This ATM presents the results of the ALSEP Prototype A Central Station Thermal Analysis design review held at BxA on 9 January 1968. Copies of the material presented are enclosed together with a brief summary of the test results and post test thermal analysis correlation.

ALSEP Central Station

Proto A Thermal Analysis

Design Review

9 January 1968

ATM 737

J. McNaughton

T. Fenske

Proto A Central Station Thermal Analysis Design Review

Attendees:

MSC

A. Carraway
D. Gerke
G. Kenney
R. Harris
J. Grayson
J. Harris

Bell Comm

P. Hickson

BxA

E. Van Valkenberg
T. Fenske
C. Ahlstrom
G. Frank
L. Hearin
L. Lewis
G. Psaros
A. Schorken
T. Fox
A. Hook
R. Shay
C. Weatherred
J. McNaughton

1. The purpose of the meeting was to present the Proto A thermal test results and review the overall Central Station pre-test thermal predictions and subsequent post test analysis correlation.

2. J. McNaughton reviewed the ALSEP Prototype A Central Station thermal test objectives which are shown in Figure 1.

3. L. Hearin then discussed the assumptions utilized in the C/S thermal analysis, reference Figure 2, together with a detailed review of the analytical techniques used to derive the digital computer thermal model of the central station. Figures 3 through 5 summarize the techniques employed along with a typical C/S radiator plate nodal heat balance.

4. Figure 6 summarizes the computer programs required for the thermal analysis of the C/S design which include: (1) Confac II for geometric view factor determination, (2) Dynatech for specular/diffuse radiation resistor determination and (3) the BxA thermal analyzer for steady-state temperature and heat flow nodal solution. Figure 6 also describes the digital computer program nodal and resistor network size.

Figure 1

ALSEP PROTOTYPE A CENTRAL STATION THERMAL TEST OBJECTIVES

PRIMARY

1.) Design verification of ALSEP Central Station thermal control under simulated lunar environmental day and night conditions to insure results comply with established limits and confirm present predicted values.

SECONDARY

1.) Determine the internal and external temperature gradients and levels on the Central Station radiator plate, primary structure, superinsulation, sunshield, electron components and cables for simulated lunar day and night environment.

2.) Assess the heat leaks into and out of the Central Station due to radiation and conduction from specular reflector, cables, thermal plate and structure for lunar day/night conditions.

3.) Determine the temperature gradients between the Central Station thermal plate and internal electronic components to provide comparison with pre-test predicted levels.

4.) Evaluate the overall performance of the Central Station thermal design to maintain 125° temperature swing at Proto A Experiment dissipation levels and 63 w RTG input power.

• ASSUMPTIONS IN THERMAL ANALYSIS

LUNAR ENVIRONMENT

LUNAR SURFACE TEMPERATURE	-300°F NIGHT +250°F NOON
SPACE SINK	-300
SOLAR CONSTANT	442 BTU/HR.FT.^{2}

• CENTRAL STATION MODEL

INTERNAL DISSIPATION:	35.1 W. NOON 35.1 W. NIGHT
RADIATOR PLATE:	$\alpha/\epsilon = .2/.9$

SURFACES EXPOSED TO RADIATION MAY HAVE: $\alpha/\epsilon = .9/.9$

SPECULAR REFLECTOR:	ρ SPECULAR = 0.9
	ρ DIFFUSE = 0.1
	ϵ = 0.1

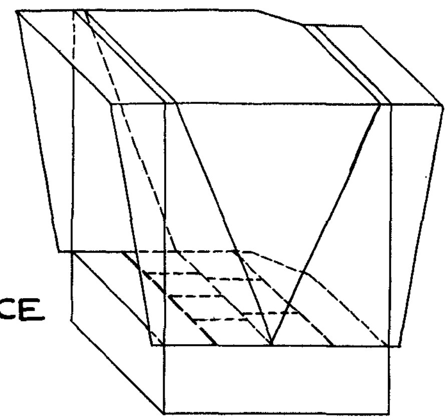
FIGURE 2

ANALYTICAL TECHNIQUES

- FINITE DIFFERENCE NODE-RESISTANCE NETWORK
- GENERAL NETWORK RESISTOR TYPES

A) RADIATION – $q_{mn} = \dfrac{\sigma T_m^4 - \sigma T_n^4}{R}$

1) SPECULAR-DIFFUSE RADIATION ENCLOSURE



(a) DIFFUSE SURFACE RESISTANCE

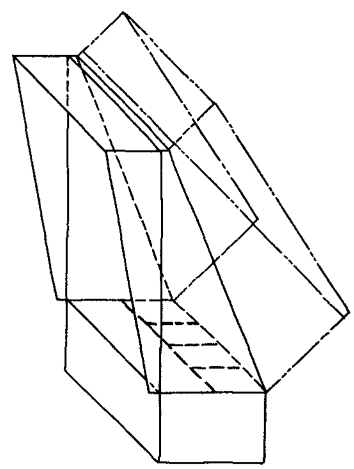
m

$$R = \frac{1-\epsilon_m}{A_m \epsilon_m}$$

(b) SPECULAR-DIFFUSE SURFACE RESISTANCE

i

$$R = \frac{\rho_{Di}}{A_i \epsilon_i (1-\rho_{Di})}$$



(c) DIFFUSE SPACE RESISTANCE

m n

$$R = \frac{1}{A_m [F_{mn} + \rho_{si} F_{mn(i)}]}$$

(d) SPECULAR-DIFFUSE SPACE RESISTANCE

$$R = \frac{1}{(1-\rho_{si}) A_m F_{mi}}$$

2) OTHER RADIATION

m n

$$R = \frac{1}{\epsilon_m \epsilon_n A_m F_{mn}}$$

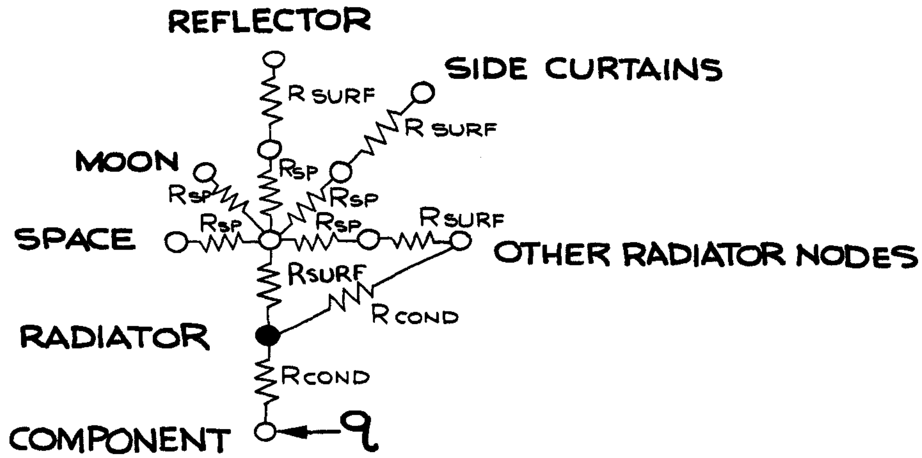
B) CONDUCTION – $q_{mn} = \dfrac{T_m - T_n}{R}$

m n

$$R = \frac{L_1}{K_1 A_1} + \frac{L_2}{K_2 A_2} + \frac{1}{h_c A_c}$$

FIGURE 3

TYPICAL RADIATOR NODE HEAT BALANCE



q = HEAT FLUX BETWEEN NODES
T = TEMPERATURE
R = RESISTANCE
A = RADIATING AREA
F = VIEW FACTOR BETWEEN SURFACES
ϵ = SURFACE EMITTANCE
ρ_{Δ} = DIFFUSE REFLECTANCE OF SURFACE
ρ_s = SPECULAR REFLECTANCE OF SURFACE
σ = STEFAN-BOLTZMANN CONSTANT

SUBSCRIPTS

m,n = RESPECTIVELY REPRESENT GENERAL DIFFUSE NODES IN SYSTEM
i = SPECULAR-DIFFUSE NODE IN SYSTEM
SURF = SURFACE
SP = SPACE

FIGURE 4

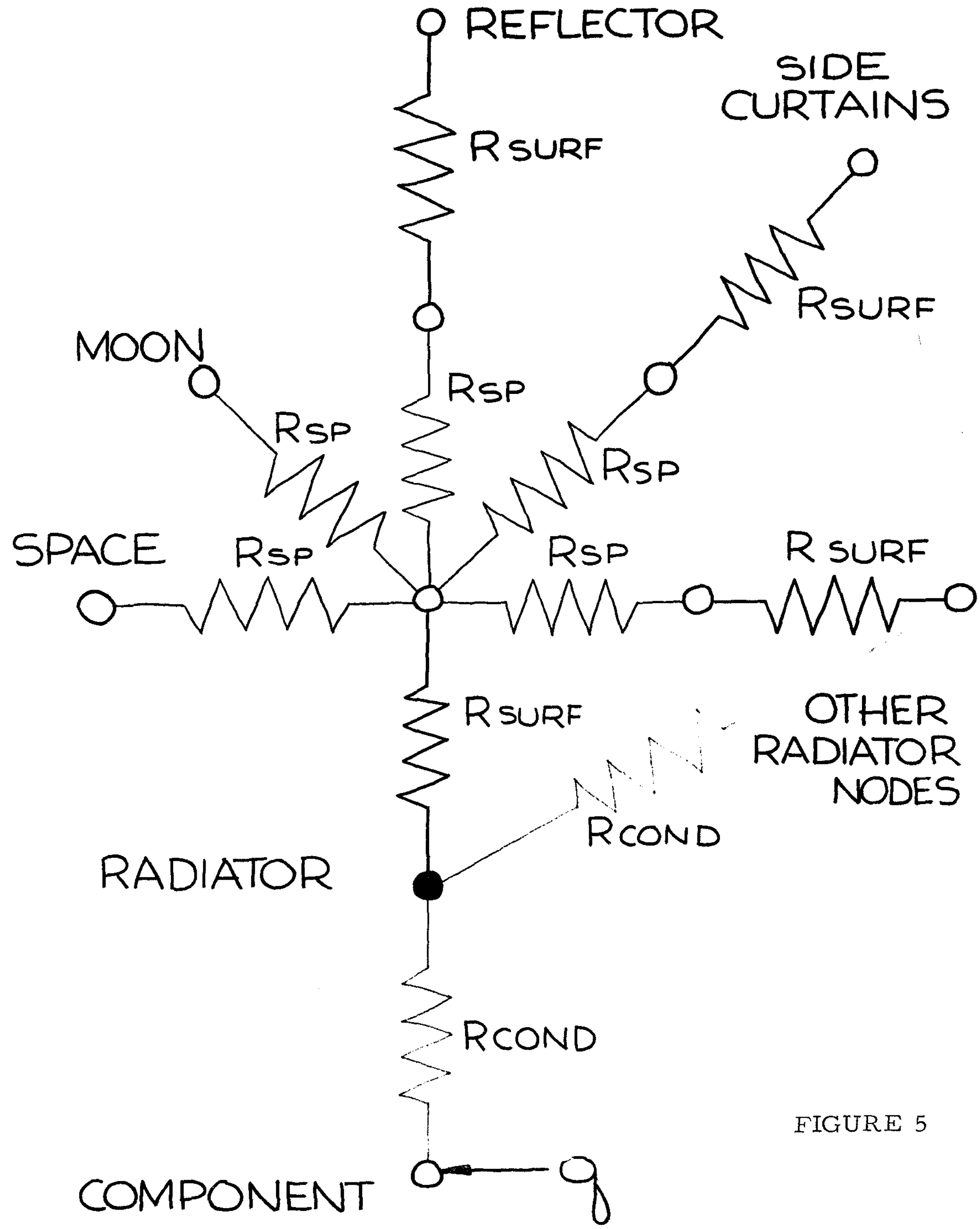


FIGURE 5

TYPICAL RADIATOR NODE HEAT BALANCE

• COMPUTER PROGRAM SUMMARY

PROGRAM TITLE	FUNCTION
CONFAC II	VIEW FACTOR DETERMINATION BETWEEN SURFACES~PERMITS RESISTOR EVALUATION TO MOON & SPACE
DYNATECH	RESISTOR DETERMINATION FOR SPECULAR-DIFFUSE ENCLOSURE
THERMAL ANALYZER	SOLVES RESISTANCE NETWORK CONSTRUCTED WITH ABOVE PROGRAMS FOR STEADY STATE NODE TEMPERATURE

• NODE-RESISTANCE NETWORK SIZE

NUMBER OF NODES	57
NUMBER OF RESISTORS	284
CONDUCTION	85
RADIATION	199

FIGURE 6

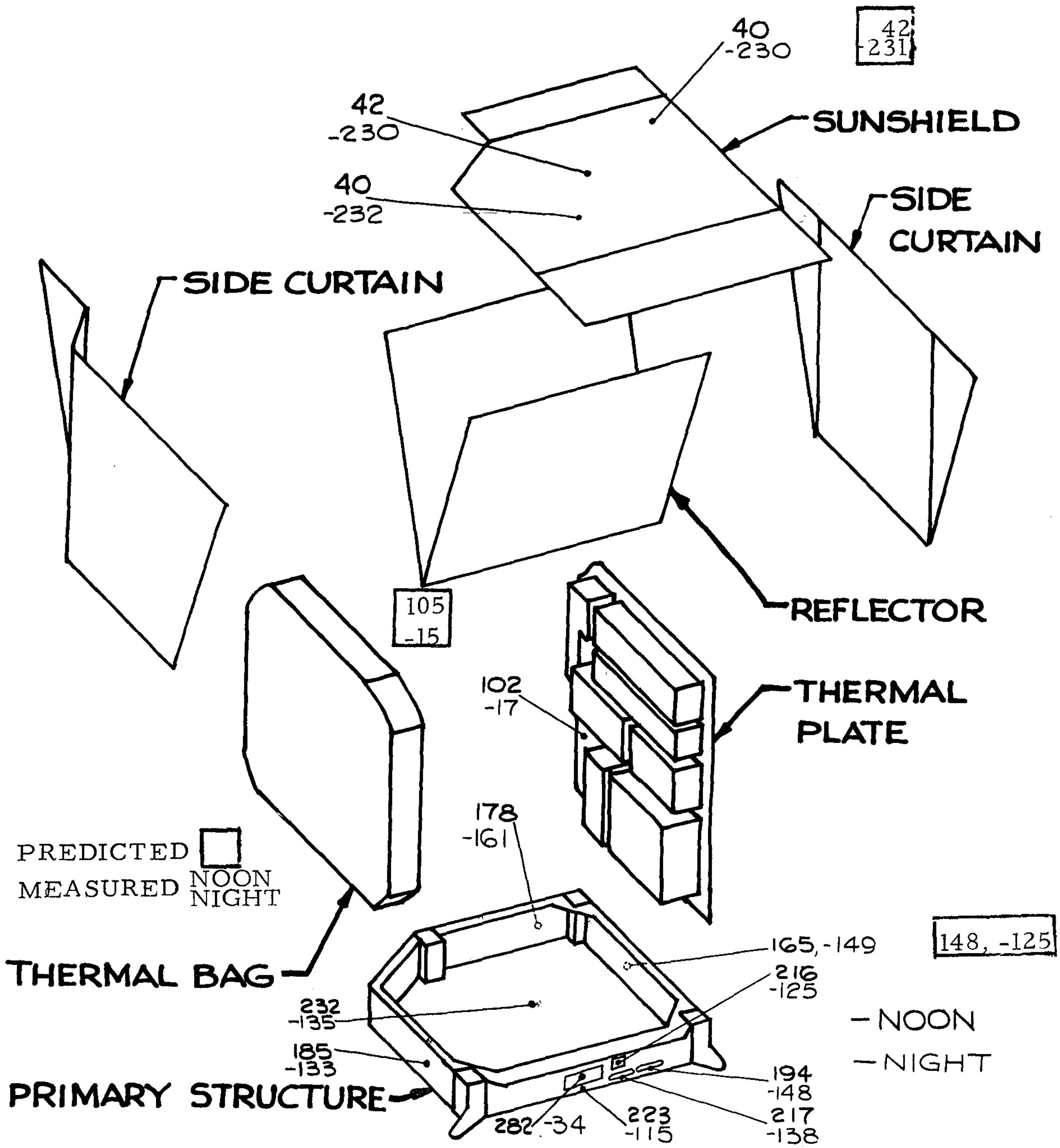
5. J. McNaughton then discussed the results of the Proto A T/V tests for the C/S lunar day and night testing. Figure 7 shows the lunar day/night temperature results for the Proto A primary structure, thermal bag, thermal plate, dump resistors and sunshield. Sunshield temperatures ranged from 40 to 42°F as compared to a predicted value of 42°F. C/S primary structure temperatures ranged from 165°F to 185°F for the lunar day and -133°F to -149°F for night as compared to predicted values of 148°F and -125°F for the two lunar conditions, respectively. The maximum PCU dump resistor plate temperature observed was 350°F at a PCU reserve power reading of 29 watts.

6. Figure 8 shows the results of the measured C/S radiation plate steady-state temperature from the Proto A lunar day/night tests. The average lunar noon temperature for the C/S thermal plate was 105°F and for lunar night -15°F with an overall swing of 120°F. These temperatures compared favorably with the analytical predicted average C/S thermal plate temperatures of 115°F for day, -14°F for night and an overall swing of 129°F. The temperature gradients on the thermal plate were approximately ± 7°F from the average values. Figures 9 and 10 show a comparison of the predicted versus the measured test result values for the lunar noon and lunar night cases, respectively.

7. Figure 11 summarizes the component temperatures inside the Central Station for the Proto A lunar noon/night tests. Maximum component temperature observed inside the C/S was the PCU transistor at 151°F. All other components temperatures ranged from 1°F to 20°F above the base plate temperature and were within the operating range predicted from pre-test component acceptance test results.

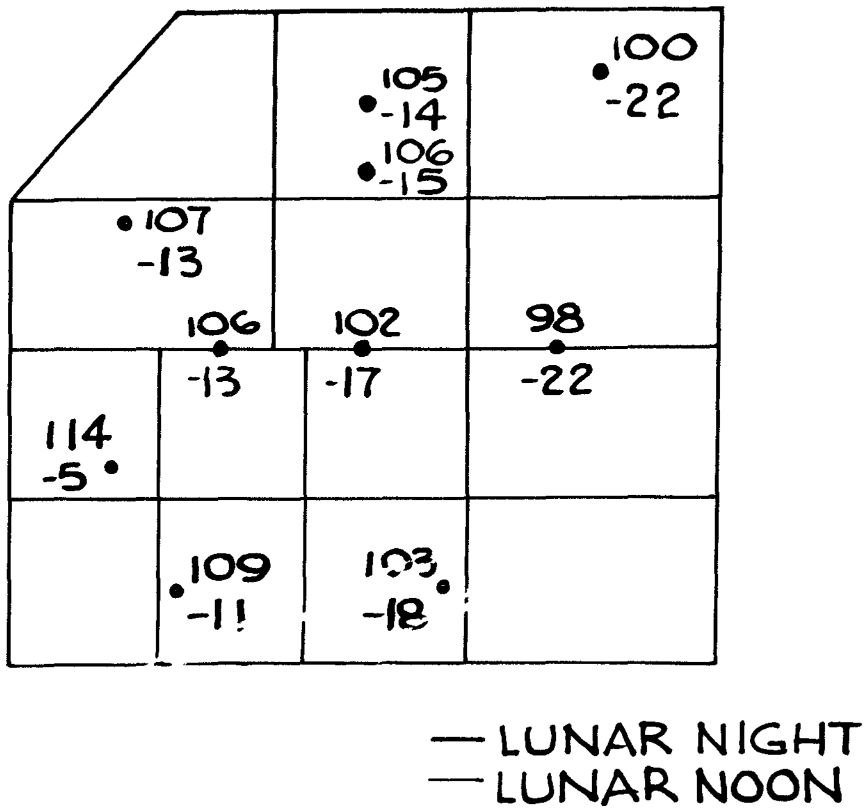
8. Figure 12 describes the Proto A lunar surface temperature distribution test results for both lunar day and night tests. The surface temperature on the average varied approximately 250° ± 20°F for lunar noon and 303° ± 2°F for lunar night. Temperature gradients were observed on the lunar surface where blockage due to the Subpackages 1 and 2 and experiments prevented the surface from seeing the cryowall.

9. Figure 13 summarized the day/night Central Station calculated heat balance from the thermal plate to the surrounding sink conditions. As noted, the C/S internal electronic dissipation for both the day and night testing was 35.1 ± 1 watt.



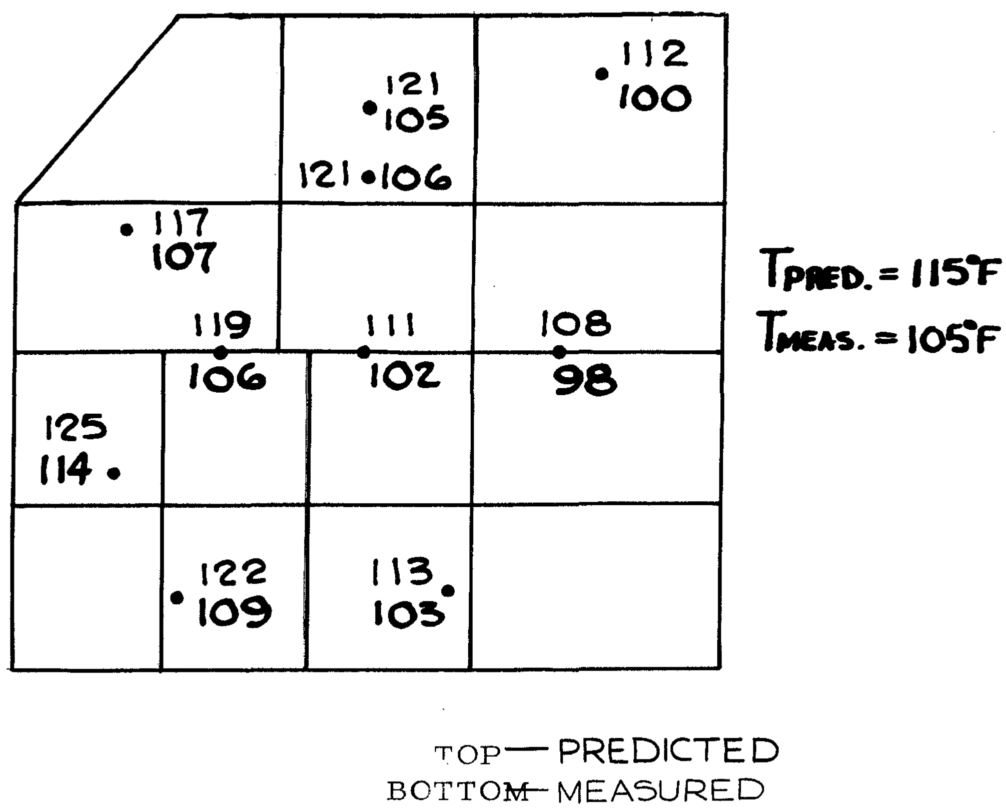
ALSEP PROTO "A" TEST TEMPERATURE RESULTS ON SUBPACKAGE № 1 FOR LUNAR NOON & LUNAR NIGHT

FIGURE 7



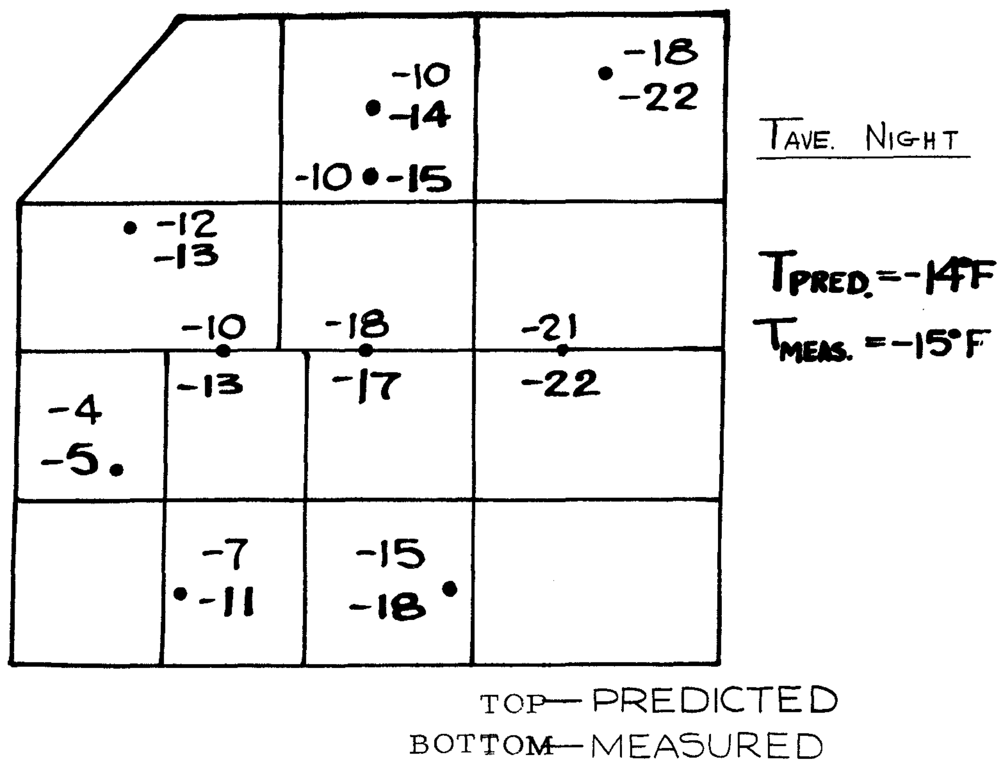
ALSEP PROTOTYPE "A" SYSTEM TEST-
MEASURED RADIATOR TEMPERATURES FOR
LUNAR NOON AND LUNAR NIGHT

FIGURE 8



ALSEP PROTOTYPE "A" SYSTEM TEST-
PREDICTED vs MEASURED RADIATOR
TEMPERATURES FOR LUNAR NOON

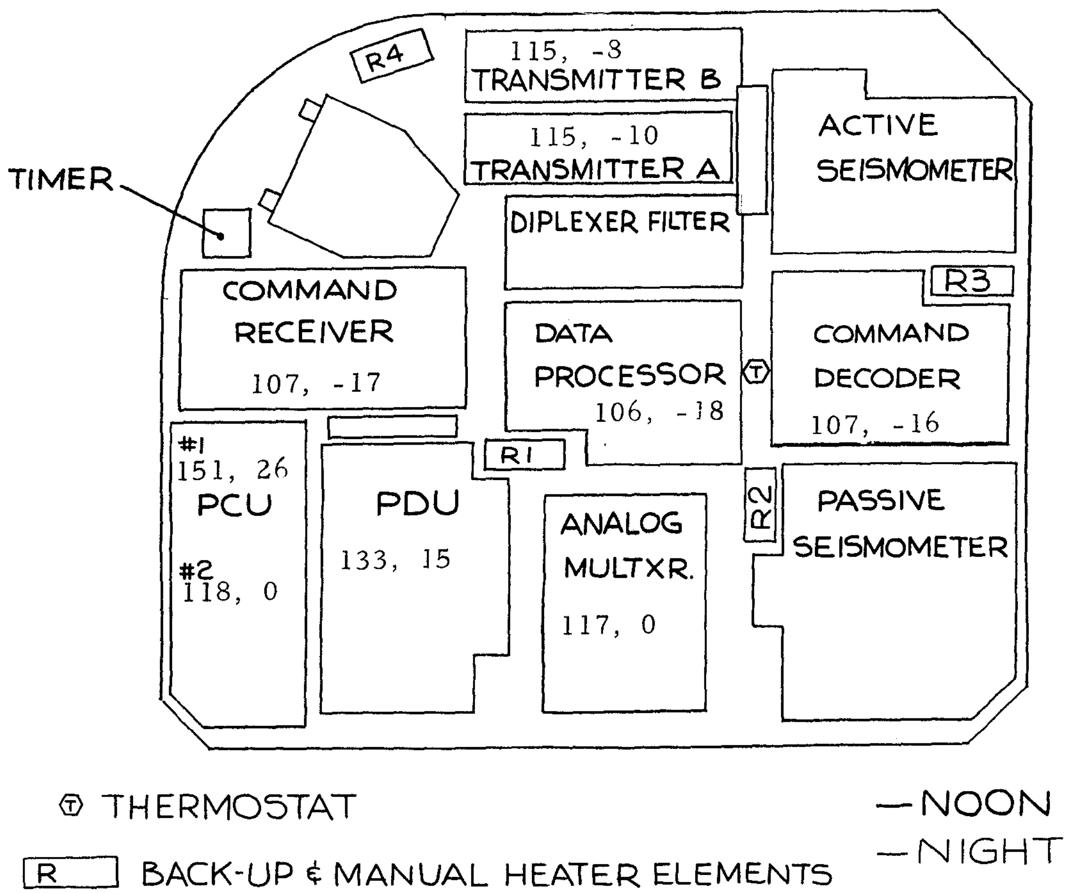
FIGURE 9



ALSEP PROTOTYPE "A" SYSTEM TEST - PREDICTED vs MEASURED RADIATOR TEMPERATURES FOR LUNAR NIGHT

FIGURE 10

Component	Component Base Temp, °F Day/Night		Component Temp, °F Day/Night		Delta Temp, °F Day/Night		Predicted Delta Temp, °F Day/Night
1. PCU Transistor #1	114	-5	151	26	37	31	60
2. PCU Transistor #2	114	-5	118	0	4	5	5
3. Transmitter A	105	-14	115	-10	10	4	20
4. Comm. Receiver	103	-19	107	-17	4	2	5
5. PDU	112	-10	133	15	21	25	20
6. Command Decoder	98	-22	107	-16	9	6	5
7. Digital Data Processor	103	-15	106	-18	3	3	5
8. Analog Multiplexer	106	-17	117	0	11	17	20



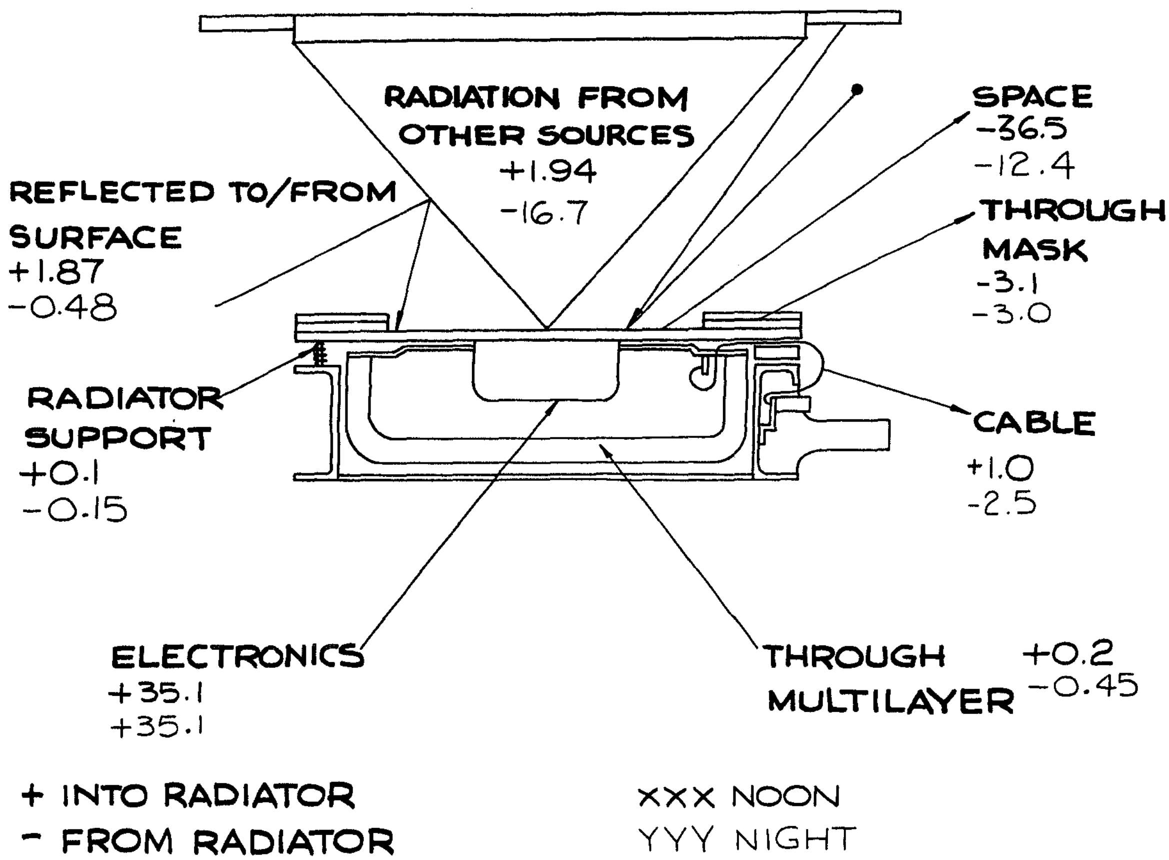
ALSEP PROTO "A" CENTRAL STATION TEST COMPONENT TEMPERATURE RESULTS FOR LUNAR NOON & LUNAR NIGHT

FIGURE 11

	230 -303	238 —	239 -303	213 -303	— -303	
236 -303	265 -303	245 -303	264 -303	270 •	268 -302	248 -302
242 -302	264 -302	237 -302	252 -302	271 -300	264 -302	242 -302
— —	272 -303	248 -301	246 —	236 -303	— —	— -303
230 -303	255 —	248 -302	286 -303	257 -302	254 -303	217 -303
239 -303	262 -303	278 -303	328 -303	250 -303	256 -303	217 -303
	250 -303	245 -303	259 -303	222 -302	241 -303	

ALSEP PROTOTYPE "A" SYSTEM TEST - LUNAR SURFACE TEMPERATURE DISTRIBUTION FOR LUNAR NOON & LUNAR NIGHT TEST CONDITIONS

FIGURE 12



ALSEP PROTO "A" CENTRAL STATION HEAT BALANCE FOR LUNAR NOON & LUNAR NIGHT

FIGURE 13

10. Figure 14 shows the post test thermal analysis correlation for the C/S test results together with the pretest predicted values. Initial pretest predictions indicated a passive temperature swing of 147°F for the day/night conditions. From the BxA post test correlation of the test results the central station thermal model was modified to bring the pretest assumptions in line with actual chamber conditions. The post test correlation changes included a reduction in view factors to the lunar surface, elimination of the lunar surface solar impingement, an increase in the reflector specular reflectivity and change to the Proto A actual component power dissipation levels. The final post test analytical temperature predicted range was 129°F which compared favorably with the actual test results of 120°F.

11. Figure 15 lists the Central Station thermal design improvements and changes for the Qual SA design. Preliminary thermal studies completed on the C/S during the past month have shown that an approximate 15°F to 20°F improvement can be obtained by removing the current awning and the attaching side curtains. This modification together with the deletion of the thermal isolation blocks (net change -13°F to -15°F) will be incorporated into the Qual SA model.

12. Figure 16 summarizes the Proto A and Qual SA Central Station temperature swing as a function of the RTG power level, the PCU loads, the current and revised design with both commandable dumps and active heater power. Figure 16 shows that the revised Qual SA design with new awnings and Proto A experiment loads is predicted to operate on the moon within the specification allowable of 125°F. With the change in experiment nighttime power loads by 8 watts from Proto to Qual, the total temperature swing for Qual, Flights 1 and 2 is predicted to increase to a maximum of 148°F for a 63 to 74 watt RTG power range and a 40 w regulation. The Central Station temperature swing can be reduced by active thermal control to a maximum value of 132°F through the use of commandable dumps during the day and the +10 w backup heater at night. The use of the 10 watt heater results in the ripple off of at least one or more experiments depending on the RTG input power, due to the already high 51 watt PCU nighttime loads. The ripple off of the experiment occurs due to the reserve power being lower than the 10 watt minimum value required. As shown in Figure 16 the use of a 68 watt RTG reduces the swing to 140°F for the (passive) case and 124°F for the active case.

POST TEST CORRELATION OF PROTO "A" CENTRAL STATION TEST RESULTS & PREDICTIONS

ORIGINAL ASSUMPTION	CHANGE	T_D (°F)	T_N (°F)	ΔT_{D-N} (°F)	$\Delta(\Delta T_{D-N})$ (°F)
INITIAL CHAMBER PREDICTION	——	131	-16	147	—
• VIEW FACTORS TO LUNAR SURFACE	REDUCE TO REALISTIC VALUES	125	-16	141	6
• SOLAR IMPINGEMENT ON MOON	ACCOUNT FOR NO SOLAR	121	-16	137	4
• REFLECTOR $\rho_s = 0.8$	$\rho_s = 0.9$	117	-17	134	3
• $Q_D = 36W, Q_N = 34W$	$Q_D = 35.1W$, $Q_N = 35.1W$	115	-14	129	5

COMPARISON WITH TEST

	T_D (°F)	T_N (°F)	ΔT_{D-N} (°F)
FINAL PREDICTION	115	-14	129
PROTO "A" TEST RESULTS	105	-15	120

FIGURE 14

CENTRAL STATION THERMAL CONTROL SYSTEM IMPROVEMENTS AND CHANGES

	IMPROVEMENT IN TEMPERATURE SWING
• REMOVE ISOLATORS	-3°F TO -5°F
• REMOVE AWNING AND MODIFY RADIATOR MASK	15° TO 20°
• NET IMPROVEMENT	13° TO 15°

FIGURE 15

C/S MODEL	LOCATION	RTG POWER-W	REG. POWER-W	TEMP SWING	TEMP SWING WITH COMM. DUMPS, °F W/O HTR.	TEMP SWING WITH COMM. DUMPS, °F WITH HTR
1. PROTO "A"	CHAMBER	62	35	120	–	100
2. PROTO "A"	MOON	62	35	140	130	115
3. QUAL "A" ① (WITH PROTO EXP. LOADS)	MOON	63	40	125	115	100
4. QUAL "A" (WITH QUAL EXP. LOADS)	MOON	63	40	148	137	132 ②
5. QUAL "A"	MOON	68	40	140	130	124 ③
6. QUAL "A"	MOON	74	40	129	121	110

① QUAL "A" = FLIGHTS 1 & 2

② +10W HEATER COMMAND RIPPLES OFF SIDE & S/W. RESERVE POWER ~ 3 WATTS

③ +10W HEATER COMMAND RIPPLES OFF SIDE. RESERVE POWER ~ 8 WATTS

COMPARISON OF ALSEP PROTO "A" C/S TEMPERATURE RANGE vs PREDICTED PROTO "A" AND QUAL "A" LUNAR PERFORMANCE

FIGURE 16

13. Figure 17 shows the PCU power dissipation inside the Central Station versus PCU electrical load for RTG input powers of 63, 68 and 74 watts. As seen from Figure 17, any increase in nighttime PCU loads at high total levels reduces the total power dissipated inside the Central Station almost proportionally for low RTG power levels.

14. Figure 18 summarizes the predicted temperature range for the improved Proto A system, Qual SA, and Flights 1, 2, 3 and 4. As reflected in Figure 18, the temperature swing for Flights 3 and 4 does not appear at the present time to be a problem unless the nighttime experiment power increases from today's current estimates. Flights 1 and 2 temperature swing can be reduced by increasing the RTG power above 63 watts with a predicted passive swing of 129°F for a 74 w generator. The off-loading of one experiment for Flights 1 and 2 brings the passive range down to approximately 130°F due to the overall reduction in total PCU experiment load and the resultant increase in central station nighttime thermal dissipation.

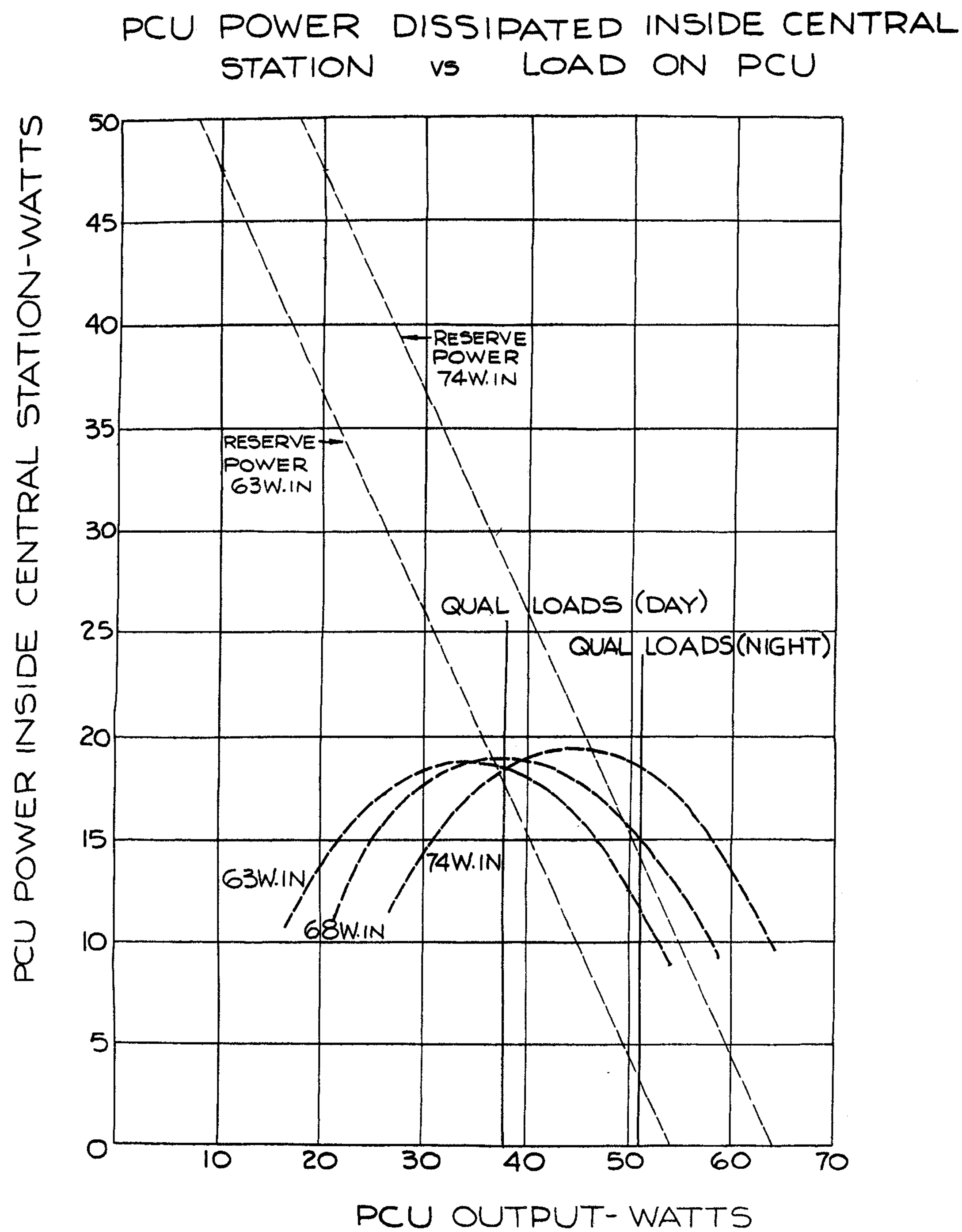

PCU POWER DISSIPATED INSIDE CENTRAL STATION vs LOAD ON PCU
PCU POWER INSIDE CENTRAL STATION-WATTS
50
45
40
35
30
25
20
15
10
5
0
10
20
30
40
50
60
70
PCU OUTPUT- WATTS
RESERVE POWER 74W. IN
RESERVE POWER 63W. IN
QUAL LOADS (DAY)
QUAL LOADS (NIGHT)
63W. IN
68W. IN
74W. IN

FIGURE 17

SUMMARY OF ALSEP CENTRAL STATION THERMAL DESIGN STATUS FOR PROTO "A", QUAL "A" & FLIGHTS 1, 2, 3 & 4

	MAX. SPECIFICATION TEMP. RANGE (PASSIVE °F)	MAX. TEMP RANGE (ACTIVE °F)
• IMPROVED PROTO "A" CENTRAL STATION DESIGN WITH 63 TO 74 WATT RTG AND PROTO "A" EXPERIMENT LOADS (38/43)	0 TO 125	0 TO 100
• IMPROVED QUAL "A", FLIGHTS 1 & 2 WITH 63 TO 74 WATT RTG AND QUAL "A" EXPERIMENTS LOADS (38/51)	0 TO 148	0 TO 132
• IMPROVED FLIGHT 3 WITH 63 TO 74 WATT RTG AND FLIGHT 3 EXPERIMENT LOADS	0 TO 130	0 TO 110
• IMPROVED FLIGHT 4 WITH 63 TO 74 WATT RTG AND FLIGHT 4 EXPERIMENT LOADS	0 TO 125	0 TO 100

FIGURE 18