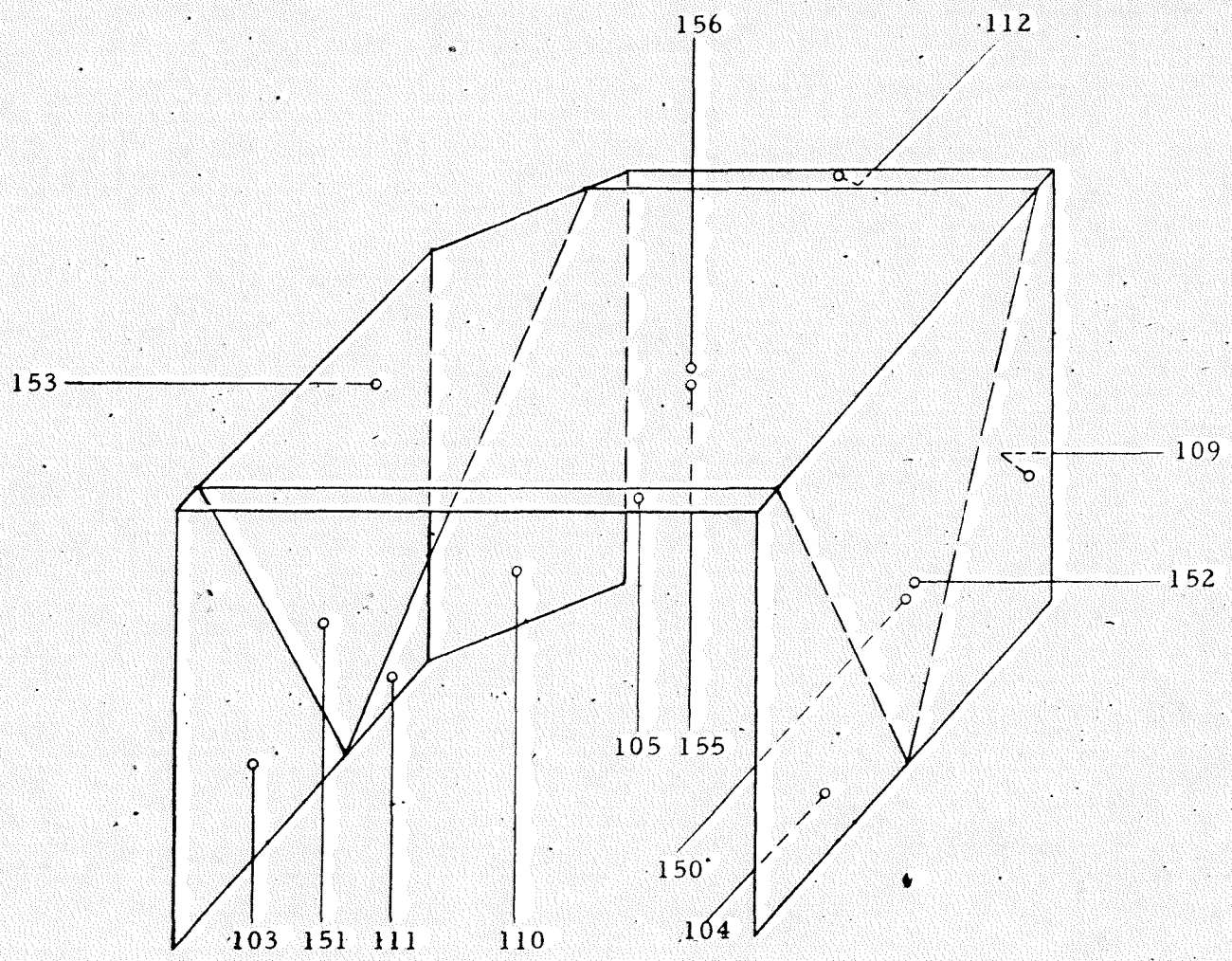


Figure 4.4 Sunshield and Side Curtain Assembly Nodal Designation

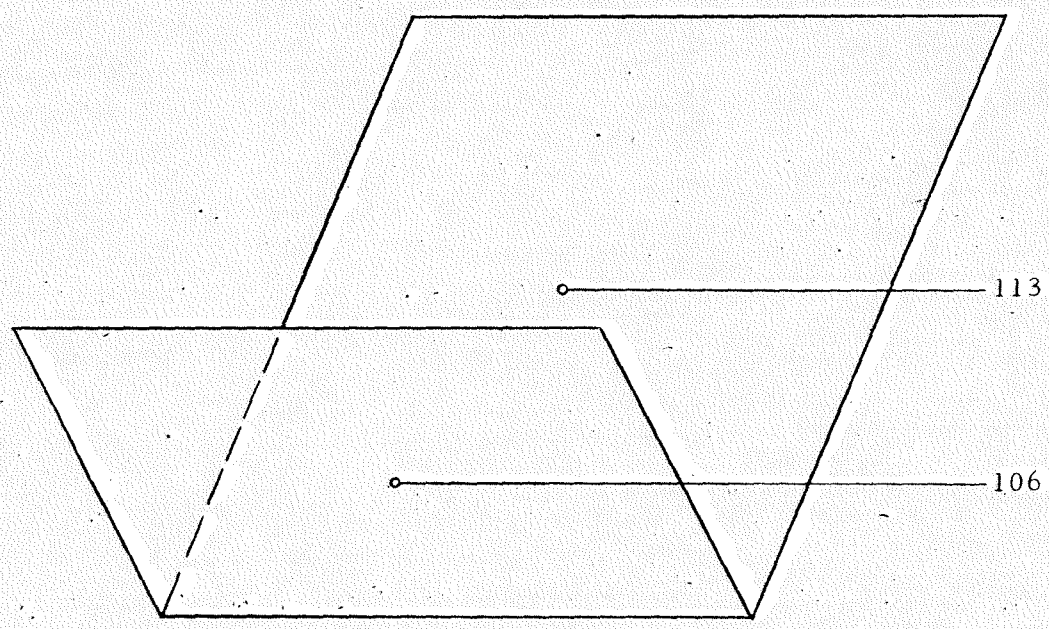
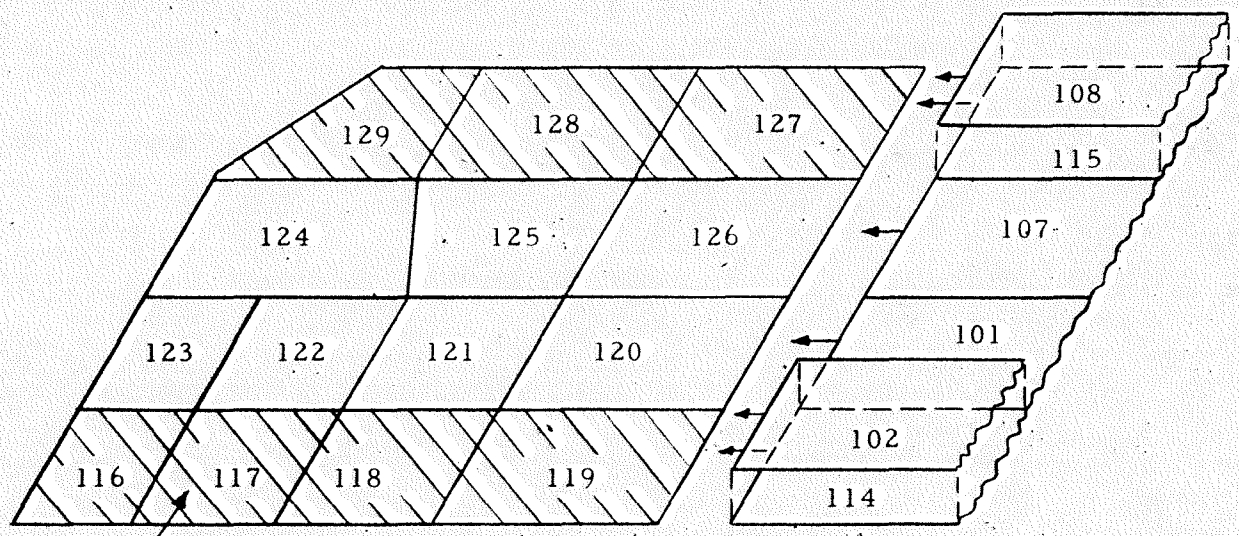


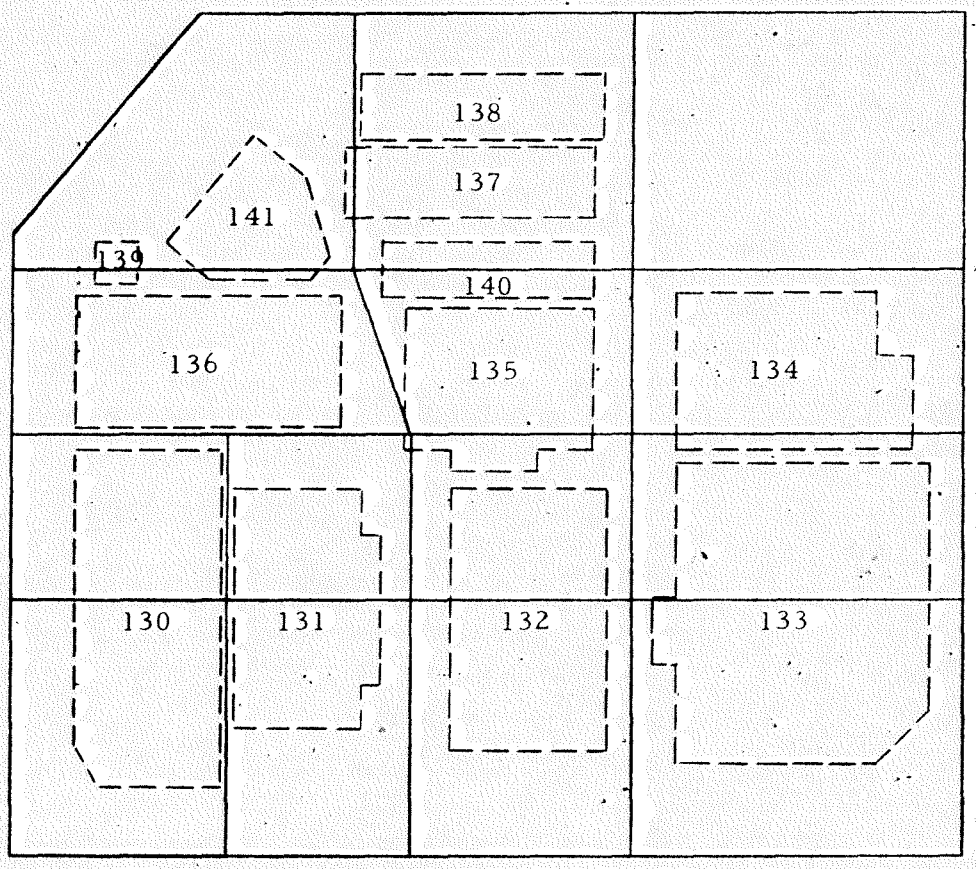
Figure 4.5 Reflector Assembly Nodal Designation



Indicates position of radiator insulation denoted by nodes 102 and 108 and position of "dummy" nodes 114 and 115 which are attached to nodes 116-119 and to 127-129, respectively, by negligible resistances

Nodes 101 and 107 are part of the radiosity network and are attached to nodes 120-123 and to 124-126, respectively, by negligible resistances.

Figure 4.6 Radiator Baseplate Assembly Nodal Designation



Top View

Figure 4.7 Radiator Baseplate Assembly With Electronic Components Nodal Designation

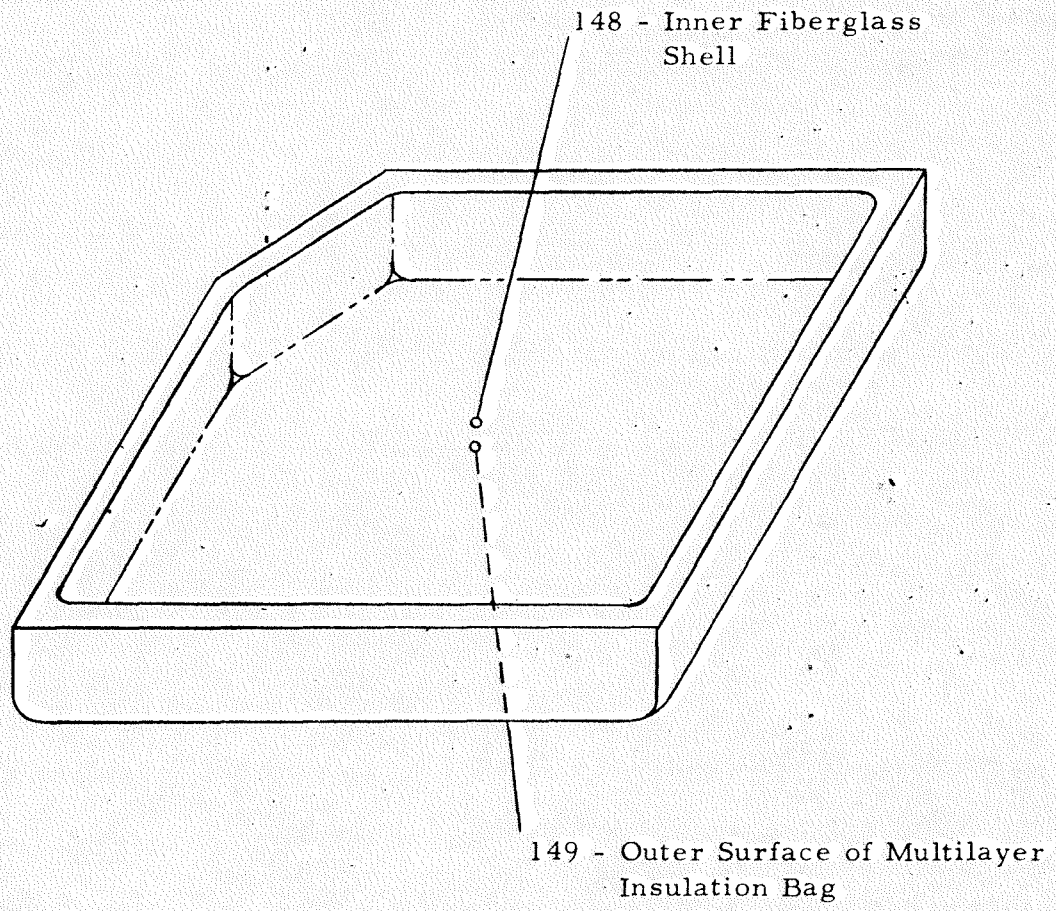


Figure 4.8 Thermal Bag Assembly Nodal Designation

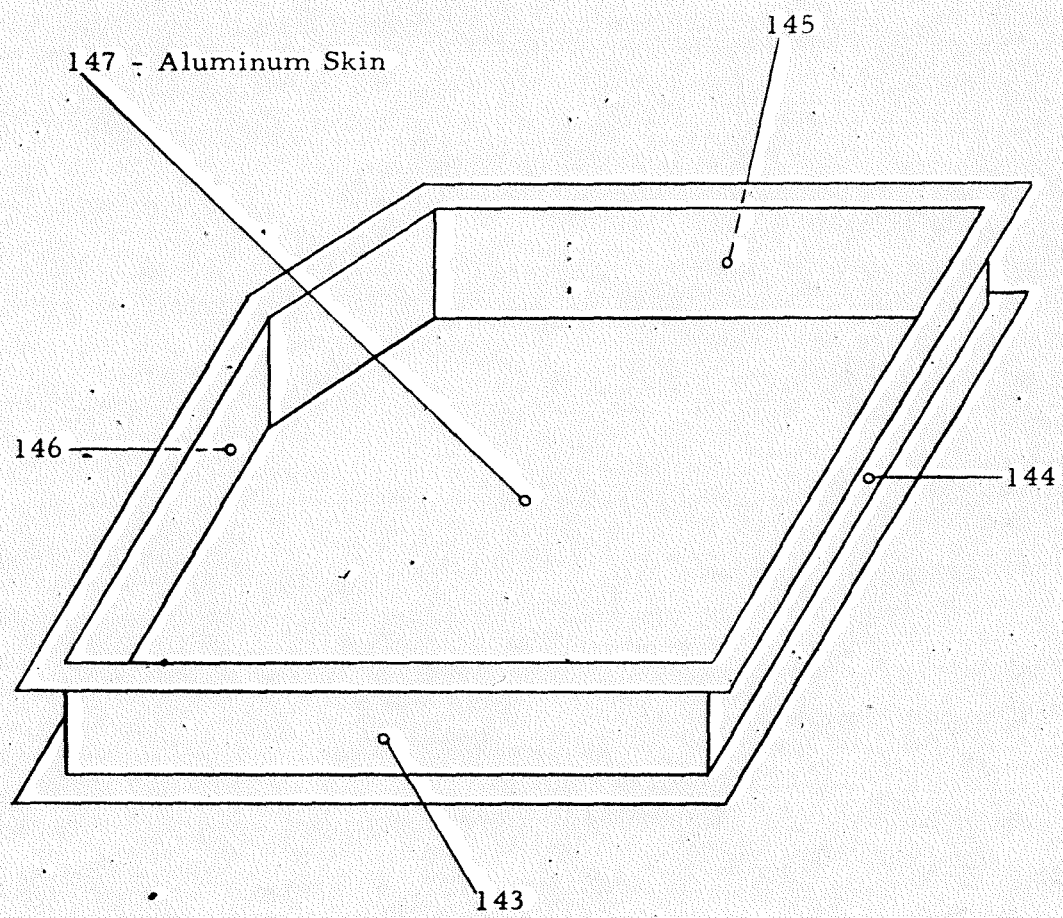


Figure 4.9 Primary Structure Assembly Nodal Designation

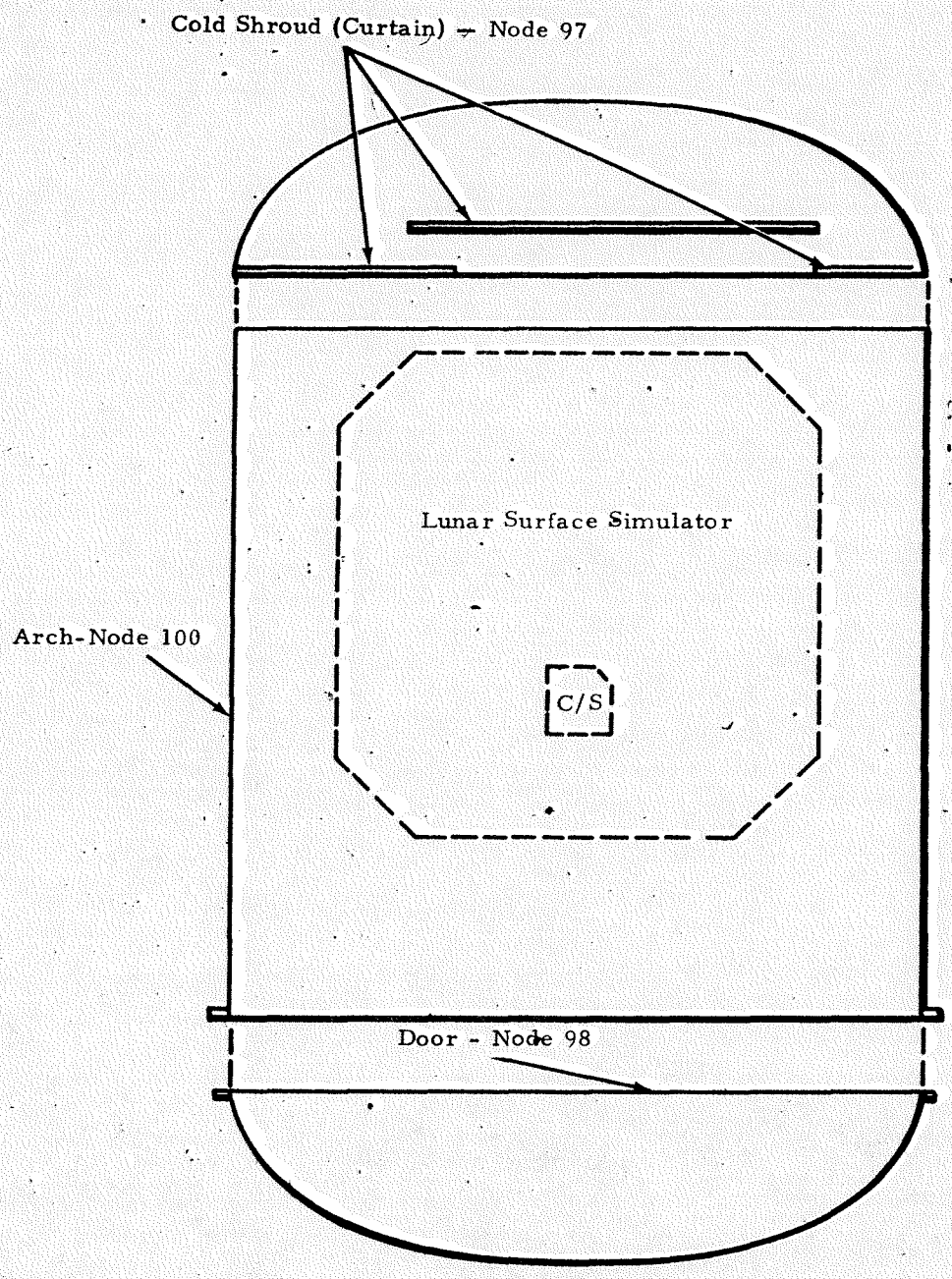


Figure 4.10 Division of T/V Chamber Cryowalls into Space Nodes

4.1.1.2 Resistance Paths

Conduction and radiation resistors connect all nodes to form a network analogous to an electrical circuit, where voltage and current are replaced by temperature and heat transfer rate, respectively. A large portion of the thermal model consists of a "radiosity" node/resistance network which simulates radiation heat transfer in each of two enclosures formed by the radiator plate, insulation mask, side curtains, sunshield overhang, specular reflector, lunar surface, and space. The radiosity network and general techniques used to evaluate resistance paths are presented in References 6 and 7 along with sample calculations. Table 4.1 summarizes all resistor values for Acceptance and Mission Simulation Test conditions. Resistors for the Design Limit Test are the same except two very small conduction resistances attach node 170 to 114 and node 171 to 115.

4.1.1.3 Thermal Analyzer Computer Program

Data on nodes and resistors are input to the "Thermal Analyzer" computer program (described in Reference 8) along with information on solar, electronic, and PDM resistor panel heating. The program, which employs a finite difference technique, performs successive energy balances on each node to establish node temperatures until a "steady-state" condition is achieved, in which case the net heat flow at each node is zero.

4.1.2 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 single node, rather than multiple nodes, represents real space at a uniform -460°F.

2. A lunar subsurface model, described in section 4.6, replaces the test lunar surface simulator model.

3. Actual moon and space temperatures are used.

TABLE 4.1

QUAL SA CENTRAL STATION THERMAL MODEL RESISTORS FOR T/V CHAMBER TEST CONDITIONS AND FOR OPERATION IN THE REAL LUNAR ENVIRONMENT

Thermal Analyzer Resistor No.	Connected Nodes	Description	Type Heat Transfer	Resistor Value (1) Chamber Test	Resistor Value (1) Real Moon
1	1-2	Radiosity Network-	Radiation	.02167	.02167
2	1-3	Involves Each of		.13148	.13148
3	1-4	the Two Enclosures		.13148	.13148
4	1-5	Consisting of a Bare		.00630	.00630
5	1-6	Radiator Plate, In-		.05058	.05058
6	1-99	sulation Mask, Re-		.00092	.04998
7	1-100	flector, Side Curtains,		.45025	.40505
8	1-101	Sunshield, Moon,		7.69500	7.69500
9	2-3	and Space		.18732	.18732
10	2-4			.18732	.18732
11	2-5			.01026	.01026
12	2-6			.05285	.05285
13	2-99			.04453	.07995
14	2-100			.74706	.71040
15	2-102			.14122	.14122
16	3-4			.11100	.11100
17	3-5			.01000	.01000
18	3-6			.04100	.04100
19	3-99			.20110	.30800
20	3-100			.39826	.29200
21	3-103			.12000	.12000
22	4-5			.00978	.00978
23	4-6			.04090	.04090
24	4-99			.20110	.30800
25	4-100			.39826	.29200
26	4-104			.12000	.12000
27	5-6			.00300	.00300
28	5-99			.03912	.04310
29	5-100			.00402	0

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.

TABLE 4.1 (Cont.)

Thermal Analyzer Resistor No.	Connected Nodes	Description	Type Heat Transfer	Resistor Value (1) Chamber Test	Resistor Value (1) Real Moon
30	5-105	Radiosity Network (Cont.)	Radiation	.09200	.09200
31	6-99			.15192	.19800
32	6-100			.17027	.12400
33	6-106			.50500	.50500
34	7-8			.02042	.02042
35	7-9			.13151	.13151
36	7-10			.14514	.14514
37	7-11			.07387	.07387
38	7-12			.00511	.00511
39	7-13			.04951	.04951
40	7-99			.00306	.03193
41	7-100			.36331	.33659
42	7-107			7.69500	7.69500
43	8-9			.17864	.17864
44	8-10			.20952	.20952
45	8-11			.04597	.04597
46	8-12			.00778	.00778
47	8-13			.04709	.04709
48	8-99			.01251	.02101
49	8-100			.60752	.59840
50	8-108			.12877	.12877
51	9-10			.11600	.11600
52	9-11			.03200	.03200
53	9-12			.01000	.01000
54	9-13			.04100	.04100
55	9-99			.23717	.29100
56	9-100			.33203	.27840
57	9-109			.12000	.12000
58	10-11			.03900	.03900
59	10-12			.00700	.00700
60	10-13			.05500	.05500
61	10-99			.15261	.18532
62	10-100			.18320	.15049
63	10-110			.12400	.12400
64	11-12			.00100	.00100

TABLE 4.1 (Cont.)

Thermal Analyzer Resistor No.	Connected Nodes	Description	Type Heat Transfer	Resistor Value (1) Chamber Test	Resistor Value (1) Real Moon
65	11-13	Radiosity Network (Cont.)	Radiation	.00800	.00800
66	11-99			.00439	.01800
67	11-100			.07959	.06700
68	11-111			.03200	.03200
69	12-13			.00200	.00200
70	12-99			.03875	.04100
71	12-100			.00330	0.
72	12-112			.07300	.07300
73	13-99			.11923	.16000
74	13-100			.13147	.08800
75	13-113			.45000	.45000
76	130-116	Electronic Components to Radiator Baseplate	Conduction	1.380	1.380
77	130-123			1.380	1.380
78	131-117			7.200	7.200
79	131-122			7.200	7.200
80	132-118			4.530	4.530
81	132-121			6.800	6.800
82	133-119			2.660	2.660
83	133-120			2.660	2.660
84	134-120			1.630	1.630
85	134-126			4.880	4.880
86	135-121			32.150	32.150
87	135-125			8.037	8.037
88	139-124			5.000	5.000
89	139-129			5.000	5.000
90	136-124			1.670	1.670
91	138-129			.180	.180
92	137-128			.180	.180
93	116-117	Radiator Node Connections		.760	.760
94	117-118			.727	.727
95	118-119			1.052	1.052
96	120-121			1.549	1.549
97	121-122			1.070	1.070
98	122-123			1.119	1.119
99	124-125			1.703	1.703

TABLE 4.1 (Cont.)

Thermal Analyzer Resistor No.	Connected Nodes	Description	Type Heat Transfer	Resistor Value (1) Chamber Test	Resistor Value (1) Real Moon
100	125-126	Radiator Node Connections (Cont.)	Conduction	1.617	1.617
101	127-128			1.151	1.151
102	128-129			1.025	1.025
103	116-123			.838	.838
104	117-122			1.283	1.283
105	118-121			.806	.806
106	119-120			.598	.598
107	124-129			.588	.588
108	125-128			.659	.659
109	126-127			.598	.598
110	123-124			.677	.677
111	122-124			1.037	1.037
112	121-125			.651	.651
113	120-126			.484	.484
114	114-101			.500	.500
115	101-107			.396	.396
116	107-115			.500	.500
117	140-125	Electronic Components to Radiator Baseplate		5.000	5.000
118	140-128			5.000	5.000
119	141-124			5.000	5.000
120	141-129			5.000	5.000
122	116-114	Radiator Node Connections		.100	.100
123	117-114			.100	.100
124	118-114			.100	.100
125	119-114			.100	.100
126	120-101	Radiator Nodes to Radiosity Network Nodes		.100	.100
127	121-101			.100	.100
128	122-101			.100	.100
129	123-101			.100	.100
130	124-107			.100	.100
131	125-107			.100	.100
132	126-107			.100	.100
133	127-115	Radiator Node Connections		.100	.100
134	128-115			.100	.100
135	129-115			.100	.100

TABLE 4.1 (Cont.)

Thermal Analyzer Resistor No.	Connected Nodes	Description	Type Heat Transfer	Resistor Value (1) Chamber Test	Resistor Value (1) Real Moon
136	102-114	Radiator to Insulation Masks	Conduction	2.405	2.405
137	108-115			2.663	2.663
138	145-127	Radiator Support Posts		1558.17	1558.17
139	145-129			1558.17	1558.17
140	143-116			1940.52	1940.52
141	143-119			1940.52	1940.52
142	143-116	Primary Structure to Radiator Baseplate	Radiation	202×10^{-7}	202×10^{-7}
143	143-117			133×10^{-7}	133×10^{-7}
144	143-118			208×10^{-7}	208×10^{-7}
145	143-119			283×10^{-7}	283×10^{-7}
146	144-119			134×10^{-7}	134×10^{-7}
147	144-120			9×10^{-6}	9×10^{-6}
148	144-126			9×10^{-6}	9×10^{-6}
149	144-127			134×10^{-7}	134×10^{-7}
150	145-127			207×10^{-7}	207×10^{-7}
151	145-128			187×10^{-7}	187×10^{-7}
152	146-129			250×10^{-7}	250×10^{-7}
153	146-124			91×10^{-7}	91×10^{-7}
154	146-123			91×10^{-7}	91×10^{-7}
155	146-116			136×10^{-7}	136×10^{-7}
156	116-148	Radiator Baseplate to Thermal Bag		.07900	.07900
157	117-148			.05175	.05175
158	118-148			.08200	.08200
159	119-148			.10950	.10950
160	120-148			.07425	.07425
161	121-148			.05575	.05575
162	122-148			.03500	.03500
163	123-148			.05350	.05350
164	124-148			.08250	.08250
165	125-148			.06175	.06175
166	126-148			.07425	.07425
167	127-148			.10950	.10950
168	128-148			.10025	.10025
169	129-148			.08050	.08050

TABLE 4.1 (Cont.)

Thermal Analyzer Resistor No.	Connected Nodes	Description	Type Heat Transfer	Resistor Value (1) Chamber Test	Resistor Value (1) Real Moon
*170	148-149	Thermal Bag Node	Conduc-	10.54	10.54
**170	148-149	Connection	tion	51.70	51.70
171	143-149	Primary Structure	Radia-	.01750	.01750
172	144-149	to Thermal Bag	tion	.01520	.01520
173	145-149			.01380	.01380
174	146-149			.01660	.01660
175	147-149			.10850	.10850
176	143-144	Structure Node	Conduc-	15.891	15.891
177	144-145	Connections	tion	16.700	16.700
178	145-146			21.040	21.040
179	146-143			13.990	13.990
180	147-143			1.486	1.486
181	147-144			2.461	2.461
182	147-145			1.958	1.958
183	147-146			1.992	1.992
184	145-160	Structure to Res. Panel Ins.		31.400	31.400
185	145-161	Structure to Res. Panel		4.004	4.004
186	160-161	Res. Panel to Insulation	Radiation	.01959	.01959
187	145-161	Structure to Res. Panel		.08663	.08663
193	135-143	Cabling from Electronic	Conduc- tion	617.0	617.0
194	134-143	Components to Structure		493.0	493.0
195	131-143			117.0	117.0
196	132-143			569.0	569.0
197	130-143			36.5	36.5
198	104-152	Side Curtain		.7750	.7750
199	150-152	Insulation		.4215	.4215
200	109-152			.7750	.7750
201	103-153			.7750	.7750
202	151-153			.4276	.4276

*Lunar Noon Only
* *Lunar Night Only

TABLE 4.1 (Cont.)

Thermal Analyzer Resistor No.	Connected Nodes	Description	Type Heat Transfer	Resistor Value (1) Chamber Test	Real Moon
203	111-153	Side Curtain Insu-	Conduc-	2.9100	2.9100
204	110-153	lation (Cont.)	tion	.7470	.7470
205	152-99	Side Curtains to	Radiation	.75063	1.03261
206	152-100	Moon & Space		1.32122	1.03924
207	153-99			.82306	1.13526
208	153-100			1.45474	1.14254
209	105-156	Sunshield Node	Conduc-	.1510	.1510
210	112-156	Connections	tion	.1510	.1510
211	155-156	Sunshield Top to Insulation		.0770	.0770
212	154-155	Sunshield Bottom to Insulation		.9524	.9524
213	156-100	Sunshield Top to Space	Radiation	NA	3.74850
214	154-106	Enclosure Behind		.0376	.0376
215	154-150	Reflectors		.0268	.0268
216	154-113			.0376	.0376
217	154-151			.0268	.0268
218	106-150			.0031	.0031
219	106-113			.0058	.0058
220	106-151			.0031	.0031
221	150-113			.0031	.0031
222	150-151			.0020	.0020
223	113-151			.0031	.0031
224	155-105	Sunshield Bottom Node	Conduc- tion	5.424	5.424
225	155-112	Connections		5.424	5.424
*230	133-143	Electronics Cabling		310.0	310.0
**230	133-143	to Structure		537.0	537.0
*231	140-162	Electronics Cabling	Cond. &	783.0	783.0
**231	140-162	to Environment	Rad.	5767.0	5767.0
*232	143-162	Structure Cabling		27.0	27.0
**232	143-162	to Environment		67.0	67.0

*Lunar Noon Only
**Lunar Night Only

TABLE 4.1 (Cont.)

Thermal Analyzer Resistor No.	Connected Nodes	Description	Type Heat Transfer	Resistor Value (1) Chamber Test	Resistor Value (1) Real Moon
297	145-99	Primary Structure	Radiation	.08707	.08310
298	145-100	to Moon & Space		.08946	.08310
299	146-163			.01798	.00402
304	143-99			.43455	.47062
305	143-100			.32847	.31398
310	144-99			.26486	.28206
311	144-98			.30002	NA
311	144-100			NA	.28226
318	146-99			.26995	.31203
319	146-97			.32811	NA
319	146-100			NA	.30797
320	147-99			.36500	NA
320	147-61		Conduction	NA	.10000
326	161-99		Radiation	.12051	.13374
327	161-100			.14002	.13383
328	147-99		Conduction	33.3	NA
330	156-97	Sunshield Top	Radiation	.22490	
331	156-98	to Space		.22490	
332	156-100			3.29870	
333	143-156	Primary Structure	Conduc-	3000.	3000.
334	144-156	to Sunshield	tion	3000.	3000.
335	145-156			3000.	3000.
336	146-156			3000.	3000.
350	61-71	Real Moon Sub-		NA	.894
351	71-70	surface Model			1.788
352	71-60				12.500
353	70-69				2.012
354	70-59				12.500
355	69-68				2.459
356	69-58				10.000
357	68-67				2.905
358	68-57				8.330
359	67-66				3.576
360	67-56				7.140
361	66-65				4.917

TABLE 4.1 (Cont.)

Thermal Analyzer Resistor No.	Connected Nodes	Description	Type Heat Transfer	Resistor Value (1) Chamber Test	Resistor Value (1) Real Moon
362	66-55	Real Moon Sub-surface Model (Cont.)	Conduction	NA	5.550
363	65-64				7.375
364	65-54				3.840
365	64-63				11.622
366	64-53				2.500
367	63-62				27.715
368	63-52				1.560
369	62-50				.447
370	62-51				.500
371	61-99				50.000

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

Table 4.1 summarizes resistance values for the real moon analysis.

4.2 Pallet 2/RTG Thermal Models

Thermal Models for the Pallet 2/RTG are described in ATM 821, (Reference 12).

4.3 Analysis Methods

Analysis methods used to construct the C/S thermal models are not presented here as they are outlined in detail in References 6 and 7.

4.4 Heat Inputs to C/S Thermal Model

Four sources of heat input to the C/S exist:

1. Thermal dissipation from electronic components.

2. Thermal dissipation at the PDM resistor panel.

3. Solar radiation.

4. Heaters on the radiator plate under insulation masks.

Values for all these heat sources at lunar noon and lunar night are listed in Tables 4.2 to 4.4 for the Acceptance, Mission Simulation, and Design Limit Tests. Solar radiation at the sunshield is simulated by infrared heaters suspended above the sunshields in the vacuum chamber. Solar heating of the lunar surface simulator is simulated by infrared heaters attached to the underside of the simulator. The importance of solar heating is discussed in detail in Section 3.1.3. The fourth heating source was used only in the Design Limit Test to force the radiator temperature to a predetermined level.

4.5 Radiation Properties of Central Station Surfaces

Radiation properties listed in Table 4.5 were used to evaluate radiation resistors. These values were often difficult to establish accurately and may vary over the operational life of the C/S. However, good analytical predictions have been obtained with the listed properties.

TABLE 4.2

THERMAL DISSIPATION AND SOLAR RADIATION AT CENTRAL STATION FOR QUAL SA T/V ACCEPTANCE TEST

Thermal Analyzer Node	Description	Computer Input Table	Thermal Dissipation ~ Watts	
			Noon	Night
130	P. C. U.	1	21.3	21.9
131	P. D. U.	2	1.73	1.73
132	Analog Multiplex Conv.	3	1.41	1.41
133	Passive Seismometer	4	4.40	4.40
134	Command Decoder	5	1.20	1.20
135	Data Processor	6	.50	.50
136	Command Receiver	7	.70	.70
137	Transmitter A	8	0	0
138	Transmitter B	8	6.40	5.80
139	Timer	—	0	0
140	Diplexer Filter	—	0	0
141	Diplexer Switch	—	0	0
—	Dust Detector	—	0*	0*
—	Electronics Total	—	37.64	37.64
156	Solar Radiation Absorbed by Sunshield	9	108.00	0
161	P. D. M. Resistors	10	20.50	9.50

*The dust detector actually has a thermal dissipation of 0.2 watts which has been added to the P. D. U. dissipation in the thermal model.

TABLE 4.3

THERMAL DISSIPATION AND SOLAR RADIATION AT CENTRAL STATION FOR QUAL SA T/V MISSION SIMULATION TEST

Thermal Analyzer Node	Description	Table	Thermal Dissipation ~ Watts	
			Noon	Night
130	P. C. U.	1	21.90	21.80
131	P. D. U.	2	1.73	1.73
132	Analog Multiplex Conv.	3	1.41	1.41
133	Passive Seismometer	4	4.40	4.40
134	Command Decoder	5	1.20	1.20
135	Data Processor	6	.50	.50
136	Command Receiver	7	.70	.70
137	Transmitter A	8	0	0
138	Transmitter B	8	5.94	5.67
139	Timer	—	0	0
140	Diplexer Filter	—	0	0
141	Diplexer Switch	—	0	0
—	Dust Detector	—	0*	0*
—	Electronics Total	—	37.78	37.41
156	Solar Radiation Absorbed by Sunshield	9	108.00	0
161	P. D. M. Resistors	10	13.20	9.00

*The dust detector actually has a thermal dissipation of 0.2 watts which has been added to the P. D. U. dissipation in the thermal model.

TABLE 4.4

THERMAL DISSIPATION AND SOLAR RADIATION AT CENTRAL STATION FOR QUAL SA T/V DESIGN LIMIT TEST

Node	Description	Table	Thermal Dissipation~ Watts
130	P. C. U.	1	18.50
131	P. D. U.	2	1.73
132	Analog Multiplex Conv.	3	1.40
133	Passive Seismometer	4	4.40
134	Command Decoder	5	1.20
135	Data Processor	6	.50
136	Command Receiver	7	.70
137	Transmitter A	8	0
138	Transmitter B	8	7.40
139	Timer	—	0
140	Diplexer Filter	—	0
141	Diplexer Switch	—	0
—	Dust Detector	—	0
—	Electronics Total	—	35.83
156	Solar Radiation Absorbed by Sunshield	9	135.00
161	P. D. M. Resistors	10	15.80
170	Radiator Heater	11	12.00
171	Radiator Heater	11	12.00

TABLE 4.5

RADIATION PROPERTIES OF QUAL SA CENTRAL STATION SURFACES

Nodes	Surface	α *	ϵ **	Surface Finish
120-126	Radiator Top Surface	.20	.90	S13-G White Paint
116-129	Radiator Bottom Surface	NA	.05	Aluminized
102&108	Radiator Insulation	.15	.50	SiO over Aluminized Mylar
106&113	Specular Reflector	NA	.05	Specular ρ = .90 Diffuse ρ = .05
152&153	Side Curtain Exterior	.15	.50	SiO over Aluminized Mylar
103, 104, 109-111, 150, 151	Side Curtain Interior	NA	.10	Aluminized Mylar
156	Sunshield Top	.20	.90	S13-G White Paint
154	Sunshield Bottom Insulation	NA	.50	Aluminized Mylar
143-146	Primary Structure Exterior, Except Bottom Skin	.20	.90	S13-G White Paint
143-147	Primary Structure Interior and Bottom Skin	NA	.05	Aluminized
148	Insulation Bag Interior	NA	1.00	
149	Insulation Bag Exterior	NA	.50	
161	Resistor Plate Exterior	.20	.90	Z93 White Paint

*Solar Absorptivity
**Thermal Emissivity

NA Not Applicable
ρ = reflectivity

4.6 Simulated "Real" Moon

For analysis predictions of C/S performance in an actual lunar environment, the lunar surface was simulated by a 500 ft. x 500 ft. "node" with an emissivity of 1.0 and at uniform temperatures of 250°F for noon and -300°F for night. In addition, the following modification was employed. When the C/S 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 the C/S was divided horizontally and vertically into a series of nodes (see Figure 4.11) to provide for this effect. "Infinite" nodes, which are unaffected by the C/S and which are at fixed temperatures, are connected to "active" nodes which are located directly under the C/S. Active nodes are allowed to achieve equilibrium temperatures along with C/S nodes in the thermal model. Construction of this "subsurface" model is described in Reference 9.

4.7 Relocation of PDM Resistor Panel

For the Prototype "A" model, excess RTG power was dumped into resistors located on the front section of the primary structure and on the handle. This caused relatively high temperatures on the structure and resistors which in turn affected radiator plate temperatures.

Consequently, for the Qual SA model, a PDM resistor panel was designed to dissipate excess power at reduced resistor temperatures as well as to isolate resulting heat from other C/S components. To avoid conflict with cables entering the C/S, the panel was fastened to the back section of the structure. Fasteners were a series of thin rods which supported the panel and which minimized heat conduction to the structure. Aluminized mylar was placed between the hot panel and structure to virtually eliminate radiation to the structure. A coating of high emissivity white paint (Z-93) on the panel allows maximum radiation heat transfer from this component to space and to the lunar surface.

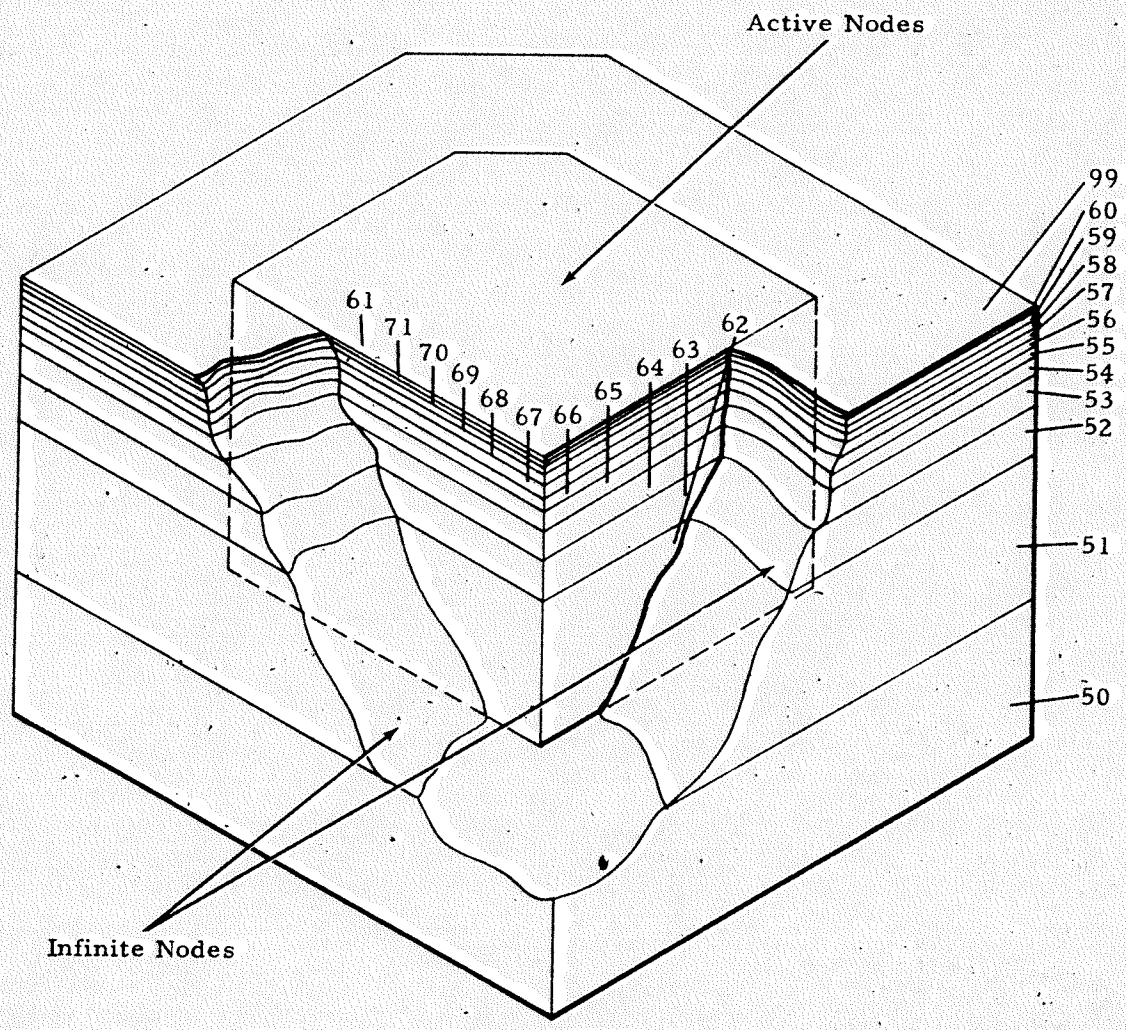


Figure 4.11 Lunar Subsurface Computer Model for Real Moon Analysis

4.8 Evaluation of PCU and PDM Thermal Dissipation

Tests were performed to evaluate thermal dissipation of the PCU and of the PDM resistor panel for a Qual SA C/S electronics system with a 55 watt PCU regulator and with 68 watts of input power from the RTG. Results are plotted versus "reserve power" in Figure 4.12, where reserve power is defined as the difference between RTG input power to the C/S and PCU input power. Reserve power was determined from DAS and HK measurements and thus provided the basis for evaluating PCU and PDM thermal dissipations.

4.9 RTG Simulation

Since the RTG is located relatively close to the C/S (about 5 ft separate the centerlines of the two pallets) during vacuum chamber testing, its heating effect on the C/S was considered in the analysis. The RTG was simulated by an 18 inch square vertical plane situated opposite the primary structure left side and at temperatures of 480°F at noon and 440°F at night. RTG effects on C/S component temperatures are discussed in Section 7.3.1.

For the real lunar environment, the RTG is located at a sufficient distance (10 ft or more) from the C/S to have virtually no effect on C/S temperatures.

4.10. Evaluation of Conduction Resistances Between Electronics and Radiator Plate

A layer of thermal grease is inserted between the radiator plate and electronic components to insure good heat conduction to the radiator. Since the resulting thickness of grease is impossible to measure, it is difficult to estimate conduction resistances between the electronics and the plate using the standard (L/KA) technique (L = grease thickness, K = thermal conductivity, and A = area). Consequently, resistors were calculated with test data and the following equation:

$$R = \frac{q}{\Delta T}$$

R = resistance

q = thermal dissipation of electronic component

Notes:

1. Curves apply for System with 68 Watts RTG Input Power and With 55 Watt PCU Regulator

2. Curves are Constructed from Power Dissipation Test Data on G. E. PCU (refer to ATM 253)

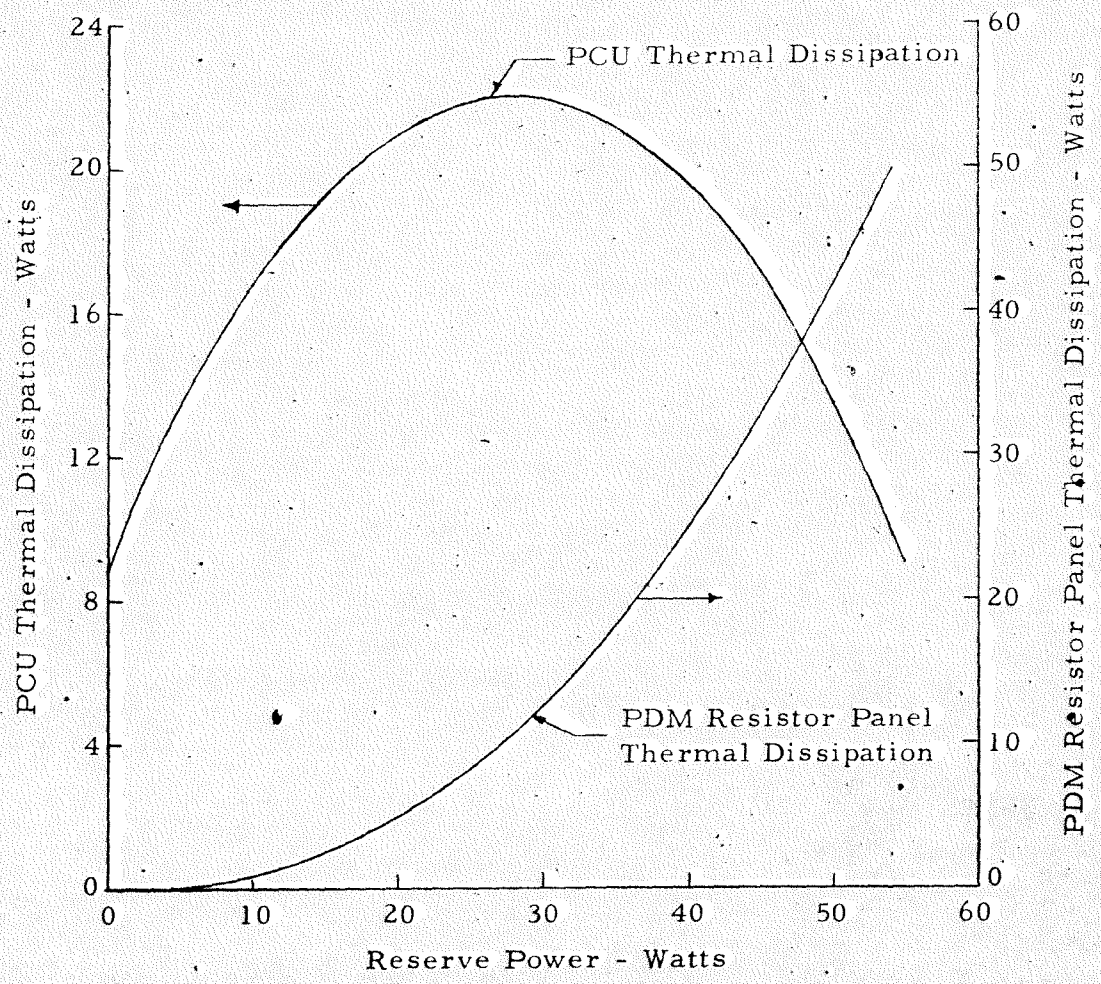


Figure 4.12 PCU and PDM Resistor Panel Thermal Dissipation vs Reserve Power

ΔT = difference between temperature measurements taken on an electronic component base and on the radiator plate adjacent to the component.

Since a small amount of heat passes through the thermal bag, cables, and radiator support posts, values of q may be somewhat in error. However, resulting resistances are of the correct order-of-magnitude and provide good analysis results.

4.11 Correction for "Non-Black" Properties of Lunar Surface Simulator

The radiosity resistance network in the computer thermal model is based on an emissivity of 1.0 for the lunar surface simulator. Since the simulator has an actual emissivity less than 1.0, test temperatures were corrected for "non-black" properties when used for correlation purposes in the computer model. An "effective" temperature was derived from test measurements with the following equation.

$$T_{effective} = \sqrt[4]{\epsilon}\ T_{measured}$$

Refer to Section 7.3.3 for the effect of lunar surface emissivity on C/S performance.

4.12 Correlation Approximations and Assumptions

1. Thermal Conductivity of Insulation Masks and Side Curtains. Since no thermal conductivity test data is available on insulation mask and side curtain materials, reasonable values were estimated for correlation work. A thermal conductivity of 10^{-2} Btu/ft hr °F for all mask and curtain components provided optimum correlation results and is the value used in the Qual SA analysis model.

2. Radiation from Primary Structure Front to Moon and Space. Due to connectors, brackets, and cables at the front of the primary structure, radiation resistors are difficult to evaluate. Also, the large overhang of of the upper flange causes more radiation to be directed at the lunar surface than to space. Consequently, it was assumed that the structure front radiates about 1.5 times more heat to the moon than to space, and good correlation results were obtained.

3. Lunar Surface Emissivity. Since the lunar surface simulator had a measured average emissivity of 0.89 and had no reflected solar energy (albedo), lunar temperatures for the analysis thermal model were adjusted as explained in Section 4.11 when correlating predicted and test results.

4. Cable Heat Leak. An assumed three inch length for cables extending from the C/S electronics to the connectors on the structure front gave maximum possible heat leaks along cables. Because these sections of cable were composed of Manganin, heat leaks were low and relatively unaffected by this assumption.

Reference 7 contains detailed discussions on all the above approximations and assumptions.

5.0 TEST METHODS

5.1 Acceptance Test Procedure

An ALSEP Deployed System Thermal Vacuum Acceptance Test was performed in the Bendix 20' x 27' Lunar Environment Simulation Chamber. During this test, ALSEP exercised a lunar start-up sequence under a simulated lunar morning environment. A SNAP 27 generator was utilized to supply power for this phase and for lunar noon and lunar night phases which followed. When verification of system turn-on had been received, power output from the generator was monitored for stabilization.

After a lunar noon environment had been established, a chamber failure occurred which resulted in coolant fluid being sprayed into the chamber and a subsequent loss of vacuum. The test was halted while chamber and ALSEP equipment repairs were made.

The test was then resumed, and a simulated lunar noon environment was established. When all systems had reached thermal equilibrium, an Integrated Systems Test (IST) was performed. Following this test, a simulated lunar night environment was established, and again all systems were allowed to reach thermal equilibrium. A second Integrated Systems Test was then performed. Upon completion of this IST, ALSEP was shut down, and the chamber was returned to room ambient conditions.

Lunar environment in the Bendix 20' x 27' Lunar Environment Simulation Chamber was simulated by chamber pressure, cold shroud temperature, lunar surface temperature and solar radiation.

A pressure of 5×10^{-6} Torr or less was maintained for the duration of this test by the chamber pumping system. The cold sink of space was simulated with a shroud cooled by liquid nitrogen and having a thermal emissivity in excess of 0.90. The lunar surface was simulated by a structure fabricated from aluminum and also having a thermal emissivity over 0.89. Low lunar surface temperature extremes were achieved by pumping LN_2 through the surface, and high temperatures were achieved with an array of infrared lamps. Radiant solar energy was also simulated with an array of infrared lamps, and the level of energy absorbed by the sunshield and Pallet 2/RTG was monitored and controlled by a radiometer calibrated to read absorbed energy.

5.2 Mission Simulation Test Procedure

While the Mission Simulation Test procedure was similar to that for the Acceptance Test, three major differences in procedure existed.

1. For Mission Simulation, the Central Station and Pallet 2/RTG were subjected to an actual lunar day-to-night cycle where the lunar surface temperature versus time profile was simulated with a total of nine step temperature changes from lunar morning to lunar night over a 28 day period. Solar heating of the C/S sunshield and Pallet 2/RTG was simulated with infrared lamps. Solar heat input corresponded to actual lunar surface temperatures obtained during the various phases of the lunar day cycle.

2. During Mission Simulation lunar noon, the 7 and 14 watt PDM dumps were activated simultaneously for about 8.5 hours.

3. During Mission Simulation lunar night, the 10 watt radiator plate heater was turned-on for 24 hours and then turned-off while the 5 watt radiator heater was activated for 14.5 hours.

5.3 Design Limit Test Procedure

At the conclusion of Mission Simulation lunar night, the lunar surface simulator average temperature was increased to 280°F, and two 12 watt heaters fastened to the radiator plate under the masks were activated. The C/S was then allowed to reach equilibrium. At this point a chamber window imploded, and the test was terminated.

5.4 Measurement Locations

5.4.1 Central Station

The Central Station is instrumented with 31 thermocouples for DAS measurements and 35 thermistors for HK measurements.

Figure 5.1 shows the locations of 4 of the thermocouples and 5 of the thermistors on the sunshield and the dust detector. Figure 5.2 shows the locations of 13 of the thermocouples and 5 of the thermistors on the radiator plate and support posts. Figure 5.3 shows locations of the remaining 14 thermocouples and 4 of the thermistors on the primary structure, connectors and PDM resistor panel. Two of the thermistors are located on the inside and on the outside of the multilayer insulation bag. The remaining 19 thermistors are located within the electronic components.

5.4.2 Pallet 2/RTG

Figures 5.4 and 5.5 specify locations of 21 DAS thermocouples on the Pallet 2 upper and bottom surfaces and on two RTG fins.

5.4.3 Simulated Lunar Environment

The lunar surface simulator was instrumented with 37 thermocouples as shown in Figure 5.6, while Figure 5.7 depicts the distribution of 40 thermocouples over the chamber cryowall.

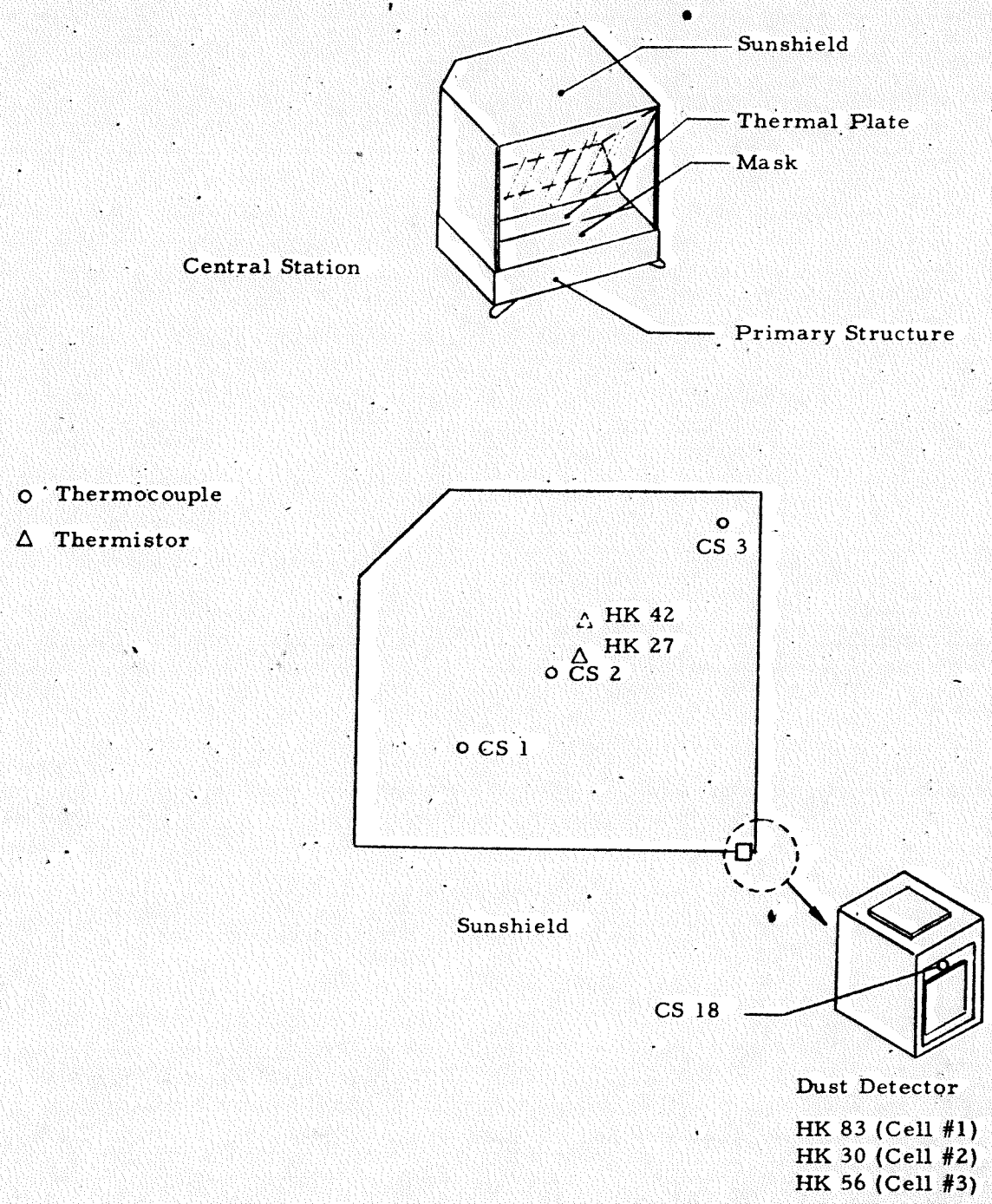


Figure 5.1 Central Station Thermocouple and Thermistor Locations - Sunshield

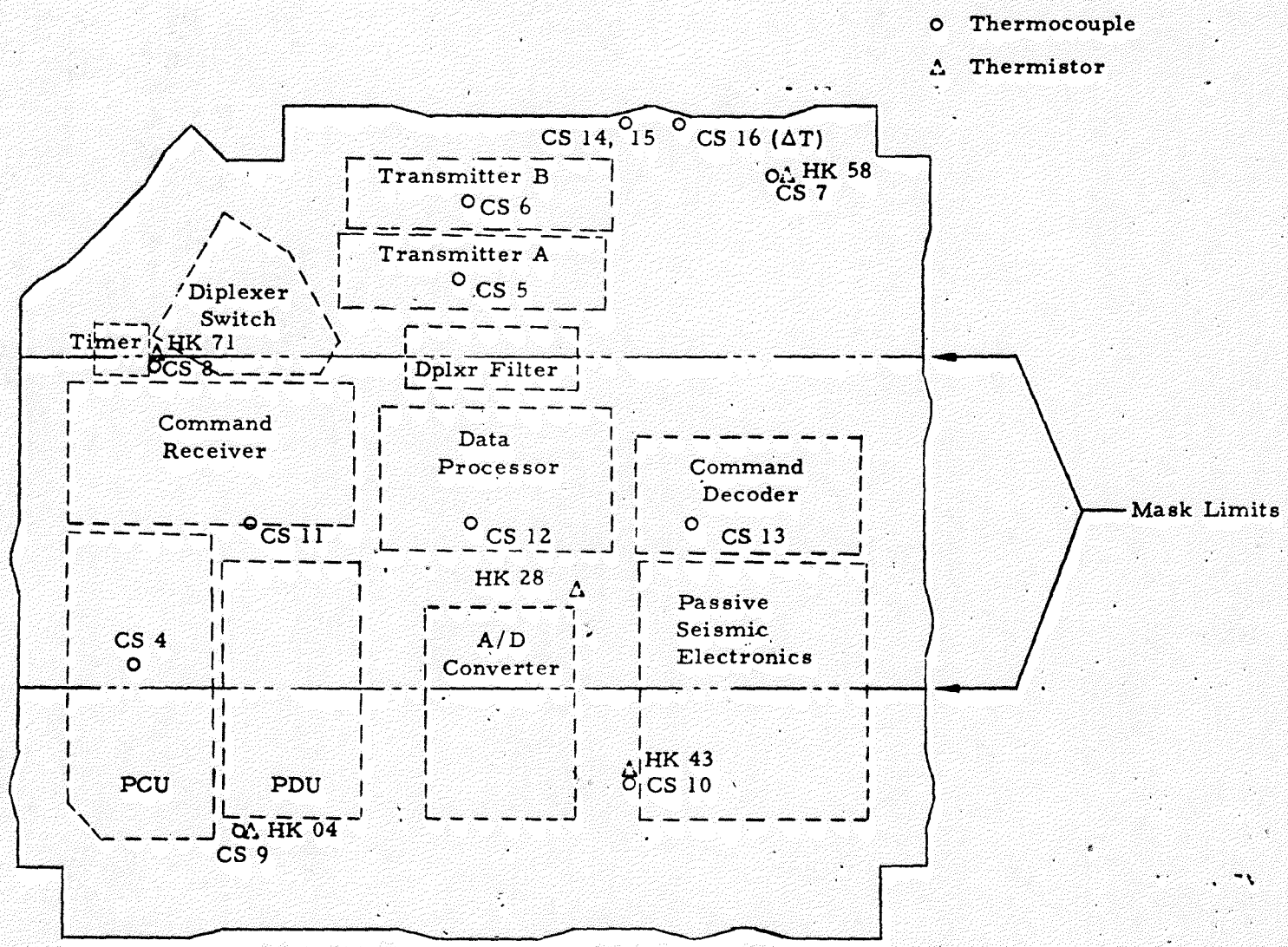


Figure 5.2 Central Station Thermocouple and Thermistor Locations - Radiator Plate

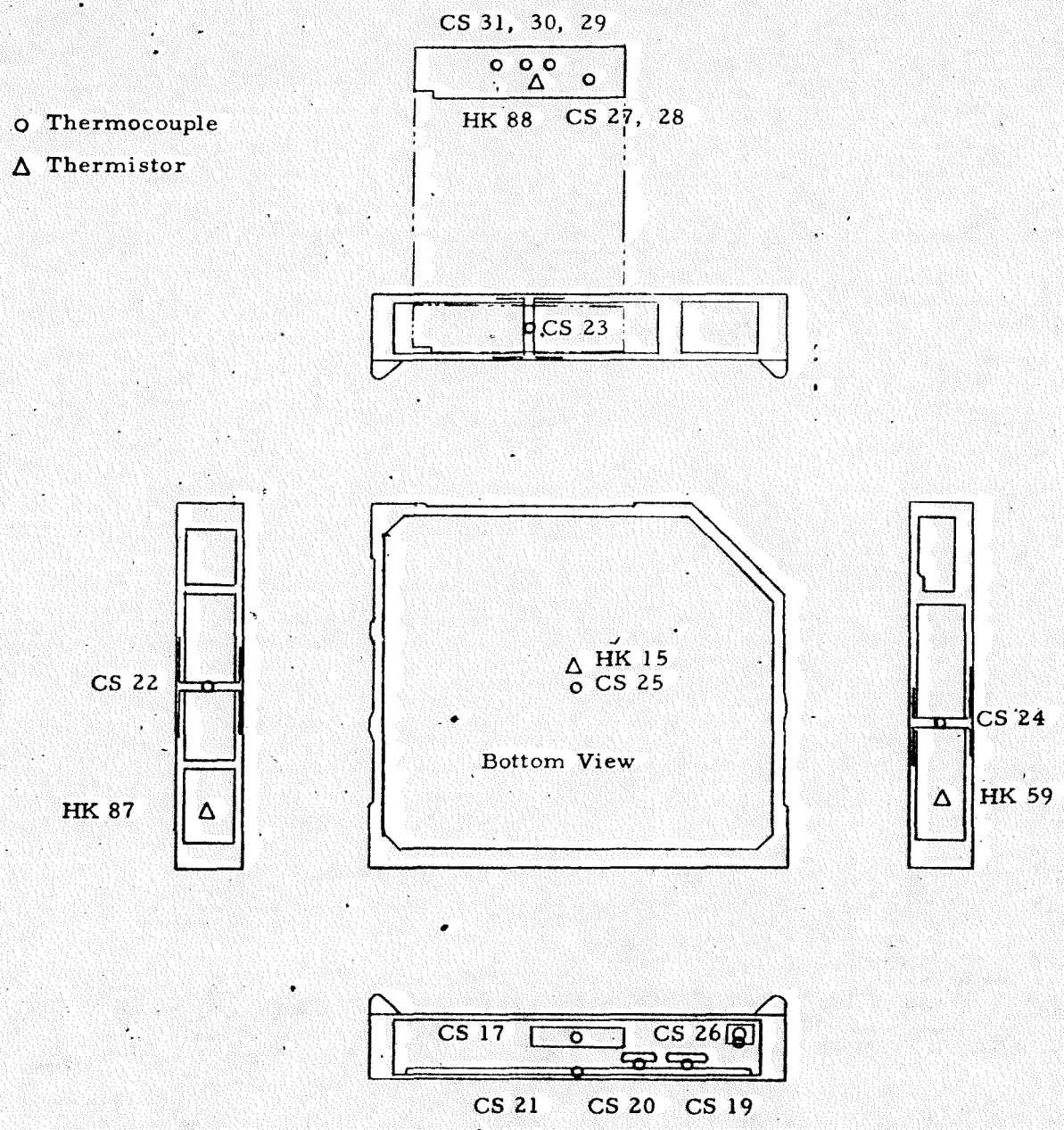


Figure 5.3 Central Station Thermocouple and Thermistor Locations - Primary Structure

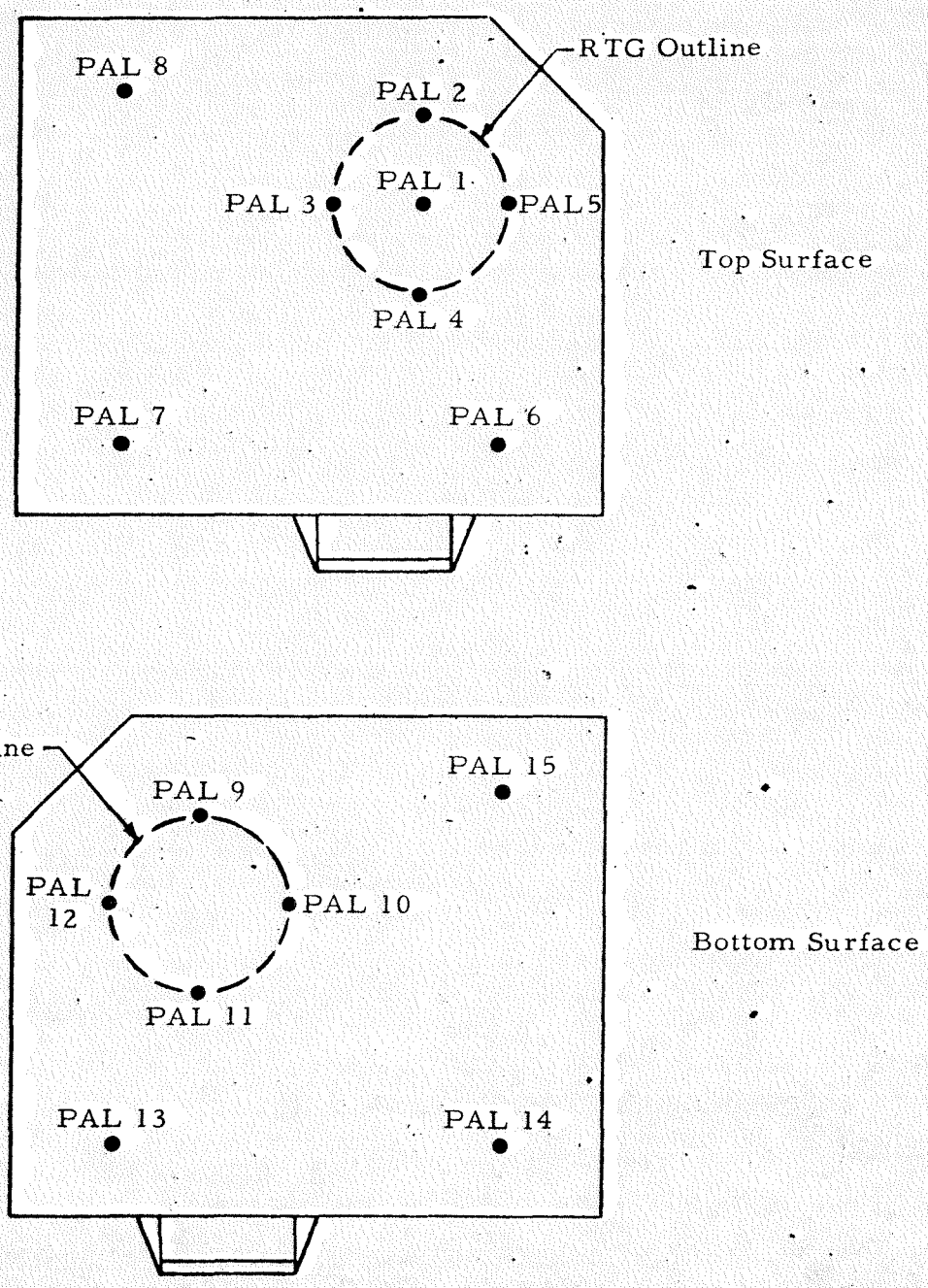


Figure 5.4 Pallet 2 Thermocouple Locations

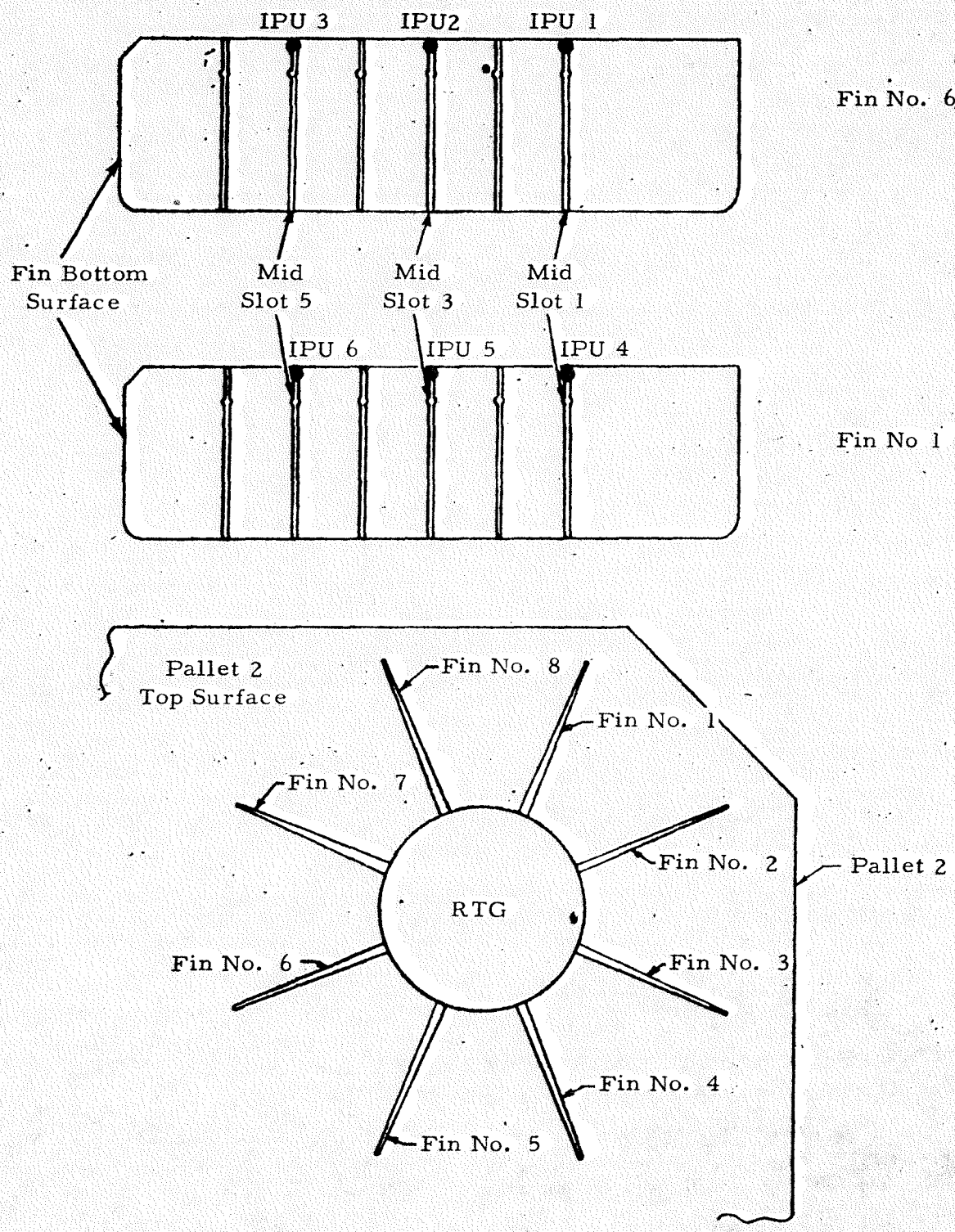


Figure 5.5 RTG Thermocouple Locations

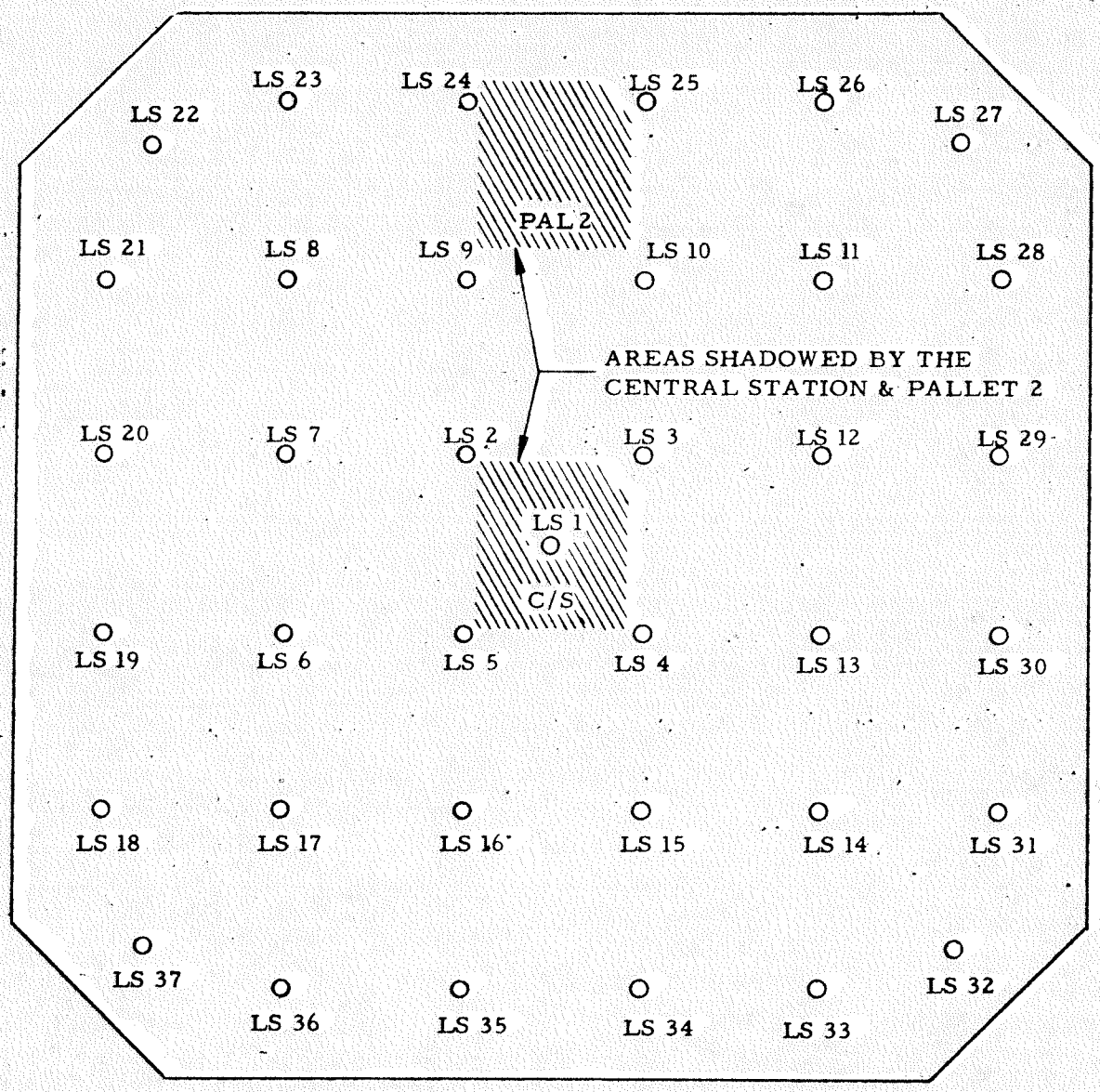
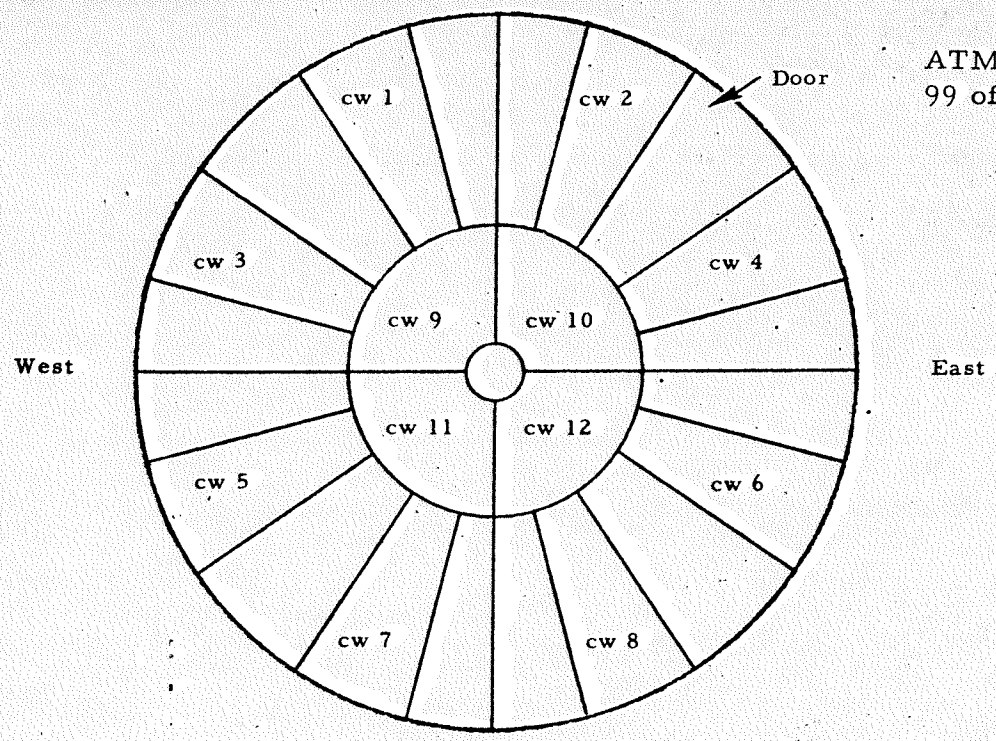
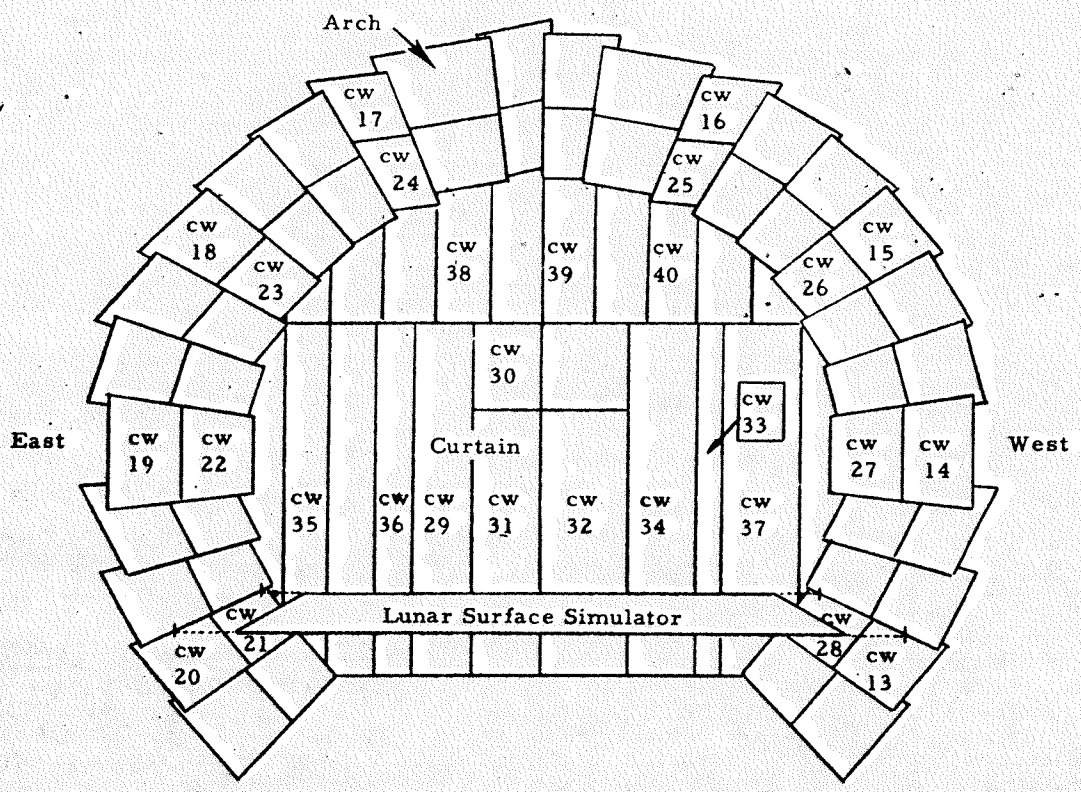


Figure 5.6 14' x 14' Lunar Surface Simulator Thermocouple Locations



View of Cryowall Looking North



View of Cryowall Looking South

Figure 5.7 Cryowall Thermocouple Locations

6.0 TEST MEASUREMENTS

Two types of data, Data Acquisition System (DAS) and Housekeeping (HK), were collected for the Acceptance, Mission Simulation, and Design Limit Tests. Data is presented in the three general forms listed below:

1. Plots of DAS-measured temperature and power versus time histories.

2. Tables of DAS steady-state measurements during lunar noon and lunar night.

3. Tables of HK steady-state measurements during lunar noon and lunar night.

Figures 6.1 through 6.44 show DAS temperature measurements versus time for the sunshield, radiator plate, radiator support, primary structure, PDM resistor panel, Pallet 2 surfaces, RTG fins, lunar surface simulator, and T/V chamber cryowalls. In addition, reserve power, solar input, and EFCS power are included.

6.1 Acceptance Test Measurements

Figures 6.1 through 6.21 show DAS temperature and power measurements versus time for the Acceptance Test. Significant test events are labeled on each figure. Also, DAS and HK data at lunar noon and night equilibrium conditions are presented in Tables 6.1 to 6.4. The listing below summarizes information contained in each figure and table applying to the Acceptance Test. Tables 6.3 and 6.4 also have data relating to the Mission Simulation and Design Limit Tests.

Type Measurement	Data	Figure(s)	Table
DAS	Central Station Temperature Histories	6.1-6.9	---
DAS	Central Station Power Histories	6.10-6.12	---
DAS	Pallet 2/RTG Power History	6.13	---

Type Measurement	Data	Figure(s)	Table
DAS	Pallet 2/RTG Temperature Histories	6.14-6.19	---
DAS	T/V Chamber Environment Histories	6.20&6.21	---
DAS	C/S Steady-State at Noon and Night	---	6.1
HK	C/S Steady State at Noon and Night	---	6.2
DAS	Pallet 2/RTG Steady-State at Noon and Night	---	6.3
DAS & HK	Reserve Power at Noon and Night	---	6.4

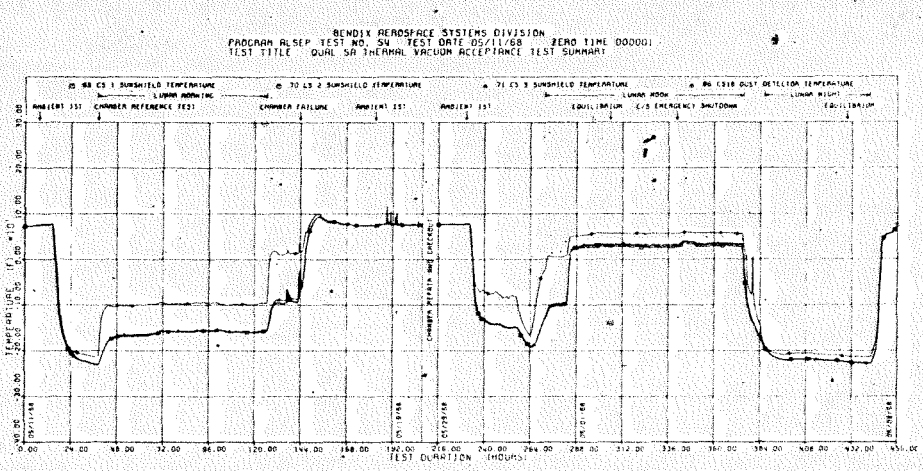


Figure 6.1 Sunshield Temperatures

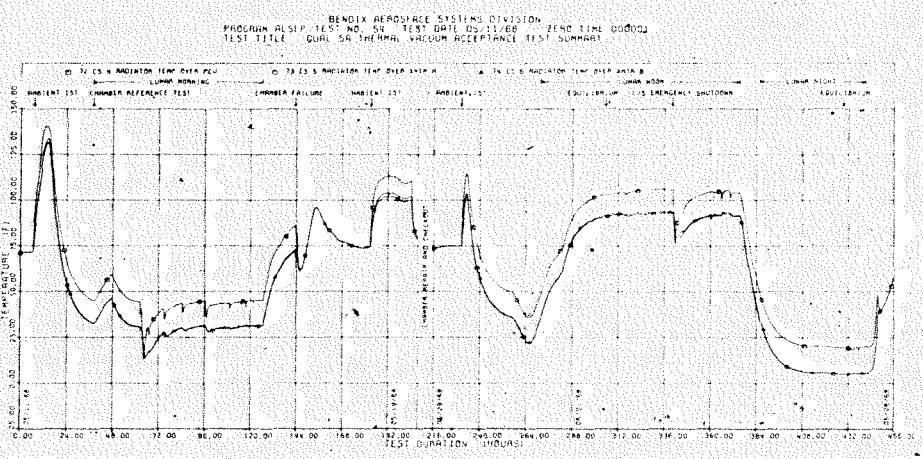


Figure 6.2 Radiator Temperatures

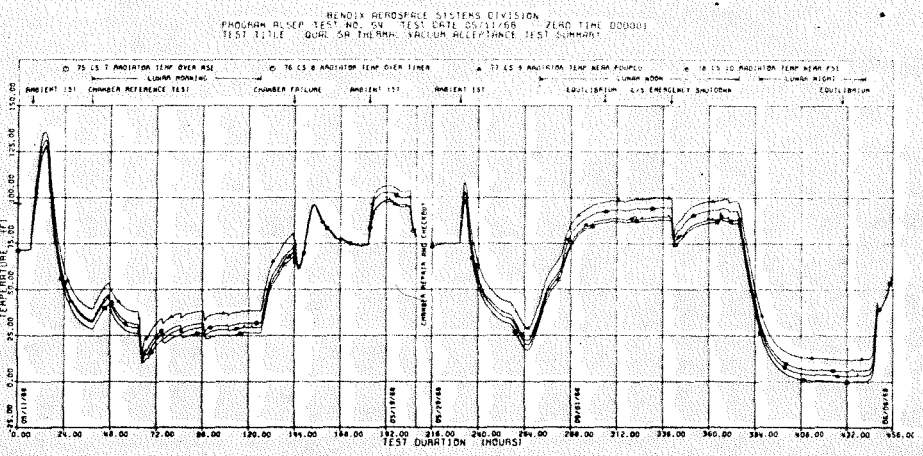


Figure 6.3 Radiator Temperatures

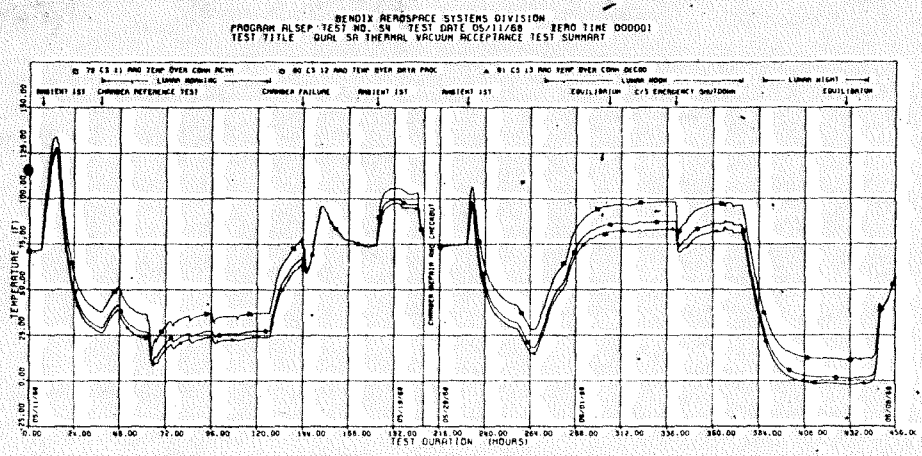


Figure 6.4 Radiator Temperatures

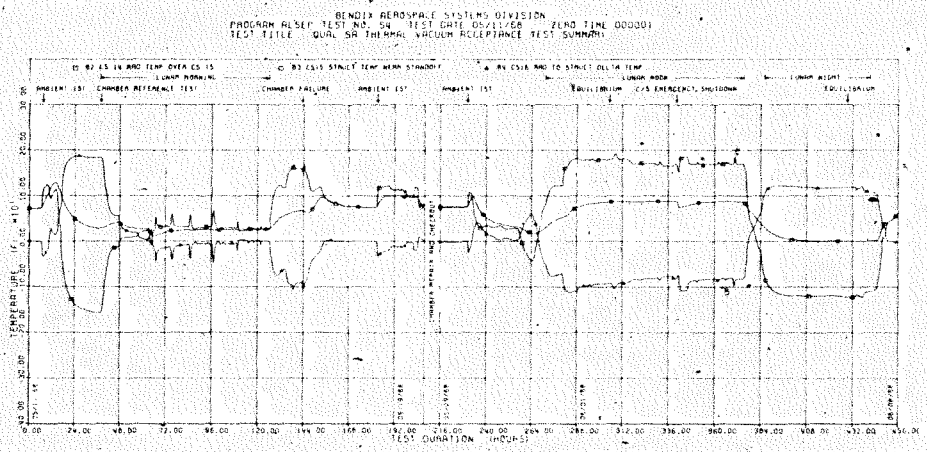


Figure 6.5 Radiator Support Temperatures

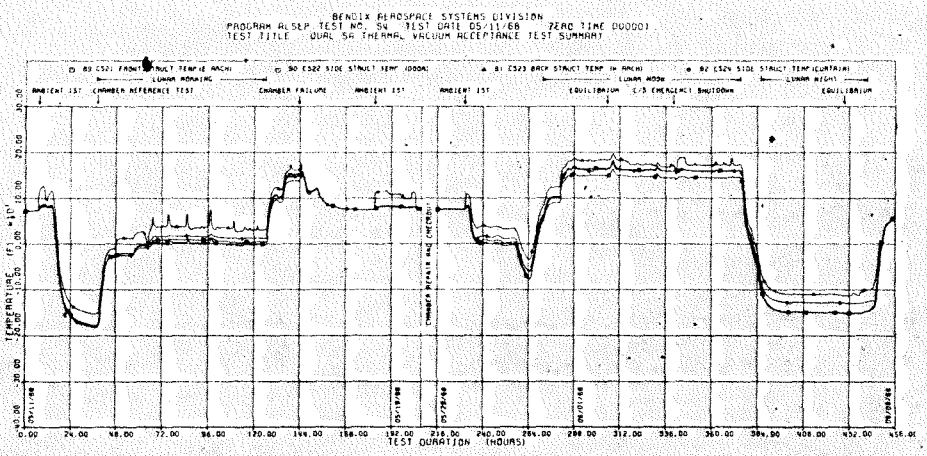


Figure 6.6 Primary Structure Temperatures

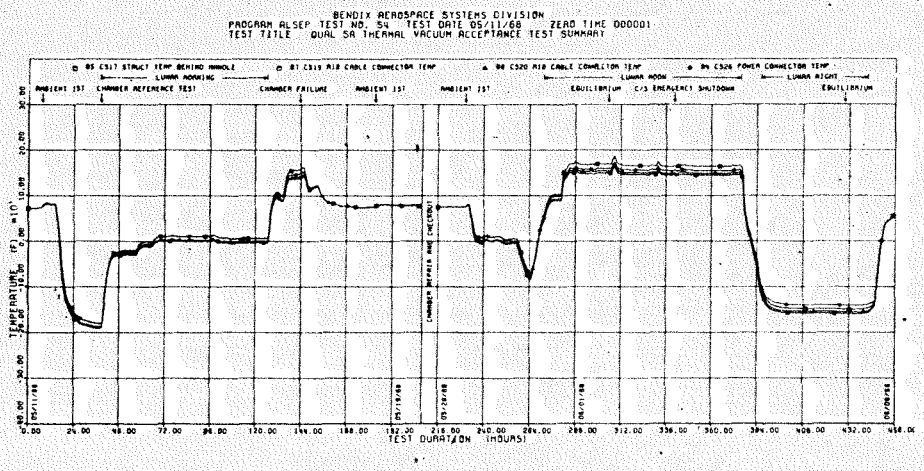


Figure 6.7 Cable Connector Temperatures

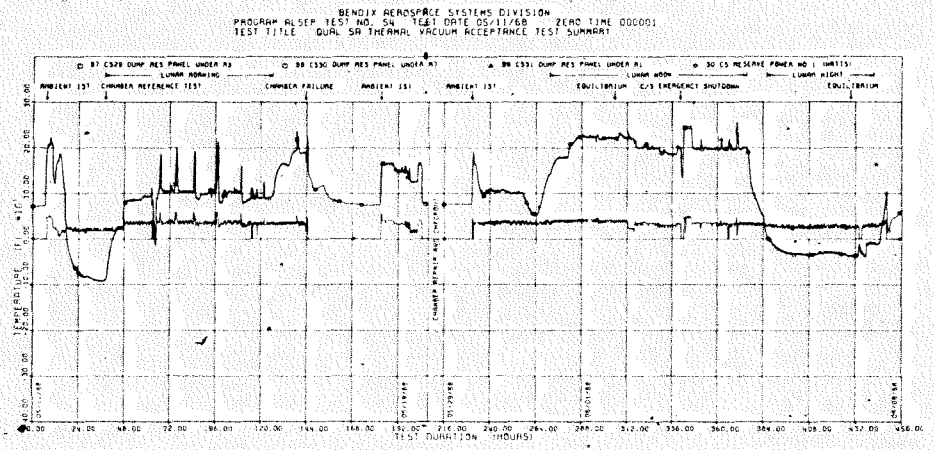


Figure 6.8 PDM Resistor Panel Temperatures

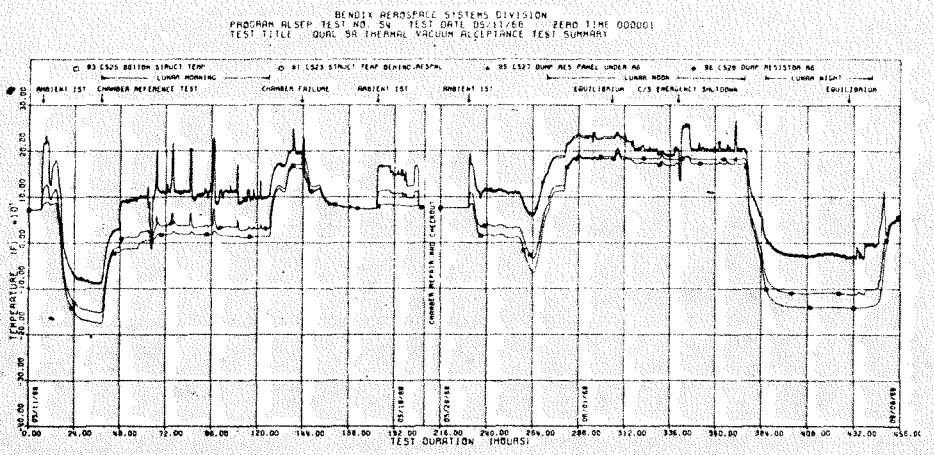


Figure 6.9 Structure and PDM Panel Temperatures

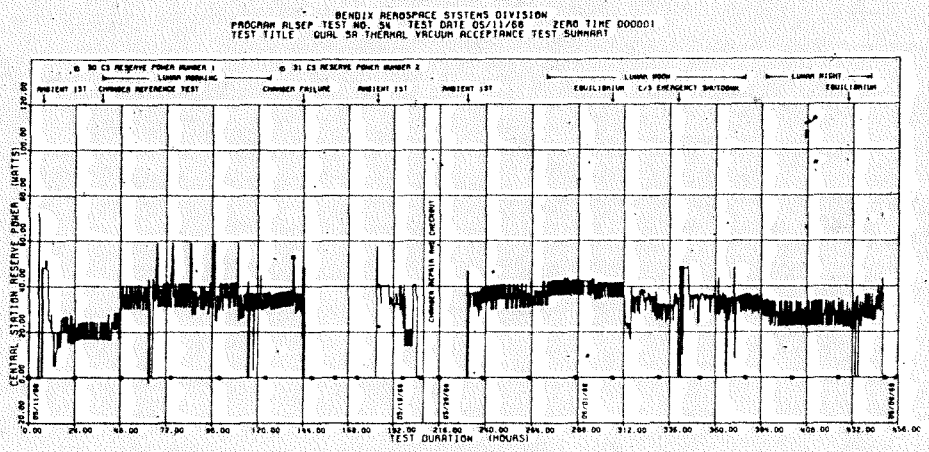


Figure 6.10 Reserve Power

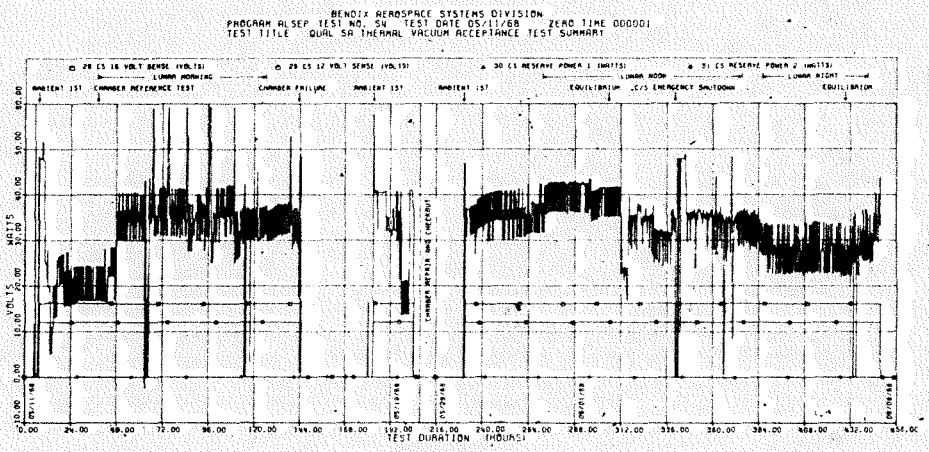


Figure 6.11 Voltage Supply and Reserve Power

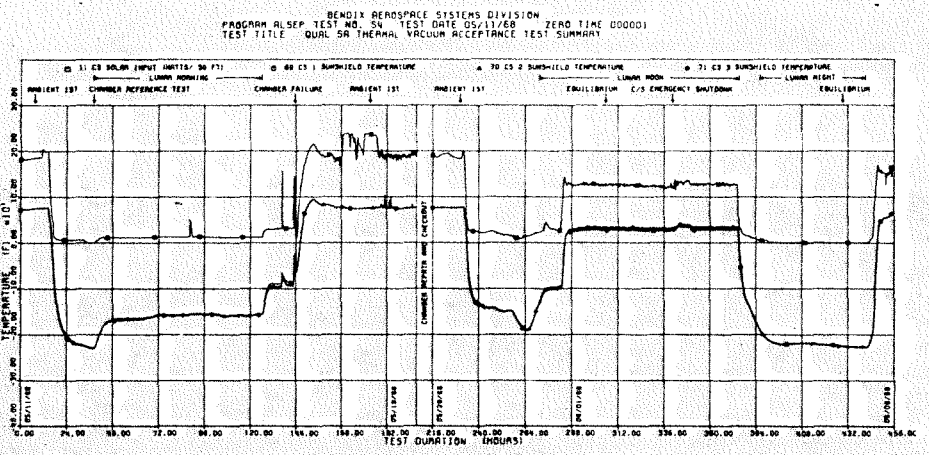


Figure 6.12 C/S Solar Input and Sunshield Temperatures

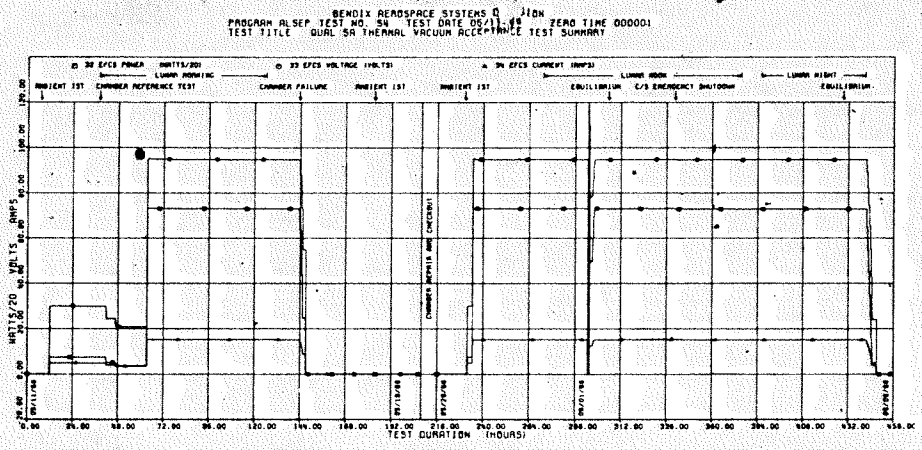


Figure 6.13 EFCS Power, Voltage, and Current

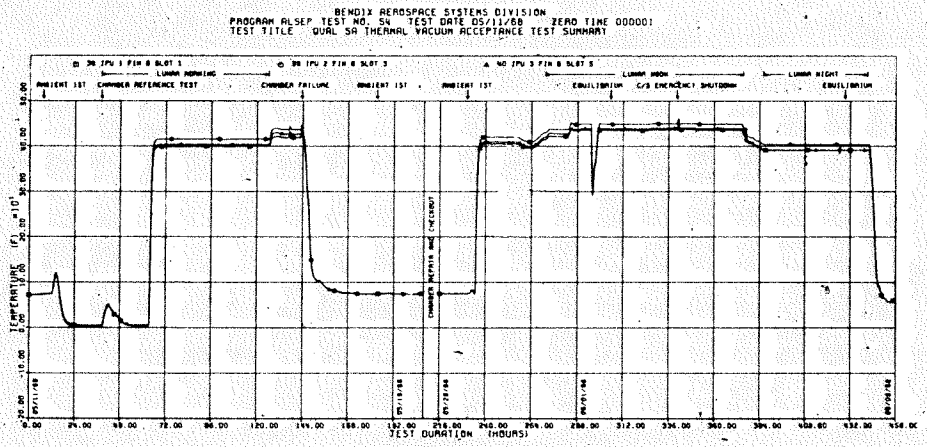


Figure 6.14 RTG Fin Temperatures

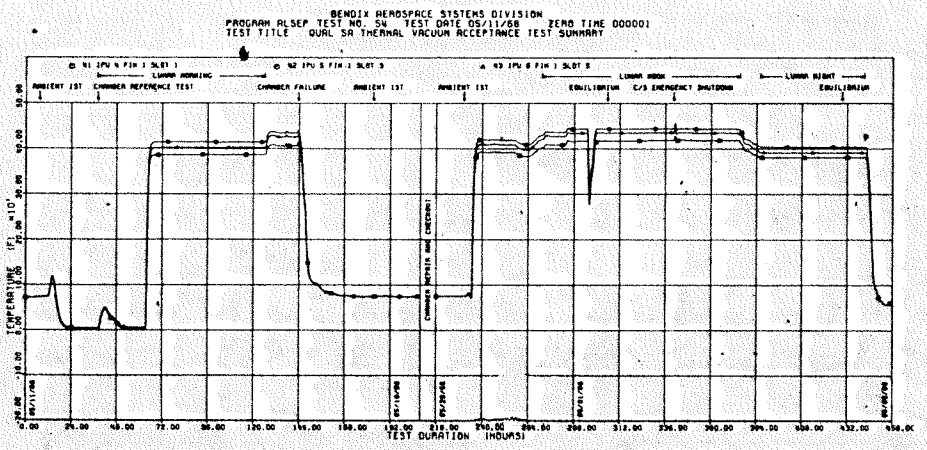


Figure 6.15 RTG Fin Temperatures

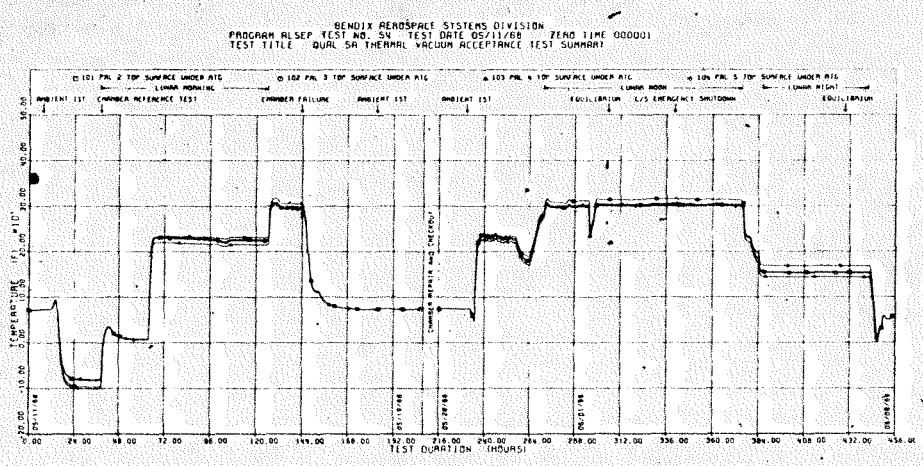


Figure 6.16 Pallet 2 Temperatures Under RTG

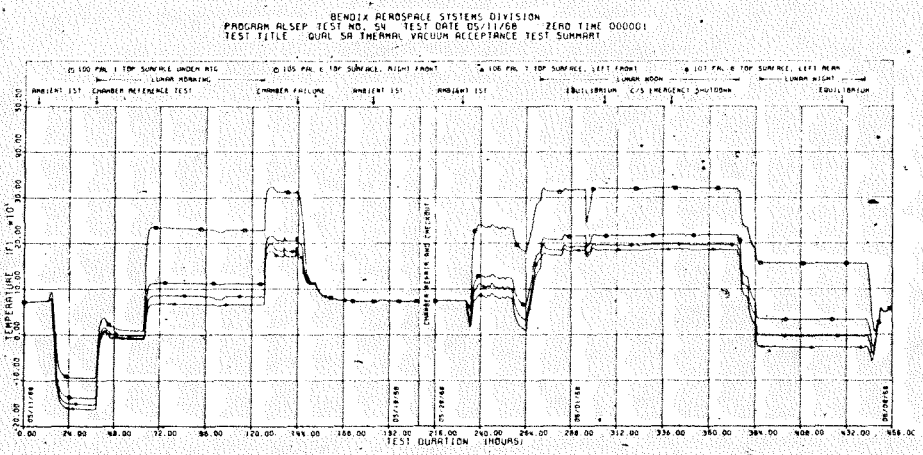


Figure 6.17 Pallet 2 Top Surface Temperatures

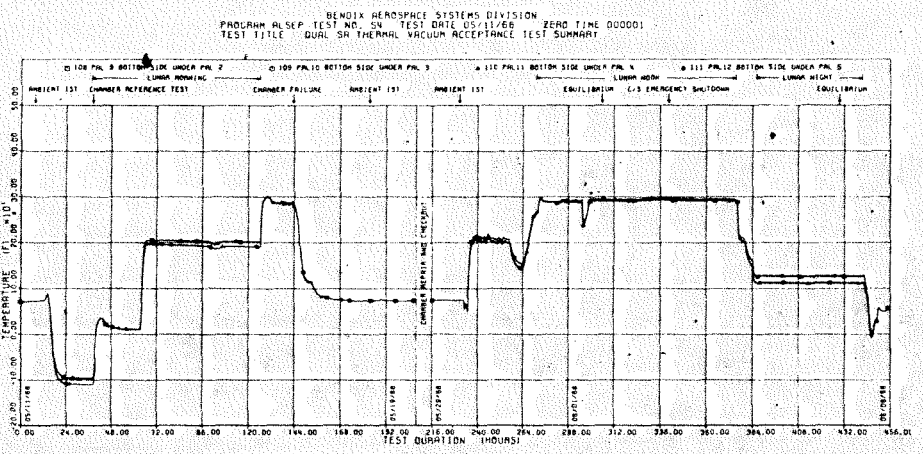


Figure 6.18 Pallet 2 Bottom Surface Temperatures

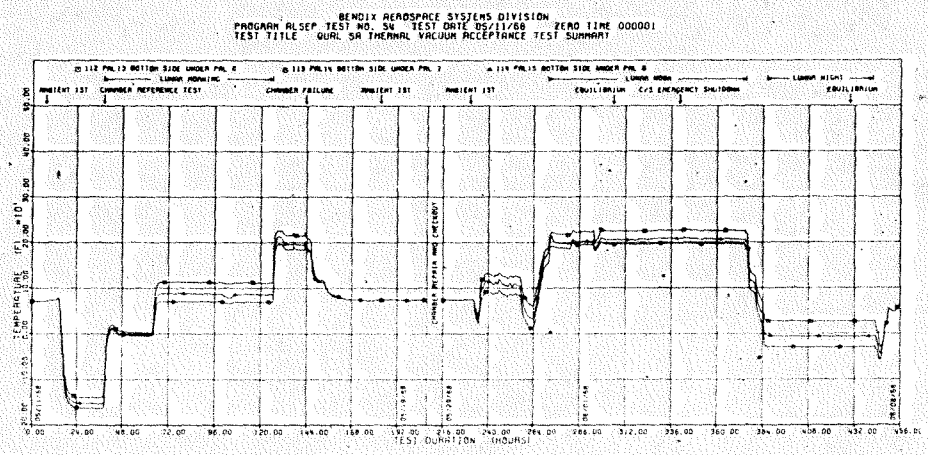


Figure 6.19 Pallet 2 Bottom Surface Temperatures

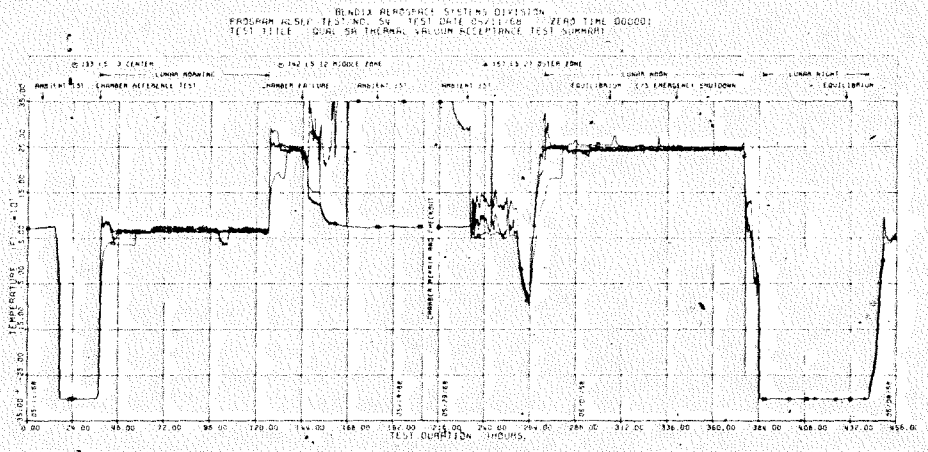


Figure 6.20 Lunar Simulator Temperatures

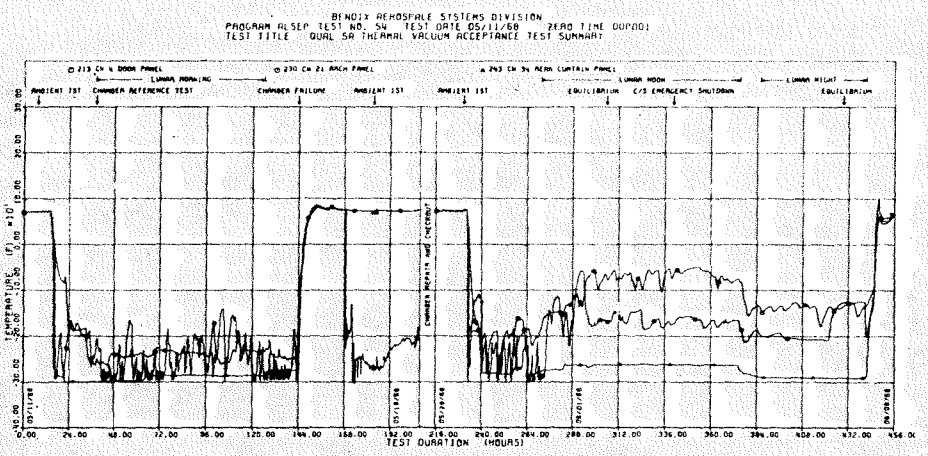


Figure 6.21 Cryowall Temperatures

TABLE 6.1

DAS TEMPERATURE MEASUREMENTS ON C/S FOR QUAL SA T/V ACCEPTANCE TEST AT LUNAR NOON AND LUNAR NIGHT

DAS Channel	Thermocouple Identification	Description	Temp. - °F Lunar Noon*	Temp. - °F Lunar Night**
069	CS01	Sunshield Top	27	-225
070	CS02	Sunshield Top	31	-225
071	CS03	Sunshield Top	34	-227
086	CS18	Dust Detector	57	-213
072	CS04	Radiator over PCU	104	19
073	CS05	Radiator over XMTRA	92	5
074	CS06	Radiator over XMTRB	93	5
075	CS07	Radiator over ASE	87	0
076	CS08	Radiator near Timer	93	6
077	CS09	Radiator near PDU	98	12
078	CS10	Radiator over PSE	89	3
079	CS11	Radiator over Command Receiver	97	11
080	CS12	Radiator over Data Processor	86	1
081	CS13	Radiator over Command Decoder	82	-2
082	CS14	Radiator near Support	179	-123
083	CS15	Structure near Support	87	0
084	CS16	Structure/Radiator across Support	-92	120
085	CS17	Structure behind Handle	169	-150
087	CS19	Ribbon Cable Connector	149	-159
088	CS20	Ribbon Cable Connector	154	-156
089	CS21	Structure Front	165	-151
090	CS22	Structure Right Side	150	-151
091	CS23	Structure Back	183	-113
092	CS24	Structure Left Side	163	-129
093	CS25	Structure Bottom	187	-141
094	CS26	Power Cable Connector	159	-142
095	CS27	PDM Resistor Panel over R6	231	-33
096	CS28	PDM Resistor R6	235	-30
097	CS29	PDM Resistor Panel over R3	227	-36
098	CS30	PDM Resistor Panel over R7	224	-37
099	CS31	PDM Resistor Panel over R1	227	-37

*Lunar Noon measurements at 21:10 on 6/2/68 (Elapsed time = 336 hours on plots)

**Lunar Night measurements at 21:10 on 6/7/68 (Elapsed time = 432 hours on plots)

TABLE 6.2

HK TEMPERATURE MEASUREMENTS ON C/S FOR QUAL SA T/V ACCEPTANCE TEST AT LUNAR NOON AND LUNAR NIGHT

HK #	Description	Temp. - °F Lunar Noon*	Temp. - °F Lunar Night**
16	Command Receiver - Local Osc. Crystal A	---	---
17	Command Receiver - Local Osc. Crystal B	90	12
18	Transmitter A - Crystal	---	---
19	Transmitter A - Heat Sink	---	---
31	Transmitter B - Crystal	96	10
32	Transmitter B - Heat Sink	95	8
33	Analog Multiplex Converter - Base	88	2
34	Analog Multiplex Converter - Internal	101	15
46	Digital Data Processor - Base	88	2
47	Digital Data Processor - Internal	97	5
48	Command Decoder - Base	84	0
49	Command Decoder - Internal	87	0
61	Command Demodulator - VCO	93	4
62	PDU - Base	98	11
63	PDU - Internal	122	32
64	PCU Power Oscillator #1	113	26
76	PCU Power Oscillator #2	104	19
77	PCU Regulator #1	154	75
78	PCU Regulator #2	110	25
4	Radiator Plate	100	12
28	Radiator Plate	87	2
43	Radiator Plate	89	2
58	Radiator Plate	88	0
71	Radiator Plate	95	7
15	Primary Structure - Bottom	---	-130
59	Primary Structure - Left Side	160	-152
87	Primary Structure - Right Side	174	-128
88	PDM Resistor Panel	---	-30
60	Thermal Bag - Inside	94	0
72	Thermal Bag - Outside	162	-110
27	Sunshield - Top	30	-214
42	Sunshield - Bottom	28	-216

*Lunar Noon measurements at 21:30 on 6/2/68

**Lunar Night measurements at 01:00 on 6/7/68

TABLE 6.3

DAS TEMPERATURE MEASUREMENTS ON PALLET 2/RTG FOR QUAL SA T/V ACCEPTANCE, MISSION SIMULATION, AND DESIGN LIMIT TESTS

Thermo. Ident.	Description	Acceptance		Mission Simulation		Design Limit
		Noon	Night	Noon	Night	
IPU 1	RTG Fin 6	435	391	440	391	452
2	RTG Fin 6	449	404	447	397	458
3	RTG Fin 6	438	391	445	393	456
4	RTG Fin 1	417	381	433	393	442
5	RTG Fin 1	444	404	439	398	448
6	RTG Fin 1	435	391	437	391	446
PAL 1	Pallet 2 Top	320	156	315	153	335
2	Pallet 2 Top	302	154	295	149	312
3	Pallet 2 Top	314	152	309	150	329
4	Pallet 2 Top	303	143	301	142	321
5	Pallet 2 Top	300	168	300	166	316
6	Pallet 2 Top	217	33	223	33	244
7	Pallet 2 Top	185	-28	191	-29	213
8	Pallet 2 Top	195	-4	198	-5	219
9	Pallet 2 Bottom	290	126	288	122	307
10	Pallet 2 Bottom	295	113	292	110	313
11	Pallet 2 Bottom	293	111	292	109	314
12	Pallet 2 Bottom	291	128	291	126	310
13	Pallet 2 Bottom	225	27	232	26	253
14	Pallet 2 Bottom	197	-30	203	-32	225
15	Pallet 2 Bottom	206	-6	209	-8	231

Measurements are for same times as C/S measurements.

TABLE 6.4

DAS AND HK RESERVE POWER MEASUREMENTS FOR QUAL SA T/V ACCEPTANCE, MISSION SIMULATION, AND DESIGN LIMIT TESTS

Test	Reserve Power Measurements					
	HK				DAS	
	Volts		Amps		Watts	
	Noon	Night	Noon	Night	Noon	Night
Acceptance	16	16	2.30	1.60	39.0	27.0
Mission Simulation (No PDM Dumps or Heaters)	16	16	1.91	1.56	35.0	23.0
Mission Simulation (7 & 14 w. PDM Dumps)	16	--	.63	----	----	----
Mission Simulation (10 w. Heater On)	--	16	----	.81	----	14.0
Mission Simulation (5 w. Heater On)	--	16	----	1.13	----	18.0
Design Limit	16	--	.81	----	13.0	----

6.2 Mission Simulation Test Measurements

Figures 6.22 through 6.44 show DAS temperature and power measurements versus time for the T/V Mission Simulation Test, except for Figure 6.32 which contains HK reserve power data. Significant test events are labeled on each figure. Note that Design Limit Test data are also presented in these figures.

Mission Simulation DAS and HK measurements are presented in Tables 6.3 to 6.7 for the following lunar noon and night conditions: (a) equilibrium, (b) 7 and 14 watt PDM dumps activated simultaneously during lunar noon, and (c) 5 and 10 watt radiator plate heaters activated separately during lunar night. The table below summarizes information contained in each figure and table pertaining to the Mission Simulation Test.

Type Measurement	Data	Figure(s)	Table
DAS	Central Station Temperature Histories	6.22-6.30	-----
DAS	Central Station Reserve Power History	6.31	-----
HK	Central Station Reserve Power History	6.32	-----
DAS	Central Station Power Histories	6.33&6.34	-----
DAS	Pallet 2/RTG Power Histories	6.35&6.36	-----
DAS	Pallet 2/RTG Temperature Histories	6.37-6.42	-----
DAS	T/V Chamber Environment Histories	6.43&6.44	-----
DAS	C/S Steady-State at Noon and Night	----	6.5

Type Measurement	Data	Figure(s)	Table
DAS	C/S for Activated PDM Dumps and Radiator Heaters	-----	6.6
HK	C/S Steady-State at Noon and Night	-----	6.7
DAS	Pallet 2/RTG Steady-State at Noon and Night	-----	6.3
DAS & HK	Reserve Power at Noon and Night	-----	6.4

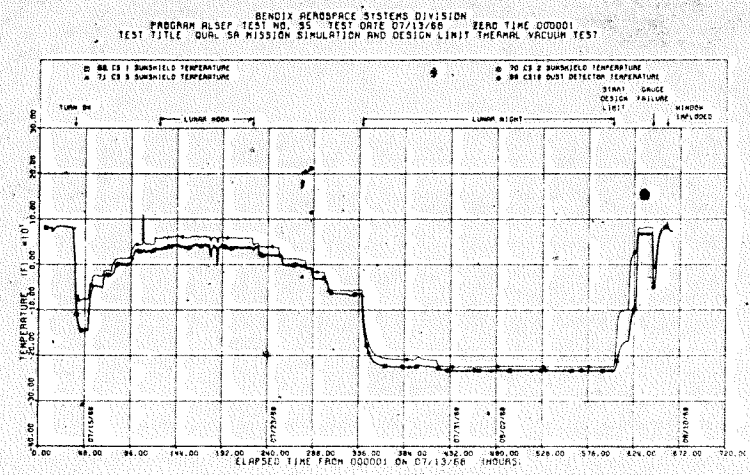


Figure 6.22 Sunshield Temperatures

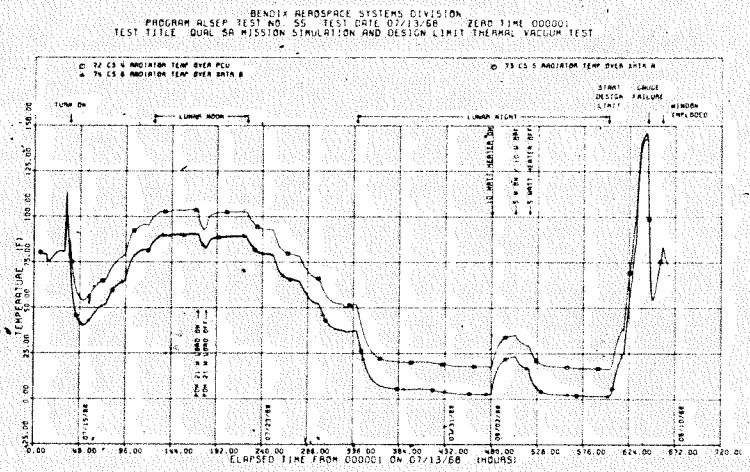


Figure 6.23 Radiator Temperatures

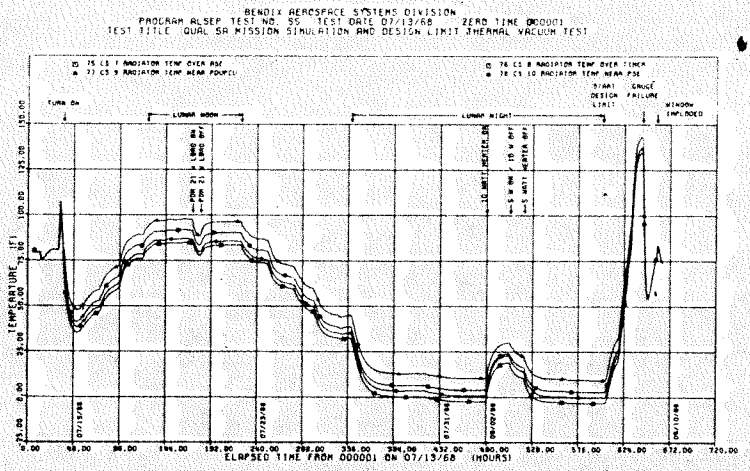


Figure 6.24 Radiator Temperatures

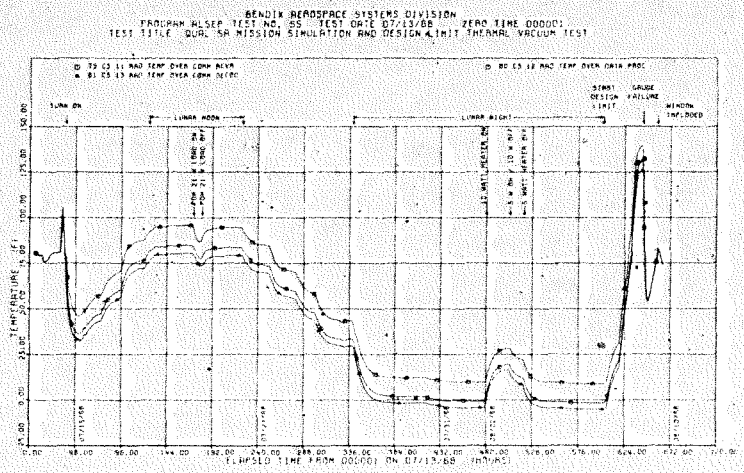


Figure 6.25 Radiator Temperatures

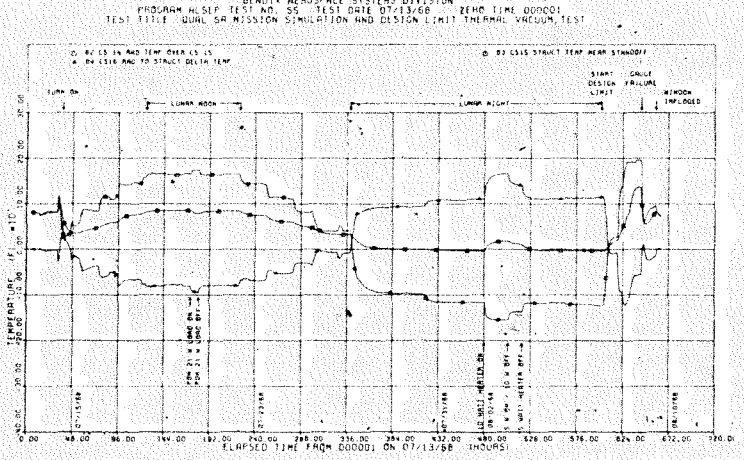


Figure 6.26 Radiator Support Temperatures

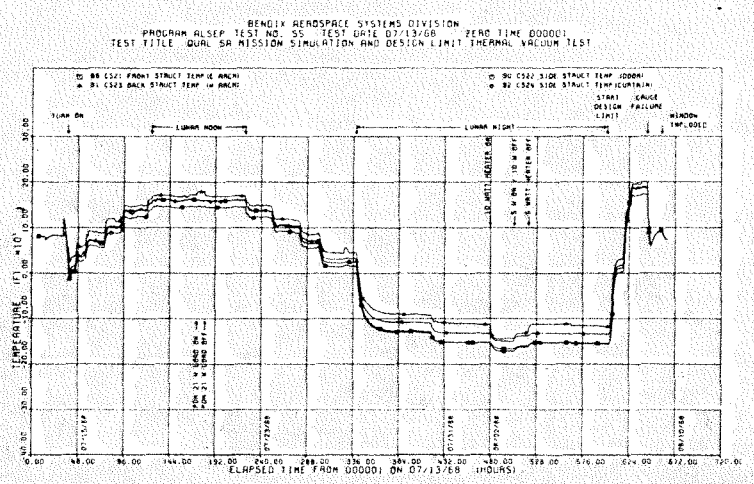


Figure 6.27 Primary Structure Temperatures

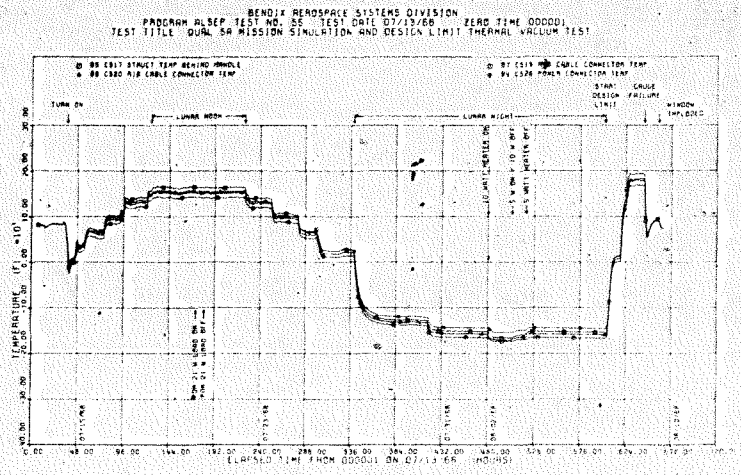


Figure 6.28 Cable Connector Temperatures

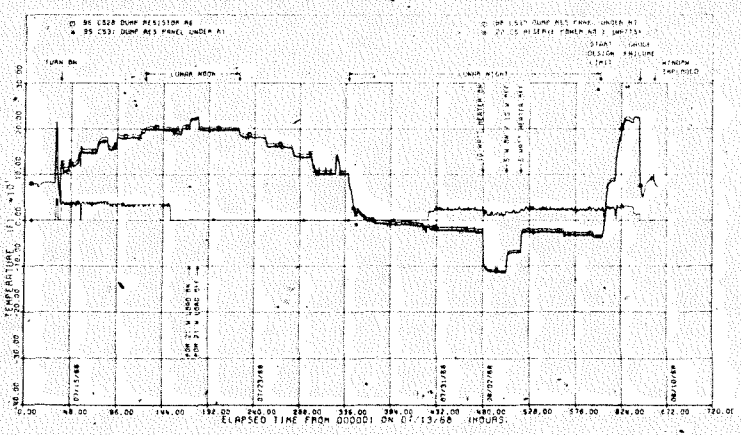


Figure 6.29 PDM Resistor Panel Temperatures

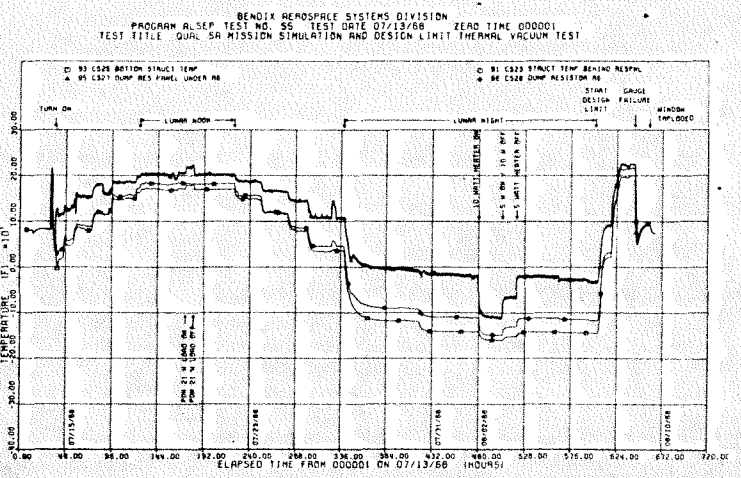


Figure 6.30 Structure and PDM Panel Temperatures

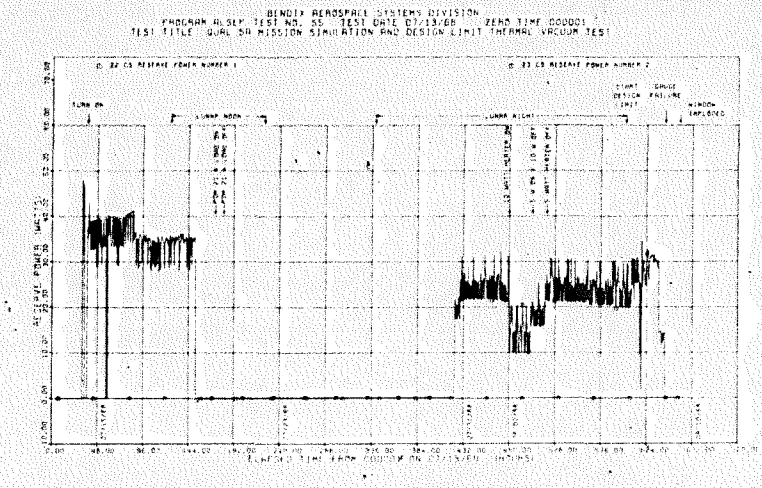


Figure 6.31 Reserve Power

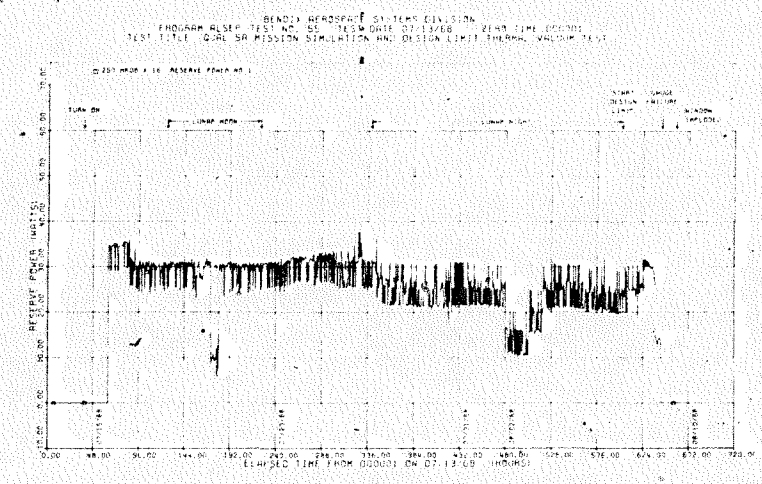


Figure 6.32 Reserve Power

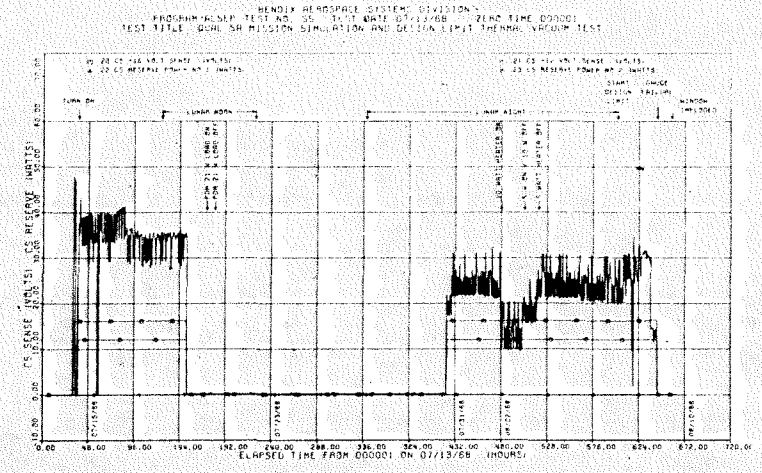


Figure 6.33 Voltage Supply and Reserve Power

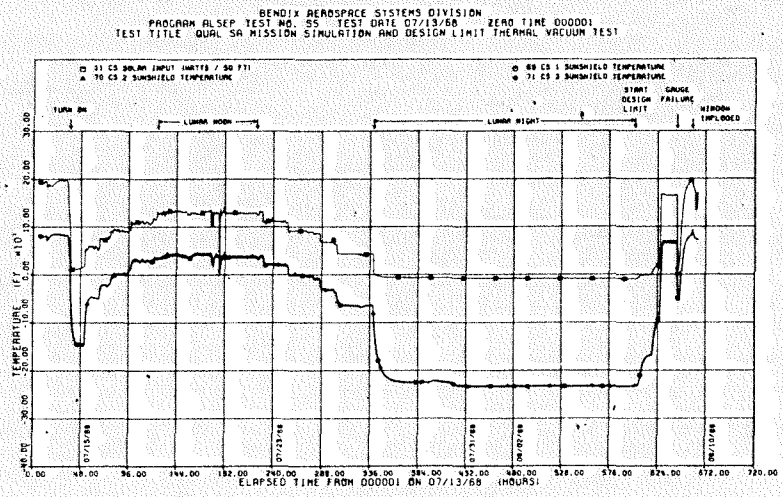


Figure 6.34 C/S Solar Input and Sunshield Temperatures

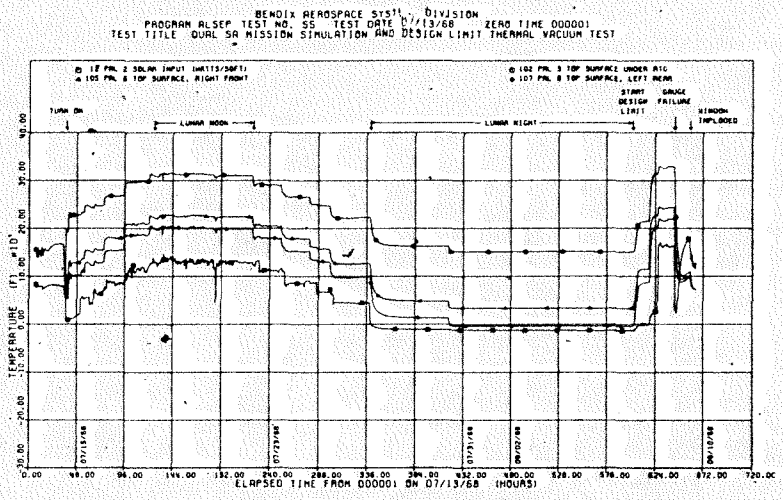


Figure 6.35 Pallet 2 Solar Input and Temperatures

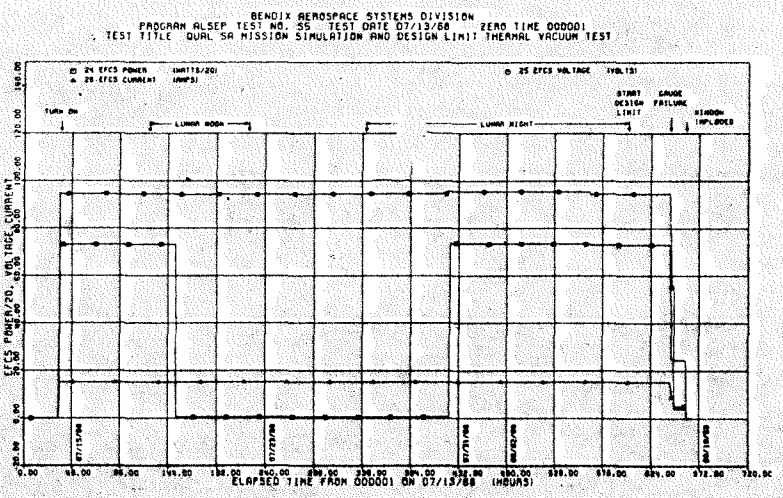


Figure 6.36 EFCS Power, Voltage, and Current

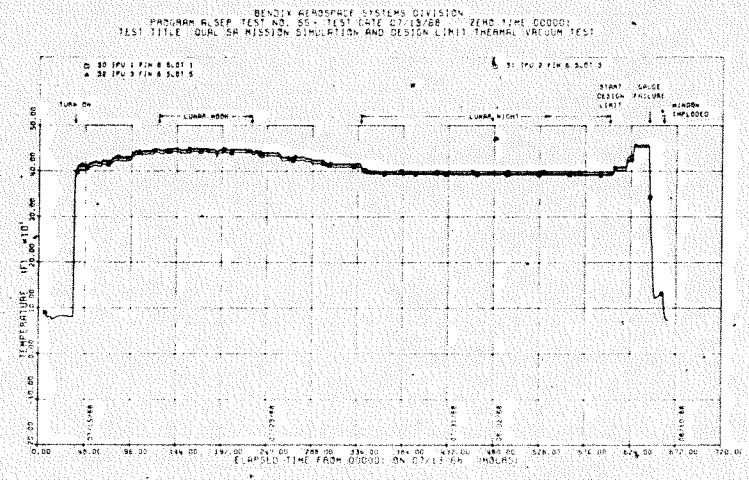


Figure 6.37 RTG Fin Temperatures

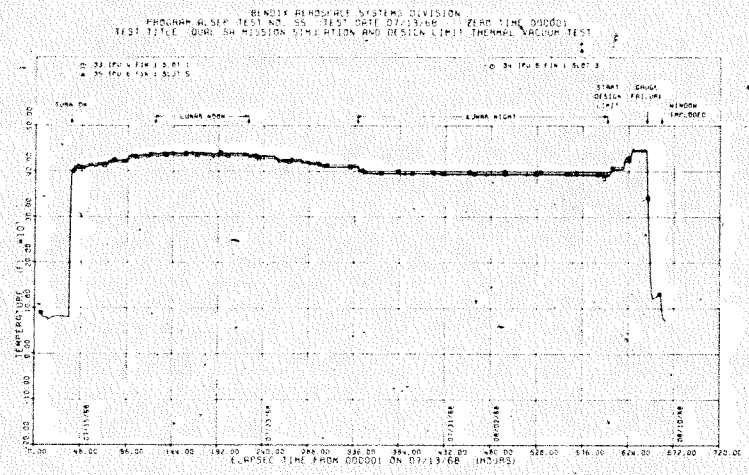


Figure 6.38 RTG Fin Temperatures

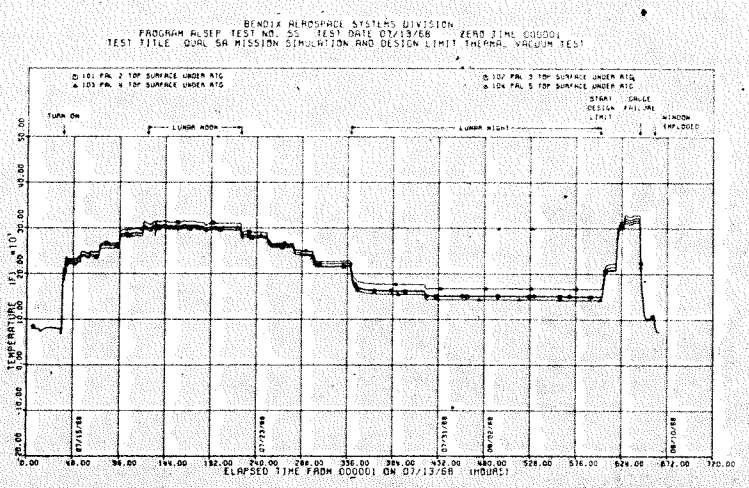


Figure 6.39 Pallet 2 Temperatures Under RTG

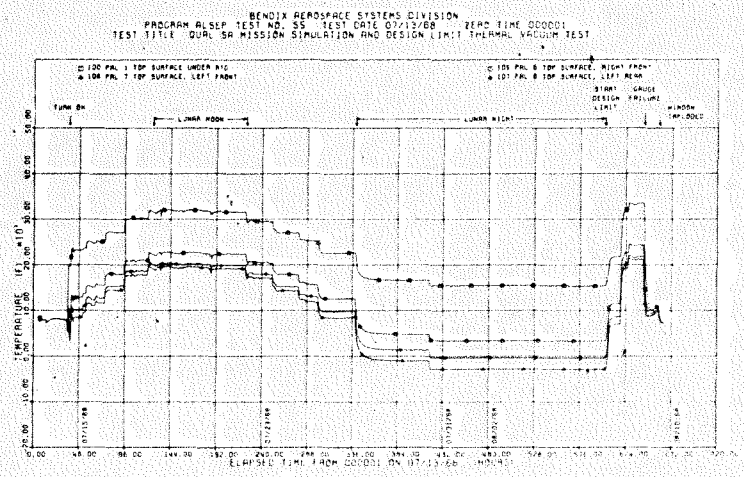


Figure 6.40 Pallet 2 Top Surface Temperatures

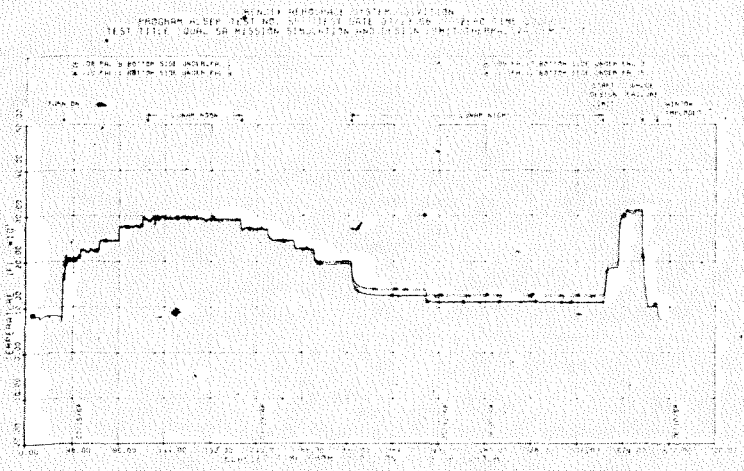


Figure 6.41 Pallet 2 Bottom Surface Temperatures

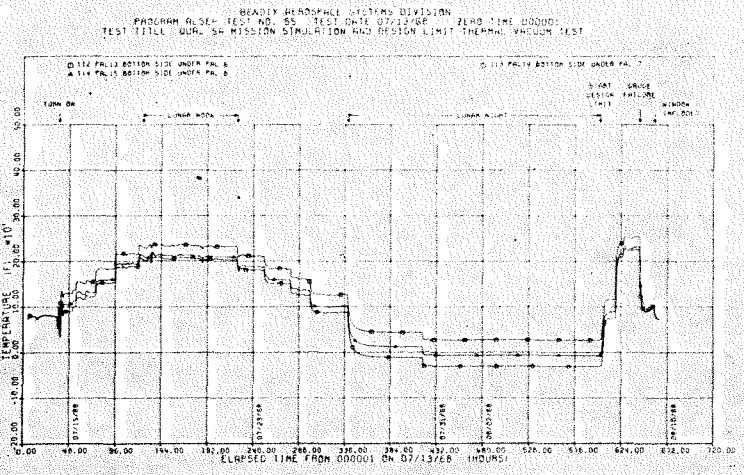


Figure 6.42 Pallet 2 Bottom Surface Temperatures

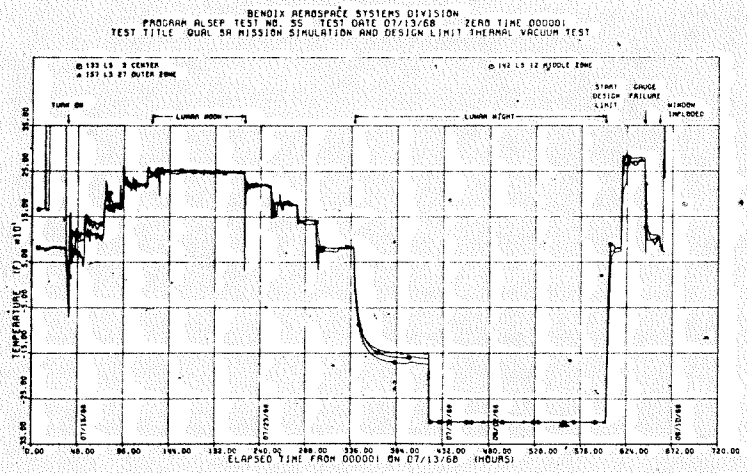


Figure 6.43 Lunar Simulator Temperatures

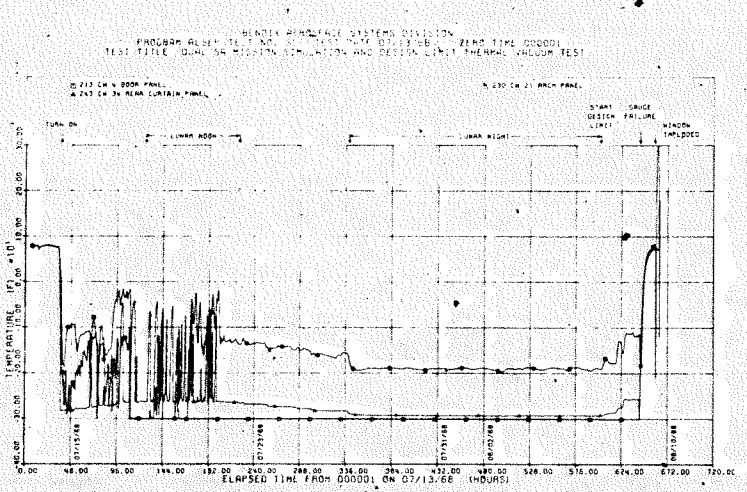


Figure 6.44 Cryowall Temperatures

TABLE 6.5

DAS TEMPERATURE MEASUREMENTS ON C/S FOR QUAL SA T/V MISSION SIMULATION TEST AT LUNAR NOON AND LUNAR NIGHT

DAS Channel	Thermocouple Identification	Description	Temp. - °F Lunar Noon*	Temp. - °F Lunar Night**
069	CS01	Sunshield Top	37	-233
070	CS02	Sunshield Top	41	-232
071	CS03	Sunshield Top	40	-234
086	CS18	Dust Detector	61	-224
072	CS04	Radiator over PCU	104	17
073	CS05	Radiator over XMTRA	90	2
074	CS06	Radiator over XMTRB	91	2
075	CS07	Radiator over ASE	85	-3
076	CS08	Radiator near Timer	92	3
077	CS09	Radiator near PDU	97	9
078	CS10	Radiator near PSE	87	0
079	CS11	Radiator over Command Receiver	96	9
080	CS12	Radiator over Data Processor	85	-2
081	CS13	Radiator over Command Decoder	80	-5
082	CS14	Radiator near Support	85	-3
083	CS15	Structure near Support	164	-123
084	CS16	Structure/Radiator across Support	-78	115
085	CS17	Structure behind Handle	162	-154
087	CS19	Ribbon Cable Connector	140	-167
088	CS20	Ribbon Cable Connector	150	-160
089	CS21	Structure Front	159	-155
090	CS22	Structure Right Side	144	-156
091	CS23	Structure Back	168	-118
092	CS24	Structure Left Side	158	-134
093	CS25	Structure Bottom	180	-146
094	CS26	Power Cable Connector	153	-146
095	CS27	PDM Resistor Panel over R6	200	-34
096	CS28	PDM Resistor R6	203	-31
097	CS29	PDM Resistor Panel over R3	---	----
098	CS30	PDM Resistor Panel over R7	195	-38
099	CS31	PDM Resistor Panel over R1	198	-36

*Lunar Noon measurements at 06:00 on 7/19/68 (Elapsed time = 146 hours on plots)

**Lunar Night measurements at 00:00 on 8/7/68 (Elapsed time = 600 hours on plots)

TABLE 6.6

DAS TEMPERATURE MEASUREMENTS ON C/S FOR QUAL SA T/V MISSION SIMULATION TEST WITH ACTIVATED PDM DUMPS AND RADIATOR PLATE HEATERS

DAS Channel	Thermo. Ident.	Description	Temperature - °F		
			21 W. PDM Dump*	10 W. Heater**	5 W. Heater***
069	CS01	Sunshield Top	39	-233	-233
070	CS02	Sunshield Top	42	-232	-232
071	CS03	Sunshield Top	41	-234	-234
086	CS18	Dust Detector	52	-224	-224
072	CS04	Radiator over PCU	94	35	29
073	CS05	Radiator over XMTRA	83	23	16
074	CS06	Radiator over XMTRB	83	23	16
075	CS07	Radiator over ASE	78	19	10
076	CS08	Radiator near Timer	84	24	16
077	CS09	Radiator near PDU	89	30	22
078	CS10	Radiator near PSE	80	23	14
079	CS11	Radiator over Command Rcvr.	87	28	22
080	CS12	Radiator over Data Processor	77	19	12
081	CS13	Radiator over Command Dcdr.	73	17	8
082	CS14	Radiator near Support	78	19	11
083	CS15	Structure near Support	175	-155	-136
084	CS16	Structure/Radiator across Support	-95	167	140
085	CS17	Structure behind Handle	163	-166	-159
087	CS19	Ribbon Cable Connector	140	-174	-170
088	CS20	Ribbon Cable Connector	150	-170	-164
089	CS21	Structure Front	159	-166	-159
090	CS22	Structure Right Side	146	-172	-162
091	CS23	Structure Rear	180	-150	-131
092	CS24	Structure Left Side	159	-144	-138
093	CS25	Structure Bottom	183	-161	-152
094	CS26	Power Cable Connector	154	-154	-149
095	CS27	PDM Resistor Panel over R6	222	-115	-60
096	CS28	PDM Resistor R6	224	-112	-58
097	CS29	PDM Resistor Panel over R3	---	----	----
098	CS30	PDM Resistor Panel over R7	226	-116	-64
099	CS31	PDM Resistor Panel over R1	228	-116	-63

*7 and 14 W. PDM dumps activated - data at 12:00 on 7/20/68

**10 Watt radiator plate heater on - data at 00:00 on 8/3/68

***5 Watt radiator plate heater on - data at 15:00 on 8/3/68

TABLE 6.7

HK TEMPERATURE MEASUREMENTS ON C/S FOR QUAL SA T/V MISSION SIMULATION TEST

HK#	Temperature - °F				
	Lunar Noon (1)	Lunar Night (2)	21 W. PDM Dump (3)	10 W. Heater (4)	5 W. Heater (5)
32	93	3	86	26	18
48	81	-4	75	16	7
77	159	72	134	85	83
78	110	21	99	39	33
4	98	9	89	28	22
28	84	-3	77	19	11
15	191	-141	19	-155	-146
59	148	-158	152	-171	-163
27	40	-230	40	-230	-230

Notes:

(1) Lunar Noon measurements at 06:00 on 7/19/68
(2) Lunar Night measurements at 00:00 on 8/7/68
(3) 7 and 14 Watt PDM dumps activated - data at 12:00 on 7/20/68
(4) 10 watt radiator plate heater on-data at 00:00 on 8/3/68
(5) 5 watt radiator plate heater on - data at 15:00 on 8/3/68

HK numbers correspond to same C/S components as for Acceptance Test.

6.3 Design Limit Test Measurements

Temperature and power measurements versus time for the Design Limit Test are contained on the Mission Simulation plots. DAS and HK data are listed in Tables 6.8 and 6.9 for the test condition of maximum radiator temperatures. The following table summarizes information presented in each figure and table applying to the Design Limit Test.

Type Measurement	Data	Figures	Table
DAS & HK	Same type as for Mission Simulation Test	6.22-6.44	---
DAS	C/S Steady-State at Max. Rad. Temp.	----	6.8
HK	C/S Steady-State at Max. Rad. Temp	----	6.9
DAS	Pallet 2/RTG Steady-State at Max. Rad. Temp.	----	6.3
DAS & HK	Reserve Power at Noon and Night	----	6.4

TABLE 6.8

DAS TEMPERATURE MEASUREMENTS ON C/S FOR QUAL SA T/V DESIGN LIMIT TEST AT MAXIMUM RADIATOR TEMPERATURE

DAS Channel	Thermocouple Identification	Description	Temp. - °F*
069	CS01	Sunshield Top	65
070	CS02	Sunshield Top	70
071	CS03	Sunshield Top	67
086	CS18	Dust Detector	82
072	CS04	Radiator over PCU	146
073	CS05	Radiator over XMTRA	143
074	CS06	Radiator over XMTRB	145
075	CS07	Radiator over ASE	135
076	CS08	Radiator near Timer	137
077	CS09	Radiator near PDU	143
078	CS10	Radiator near PSE	137
079	CS11	Radiator over Command Receiver	139
080	CS12	Radiator over Data Processor	131
081	CS13	Radiator over Command Decoder	126
082	CS14	Radiator near Support	137
083	CS15	Structure near Support	195
084	CS16	Structure/Radiator across Support	-55
085	CS17	Structure behind Handle	193
087	CS19	Ribbon Cable Connector	168
088	CS20	Ribbon Cable Connector	178
089	CS21	Structure Front	188
090	CS22	Structure Right Side	172
091	CS23	Structure Rear	200
092	CS24	Structure Left Side	187
093	CS25	Structure Bottom	215
094	CS26	Power Cable Connector	183
095	CS27	PDM Resistor Panel over R6	223
096	CS28	PDM Resistor R6	225
097	CS29	PDM Resistor Panel over R3	227
098	CS30	PDM Resistor Panel over R7	224
099	CS31	PDM Resistor Panel over R1	226

*Measurements at 17:40 on 8/8/68

TABLE 6.9

HK TEMPERATURE MEASUREMENTS ON C/S FOR QUAL SA T/V DESIGN LIMIT TEST AT MAXIMUM RADIATOR TEMPERATURE

HK#	Description	Temp. - °F*
32	Transmitter B Heat Sink	146
48	Command Decoder - Base	128
77	PCU Regulator #1	190
78	PCU Regulator #2	150
4	Radiator Plate	146
28	Radiator Plate	131
15	Primary Structure - Bottom	230
59	Primary Structure - Left Side	180
27	Sunshield - Top	70

*Measurements at 17:30 on 8/8/68

7.0 DISCUSSION

7.1 Analytical and Test Results

Table 7.1 compares predicted and test temperatures for the Acceptance Test, while Table 7.2 compares temperature predictions for the T/V chamber and actual lunar environments. Temperatures are presented as a function of thermal model node number. Similarly, Tables 7.3 and 7.4 present Mission Simulation results, and Table 7.5 compares predicted and T/V test temperatures for the Design Limit Test. In all cases, except for the sunshield, correlation was excellent as differences between test and predicted figures were generally less than 10°F. Correlation of average radiator plate temperature was ± 3°F. The relatively large discrepancy between predicted and test temperatures for the sunshield at lunar night was discussed in Section 2.3.

Results in Tables 7.1 - 7.5 are based on the following values of reserve power, PDM resistor panel dumps, and electronics thermal dissipation.

Heat Source	Power/Thermal Dissipation ~ Watts				
	Acceptance		Mission Sim.		
	Noon	Night	Noon	Night	Design Limit
Reserve Power	36.8	26.5	30.5	25.0	13.0
Electronics Thermal Dissipation	37.6	37.6	37.8	37.4	35.8
Thermal Dissipation from Radiator Heaters	0	0	0	0	24.0
PCU Load Dumps on PDM Panel	0	0	0	0	14.0
Reserve Power Dump on PDM Panel	20.5	9.5	13.2	9.0	1.8
Total Thermal Dissipation on Radiator	37.6	37.6	37.8	37.4	59.8
Total Thermal Dissipation at PDM Panel	20.5	9.5	13.2	9.0	15.8

TABLE 7.1

COMPARISON OF CENTRAL STATION PREDICTED AND T/V TEST TEMPERATURES FOR QUAL SA ACCEPTANCE CONFIGURATION

Thermal Analyzer Node No.	Node Description	Temperatures ~ °F			
		Lunar Noon		Lunar Night	
		Pred.	Test(1)	Pred.	Test(1)
97	Space (Cryowall Curtain)	-202	-202	-258	-258
98	Space (Cryowall Door)	-210	-210	-239	-239
99	Lunar Surface Simulator	241(2)	250	-300	-300
100	Space (Cryowall Arch)	-263	-263	-289	-289
101	Radiator Plate for Radiosity Network	87		6	
102	Radiator Insulation Mask	72		-9	
103	Side Curtain Internal Surface	82		-256	
104	Side Curtain Internal Surface	82		-262	
105	Sunshield Overhang, Bottom Surface	40		-272	
106	Specular Reflector	93		-183	
107	Radiator Plate for Radiosity Network	84		2	
108	Radiator Insulation Mask	68		-14	
109	Side Curtain Internal Surface	84		-262	
110		83		-256	
111		79		-255	
112	Sunshield Overhang, Bottom Surface	40		-272	
113	Specular Reflector	92		-171	

TABLE 7.1 (CONT)

Thermal Analyzer Node No.	Node Description	Temperatures ~°F			
		Lunar Noon		Lunar Night	
		Pred.	Test(1)	Pred.	Test(1)
114	Radiator Under Insulation Mask	94		11	
115	Radiator Under Insulation Mask	87		5	
116	Radiator Plate	96		13	
117		94	98	11	12
118		93	89	11	3
119		94		11	
120		89	82	6	-2
121		88	86	6	1
122		88	97	6	11
123		91	104	9	19
124		86	93	4	6
125		85	86	3	1
126		86	82	3	-2
127		87	87	4	0
128		87	92	6	5
129		89	93	5	6
130	P.C.U.	144	154(3)	62	75(3)
131	P.D.U.	114	122(3)	24	32(3)
132	Analog Multiplex Converter	105	101(3)	22	15(3)
133	Passive Seismometer	111		28	
134	Command Decoder	93	93(3)	7	4(3)
135	Data Processor	98	97(3)	6	5(3)

TABLE 7.1 (CONT)

Thermal Analyzer Node No.	Node Description	Temperatures ~ °F			
		Lunar Noon		Lunar Night	
		Pred.	Test(1)	Pred.	Test(1)
136	Command Receiver	90	90(3)	12	12(3)
137	Transmitter A	87		6	
138	Transmitter B	93	95(3)	10	10(3)
139	Timer	88		4	
140	Diplexer Filter	87		4	
141	Diplexer Switch	88		4	
143	Primary Structure Front	161	165	-141	-151
144	Primary Structure Right Side	145	150	-146	-151
145	Primary Structure Rear	183	183	-106	-113
146	Primary Structure Left Side	157	163	-121	-129
147	Primary Structure Bottom	182	187	-134	-141
148	Thermal Bag Internal Surface	94		4	
149	Thermal Bag External Surface	155		-93	
150	Side Curtain Internal Surface	84		-263	
151	Side Curtain Internal Surface	83		-257	
152	Side Curtain External Surface	84		-263	
153	Side Curtain External Surface	83		-257	
154	Sunshield Insulation	45		-271	
155	Sunshield Bottom Surface	40		-272	
156	Sunshield Top Surface	39	31	-272	-226
160	PDM Resistor Panel Insulation	209		-91	

TABLE 7.1 (CONT)

Thermal Analyzer Node No.	Node Description	Temperatures ~ °F			
		Lunar Noon		Lunar Night	
		Pred.	Test(1)	Pred.	Test(1)
161	PDM Resistor Panel	228	227	-44	-36
162	Environment for Cable Heat Leak	221		-300	
163	RTG	480	450	440	400

Notes: (1) Test values are from Data Acquisition System (DAS) measurements unless otherwise noted.

(2) This value is corrected for "non-black" properties of test lunar surface with the method in Section 4.11.

(3) "Hot" or internal electronics Housekeeping (HK) data.

TABLE 7.2

COMPARISON OF PREDICTED TEMPERATURES FOR QUAL SA CENTRAL STATION IN T/V ACCEPTANCE TEST AND REAL LUNAR ENVIRONMENTS

Thermal Analyzer Node No.	Node Description	Temperatures ~ °F			
		Lunar Noon		Lunar Night	
		Chamber	Moon	Chamber	Moon
50	Real Moon Subsurface Model	NA	-25	NA	-25
51			-22		-28
52			-4		-46
53			22		-72
54			54		-104
55			84		-134
56			114		-164
57			144		-194
58			174		-224
59			204		-254
60			234		-284
61			164		-178
62			-23		-27
63			-1		-49
64			27		-77
65			60		-109
66			90		-138
67			116		-162
68			138		-180
69			155		-191

TABLE 7.2 (CONT)

Thermal Analyzer Node No.	Node Description	Temperatures ~ °F			
		Lunar Noon		Lunar Night	
		Chamber	Moon	Chamber	Moon
70	Real Moon Subsurface Model	NA	164	NA	-194
71	Real Moon Subsurface Model	NA	167	NA	-188
97	Space (Cryowall Curtain)	-202	NA	-258	NA
98	Space (Cryowall Door)	-210	NA	-239	NA
99	Lunar Surface	241	250	-300	-300
100	Space or Cryowall Arch	-263	-459	-289	-459
101	Radiator Plate for Radiosity Network	88	122	6	2
102	Radiator Insulation Mask	72	106	-9	-12
103	Side Curtain Internal Surface	82	133	-256	-272
104	Side Curtain Internal Surface	82	133	-262	-279
105	Sunshield Overhang, Bottom Surface	40	41	-272	-278
106	Specular Reflector	93	137	-183	-188
107	Radiator Plate for Radiosity Network	84	119	2	-1
108	Radiator Insulation Mask	68	99	-14	-17
109	Side Curtain Internal Surface	84	133	-262	-279
110	↓	83	132	-256	-271
111	↓	79	129	-255	-271
112	Sunshield Overhang, Bottom Surface	40	41	-272	-278
113	Specular Reflector	92	135	-171	-176
114	Radiator Under Insulation Mask	94	128	11	8

TABLE 7.2 (CONT)

Thermal Analyzer Node No.	Node Description	Temperatures ~ °F			
		Lunar Noon		Lunar Night	
		Chamber	Moon	Chamber	Moon
115	Radiator Under Insulation Mask	87	122	5	1
116	Radiator Plate	96	131	13	10
117		94	128	11	8
118		93	128	11	7
119		94	128	11	7
120		89	123	6	3
121		88	123	6	3
122		88	123	6	3
123		91	125	9	5
124		86	120	4	0
125		85	120	3	0
126		86	120	3	0
127		87	121	4	1
128		87	122	6	3
129		89	123	5	1
130	P. C. U.	144	178	62	59
131	P. D. U.	114	147	24	17
132	Analog Multiplex Converter	105	139	22	19
133	Passive Seismometer	111	146	28	25
134	Command Decoder	93	127	7	3
135	Data Processor	98	132	6	3
136	Command Receiver	90	124	12	8

TABLE 7.2 (CONT)

Thermal Analyzer Node No.	Node Description	Temperatures ~ °F			
		Lunar Noon		Lunar Night	
		Chamber	Moon	Chamber	Moon
137	Transmitter A	87	122	6	3
138	Transmitter B	93	128	10	7
139	Timer	88	122	4	1
140	Diplexer Filter	87	121	4	1
141	Diplexer Switch	88	122	4	1
143	Primary Structure Front	161	164	-141	-178
144	Primary Structure Right Side	145	148	-146	-183
145	Primary Structure Rear	183	179	-106	-146
146	Primary Structure Left Side	157	152	-121	-177
147	Primary Structure Bottom	182	163	-134	-177
148	Thermal Bag Internal Surface	94	126	4	1
149	Thermal Bag External Surface	155	153	-93	-115
150	Side Curtain Internal Surface	84	134	-263	-280
151	Side Curtain Internal Surface	83	133	-257	-273
152	Side Curtain External Surface	84	135	-263	-280
153	Side Curtain External Surface	83	134	-257	-273
154	Sunshield Insulation	45	52	-271	-277
155	Sunshield Bottom Surface	40	40	-272	-278
156	Sunshield Top Surface	39	39	-272	-278
160	PDM Resistor Panel Insulation	209	209	-91	-133
161	PDM Resistor Panel	228	232	-33	-68
162	Environment for Cable Heat Leak	221	227	-300	-340
163	RTG	480	480	440	440

NA - Not Applicable

TABLE 7.3

COMPARISON OF CENTRAL STATION PREDICTED AND T/V TEST TEMPERATURES FOR QUAL SA MISSION SIMULATION CONFIGURATION

Thermal Analyzer Node No.	Node Description	Temperatures ~ °F			
		Lunar Noon		Lunar Night	
		Pred.	Test(1)	Pred.	Test(1)
97	Space (Cryowall Curtain)	-255	-255	-255	-289
98	Space (Cryowall Door)	-297	-297	-295	-295
99	Lunar Surface Simulator	241(2)	250	-300	-300
100	Space (Cryowall Arch)	-219	-219	-283	-283
101	Radiator Plate for Radiosity Network	90		5	
102	Radiator Insulation Mask	75		-9	
103	Side Curtain Internal Surface	84		-254	
104	Side Curtain Internal Surface	84		-260	
105	Sunshield Overhang, Bottom Surface	43		-272	
106	Specular Reflector	95		-182	
107	Radiator Plate for Radiosity Network	87		2	
108	Radiator Insulation Mask	71		-14	
109	Side Curtain Internal Surface	86		-260	
110	Side Curtain Internal Surface	85		-254	
111	Side Curtain Internal Surface	81		-253	
112	Sunshield Overhang, Bottom Surface	43		-272	
113	Specular Reflector	94		-171	
114	Radiator Under Insulation Mask	96		11	

TABLE 7.3 (CONT)

Thermal Analyzer Node No.	Node Description	Temperatures ~ °F			
		Lunar Noon		Lunar Night	
		Pred.	Test(1)	Pred.	Test(1)
115	Radiator Under Insulation Mask	90		4	
116	Radiator Plate	99		13	
117		96	97	11	9
118		96	87	11	0
119		96		11	
120		91	80	6	-5
121		91	85	6	-2
122		91	96	6	9
123		93	104	9	17
124		88	92	3	3
125		88	85	3	-2
126		88	80	3	-5
127		89	85	4	-3
128		89	90	6	2
129		91	92	4	3
130	P. C. U.	148	160(3)	62	77(3)
131	P. D. U.	116		21	
132	Analog Multiplex Converter	107		22	
133	Passive Seismometer	114		28	
134	Command Decoder	95		7	
135	Data Processor	100		6	
136	Command Receiver	92		11	

TABLE 7.3 (CONT)

Thermal Analyzer Node No.	Node Description	Temperatures ~ °F			
		Lunar Noon		Lunar Night	
		Pred.	Test(1)	Pred.	Test(1)
137	Transmitter A	90		6	
138	Transmitter B	95	93(3)	10	8(3)
139	Timer	90		4	
140	Diplexer Filter	89		4	
141	Diplexer Switch	90		4	
143	Primary Structure Front	160	159	-146	-155
144	Primary Structure Right Side	143	144	-153	-156
145	Primary Structure Rear	172	168	-116	-118
146	Primary Structure Left Side	154	158	-126	-134
147	Primary Structure Bottom	179	180	-140	-146
148	Thermal Bag Internal Surface	96		4	
149	Thermal Bag External Surface	153		-97	
150	Side Curtain Internal Surface	86		-261	
151	Side Curtain Internal Surface	85		-255	
152	Side Curtain External Surface	86		-261	
153	Side Curtain External Surface	85		-255	
154	Sunshield Insulation	48		-271	
155	Sunshield Bottom Surface	43		-272	
156	Sunshield Top Surface	42	40	-272	-233
160	PDM Resistor Panel Insulation	187		-104	
161	PDM Resistor Panel	199	198	-51	-36
162	Environment for Cable Heat Leak	221		-300	
163	RTG	480	450	440	400

Notes: (1) Test values are from DAS measurements unless otherwise noted.
(2) Corrected for "non-black" properties of test lunar surface.
(3) "Hot" or internal electronics Housekeeping (HK) data.

TABLE 7.4

COMPARISON OF PREDICTED TEMPERATURES FOR QUAL SA CENTRAL STATION IN T/V SIMULATION TEST AND REAL LUNAR ENVIRONMENTS

Thermal Analyzer Node No.	Node Description	Temperatures ~ °F			
		Lunar Noon		Lunar Night	
		Chamber	Moon	Chamber	Moon
50	Real Moon Subsurface Model	NA	-25	NA	-25
51			-22		-28
52			-4		-46
53			22		-72
54			54		-104
55			84		-134
56			114		-164
57			144		-194
58			174		-224
59			204		-254
60			234		-284
61			161		-180
62			-23		-27
63			-1		-49
64			27		-77
65			60		-110
66			90		-138
67			116		-162
68			137		-180
69			153		-192

TABLE 7.4 (CONT)

Thermal Analyzer Node No.	Node Description	Temperatures ~ °F			
		Lunar Noon		Lunar Night	
		Chamber	Moon	Chamber	Moon
70	Real Moon Subsurface Model	NA	162	NA	-195
71	Real Moon Subsurface Model	NA	164	NA	-189
97	Space (Cryowall Curtain)	-255	NA	-289	NA
98	Space (Cryowall Door)	-297	NA	-295	NA
99	Lunar Simulator or Real Moon	241	250	-300	-300
100	Space or Cryowall Arch	-219	-459	-283	-459
101	Radiator Plate for Radiosity Network	90	122	5	2
102	Radiator Insulation Mask	75	106	-9	-12
103	Side Curtain Internal Surface	84	133	-254	-272
104	Side Curtain Internal Surface	84	133	-260	-280
105	Sunshield Overhang, Bottom Surface	43	40	-272	-278
106	Specular Reflector	95	137	-182	-189
107	Radiator Plate for Radiosity Network	87	118	2	-2
108	Radiator Insulation Mask	71	99	-14	-17
109	Side Curtain Internal Surface	86	133	-260	-279
110	Side Curtain Internal Surface	85	132	-254	-271
111	Side Curtain Internal Surface	81	129	-253	-271
112	Sunshield Overhang, Bottom Surface	43	40	-272	-278
113	Specular Reflector	94	135	-171	-176

TABLE 7.4 (CONT)

Thermal Analyzer Node No.	Node Description	Temperatures - °F			
		Lunar Noon		Lunar Night	
		Chamber	Moon	Chamber	Moon
114	Radiator Under Insulation Mask	96	128	11	7
115	Radiator Under Insulation Mask	90	124	4	1
116	Radiator Plate	99	131	13	9
117		96	128	11	7
118		96	128	11	7
119		96	128	11	7
120		91	123	6	2
121		91	123	6	2
122		91	123	6	2
123		93	126	9	5
124		88	120	3	0
125		88	119	3	-1
126		88	120	3	-1
127		89	121	4	0
128		89	121	6	2
129		91	123	4	0
130	P. C. U.	148	179	62	58
131	P. D. U.	116	147	21	17
132	Analog Multiplex Converter	107	139	22	18
133	Passive Seismometer	114	146	28	24
134	Command Decoder	95	127	7	3
135	Data Processor	100	131	6	2

TABLE 7.4 (CONT)

Thermal Analyzer Node No.	Node Description	Temperatures ~ °F			
		Lunar Noon		Lunar Night	
		Chamber	Moon	Chamber	Moon
136	Command Receiver	92	124	11	8
137	Transmitter A	90	121	6	2
138	Transmitter B	95	127	10	6
139	Timer	90	122	4	0
140	Diplexer Filter	89	121	4	0
141	Diplexer Switch	90	122	4	0
143	Primary Structure Front	160	163	-146	-179
144	Primary Structure Right Side	143	146	-153	-185
145	Primary Structure Rear	172	168	-116	-149
146	Primary Structure Left Side	154	150	-126	-179
147	Primary Structure Bottom	179	160	-140	-179
148	Thermal Bag Internal Surface	96	126	4	0
149	Thermal Bag External Surface	153	150	-97	-116
150	Side Curtain Internal Surface	86	133	-261	-280
151	Side Curtain Internal Surface	85	133	-255	-273
152	Side Curtain External Surface	86	135	-261	-280
153	Side Curtain External Surface	85	134	-255	-273
154	Sunshield Insulation	48	52	-271	-277
155	Sunshield Bottom Surface	43	40	-272	-278
156	Sunshield Top Surface	42	39	-272	-278
160	PDM Resistor Panel Insulation	187	187	-104	-137
161	PDM Resistor Panel	199	203	-51	-75
162	Environment for Cable Heat Leak	221	227	-300	-340
163	RTG	480	480	440	440

NA - Not Applicable

TABLE 7.5

COMPARISON OF CENTRAL STATION PREDICTED AND T/V TEST TEMPERATURES FOR QUAL SA DESIGN LIMIT CONFIGURATION

Thermal Analyzer Node No.	Node Description	Temperatures ~ °F	
		Pred.	Test(1)
97	Space (Cryowall Curtain)	-271	-271
98	Space (Cryowall Door)	-291	-291
99	Lunar Surface Simulator	271(2)	280
100	Space (Cryowall Arch)	-270	-270
101	Radiator Plate for Radiosity Network	134	
102	Radiator Insulation Mask	113	
103	Side Curtain Internal Surface	105	
104	Side Curtain Internal Surface	106	
105	Sunshield Overhang, Bottom Surface	67	
106	Specular Reflector	120	
107	Radiator Plate for Radiosity Network	132	
108	Radiator Insulation Mask	112	
109	Side Curtain Internal Surface	108	
110	Side Curtain Internal Surface	107	
111	Side Curtain Internal Surface	103	
112	Sunshield Overhang, Bottom Surface	67	
113	Specular Reflector	119	
114	Radiator Under Insulation Mask	145	
115	Radiator Under Insulation Mask	142	
116	Radiator Plate	147	

TABLE 7.5 (CONT)

Thermal Analyzer Node No.	Node Description	Temperatures ~ °F	
		Pred.	Test(1)
117	Radiator Plate	145	143
118		145	137
119		145	
120		136	126
121		135	131
122		135	139
123		138	146
124		134	137
125		134	131
126		134	126
127		140	135
128		141	145
129		142	137
130	P.C.U.	186	189(3)
131	P.D.U.	162	
132	Analog Multiplex Converter	154	
133	Passive Seismometer	161	
134	Command Decoder	141	
135	Data Processor	145	
136	Command Receiver	138	
137	Transmitter A	141	
138	Transmitter B	147	145(3)
139	Timer	138	
140	Diplexer Filter	137	

TABLE 7.5 (CONT)

Thermal Analyzer Node No.	Node Description	Temperatures ~ °F Pred.	Test(1)
141	Diplexer Switch	138	
143	Primary Structure Front	186	188
144	Primary Structure Right Side	168	172
145	Primary Structure Rear	199	200
146	Primary Structure Left Side	179	187
147	Primary Structure Bottom	208	215
148	Thermal Bag Internal Surface	143	
149	Thermal Bag External Surface	186	
150	Side Curtain Internal Surface	107	
151	Side Curtain Internal Surface	106	
152	Side Curtain External Surface	107	
153	Side Curtain External Surface	107	
154	Sunshield Insulation	72	
155	Sunshield Bottom Surface	66	
156	Sunshield Top Surface	66	67
160	PDM Resistor Panel Insulation	216	
161	PDM Resistor Panel	228	225
162	Environment for Cable Heat Leak	221	
163	RTG	480	460
170	Radiator Plate Heater	149	
171	Radiator Plate Heater	146	

Notes: (1) Test values are from DAS measurements unless otherwise noted.
(2) Corrected for "non-black" properties of test lunar surface.
(3) "Hot" or internal electronics Housekeeping (HK) data.

7.1.1 Test Results for Activated PDM Dumps and Radiator Heaters

As described previously (in Section 2), PDM dumps and radiator heaters were activated for short periods during lunar noon and night phases of the Mission Simulation Test. Temperature histories (See Section 6) indicated that the radiator plate was close to if not at equilibrium when the dumps or heaters were deactivated. Consequently, equilibrium was assumed, and temperature predictions were made based on measured reserve power. Test and predicted results are compared in Table 7.6, with predicted figures agreeing very well with test data. The table shows that sizable reductions in radiator lunar noon-to-night temperature swing can be realized by activating the dumps and/or heaters. If both the 7 and 14 watt dumps are turned-on simultaneously at lunar noon and the 10 watt heater activated at night, a 29°F maximum reduction in temperature swing is indicated which is a significant improvement in C/S thermal performance.

7.2 Evaluation of Reserve Power

Reserve power was an important test measurement since PCU and PDM power dissipations were not recorded. As shown by reserve power histories on Figures 6.10, 6.31, and 6.32 in Section 6, this parameter exhibited large and rapid fluctuations throughout Qual SA testing. This, of course, made it difficult to establish a "mean" value for correlation work. Fortunately, most reserve power readings fell within the range (20 to 35 watts) where PCU thermal dissipation varies only slightly, as shown by Figure 4.12. Consequently, it was not difficult to establish PCU dissipation within reasonable accuracy. However, PDM thermal dissipation is quite sensitive to the level of reserve power. Figure 4.12 shows that a one watt change in reserve power can produce up to a one watt variation in PDM dissipation, which in turn causes about a 10°F change in PDM panel temperature at lunar night. Therefore, the difficulty in establishing accurate reserve power values could be the primary reason for the relatively large 15°F discrepancy between PDM panel test and predicted lunar night temperatures for the Mission Simulation Test. Otherwise, temperature correlation for the panel was within ±8°F.

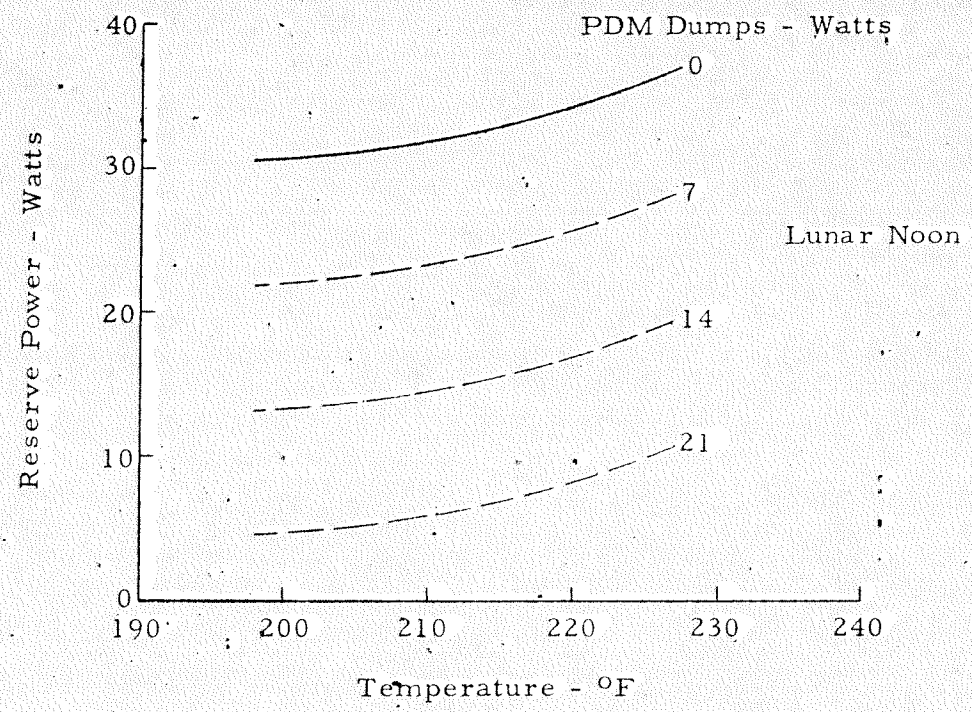
From Qual SA data, reserve power was plotted versus PDM resistor panel temperature for various PDM dump levels in Figure 7.1 at lunar noon and night. Since PDM panel temperature does not respond to instantaneous variations in power and therefore does not fluctuate rapidly, it was felt that these curves might provide a better method for estimating reserve power than by reducing power data.

TABLE 7.6

TEST RESULTS FOR ACTIVATED PDM DUMPS AND RADIATOR HEATERS WITH COMPARISON TO PREDICTED VALUES

Condition	Test Phase	Reserve Power, Watts	Electronics Thermal Dissipation, Watts	Average Radiator Steady-State Temperature, °F		Reduction in Test Radiator Temperature Swing, °F
				Test	Predicted	
No Dumps or Heaters Activated	Lunar Noon	30.5	37.8	91	91	0
7 and 14 Watt PDM Dumps Activated	Lunar Noon	10.0	32.8	83	81	8
No Dumps or Heaters Activated	Lunar Night	25.0	37.4	3	6	0
10 Watt Radiator Heater Activated	Lunar Night	14.5	34.8	24	24*	21
5 Watt Radiator Heater Activated	Lunar Night	18.0	36.6	16	16*	13

*Adjusted for discrepancy between test and predicted values corresponding to condition of no activated heaters.



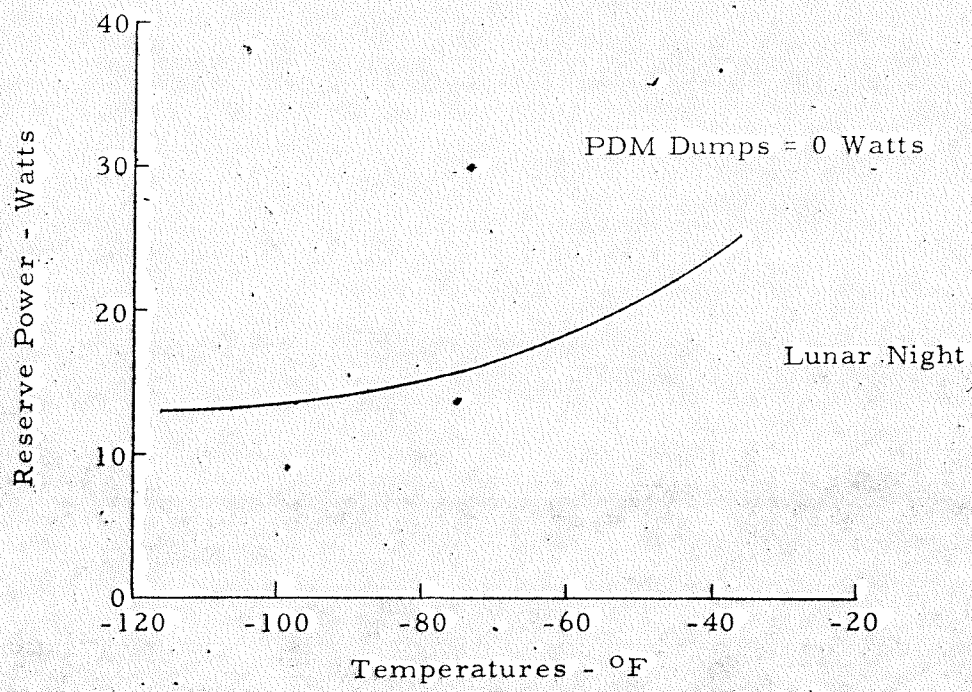


Figure 7.1 Qual SA Reserve Power vs PDM Resistor Panel Temperature for Various PDM Dump Levels

Two PDM dumps (7 and 14 watts) are located on the resistor panel which can be activated and which cause a shift in the reserve power versus temperature characteristics. However, the only time these dumps were activated during Qual SA testing was simultaneously for one 8 hour period of Mission Simulation lunar noon. Therefore, a single data point exists for an activated 21 watt total dump condition. Curves on Figure 7.1 for dump levels other than zero were estimated, as designated by the dashed lines, and should be used only for rough indications of reserve power levels.

7.3 Effect of Various Parameters on Central Station Thermal Performance

Several aspects or parameters involved in lunar environment simulation and their effect on C/S thermal performance were discussed in Section 3. Additional parameters pertaining to C/S deployment on the moon, T/V chamber conditions, and C/S component temperatures also affect C/S thermal performance. Thermal effects of these parameters are discussed in following subsections, with emphasis being placed on effects on radiator performance.

7.3.1 Effect of RTG

The following table compares C/S structure and average radiator plate temperature predictions with and without RTG effects for Acceptance Test conditions.

C/S Component	Temperatures ~ °F					
	Noon			Night		
	No RTG	RTG	ΔT	No RTG	RTG	ΔT
Structure Front	159	161	2	-167	-144	23
Structure Right Side	143	145	2	-171	-149	22
Structure Rear	181	183	2	-136	-112	24
Structure Left Side	141	157	16	-172	-123	49
Structure Sides, average	156	162	6	-160	-131	29
Structure Bottom	178	182	4	-165	-137	28
Radiator, Average	89	89	0	6	6	0
PDM Resistor Panel	228	228	0	-59	-44	15

Above results show that the RTG had a significant effect on the structure left side at lunar noon and on all structure surfaces at lunar night. However, its effect on radiator temperatures was negligible. Similar conclusions were reached for the Mission Simulation and Design Limit Tests. Furthermore, the RTG will be located about twice as far from the C/S on the moon as in the T/V Chamber and will have virtually no effect on any C/S component temperatures for this condition.

7.3.2 Effect of Lunar Noon Temperature Distribution Over Lunar Surface Simulator

A listing below compares C/S component lunar noon temperature predictions for a uniform temperature lunar surface with a non-uniform temperature surface which simulates lunar noon Acceptance Test conditions.

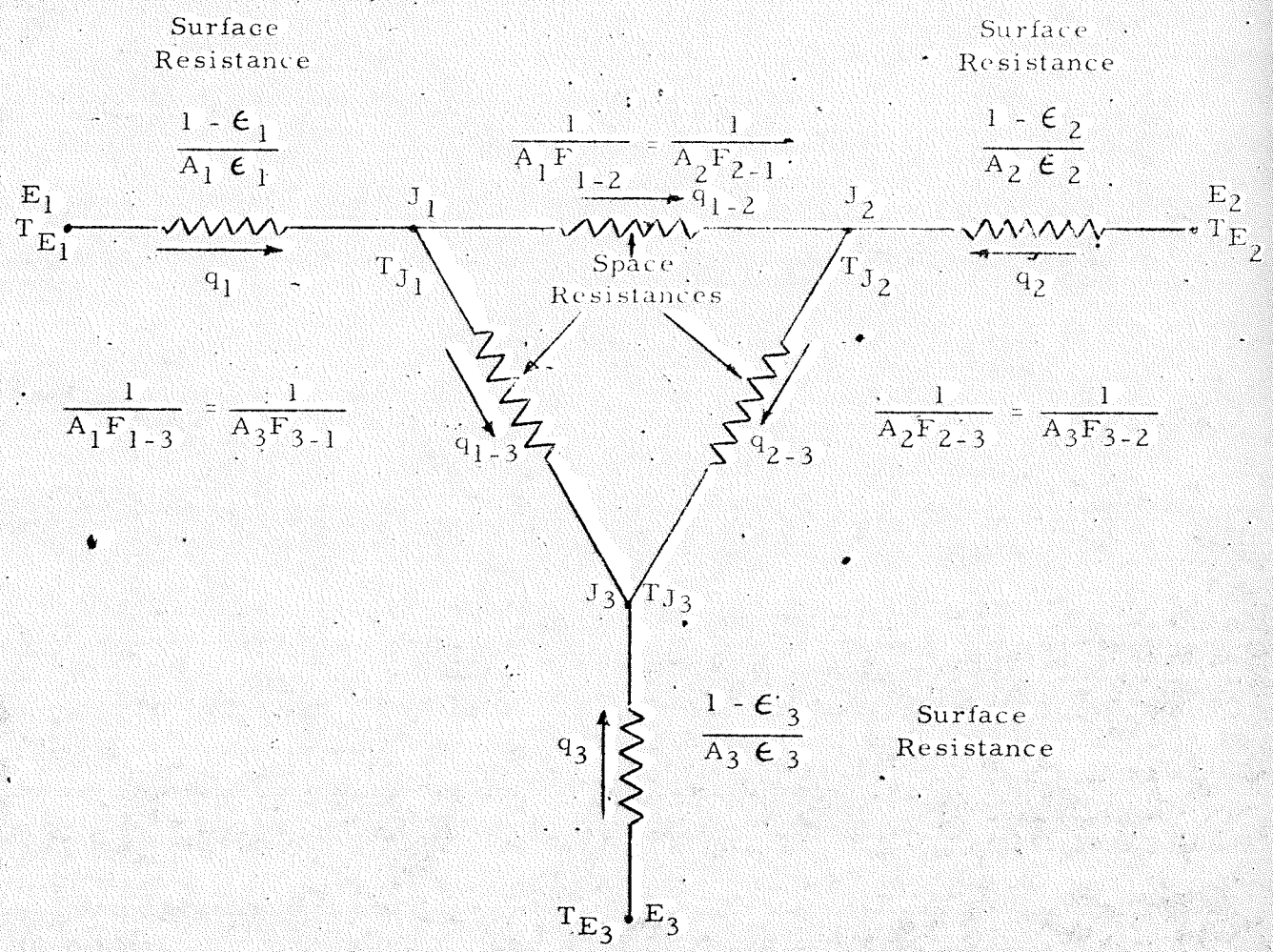
C/S Component	Uniform Temperature	Non-Uniform Temperature	ΔT
Structure Front	161	161	0
Structure Right Side	146	146	0
Structure Rear	186	186	0
Structure Left Side	156	158	2
Structure Sides, average	162	163	1
Structure Bottom	183	186	3
Radiator Plate, average	90	90	0
PDM Resistor Panel	135	135	0

As seen by the above results, consideration of non-uniform lunar simulator temperature had no effect on radiator temperature and little effect on structure temperatures. Similar results were obtained for the Mission Simulation and Design Limit Tests. No such study was necessary for lunar night since the desired -300°F uniform temperature over the lunar simulator was always achieved.

To obtain the above analysis results, the lunar simulator was divided into two sets of areas to simulate the Acceptance Test temperature distribution. One set, shown in Figure 7.2, was used to obtain radiation resistances from the lunar simulator to the structure front, structure rear, and PDM resistor panel. Resistances to the structure sides were evaluated with the area set illustrated in Figure 7.3. Note that all sections with equal temperatures are assigned the same Thermal Analyzer node number.

7.3.3 Effect of Thermal Emissivity of Vacuum Chamber Surfaces

Studies were conducted to determine the effect of lunar surface simulator and cryowall thermal emissivity on radiator plate temperature. To help explain how the emissivity of these surfaces can affect the radiator, refer to the simplified three-node "radiosity" network below (see reference 7 for detailed description):



xxx Node Identification
(xxx) Node Temperature

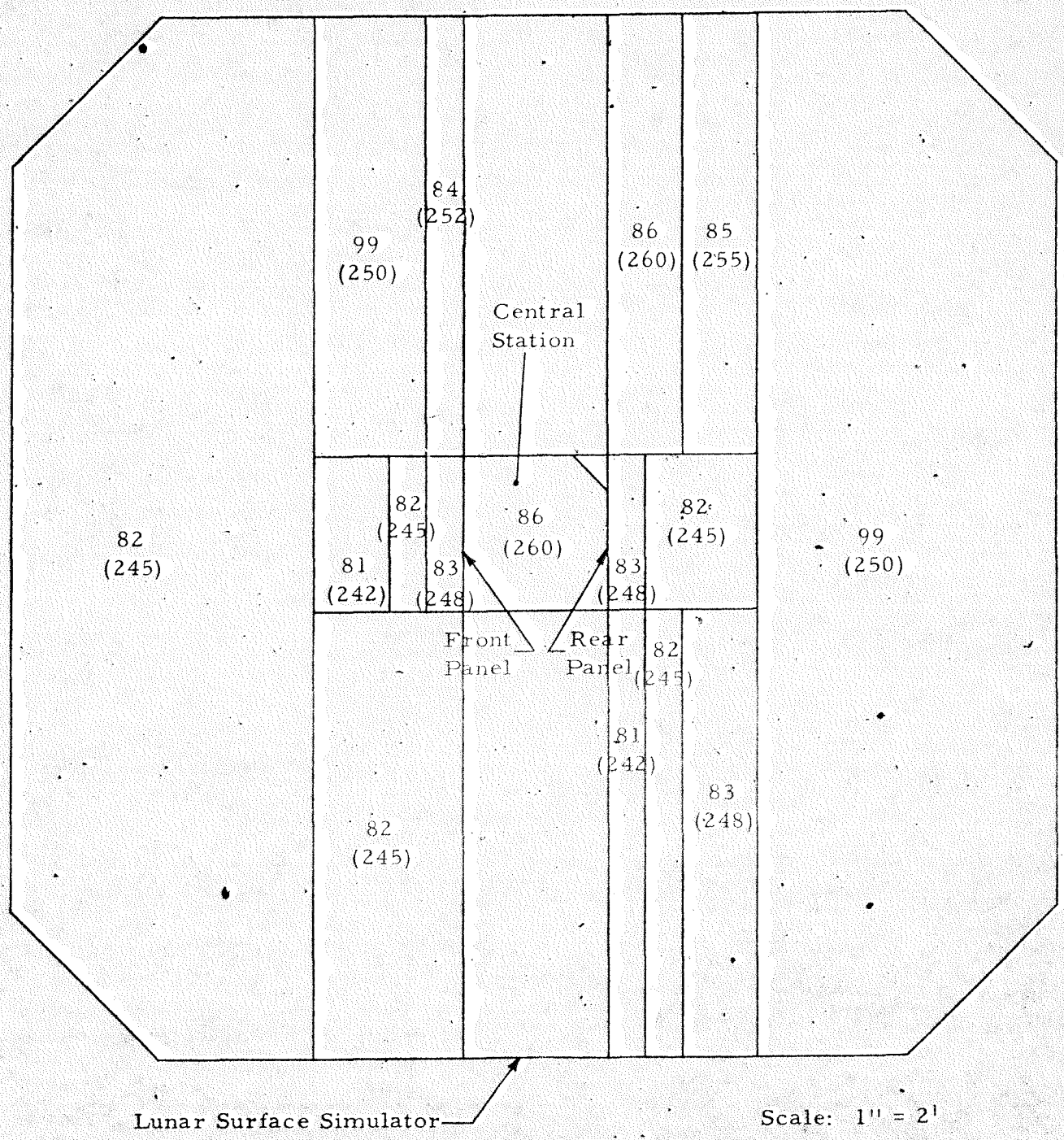


Figure 7.2 Nodal Division of Qual SA Lunar Surface Simulator at Noon for Structure Front and Rear Panels - Acceptance and Mission Simulation Tests

xxx Node Identification
(xxx) Node Temperature

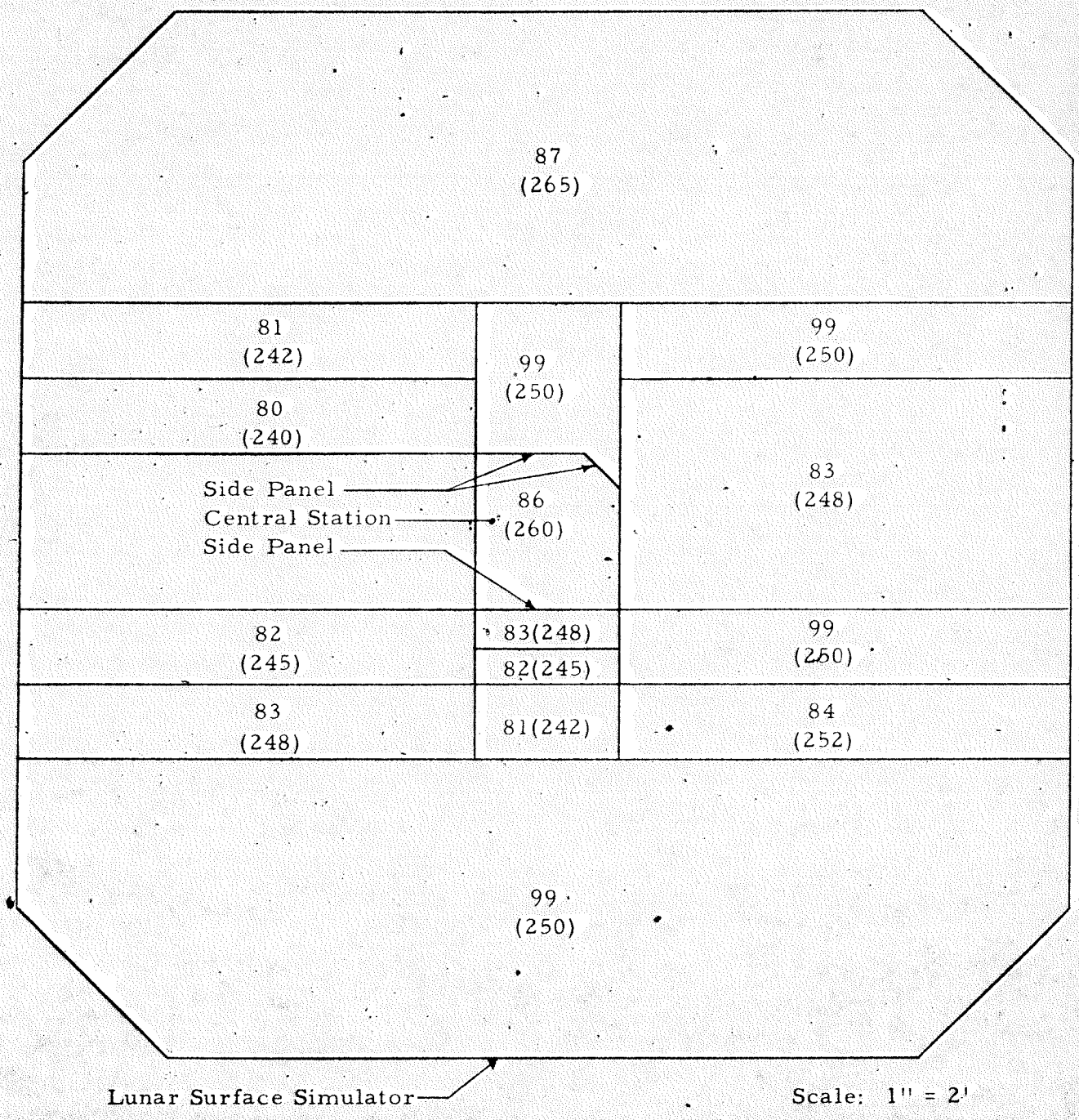


Figure 7.3 Nodal Division of Qual SA Lunar Surface Simulator at Noon for Structure Side Panels - Acceptance and Mission Simulation Tests

Nodes 1, 2 and 3 represent the C/S, lunar simulator, and cryowall. As shown, a radiation path between two nodes can be represented by two "surface" resistors and a "space" resistor. While the network assumes each node is at "black-body" potential, a surface resistor accounts for non-black properties of a node. The space resistor allows for that portion of radiant energy exchanged "directly" between two nodes. A dummy or "radiosity" node, at potential J, connects the surface and space resistors. Nomenclature is as follows:

q = heat transfer rate

E = black-body emissive power of surface = σT^4

T_E = surface temperature of node

T_J = "effective" or "radiosity" node temperature

σ = Stefan-Boltzmann Constant

J = total diffuse radiation leaving surface (diffuse radiosity)

A = radiator surface area

ϵ = surface thermal emissivity

F_{m-n} = form factor from surface m to surface n.

The diffuse radiosity, J, includes both emitted and reflected radiation. To calculate steady-state temperatures, one may assume that J, as well as E, is represented by σT^4.

For the T/V chamber test environment, surface resistances of the lunar simulator and cryowall are very small in comparison to C/S surface resistance because of the relatively large areas of these components. Also, their thermal emissivities are quite high. However, during lunar noon a tremendous amount of heat flows from the lunar simulator to the cryowall. Thus, for surface emissivities less than 1.0, T_E and T_J for each of these two nodes can become significantly different in order to provide the potential for the heat transfer to occur. (This is analogous to voltage potential.)

T_{E_2} and T_{E_3} are held constant during lunar noon testing. Consequently, since T_{J_2} and T_{J_3} are the "effective" environmental temperatures with which the C/S exchanges heat, radiator temperature is influenced directly by emissivitiy of the lunar simulator and cryowall surfaces.

Figures 7.4 and 7.5 show the effect of lunar simulator and cryowall emissivity on C/S radiator plate temperature. A change of 0.1 in lunar surface emissivity produces about a 6°F change in radiator temperature for nominal C/S thermal dissipation. Similarly, a 0.1 change in cryowall emissivity creates a 5 to 8°F change in radiator temperature. As illustrated by the figures, an increase in lunar simulator emissivity causes an increase in radiator temperature, while the reverse occurs for an increase in cryowall emissivity.

At lunar night, relatively little heat flows across the lunar simulator and cryowall surfaces. Consequently, there is little difference between T_E and T_J over the range of emissivities measured on these surfaces, and emissivity has negligible effect on radiator temperature.

7.3.4 Effect of C/S Primary Structure Temperature

The effect of C/S primary structure temperature on radiator temperature is illustrated in Figure 7.6, which shows that a 1°F change in radiator temperature occurs for changes in average structure temperature of 15°F at lunar noon and 20°F at lunar night. Thus, the radiator is relatively uninfluenced by fluctuations in structure temperature.

7.3.5 Effect of Side Curtain Incomplete Deployment

Side curtains of the C/S are folded back approximately 2" while in the stowed configuration. Upon deployment, springs mounted on the fold lines unfold the curtains, but not necessarily to a planar configuration. The design is such that at the top of the curtain complete unfolding (180°) is achieved, while at the bottom only partial unfolding (120° to 160°) is achieved.

Partial unfolding allows direct solar heating of the masks at all sun angles less than 90° (assuming no misalignment). A series of thermal analyses accounting for this incomplete unfolding were performed using the simplified C/S computer model (radiosity network) described in Section 7.3.6.

Cryowall Temperature = -300°F
Cryowall Thermal Emissivity = 1.0
Lunar Surface Simulator Temperature = 250°F
Lunar Surface Simulator Area = 184 ft^2

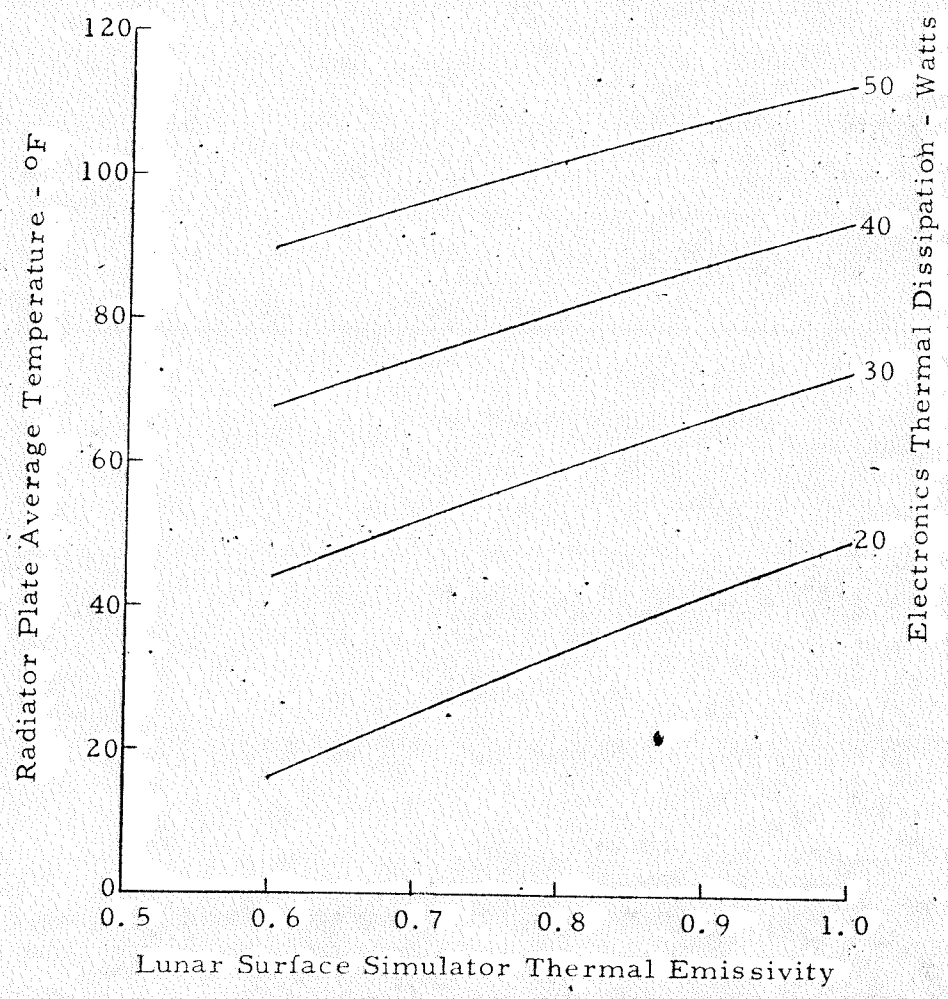


Figure 7.4 Effect of Lunar Simulator Thermal Emissivity on Radiator Plate Temperature at Lunar Noon

Lunar Surface Simulator Temperature = 250°F
Lunar Surface Simulator Thermal Emissivity = 0.95
Cryowall Temperature = -300°F
Cryowall Area (That Portion "Seeing" C/S) = 1110 ft^2

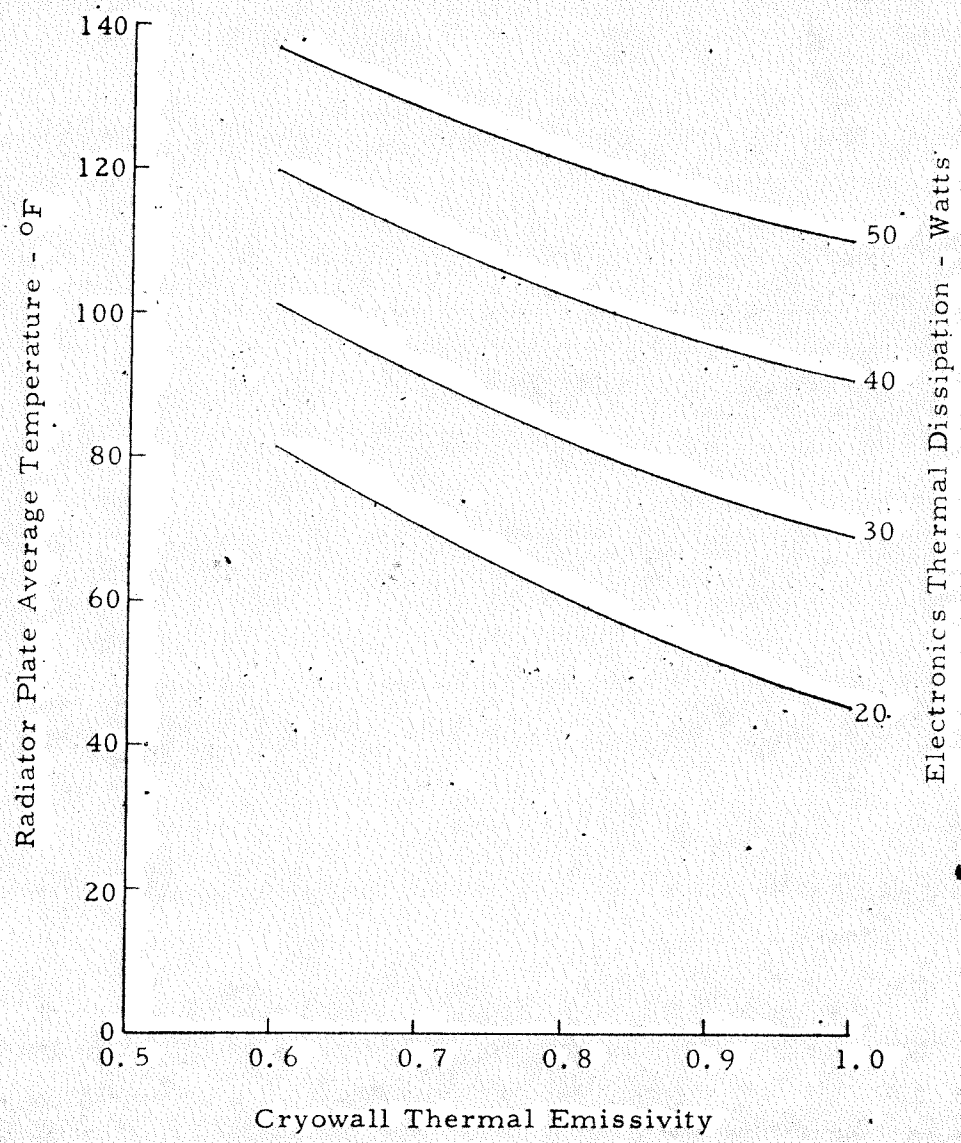


Figure 7.5 Effect of Cryowall Thermal Emissivity on Radiator Plate Temperature at Lunar Noon

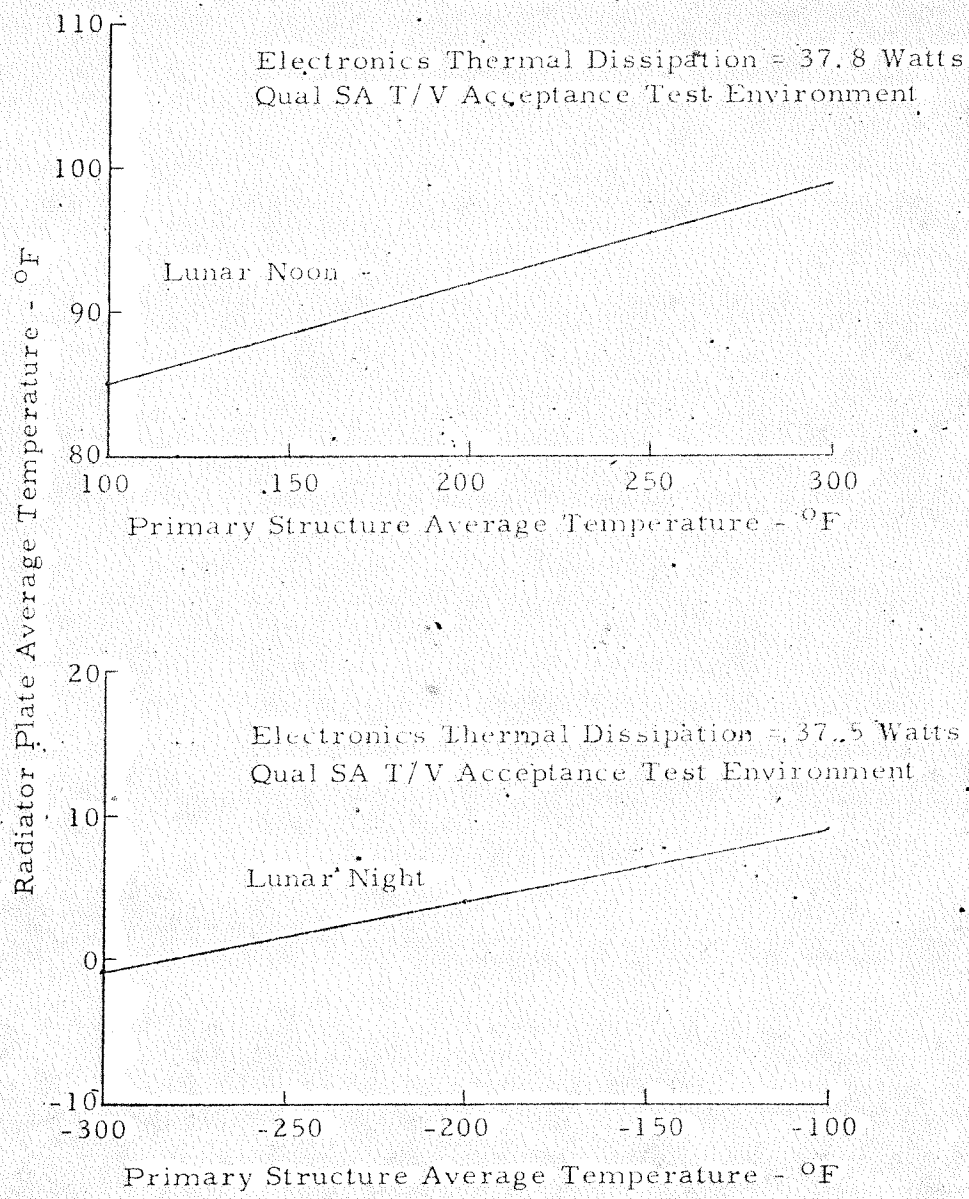


Figure 7.6 Effect of Primary Structure Temperature on Raidator Plate Temperature

For these analyses the following conservative assumption was made: each curtain unfolds completely at the top (180°) but only 90° at the bottom.

Analysis results show that maximum solar heating occurs at fairly low sun angles (30° to 40°) and as such does not raise the radiator temperature beyond the maximum expected at lunar noon where no direct solar heating occurs. Therefore, even with the assumed position of the deployed curtain stated above, the thermal effects are not critical.

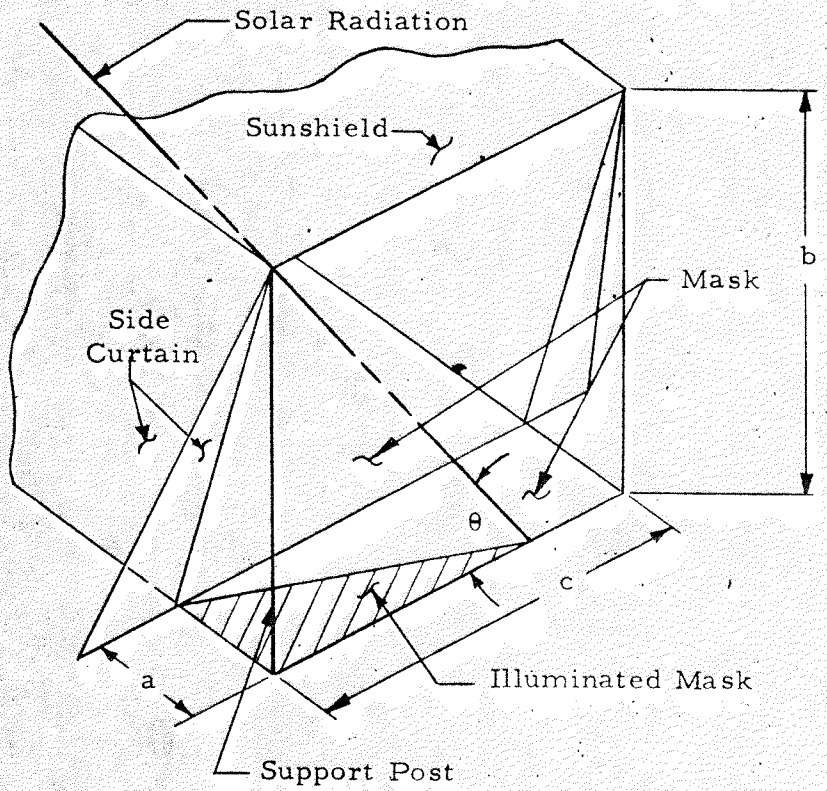
With the assumed configuration, the masks are exposed to direct solar radiation through triangular shaped openings 25-7/16" high by 2" wide at the base. To avoid an analysis of complex solar energy reflection within the C/S enclosure, the solar absorptance (α) and infrared emittance (ϵ) of the masks were both assumed equal to 1.0. The increased form factors from the "bowed" side curtains to the lunar surface and space were neglected due to predicted negligible influence on the analysis. Also, this was probably conservative since the curtains "see" more space than lunar surface.

Solar radiation incident upon the masks is a function of sun angle and C/S geometric configuration. Figure 7.7 shows two models used to evaluate the solar radiation absorbed by the masks. Model I is used for all sun angles which cause triangular-shaped illuminated areas on the masks, while Model II is used for all sun angles which produce trapezoidal-shaped illuminated areas. Equations developed for calculating radiation absorbed by each mask are presented in the figure.

Equations in Figure 7.7 were evaluated for a series of sun angles, and the results are presented in Figure 7.8. Maximum solar radiation absorbed by each mask was obtained by setting the derivative (dq/dt) of the Model II equation equal to zero and then solving the remaining expression for θ. The resultant sun angle was approximately 37.5 degrees, which corresponded to 59.2 Btu/hr absorbed solar energy.

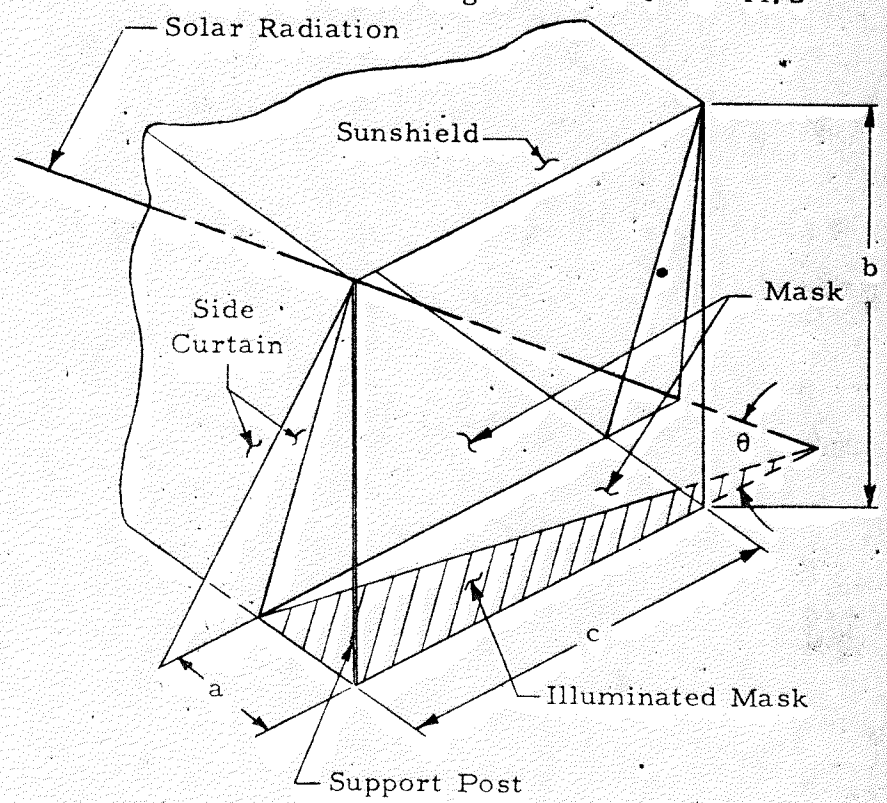
Various values from Figure 7.8 were used as input data for the Qual SA C/S computer model to determine the variation of radiator plate temperature with sun angle. Results are presented in Figure 7.9 and compared with lunar surface temperature and radiator temperature for no solar heating.

Model I: Solar Angle $44.2^{\circ} \leq \theta \leq 90^{\circ}$



$q = 1/2\ ab\alpha Q_s \cos\theta$

Model II: Solar Angle $0 \leq \theta \leq 44.2^{\circ}$



$q = 1/2\ ac\alpha Q_s \sin\theta \left[2 - (c/b) \tan\theta \right]$

a = 2.00"
b = 25.44"
c = 26.14"
q = absorbed solar radiation, BTU/hr
Q_s = solar radiation constant = 442 BTU/ft^{2}hr
θ = solar angle

Figure 7.7 Models for Solar Heating of Insulation Masks

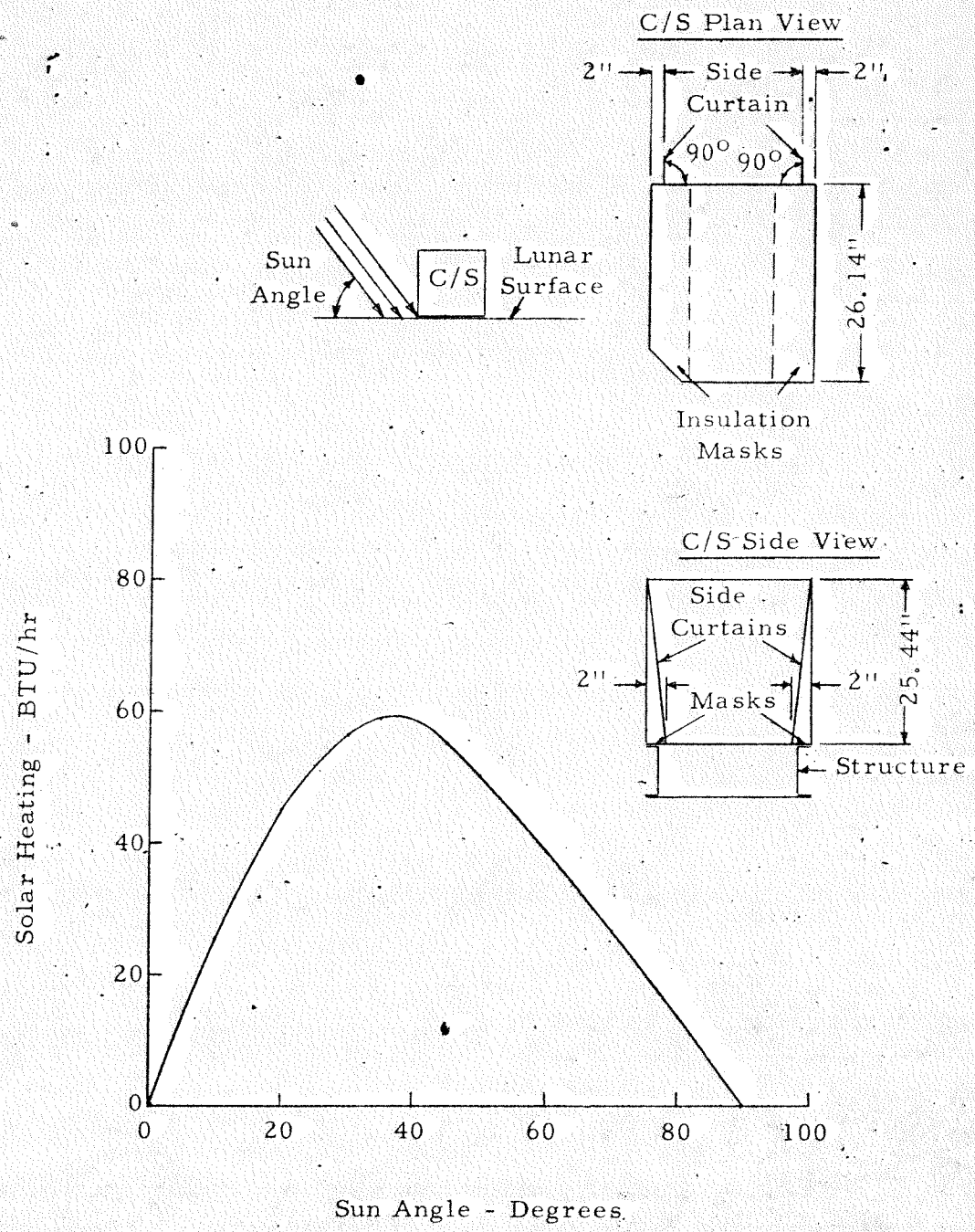


Figure 7.8 Solar Radiation Absorbed by Each Insulation Mask vs Sun Angle for "Bowed" Side Curtains

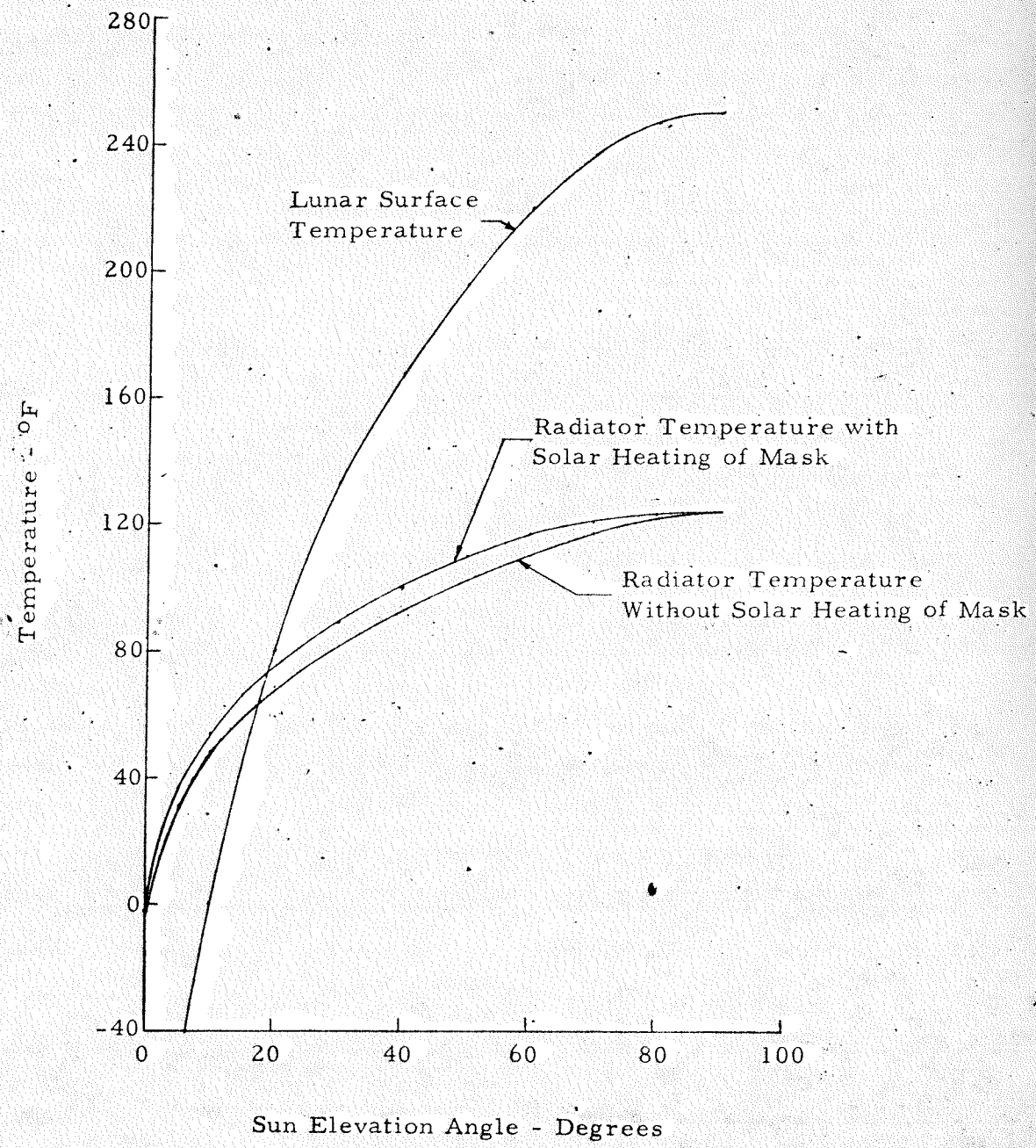


Figure 7.9 Temperature versus Sun Angle

Note that the radiator temperature never exceeds the value at a 90° sun angle or lunar "noon". Since no solar energy impinges on the masks when $\theta = 90^{\circ}$, the failure of the side curtains to completely unfold in the deployed configuration is not considered critical.

7.3.6 Effect of Central Station Misalignment

If the Central Station is perfectly aligned on the lunar surface, no solar radiation impinges on the radiator plate or insulation masks. A study was conducted (Reference 10) to evaluate the maximum increase in radiator temperature due to misalignment of the C/S on the moon and consequent direct impingement of solar energy on the masks. Variable parameters were size, radiation properties, and effective thermal conductivity of the radiator masks. Lunar noon was established as the time of maximum heating of the radiator resulting from misalignment, and all following analysis results are based on this condition. With the current C/S design, a maximum possible increase of 7°F in radiator temperature over a perfect alignment condition is predicted.

The following study was based on a simplified version of the Qual SA thermal model, which had the primary function of determining variation of radiator plate average temperature with critical parameters (such as insulation mask size) with minimum expenditure of computer time. The model consists mainly of a "radiosity" node/resistance network which simulated radiation heat transfer in each of the two enclosures formed by the radiator plate, insulation mask, side curtains, sunshield overhang, specular reflector, surface, and space. Electronic thermal dissipation and solar heating as well as estimates of cable and thermal bag heat leaks were treated as inputs to the model. This model is capable of good approximations of radiator plate average temperature and is quite accurate for predicting variation of radiator temperature with critical parameters.

Solar heating resulting from C/S misalignment was determined with the Gebhart absorption factor technique (see Reference 11) because of the interreflection of solar energy within the two enclosures.

7.3.6.1 Analysis Criteria and Parameters

A number of criteria and parameters, discussed below, formed the basis for the analysis, which covered mask sizes from 6 to 8 inches.

1. Solar Impingement — The maximum predicted landing site displacement from the equator and misleveling of the C/S are 7° and 5°, respectively, which produces a combined 12° off-normal sun angle and a resulting 5.4 inch depth of solar impingement on each mask (see Figure 7.10). For conservatism, solar impingement was assumed over a 6 inch depth on all masks, which is equivalent to an off-normal sun angle of about 13.3^{o} at lunar noon.

2. Radiation Properties of Mask Surfaces — Four mask surface materials were analyzed: (1) aluminized mylar (α / ϵ = .12/.10), (2) silicon monoxide (α/ϵ = .15/.50, current mask design), (3) white paint (α/ϵ = .20/.90), and (4) black paint (α/ϵ = .95/.95). Items (1) to (3) were investigated in order to select the best mask surface material, while the black mask was assumed to give approximate results for a dust-covered surface.

3. Three values of K, the effective thermal conductivity perpendicular to mask insulation layers, were considered:

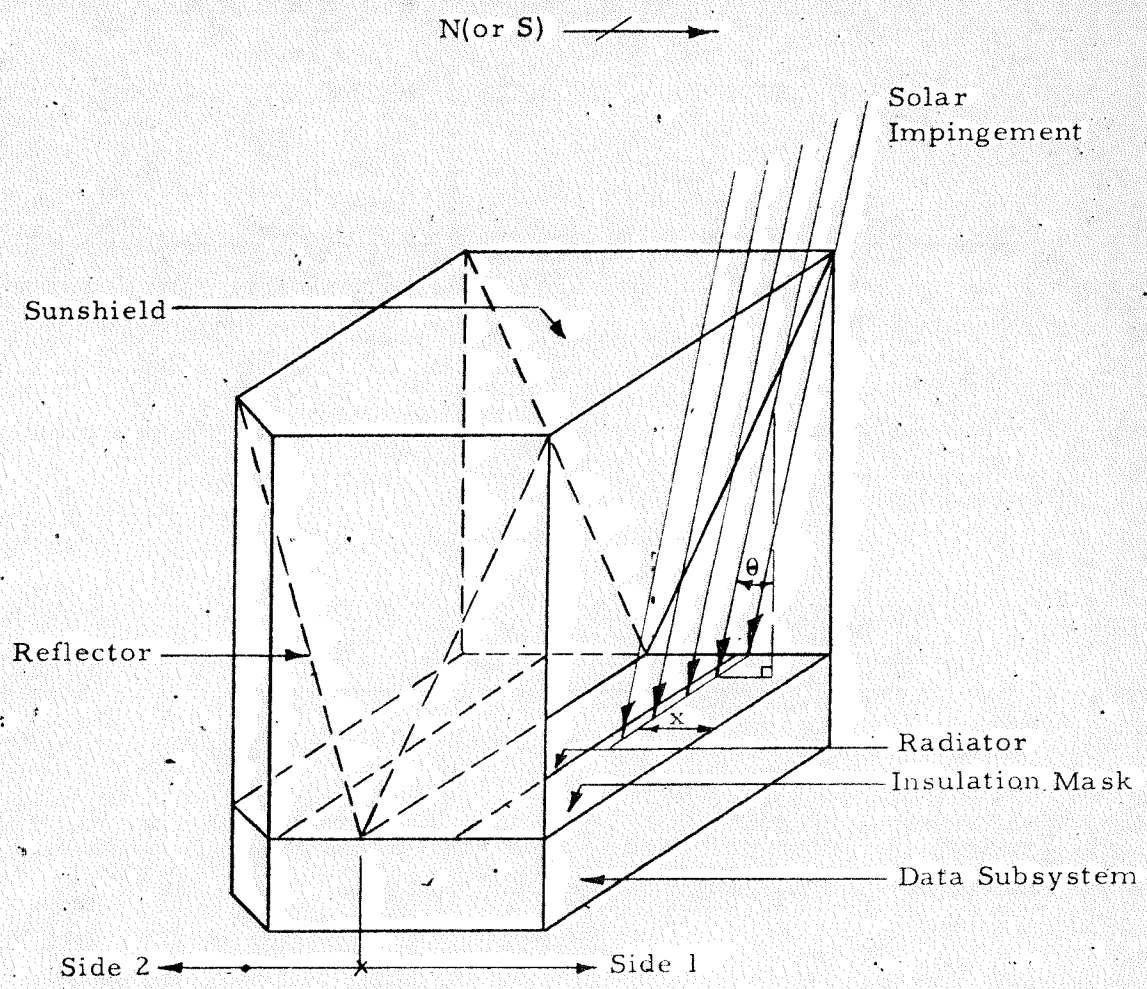
   a. Perfect insulation, K = 0

   b. $K = 10^{-3}$ Btu/ft - hr - ^{o}F

   c. $K = 10^{-4}$ Btu/ft - hr - ^{o}F.

7.3.6.2 Analysis Results

Analysis results are presented in Table 7.7 and in Figure 7.11 in terms of radiator temperature for "side 1" and "side 2". With the specular reflector apex dividing the radiator in half, side 1 is the rectangular half while side 2 represents the portion with one corner removed. The basic analysis was done on side 1, but two "points" were computed for side 2. These points are noted and extrapolated with dashed lines in Figure 7.11. Several conclusions may be drawn from the results:



$X_{assumed} = 6''$

$X_{specification} = 5.4''$

$\theta_{assumed} = 13.3^{o}$

$\theta_{specification} = 12^{o}\ (7^{o} + 5^{o})$

Figure 7.10 Solar Impingement Angle on Central Station Radiator Mask

TABLE 7.7

EFFECT OF MASK SOLAR HEATING ON CENTRAL STATION SIDE 1 RADIATOR TEMPERATURE

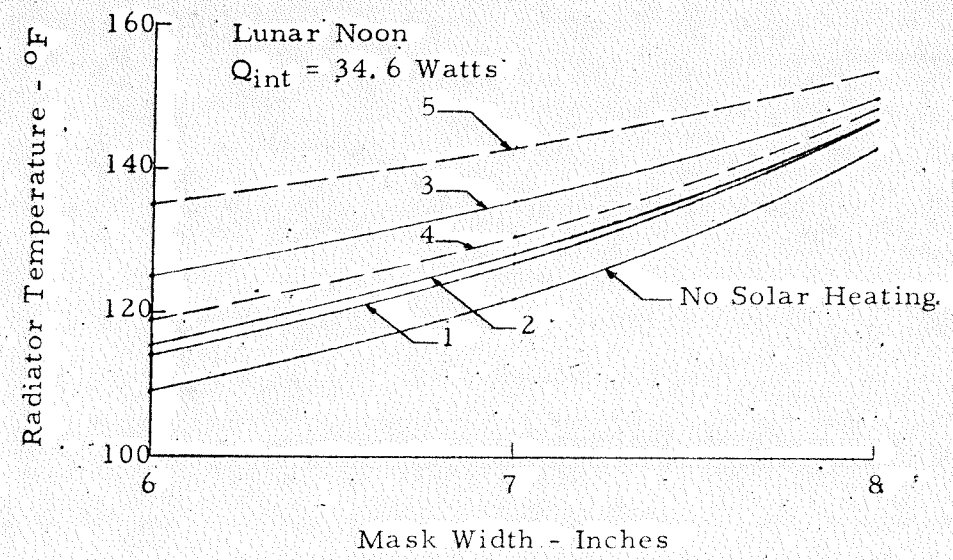
Mask Surface Type	α_s/ϵ (Mask)	T_{rad} °F		T_{mask} °F		Mask Conductivity Btu-ft/hr-ft^2-°F
		6" Mask	8" Mask	6" Mask	8" Mask	
Aluminized Mylar	.12/.1	114	146.5	329	284	0
		114.5	147.5	327	283	10^{-4}
		117	149	310	273	10^{-3}
SiO Over Aluminized Mylar	.15/.5	114	147.5	152	136	0.
		114.5	146.5	152	136	10^{-4}
		115	146.5	150	137	10^{-3}
White Paint	.2/.9	114.5	147	128	118	0
		114.5	147	128	117	10^{-4}
		115	146.5	128	119	10^{-3}
Black Paint	.95/.95	122.5	151.5	293	228	0
		123	152	293	228	10^{-4}
		125	150	291	227	10^{-3}

α_s = solar absorptivity

ϵ = thermal emissivity

Mask Properties

(1) SiO, Alum. Mylar, White Paint, $K = 10^{-4}$ BTU/hr-ft - °F
(2) SiO, $K = 10^{-3}$ BTU/hr-ft - °F
(3) Black Paint, $K = 10^{-3}$ BTU/hr-ft - °F
(4) Side 2, SiO, $K = 10^{-3}$ BTU/hr-ft - °F
(5) Side 2, Black Paint, $K = 10^{-3}$ BTU/hr-ft - °F



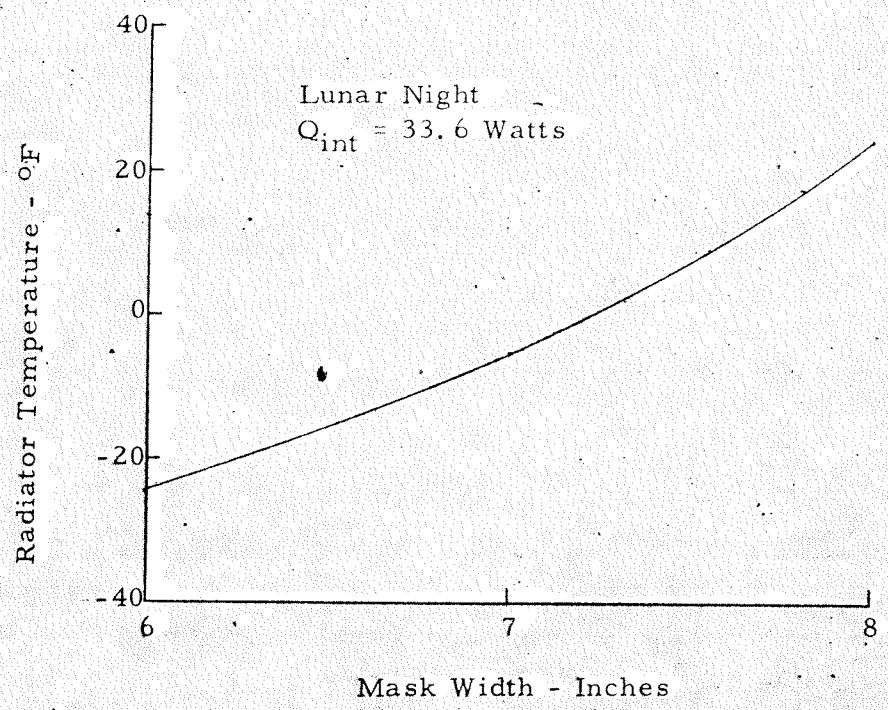


Figure 7.11 Effect of Mask Solar Heating on Central Station Radiator Temperature

1. The selected mask surface finish (SiO over aluminized mylar) is optimum with white paint and aluminized mylar nearly as good. A low α/ϵ ratio is desirable, with solar absorptivity being the controlling surface property.

2. Mask thermal conductivity was relatively unimportant in this study compared to radiation properties of the mask surface. For example, a 6 inch mask coated with SiO has a $5^{o}F$ temperature rise with $K = 0$ versus a $6^{o}F$ rise for $K = 10^{-3}$ Btu/ft-hr-^{o}F.

3. The misalignment effect is slightly worse on side 2 than on side 1 because side 2 has a smaller "view" to space.

4. For the selected mask design, the increases in radiator temperature on sides 1 and 2 at lunar noon due to C/S misalignment are $5^{o}F$ and $9^{o}F$, respectively, which gives an average increase of $7^{o}F$.

7.4 Design Improvements for Qual SA Model

After completion of the Proto A test program, several electrical and thermal performance changes were established for the Qual SA configuration. These changes are presented below in a comparison of Proto A performance with the predicted performance of the Qual SA model.

Performance Change	Power/Thermal Change-Watts Proto A	Qual SA
RTG Input Power	56 (minimum)	63-74
Experiment Loads at Lunar Night	43	51
PCU Regulator Range	40	55
Electronics Thermal Dissipation during Lunar Day	32	41 (maximum)
Electronics Thermal Dissipation during Lunar Night	31	32 (minimum)

As the above table shows, performance changes consisted of increases in C/S power and thermal dissipation. Based on Proto A test results and on increased electronics loads for future C/S designs, several thermal design improvements, which are discussed below, were required and incorporated into the Qual SA and subsequent Flight C/S models.

7.4.1 Removal of Sunshield Awnings and Side Curtain Extensions

All sunshield awnings and side curtain extensions were removed, which reduces the lunar noon operating temperature of the radiator plate by 28°F (as shown by Figure 7.12). As a consequence of this action, the radiator masks had to be redesigned to adjust for (1) the increased "view" of space by the radiator which decreases both the radiator temperature during lunar night and the temperature swing by 14°F and (2) the cutouts on the masks (for sunshield spacers) which expose the radiator to direct impingement of solar radiation. The problem in Item 2 is obvious and was corrected by use of an automatically deploying folded mask. The problem in Item 1 was that radiator night temperatures would be too small. As illustrated in Figure 7.12, a simple increase in mask size from 6 to 7 inches improved both temperature swing and lunar night temperature with little penalty on lunar day temperature. A rather detailed study, which is discussed in Reference 3 and below, was performed to size the masks.

7.4.2 Increase in Radiator Mask Size

Qual SA masks were sized with results of a parametric study which showed radiator thermal performance on the moon as a function of mask size and C/S power dissipation. Analysis results were based on the simplified thermal model described in Section 7.3.6 with no misalignment effects and are presented in both Figures 7.12 and 7.13. Qual SA Acceptance Test electronics thermal dissipation at lunar noon and night was 37.6 watts. Figure 7.13 shows that the radiator temperature rises 13°F at lunar noon and 18°F at lunar night due to the increase in mask width from 6 inches to 7 inches. A net decrease of 5°F in temperature swing is thus realized.

7.4.3 Addition of Backup Heaters

Additional "backup" heaters of 5 and 10 watts were attached to the Qual SA radiator plate to provide contingency power at lunar night to optimize temperature swing. Section 7.1.1 presents the effect of these heaters on lunar night radiator temperature during the Mission Simulation Test.

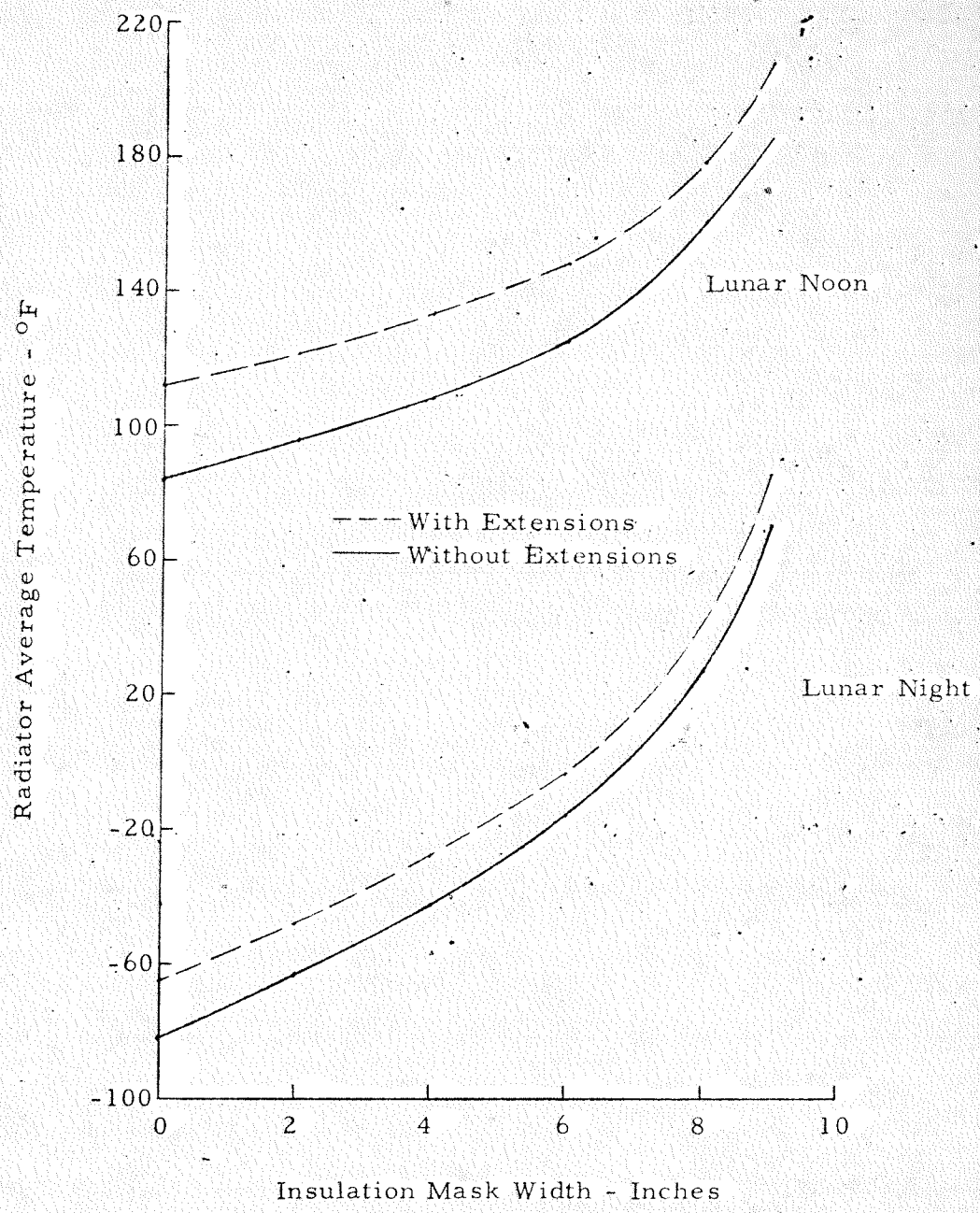


Figure 7.12 Central Station Thermal Performance Comparison With and Without Extensions at Lunar Noon and Lunar Night

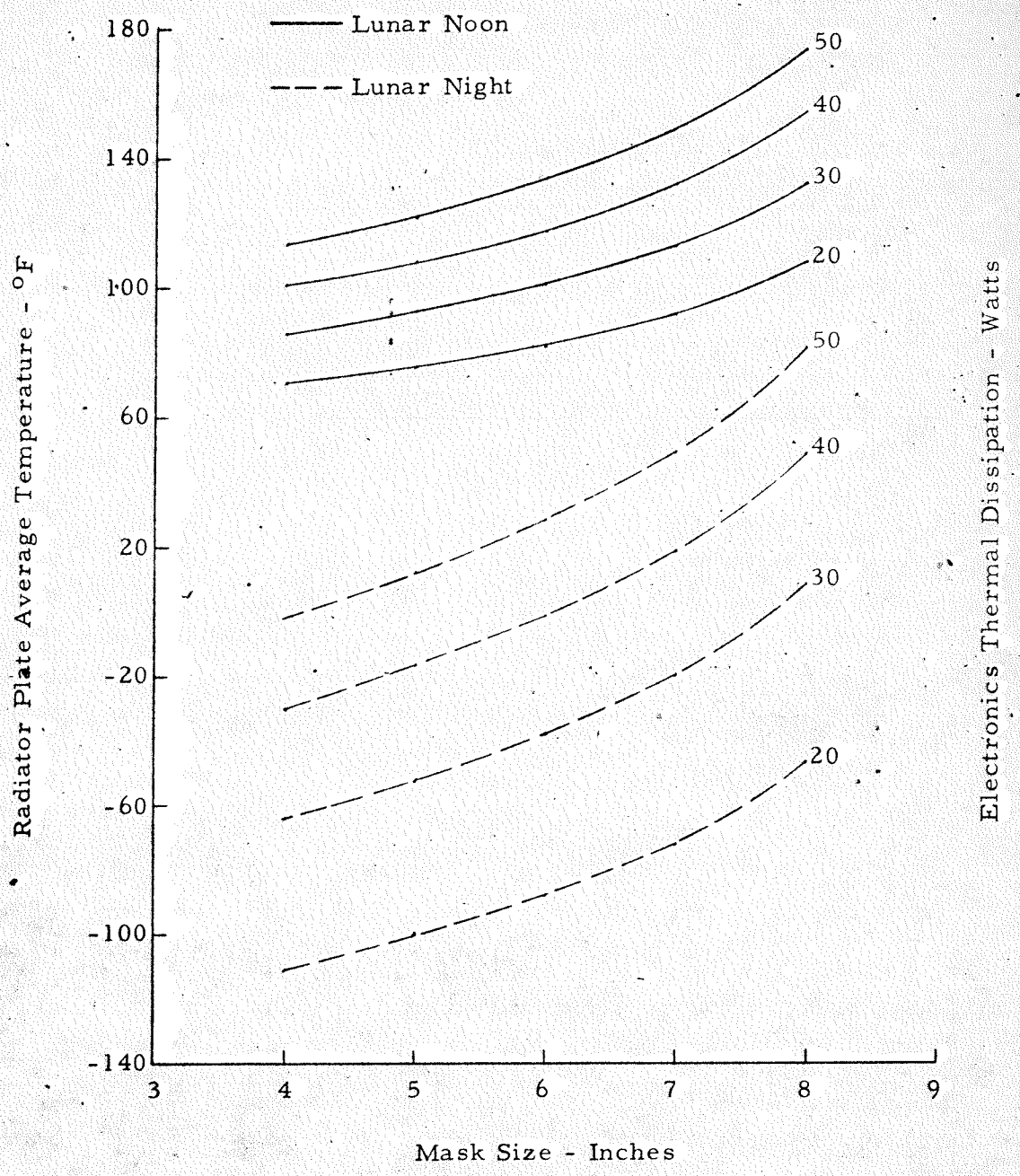


Figure 7.13 Central Station Radiator Average Temperature versus Mask Size

7.4.4 Net Improvement by Design and Performance Changes

An overall improvement in C/S predicted real moon operation of the Qual SA model over the Proto A model was realized due to thermal design and electrical performance changes. Individual effects of the changes are summarized below in terms of radiator plate temperature. A plus sign indicates a temperature increase in the Qual SA model over the Proto A model.

Design/Performance Change	Temperature Change ~ °F Noon	Night	Swing
Removal of Sunshield and Side Curtain Extensions	+28	-14	-14
Increased Mask Width from 6 inches to 7 inches	+13	+18	-5
Increased C/S Electronics Thermal Dissipation	+9	+21	-12
Net Change	-6	+25	-31

Thus, the predicted performance in a real lunar environment of the Qual SA model excels Proto A by 31°F in temperature swing. T/V chamber test results supported the predictions, as shown by the comparison below:

Model	Radiator Temp. ~ °F Noon	Night	Temp. Swing ~ °F
Proto A	104	-15	119
Qual SA (Acceptance)	92	6	86

The above table shows the following improvements in T/V chamber performance of the Qual SA radiator over the Proto A radiator:

1. A 12°F decrease in lunar noon temperature.

2. A 21°F increase in lunar night temperature.

3. A 33°F decrease in temperature swing.

7.5 Radiator Plate Thermal Balances

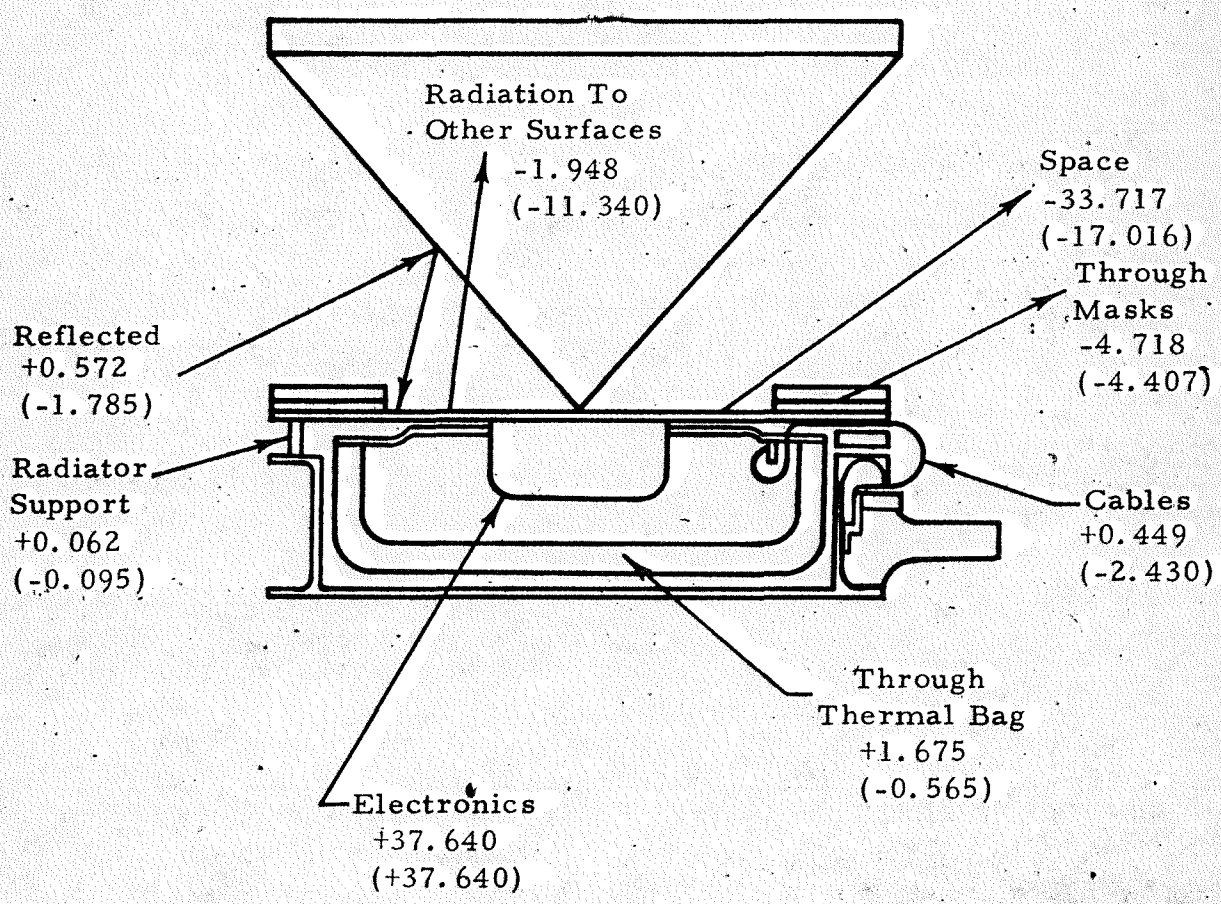
Heat flow at the radiator plate is depicted in Figures 7.14, 7.16, and 7.18 for the T/V chamber Acceptance, Mission Simulation, and Design Limit Test environments at lunar noon and night. Figures 7.15 and 7.17 show the predicted real moon thermal performance of the radiator for Acceptance and Mission Simulation electrical loads.

Since the thermal balances are for steady-state conditions, the net heat flow at the radiator must always be zero. For example, the net heat flow at lunar noon for the T/V Acceptance Test is as follows:

$$\text{Net Heat Flow} = \sum \text{Heat in} - \sum \text{Heat Out}$$

$$= 37.640 + 1.675 + .449 + .572 + .062$$

$$- 4.718 - 33.717 - 1.948 \approx 0$$

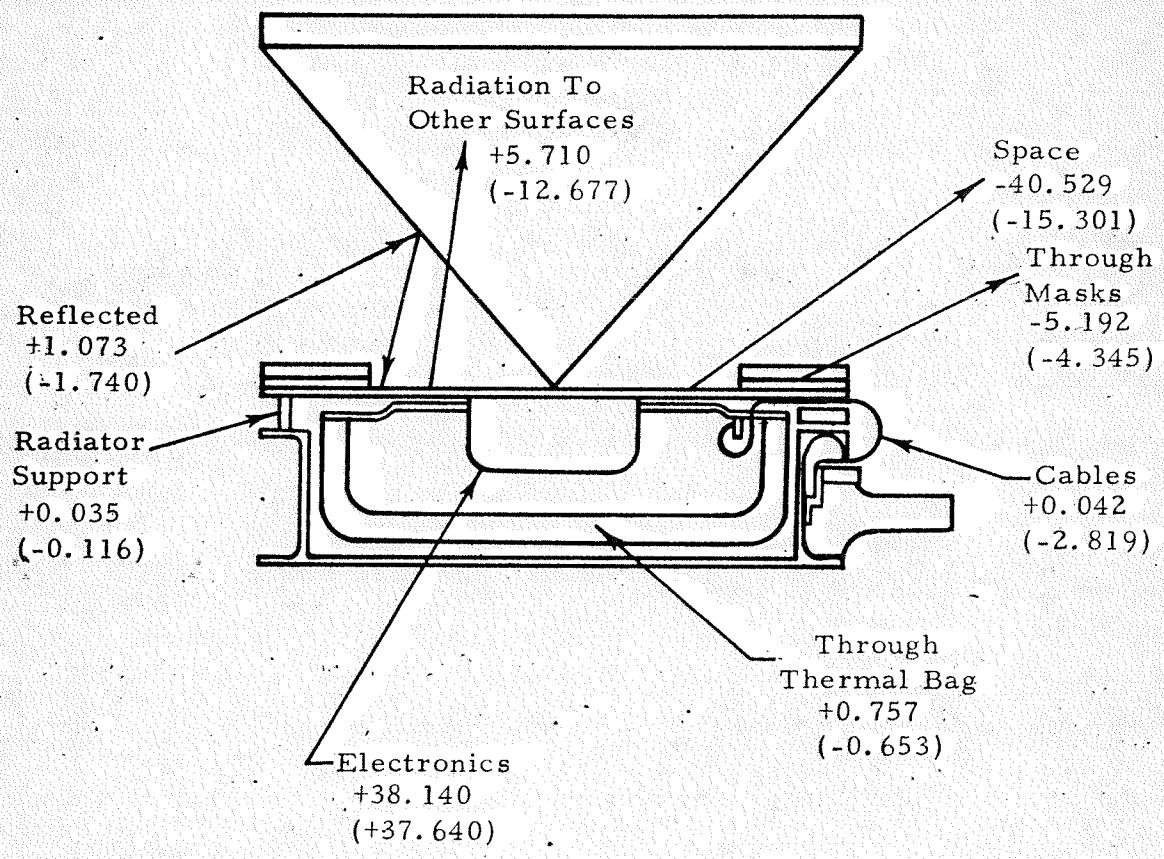


\+ Into Radiator
\- From Radiator

xxx Noon
(xxx) Night

All values are in watts

Figure 7.14 Thermal Balance on Qual SA T/V Acceptance Test Radiator Plate at Lunar Noon and Lunar Night

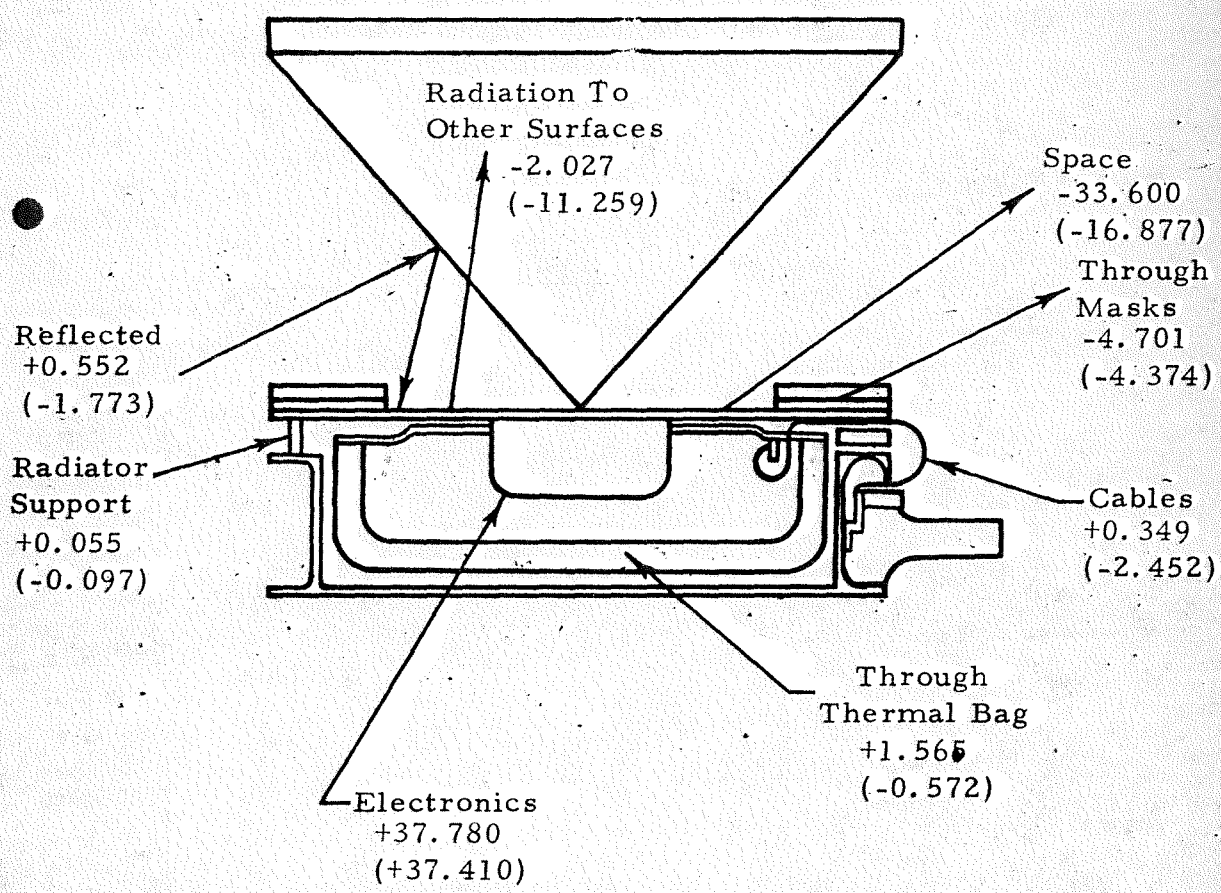


\+ Into Radiator
\- From Radiator

xxx Noon
(xxx) Night

All values are in watts

Figure 7.15 Thermal Balance on Radiator Plate of Qual SA Acceptance Model in Real Lunar Environment

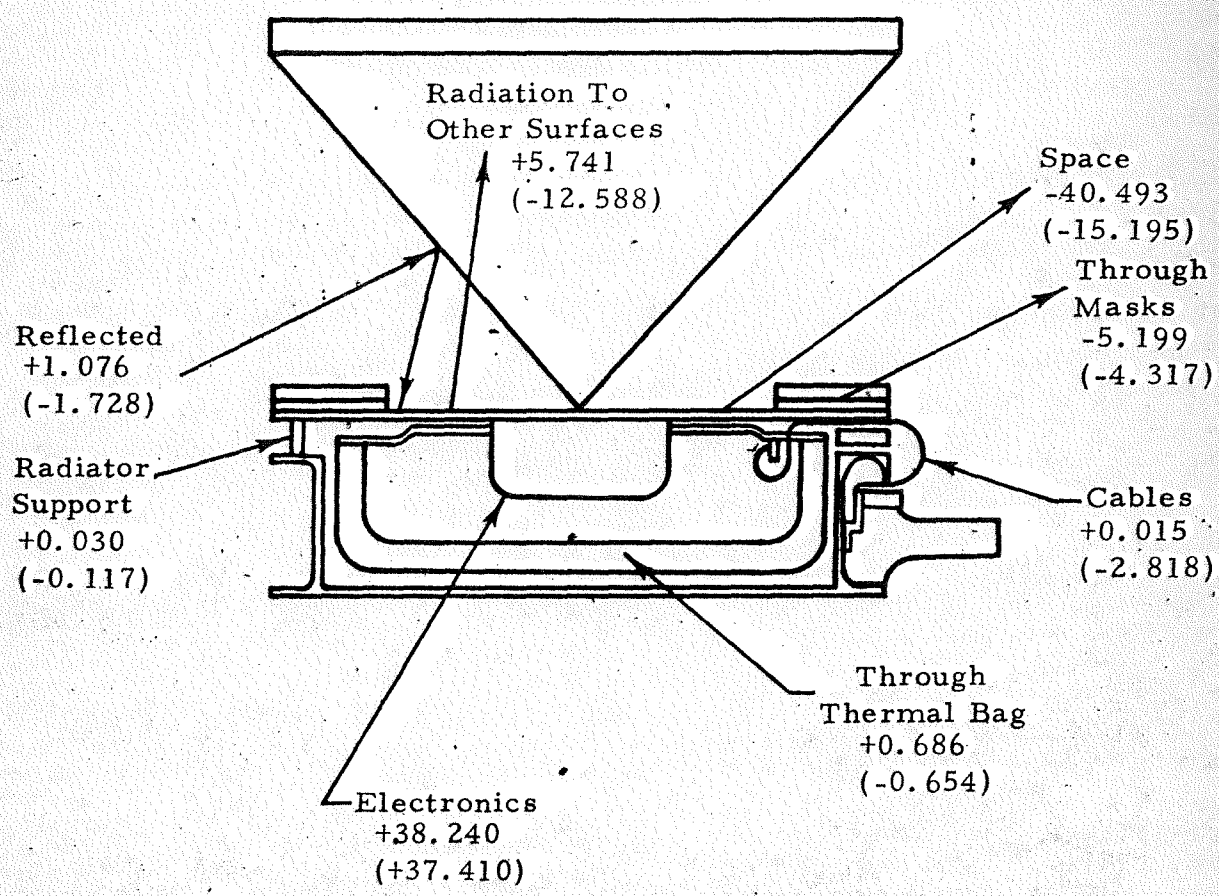


\+ Into Radiator
\- From Radiator

xxx Noon
(xxx) Night

All values are in watts

Figure 7.16 Thermal Balance on Qual SA T/V Mission Simulation Test Radiator Plate at Lunar Noon and Lunar Night

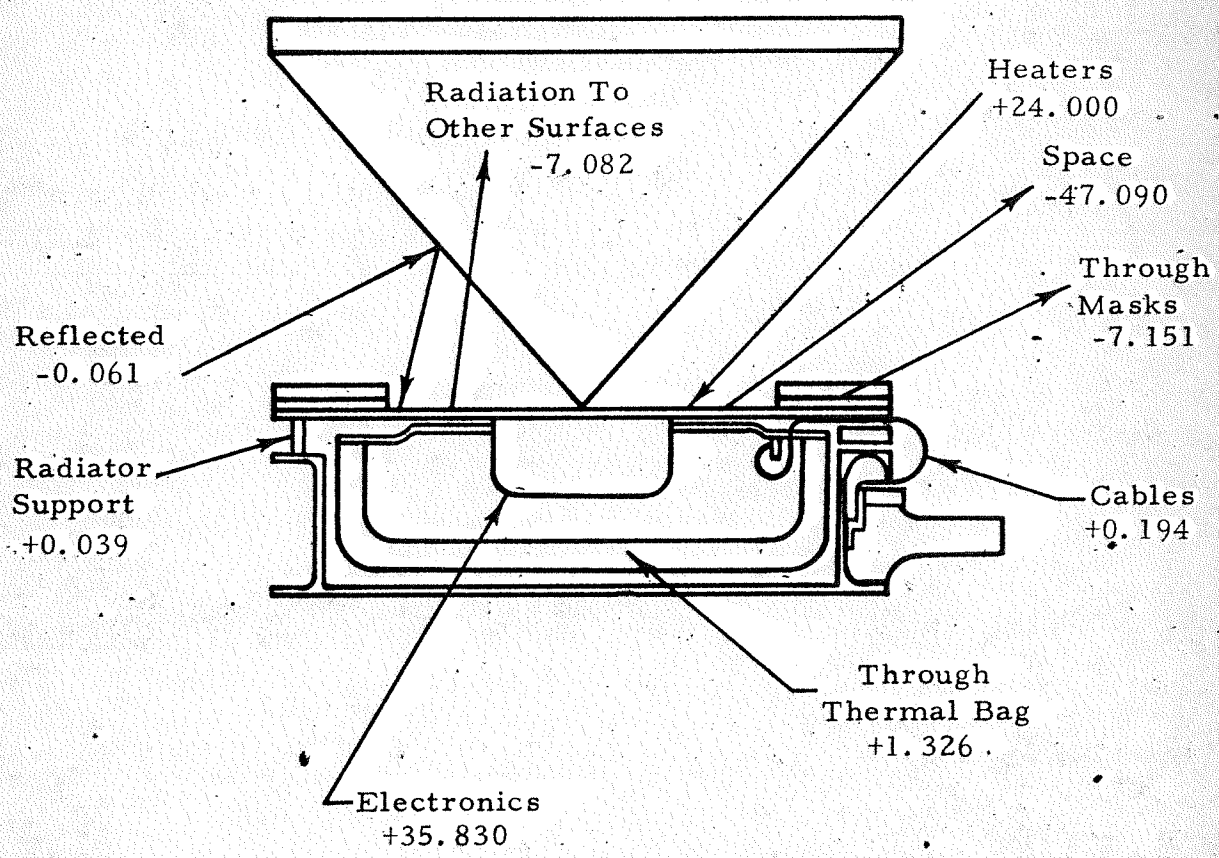


\+ Into Radiator
\- From Radiator

All values are in watts

xxx Noon
(xxx) Night

Figure 7.17 Thermal Balance on Radiator Plate of Qual SA Mission Simulation Model in Real Lunar Environment



\+ Into Radiator
\- From Radiator

All values are in watts

xxx Noon
(xxx) Night

Figure 7.18 Thermal Balance on Qual SA T/V Design Limit Test Radiator Plate for Maximum Radiator Temperature

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