Bendix

Aerospace Systems Division

ALSEP/Cask/LM Thermal Qualification Final Test Report

NO.	REV. NO.
ATM-834	
PAGE ____ OF ____	
DATE 2 July 1969	

This ATM presents the ALSEP/Cask/LM Cask Cooling and Thermal Vacuum Qualification test results which were derived from the BxA test program conducted at GE-MSD, Valley Forge, Pa. during the period from 28 January through 4 February 1969. In the ATM the thermal qualification results are summarized versus Bendix interface requirements for the LM vehicle, the graphite fuel cask, the crew and cask cooling. In addition to the thermal qualification results, a brief comparison of prototype and qualification T/V and cask cooling test results is presented.

Prepared by: ______________________
D. Butts

Approved by: ______________________
J. McNaughton

CONTENTS

List of Figures

List of Figures (Continued)

List of Figures (continued)

List of Figures (continued)

List of Figures (continued)

List of Tables

1.0 Introduction

1.1 Scope

This report presents the thermal test results of the integrated ALSEP/Cask/LM interface configuration forced convection and thermal/vacuum qualification testing which was performed at the GE-MSD Valley Forge, Pa., from 28 January thru 4 February 1969. The forced convection or cask cooling portion of the test was conducted in order to verify ACA temperature levels over a predicted range of KSC on pad, prelaunch environmental conditions. Besides presenting ALSEP/Cask/LM interface system equilibrium temperatures which were obtained while purging the system with cooling air at various flowrates and inlet supply temperatures, free convection equilibrium temperatures are presented.

Referring to thermal/vacuum (T/V) testing, three T/V runs were made which simulated: (a) earth orbit with solar heating (Spacecraft/ LM/Adapter (SLA) on with sun), (b) translunar orbit with solar heating (SLA off with sun), and (c) translunar orbit without solar heating (SLA off without sun). Equilibrium temperatures are presented for the three thermal/vacuum runs.

The ALSEP/Cask/LM structural configuration shown in Figures 1a and 1b utilized during both the forced convection and T/V testing consisted of cask bands, support struts, tilt mechanism and thermal shield, the astronaut guard, the Hitco graphite fuel cask, the fuel capsule assembly (FCA), the Lunar Module (LM) support struts, the LM vehicle thermal canister which included the North American Rockwell (NAR) Spacecraft LM Adapter Simulator.

1.2 Objective

The purpose of the air soak and thermal vacuum testing of the integrated ALSEP/Cask/LM qualification configuration was to demonstrate the integrity of the design to survive the environments to be encountered during prelaunch on pad conditions, launch and boost, earth orbit, and during translunar orbit. Specific thermal requirements which were verified during the qualification test program are shown in Table 6.

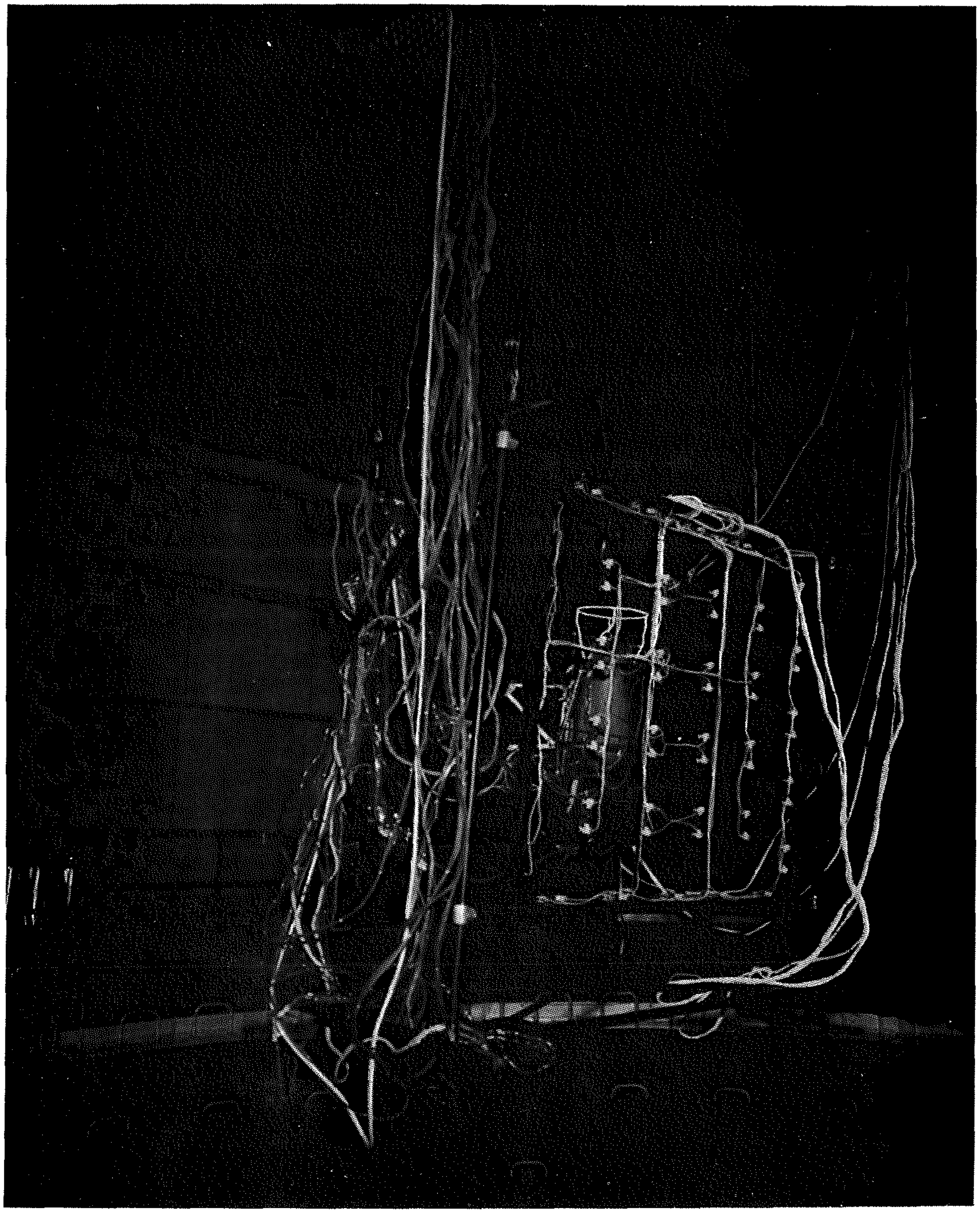


Figure 1a SLA Off Thermal Vacuum Test With ACA and IR Solar Array

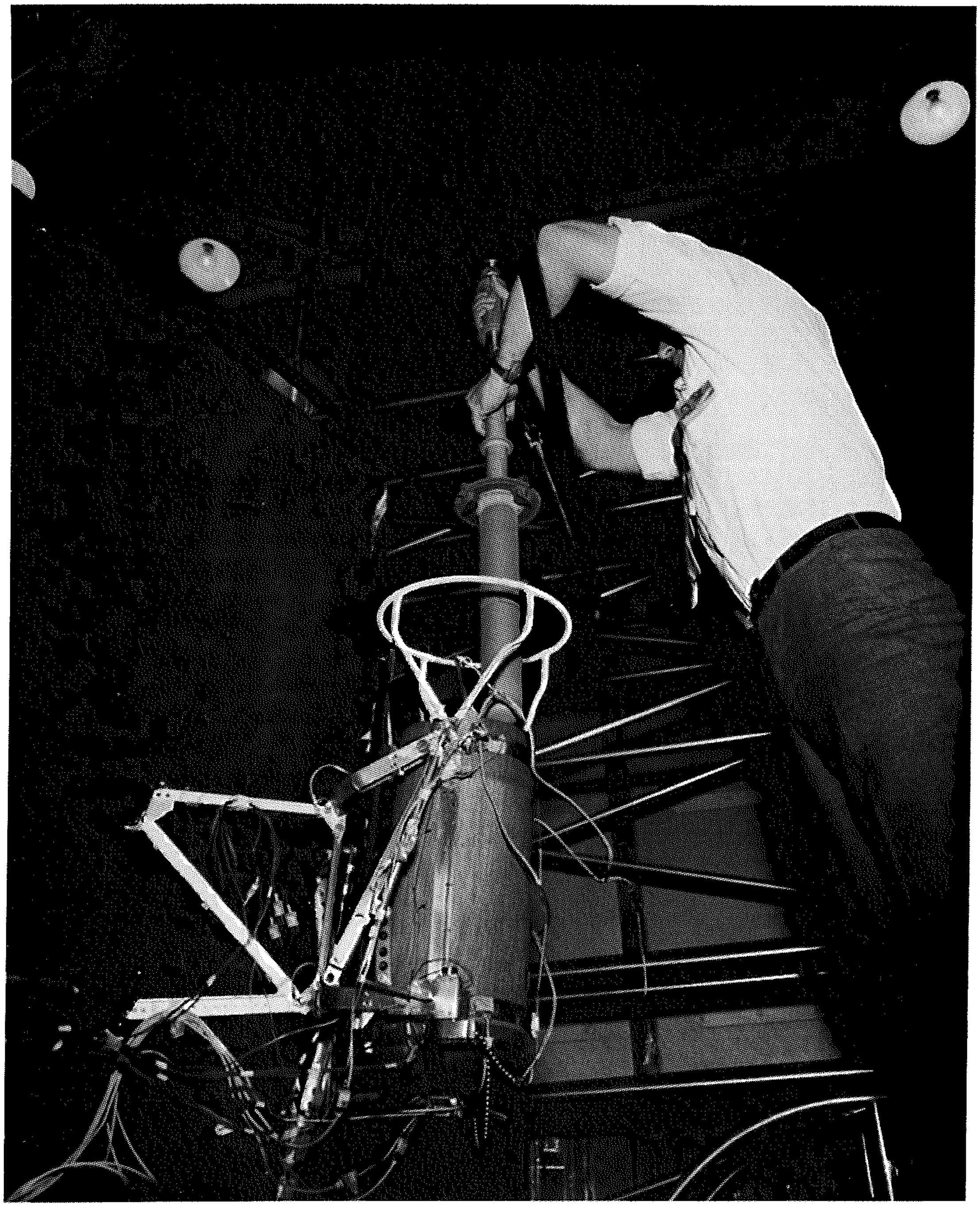


Figure 1b Fuel Capsule Insertion Into ALSEP Cask Assembly

2.0 Summary of Tests

2.1 Cask Cooling Test Conditions

Cask cooling testing was performed with the objective of simulating the anticipated on pad cooling air flowrates and pressures as supplied by the Saturn IV B Instrumentation Unit (I. U.) air conditioning manifold. Ten equilibrium air soak runs were made with air flowrates between 15 to 35 lb/min at temperatures of 80 and 130°F. Corresponding pressures, temperatures, and velocities recorded are shown in Table II. Also included in Table II are the recorded pump speeds and heater voltages.

Prior to and leading up to air soak run #1, ACA temperatures were recorded from the time of the insertion of the FCA into Graphite LM Fuel Cask (GLFC). Transient temperatures also were obtained for the time period immediately following the removal of the cooling air from the ACA system up to the time free convection steady-state conditions were reached.

2.2 Thermal/Vacuum Test Conditions

Since the T/V testing immediately followed the cask cooling testing, the FCA was already installed in the GLFC which was in turn placed into the Air Force #1 39 ft vacuum chamber. The chamber was evacuated to a pressure of less than 1×10^{-5} torr and then the earth orbit (SLA on with sun) simulation was commenced. Solar heating to the SLA was simulated by energizing the canister panel heaters and fixing the SLA temperature at 250°F and side panels at 170°F. After system thermal stabilization was reached and held for 10 hours, testing at the above conditions was completed.

For the translunar T/V test (SLA off with solar heating), the SLA and LM side panels were removed and the chamber pressure was reduced to a pressure of less than 1×10^{-5} torr. Solar heating to the ALSEP/Cask/LM configuration was simulated with solar array lamps and space was simulated by maintaining the space chamber cryowall at -320°F.

The ALSEP/Cask/LM configuration reached thermal equilibrium and was held at stabilization conditions for a period of 36 hours at which time the solar array lamps were de-energized. Once stabilization conditions were reached with the SLA off without sun configuration, equilibrium conditions were maintained for a period of 36 hours. This completed the three T/V runs.

3.0 Test Results

3.1 Band Strain Levels

At the initiation of the air soak testing the insertion of the FCA into the GLFC was successfully completed, the dome was replaced, and the axial bands were tensioned with the final strain gage readings being obtained as follows:

Strain Gage	Strain (micro-in/in)
J1	1826
J2	1784
J3	1723
J4	1666
J5	1640
J6	1340

Strain gage readings which were taken at the equilibrium conditions of the ten air soak runs are shown in Table I.

3.2 Cask Cooling Test Results

Figures 1-3 depict the thermocouple numbers and locations for the ALSEP cask, bands, support structure, thermal shield, and the Grumman struts. Thermocouple numbers and locations were identical for the air soak testing and the thermal/vacuum testing.

Qualification thermal results which were obtained from air soak testing are tabularly summarized in Tables 1-6. Figures 4-54 contain information dealing with both air soak and T/V testing with 39 of the figures presenting air soak test data. Most of the tables and figures combine air soak and T/V test results.

To correlate the ten forced convection runs, date and time of run with the various flow conditions and geometric configurations, it is necessary to compare Tables I and II. From Table II, it can be seen that the cooling air purge was supplied at either ambient or 130°F, and at flowrates of 15, 25, or 34 lb/min. As might be expected the nozzle configuration (offset 2" right) and flow conditions (15 lb/min @ 130°F) related to Run 7 provided the worst case forced air cooling condition with respect to the cask surface maximum temperature. The best case forced air cooling condition occurred with the standard nozzle configuration, i.e., the test configuration with the nozzle being directly beneath the axial centerline of the GLFC with a cooling air flowrate being supplied at 33.5 lb/min and at ambient temperature (Run 3). From Table 3, the forced cooling testing best and worst case cask surface maximum temperatures were 194 and 287°F, respectively.

Of the other structural members whose temperatures are shown in Table 3, only the ACA upper circumferential band experienced temperatures in excess of 200°F. An upper circumferential band maximum temperature of 245°F was measured during Run 8 (nozzle offset 2" left, air @ 15 lb/min, 130°F) whereas a band maximum temperature of 165°F was recorded for Run 3 (standard nozzle configuration, air @ 33.5 lb/min, 93°F). For structural members such as the cask surface and the upper and lower circumferential bands whose temperature gradients were considered to be significant, high/low temperature ranges are shown in Table 3. For example, for the ACA upper circumferential band, a maximum temperature differential of 24°F is seen to have existed during Run 8 with a maximum gradient of 4°F for Run 3. For the cask surface, the temperature gradients were more severe with the maximum gradient of 121°F occurring during Run 1 and a maximum gradient of 70°F being reached during Run 4.

Table 4 lists averages of measured equilibrium temperatures of various regions of the ALSEP/Cask/LM interface system. Compare Tables 3 and 4 to correlate group average number, the recording channel number and the thermocouple number corresponding to each. The worst case average temperature of 256°F was recorded during Run 8 for the GLFC (T/C #25 and 27, see Figure 1). In addition to the average temperature listings, other measurements which were taken during the air soak testing are shown under average numbers 16-21. Average numbers 16-21 include nozzle throat gage pressure, upstream and nozzle entrance pressure, nozzle exit velocity, and the thermal resistance patch temperature which was measured on the outer insulation layer of the thermal shield facing LM.

Figures 4-8 show the effect of nozzle inlet pressure and thus the effect of cooling air flowrate on the temperatures of various ALSEP/Cask/LM structural members. Plotted in Figure 4 is the cask maximum surface temperature as a function of the nozzle inlet pressure and also as a function of cooling air inlet supply temperature. The term misaligned refers to the fact the cooling air nozzle was offset 2 inches from the centerline of the GLFC during the time the applicable data was recorded. As can be seen from Figure 4, the misaligned configuration with the 130°F inlet supply temperature caused the cask surface maximum temperature to run approximately 8°F higher than with the same inlet supply temperature and with the standard nozzle configuration with the nozzle centerline coinciding and being parallel with the GLFC centerline. This indicates that the standard nozzle configuration should be employed for flight independent of the cooling air inlet supply temperature or flowrate.

By using an inlet supply temperature of 80°F as opposed to 130°F, a decrease in the cask surface maximum temperature of approximately 15°F can be expected for a cooling air mass flowrate of 25 lb/min and with the standard nozzle configuration.

Figures 5-7 illustrate temperature bands of the cask surface, the cask upper circumferential band, and the cask lower circumferential band as a function of the inlet supply pressure and temperature. For the temperature range which was derived from the 130°F inlet supply temperature, the misaligned nozzle configuration data was used. For the misaligned nozzle configuration with the 130°F inlet temperature, the cask upper circumferential band maximum temperature ran approximately 50°F lower than the cask surface maximum temperature for the same test conditions.

Figure 8 shows that the cask heat shield back temperature is affected only slightly by the nozzle inlet pressure and that the inlet temperature of 130°F compared to 80°F causes the heat shield back temperature to run about 4°F higher.

Presented in Figures 9 and 10 are warm-up curves which were obtained by using temperature recordings that were made during and after the insertion of the fuel capsule into the GLFC. Warm-up curves are shown for the ACA cask barrel, the upper and lower dome, the upper and lower circumferential bands, and the heat shield front and back. Warm-up data of Figures 9 and 10 was recorded during the test period which preceeded the stabilization conditions of Run 1.

Listed in Figures 13 and 14 are temperature envelopes which result from data obtained when the forced cooling air was removed from the system. Warm-up data of Figures 13 and 14 were obtained during the test period leading up to the free convection equilibrium conditions of Run 11. With the initial cask barrel maximum surface temperature of 203°F, 4.33 minutes were taken for the cask barrel surface to attain a maximum temperature of 350°F under free convection conditions. At the end of 10.3 minutes, the cask barrel maximum temperature was up to 433°F. After free convection stabilization conditions of Run 11 had been reached, the cask barrel surface maximum temperature was 623°F and the minimum temperature was 498°F.

The temperatures of the Electric Fuel Capsule Simulator (EFCS) which are shown under the free convection, on pad condition of Table 5 were not recorded during Run 11 but were recorded a few weeks before the actual qualification testing was initiated. The live fuel capsule was used during qualification testing.

In summarizing the air soak test results, cask and band equilibrium temperatures for Runs 1-11 are shown in Figures 15-26. Free convection equilibrium temperatures for various structural members also are depicted in Figures 29, 33, 37, 41, 45, and 49-54.

3.3 Thermal/Vacuum Test Results

Of the three thermal/vacuum runs that were made, the translunar orbit case (Run 13, SLA off with solar heating) proved to be the most critical with respect to system maximum temperatures. For Run 13, the cask barrel surface maximum temperature was 830°F and the cask barrel surface minimum temperature was 726°F. The high/low temperature range for the thermal shield front was running at 598 to 549°F while the thermal shield back was running at 224 to 213°F for the same test conditions. The cask lower dome at 602°F appeared to have been approximately 55°F higher than the cask upper dome. From Table 5, the upper dome axial band was 59°F lower than the upper dome and the lower dome axial band temperature was 116°F lower than the temperature of the lower dome.

Table 5 also lists high/low temperature ranges of ALSEP/Cask/LM components for the SLA on with sun and the SLA off without sun runs, Runs 12 and 14 respectively. In general, system maximum temperatures were significantly lower for Runs 14 (SLA off without sun) than those maximum temperatures recorded during Runs 12 and 13. For example, the maximum cask surface temperature was 830°F for Run 13, whereas for Run 14, the corresponding temperature was 792°F.

The average temperatures of various ALSEP/Cask/LM regions are shown in Table 4. It is of interest to note that the average temperature of the thermal shield front was 471°F while the backside temperature was only 24°F for the translunar orbit run (SLA off without sun). This was pointed out to emphasize the effectiveness of the insulation that comprised the thermal shield.

Cask barrel equilibrium temperatures for Runs 12-14 are shown in Figures 26-28. Cask band equilibrium temperatures for Runs 12-14 are listed in Figures 30-32, 34-36, 38-40, 42-44, and 46-48. Figures 49-54 summarize equilibrium temperatures of various ALSEP/Cask/LM components for the thermal/vacuum Runs 12-14.

At the completion of Run 12 (SLA off without sun), the fuel capsule was removed from the GLFC a system cooldown. Figures 11 and 12 show selected ALSEP/Cask/LM component temperature histories that were induced by the removal of the FCA. Approximately 3 hours and 20 minutes were required to bring to cask surface maximum temperature down to 100°F. For the same cooldown period, the cask circumferential band temperatures were approximately 145°F, which showed a 45°F temperature lag between the barrel and the bands.

4.0 Comparison of Prototype and Qualification Test Results

Using the qualification test results of air soak Run 9 (cooling air @ 15 lb/min, 138°F) and the three T/V Runs 12-14 with prototype test results obtained from previous BxA ALSEP/Cask/LM prototype testing at similar test conditions, a prototype versus qualification tests results comparison can be made as shown in Table 5. Although some temperature measurements were not made for Qual that were made for Proto, such as group numbers 23-29, additional prototype test results are presented as supplimentary information.

Considering the comparison of the forced convection runs, the cask barrel surface maximum temperature for Qual was 274°F and 234°F for Proto and the corresponding average temperatures were 241°F and 207°F which shows that the cask surface ran on the average of 34°F hotter during qualification testing as compared to prototype testing. For the same test conditions, other components exhibited the same general trend with Qual temperatures running slightly higher than those of Proto.

Looking at the similarity between the prototype and qualification free convection cases, most prototype temperatures again were running lower than those of qualification. The Proto to Qual Cask surface maximum temperature analogy was 609°F to 623°F with the corresponding cask surface averages being 576°F to 588°F.

One of the components that exhibited temperature characteristics which contrasted with the trend of the qualification temperatures being higher than those of prototype was the cask upper dome. Although the free convection prototype upper dome temperature was higher than that of qualification, the temperature differential was only 2°F. The prototype cask lower dome maximum temperature was 385°F as compared to 412°F for qualification. The fact that temperature trends between the two types of testing vary slightly is attributed to the effects caused by the differences in the material properties of prototype and qualification fuel casks and to the test method used to generate the heat dissipation within the GLFC. The thermal conductivity of the qualification cask was appreciably lower than that of the prototype cask which would tend to induce localized hot spots within the cask whereas temperatures within the prototype cask with a higher thermal conductivity would tend to equalize throughout the cask. Furthermore, for prototype testing, the EFCS was inserted into the GLFC, and the live fuel capsule was used during qualification testing.

Referring to the three thermal/vacuum runs shown in Table 5, the SLA off with sun run resulted in worst case system temperatures. For instance the qualification cask surface maximum temperature was 830°F with the corresponding prototype temperature being 799°F. Since the SLA off with sun temperatures were worst case values and are within specification limits, no temperature problems are anticipated.

5.0 Specification Requirements versus Qualification Test Results

A comparison of ALSEP/Cask/LM interface specification requirements versus qualification test results is given in Table 6. Besides the qualification test results shown in Table 6, a summary of forced convection and thermal/vacuum qualification test results is given in Figure 55 which can be used in comparing prototype and qualification test results. The fuel cask surface maximum temperature obtained during qualification testing was 830°F compared to a specification value of 835°F. While the fuel cask surface maximum temperature was within 5°F of the specification value, the fuel cask circumferential maximum temperature gradient of 112°F was well within the specification value of 150°F.

In the case of the total heat leak into LM attributed to the GLFC. 26 Btu/hr were due to conduction and 7 Btu/hr were due to radiation. The radiation heat leak was calculated directly from qualification test results and the conduction portion of the total heat leak was considered to be the same as that calculated from worst case prototype testing. The reason that prototype test results were used for the conduction heat leak was due to the fact that more extensive thermal instrumentation was utilized for the GAEC struts during prototype testing than during qualification testing. Since conservatively high conductances were used in calculating the prototype conductive heat leak to LM, it is concluded that the qualification GLFC to LM total heat leak value of 33 Btu/hr is conservative. The specification value is 100 Btu/hr.

By comparing specification requirements with test values for the remaining components listed in Table 6, it can be seen that all specification requirements were met.

6.0 Conclusion

From qualification test results, it can be concluded that the ALSEP/Cask/LM interface system will successfully endure environmental conditions to be encountered during on pad, prelaunch, lift-off and boost, earth orbit, translunar orbit, lunar descent, and lunar deployment.

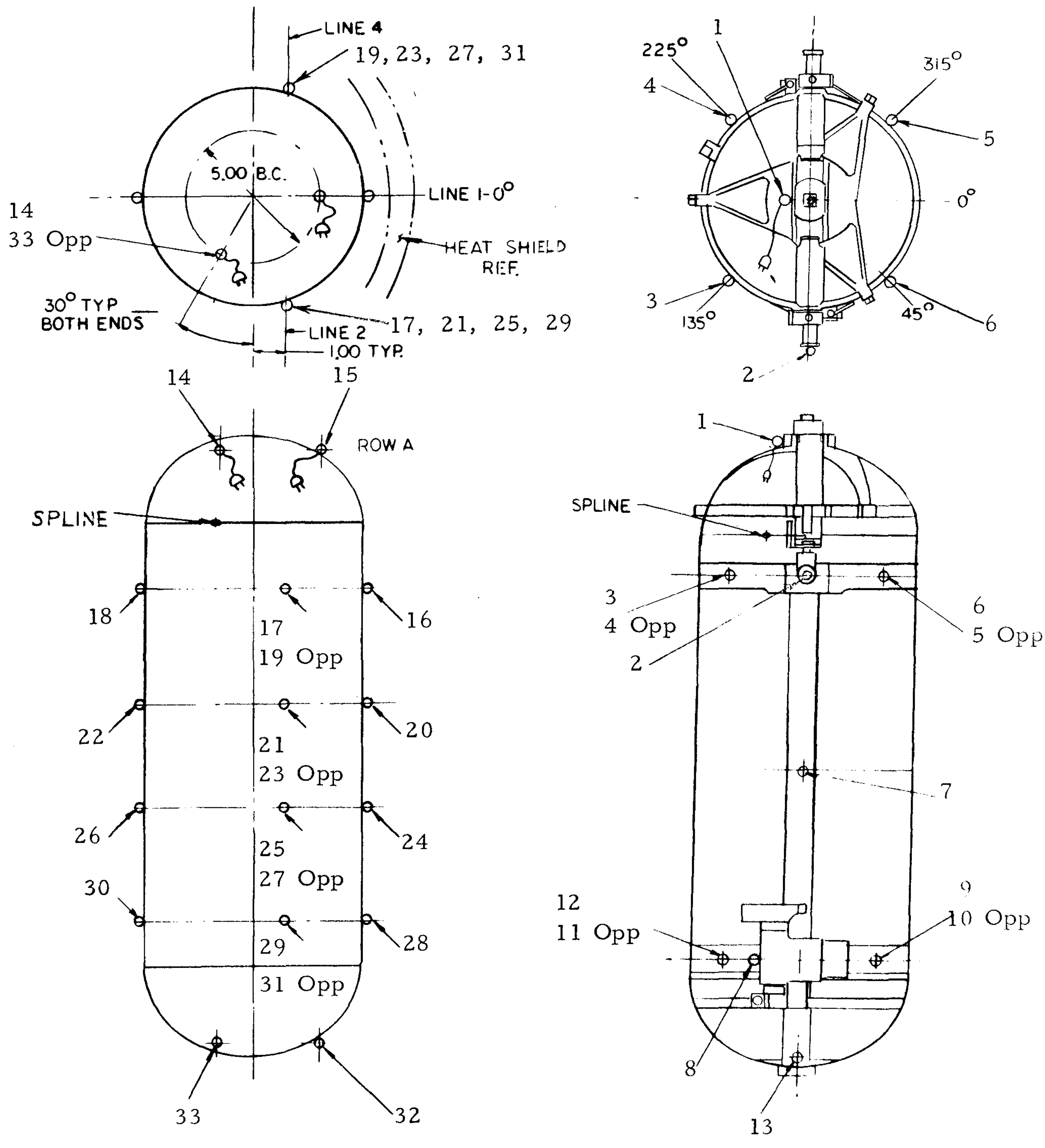


Figure 1C. Thermocouple Locations for ALSEP Cask and Bands.

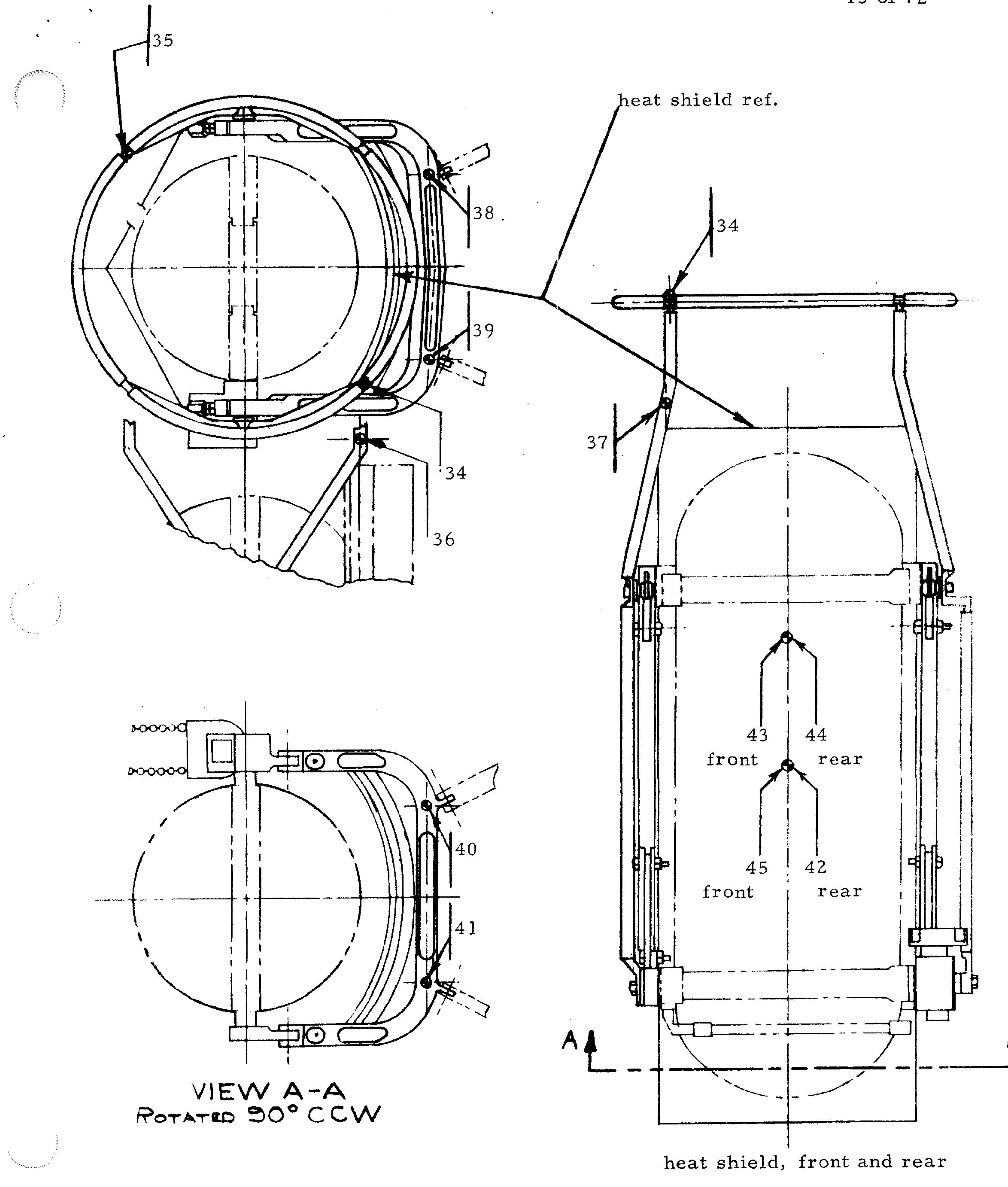


Figure 2. Thermocouple Locations for ALSEP Cask Support Structure.

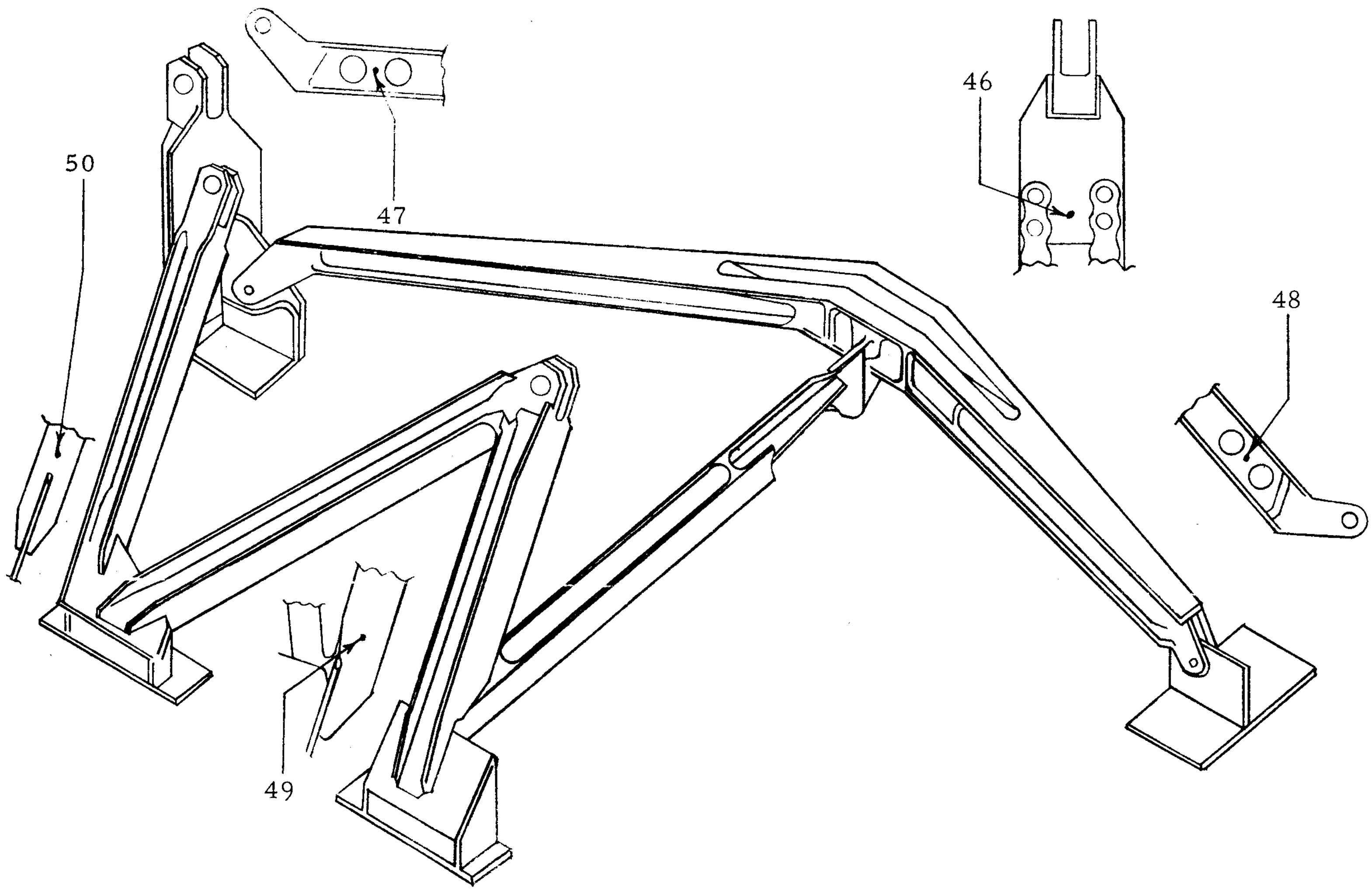


Figure 3. Thermocouple Locations for Grumman Struts.

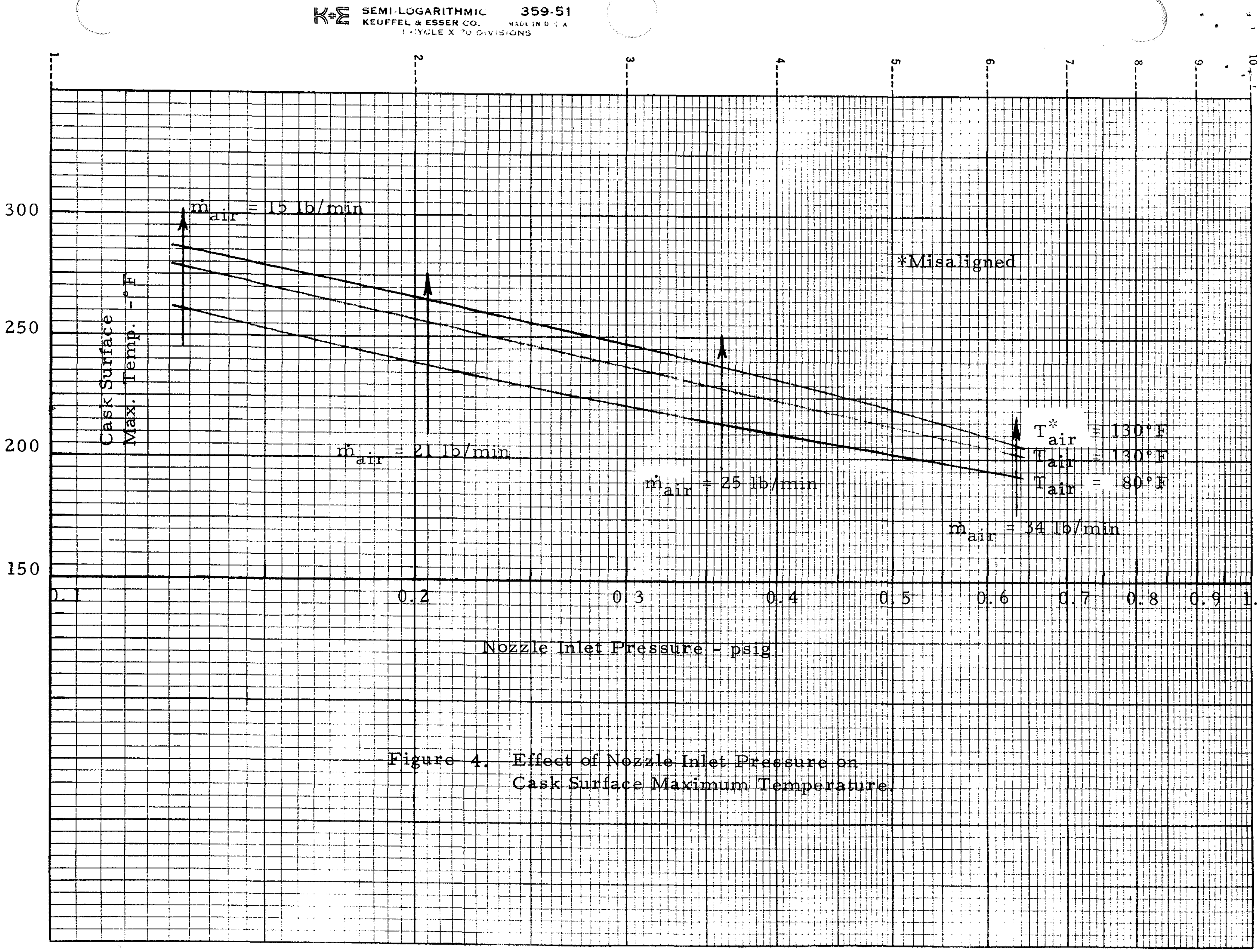


Figure 4. Effect of Nozzle Inlet Pressure on Cask Surface Maximum Temperature.

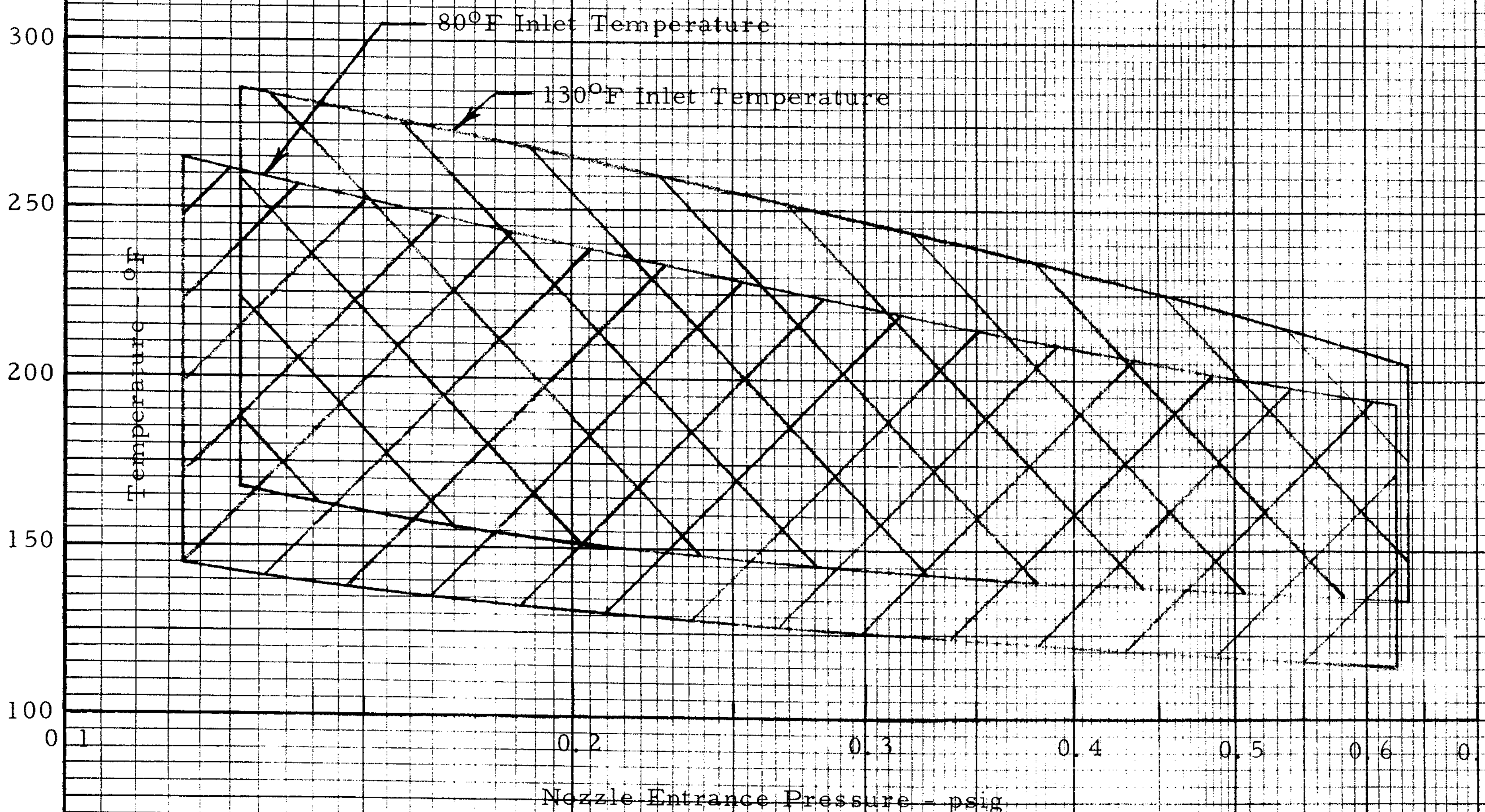


Figure 5. ACA Cask Temperature Envelope.

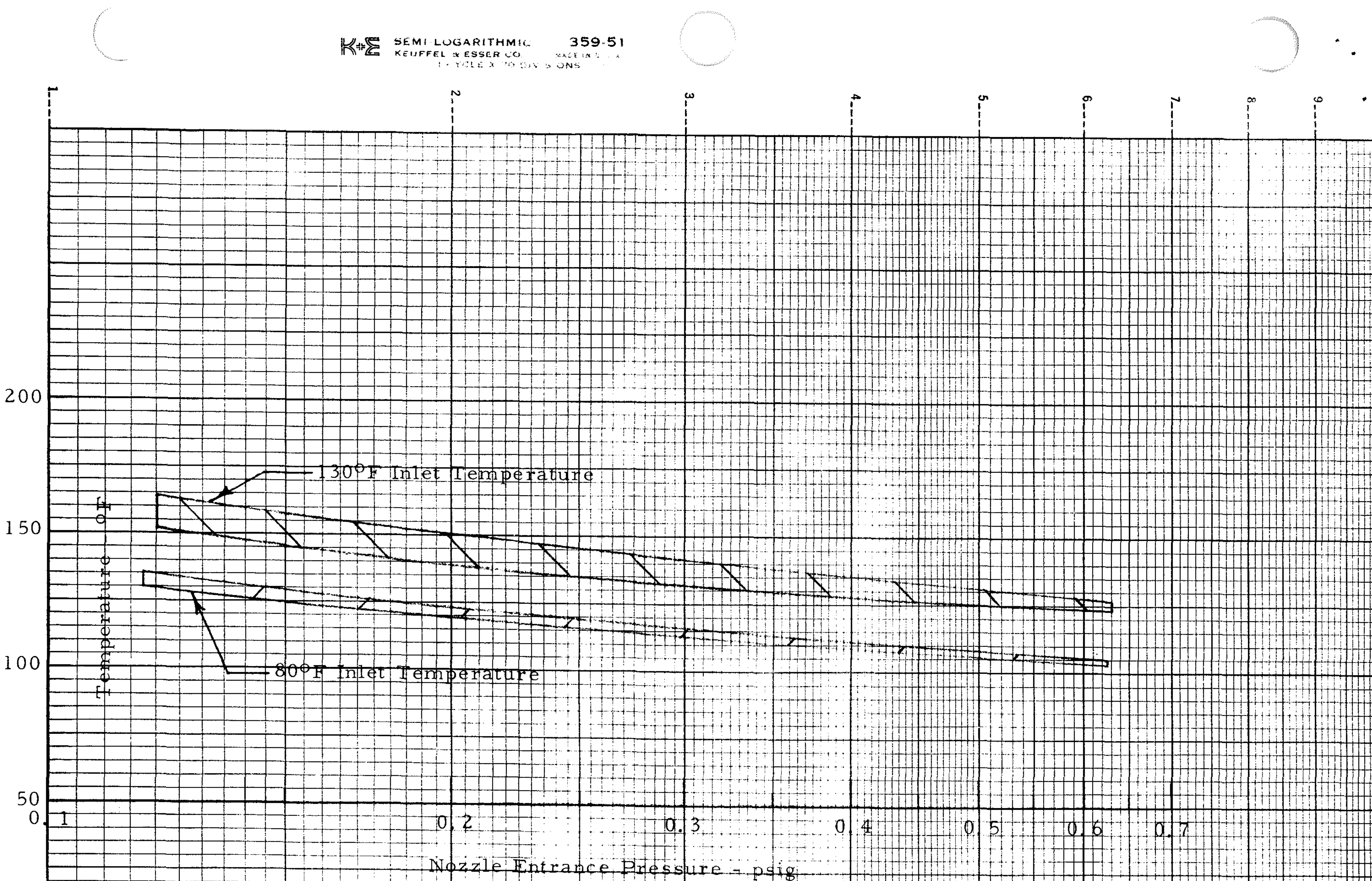


Figure 6. ACA Lower Circumferential Band Temperature Envelope

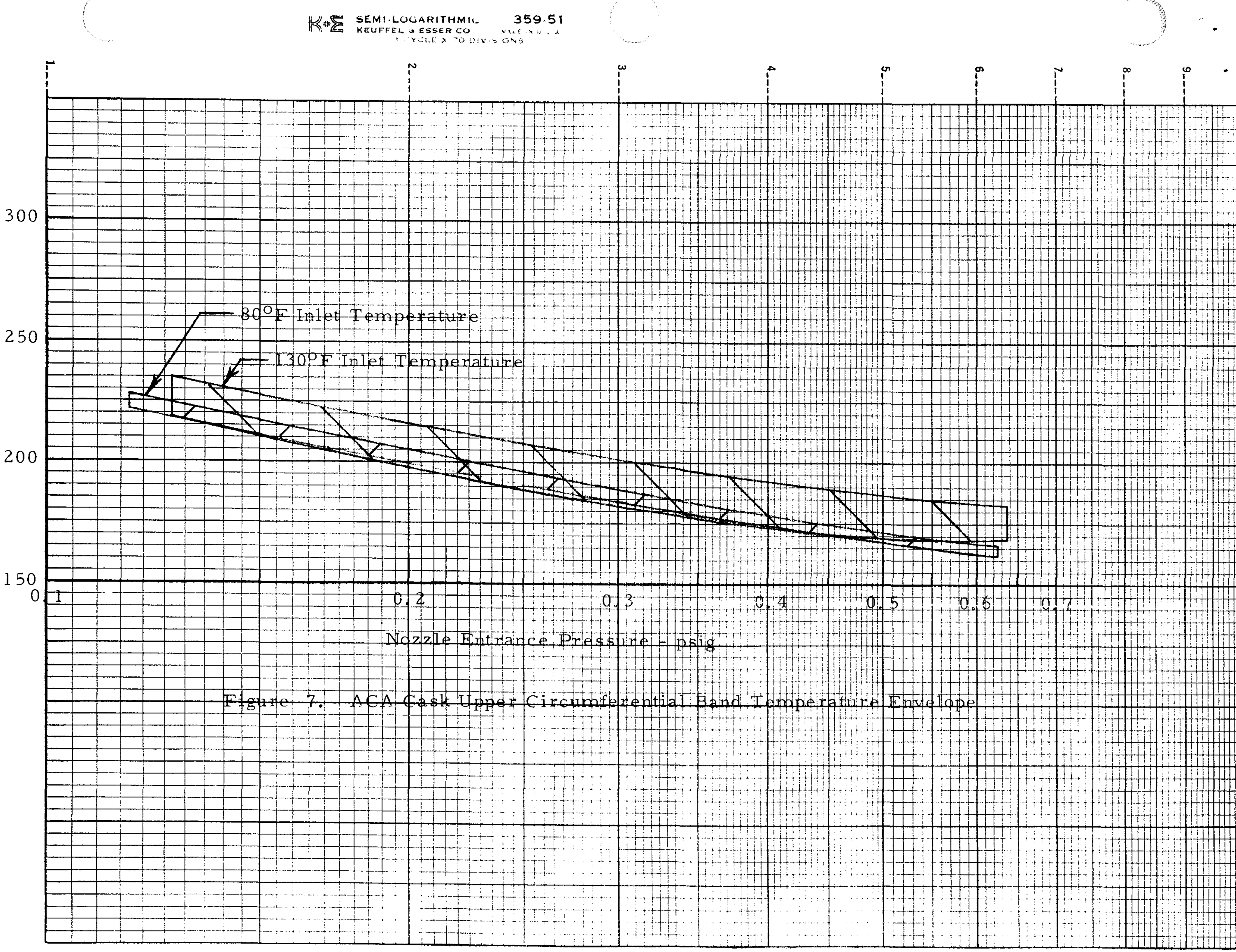


Figure 7. ACA Cask Upper Circumferential Band Temperature Envelope

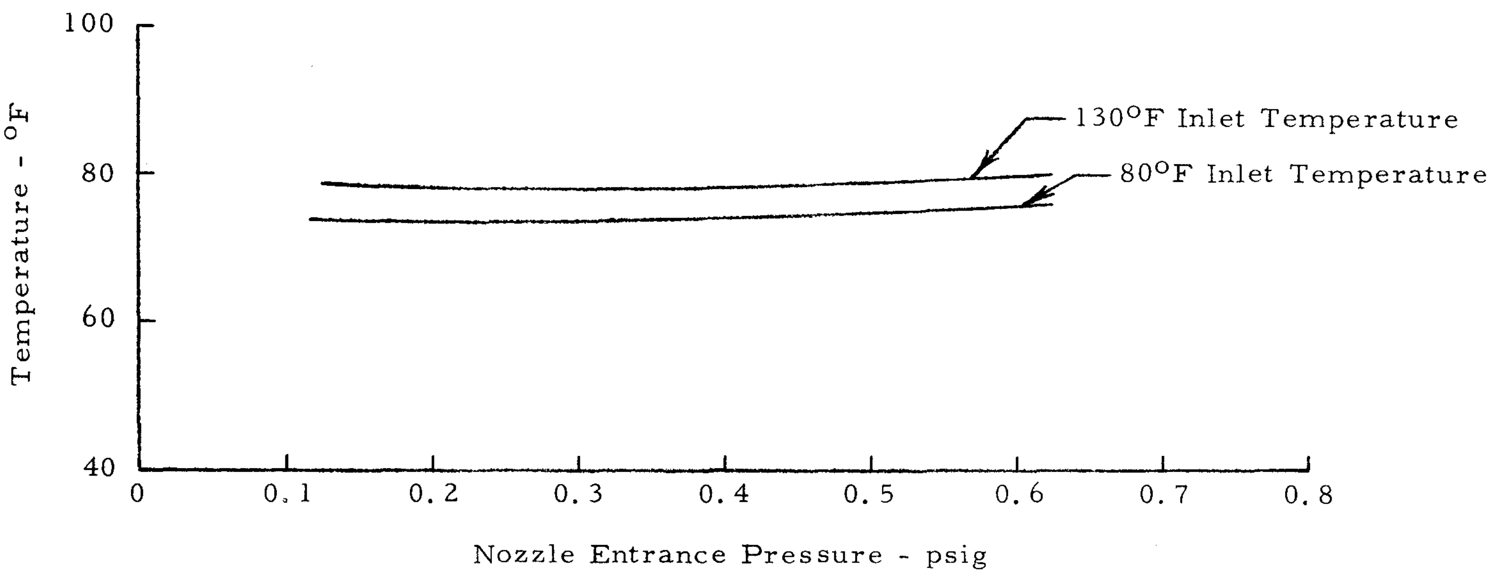


Figure 8. ACA Cask Heat Shield Back Temperature.

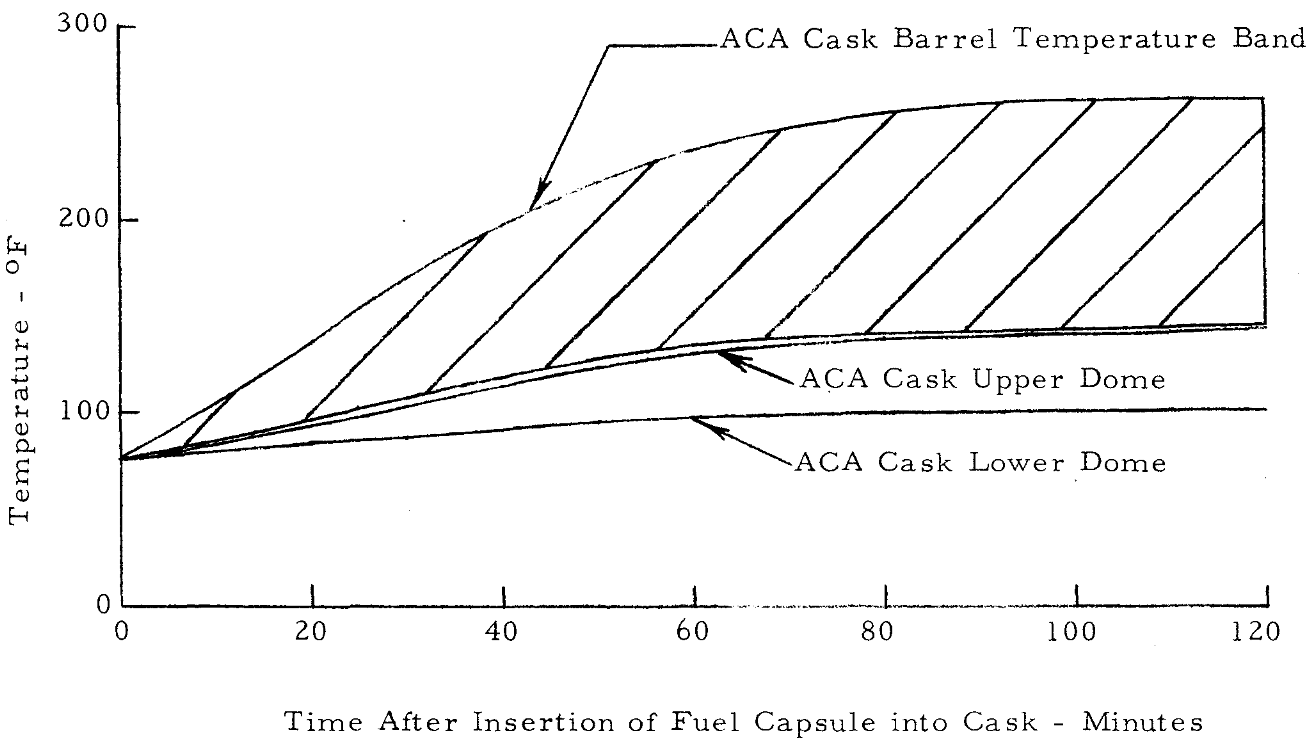


Figure 9. ACA Cask Transient Temperature Rise Induced by Fuel Capsule Insertion.

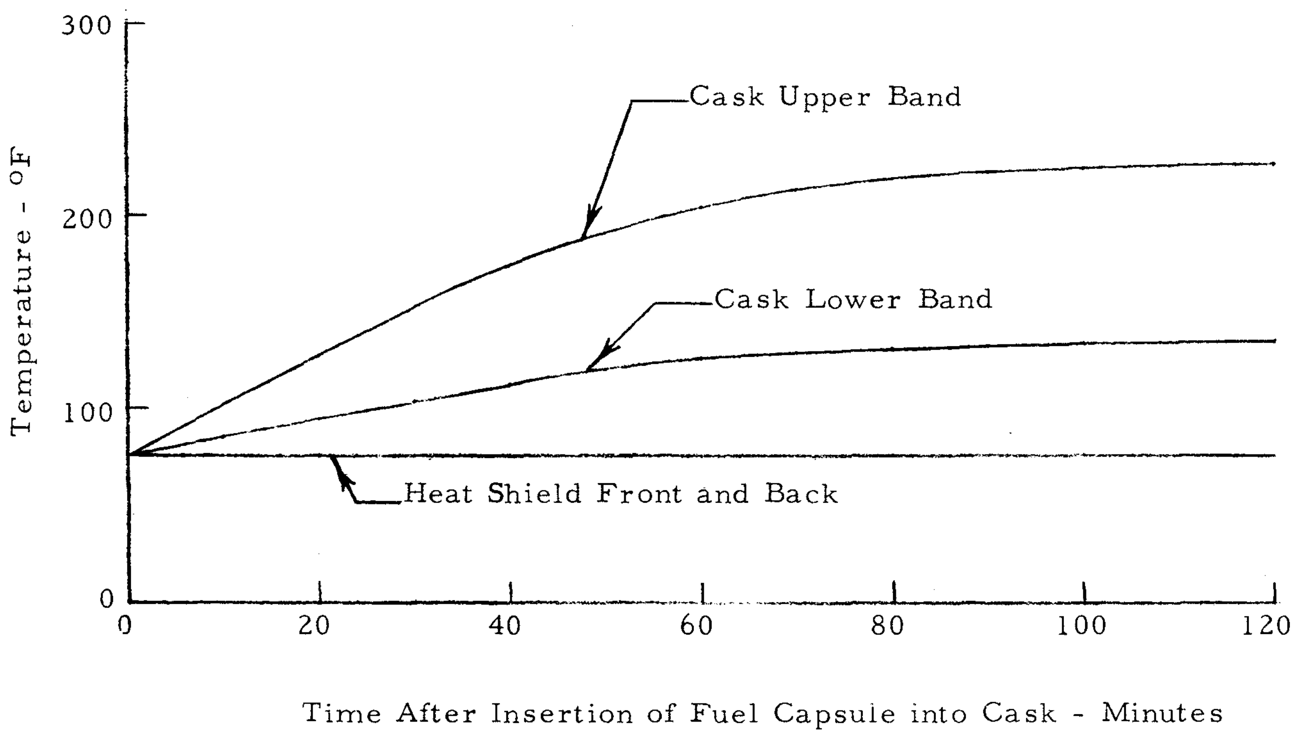


Figure 10. ACA Cask Upper and Lower Bands, and Heat Shield Temperature Rise Induced by Insertion of Fuel Capsule.

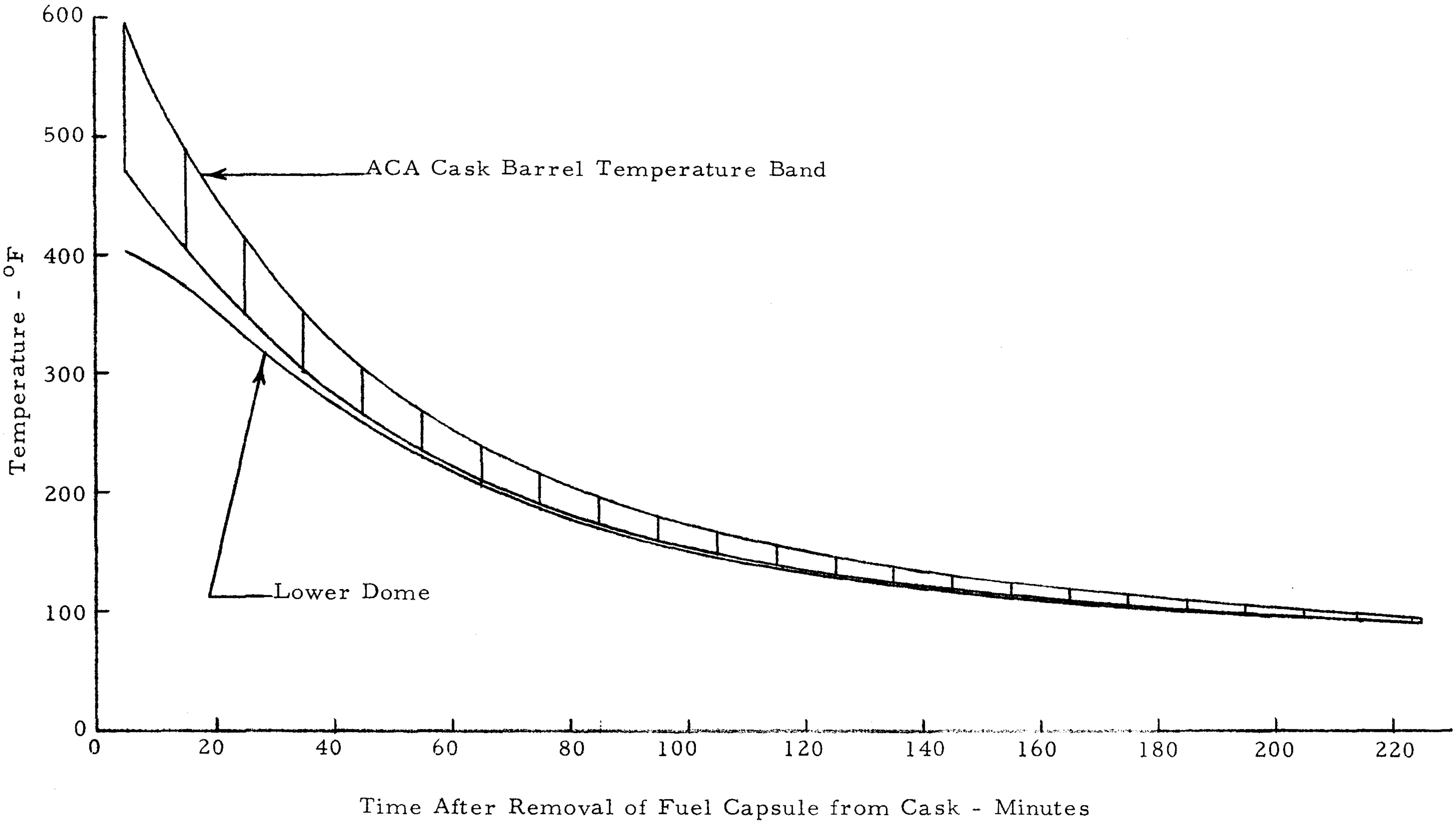


Figure 11. ACA Cask Cool-down Induced by Fuel Capsule Removal.

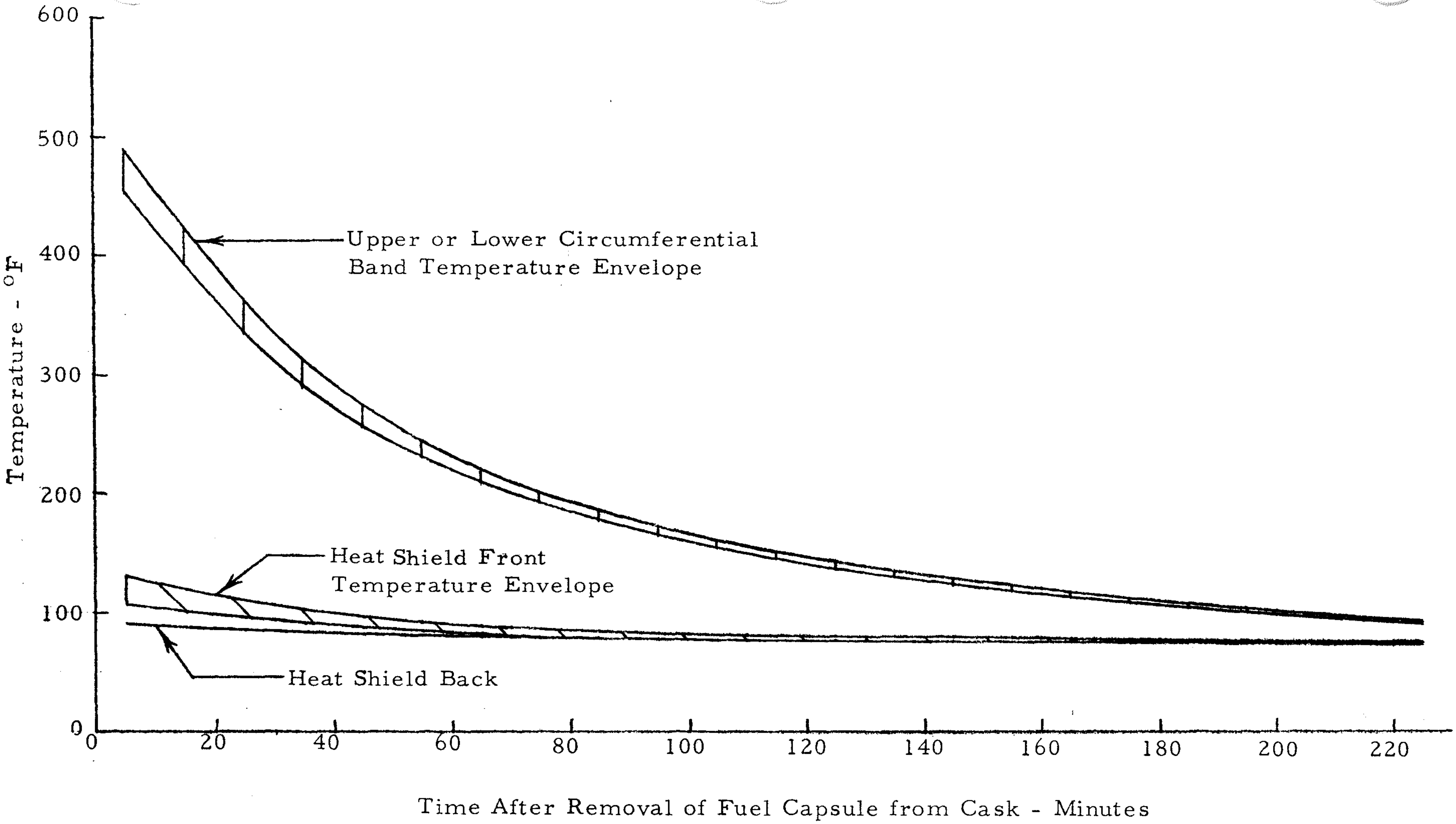


Figure 12. ACA Circumferential Bands and Heat Shield Cool-down Induced by Fuel Capsule Removal

Figure 13. ACA Cask Transient Temperature Rise.

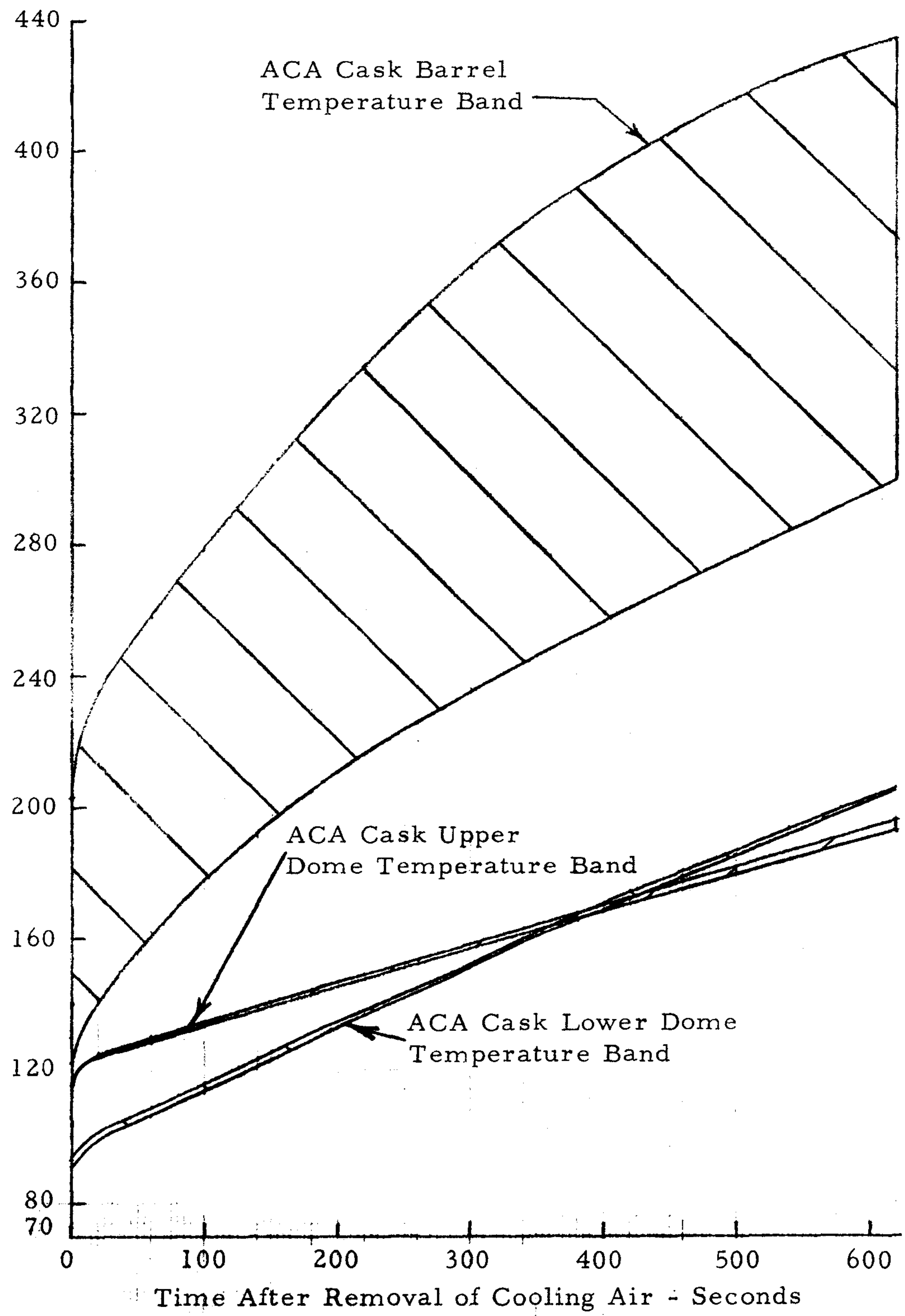
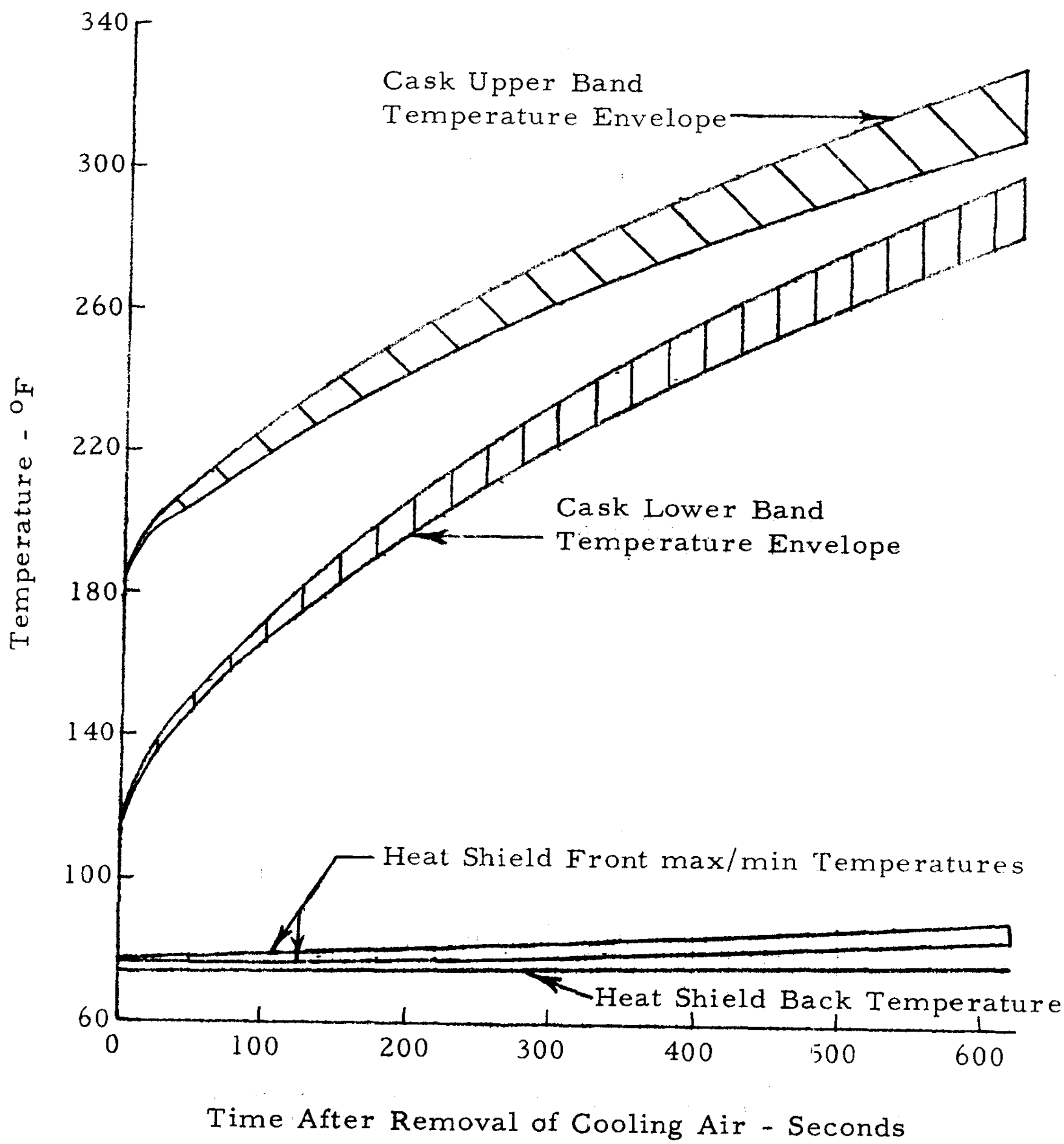


Figure 14. ACA Cask Upper and Lower Bands, and Heat Shield Front Transient Temperature Rise.



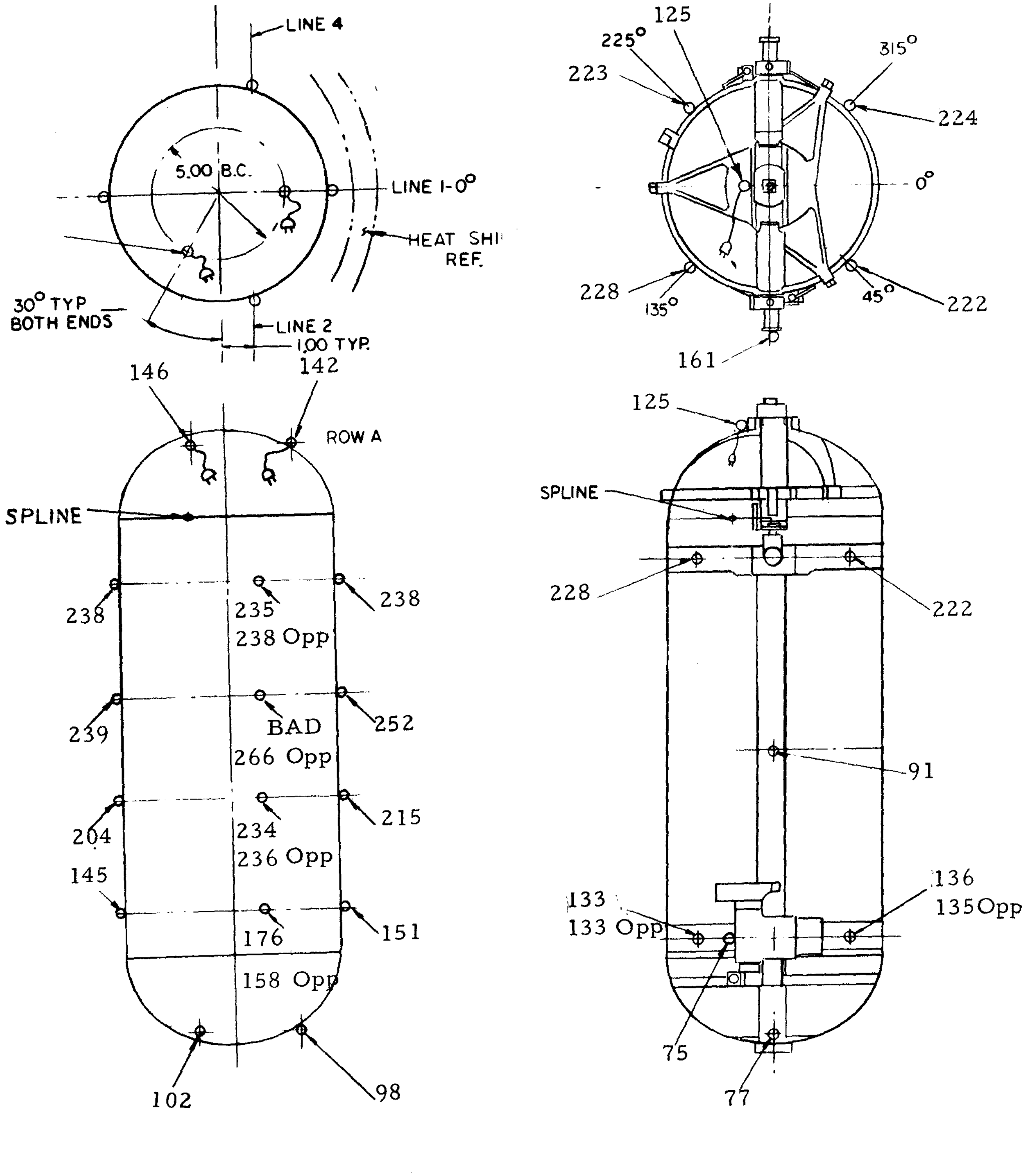


Figure 15. ACA Cask and Band Equilibrium Temperatures for Cask Cooling Run 1 (15.1 lb/min at 80°F).

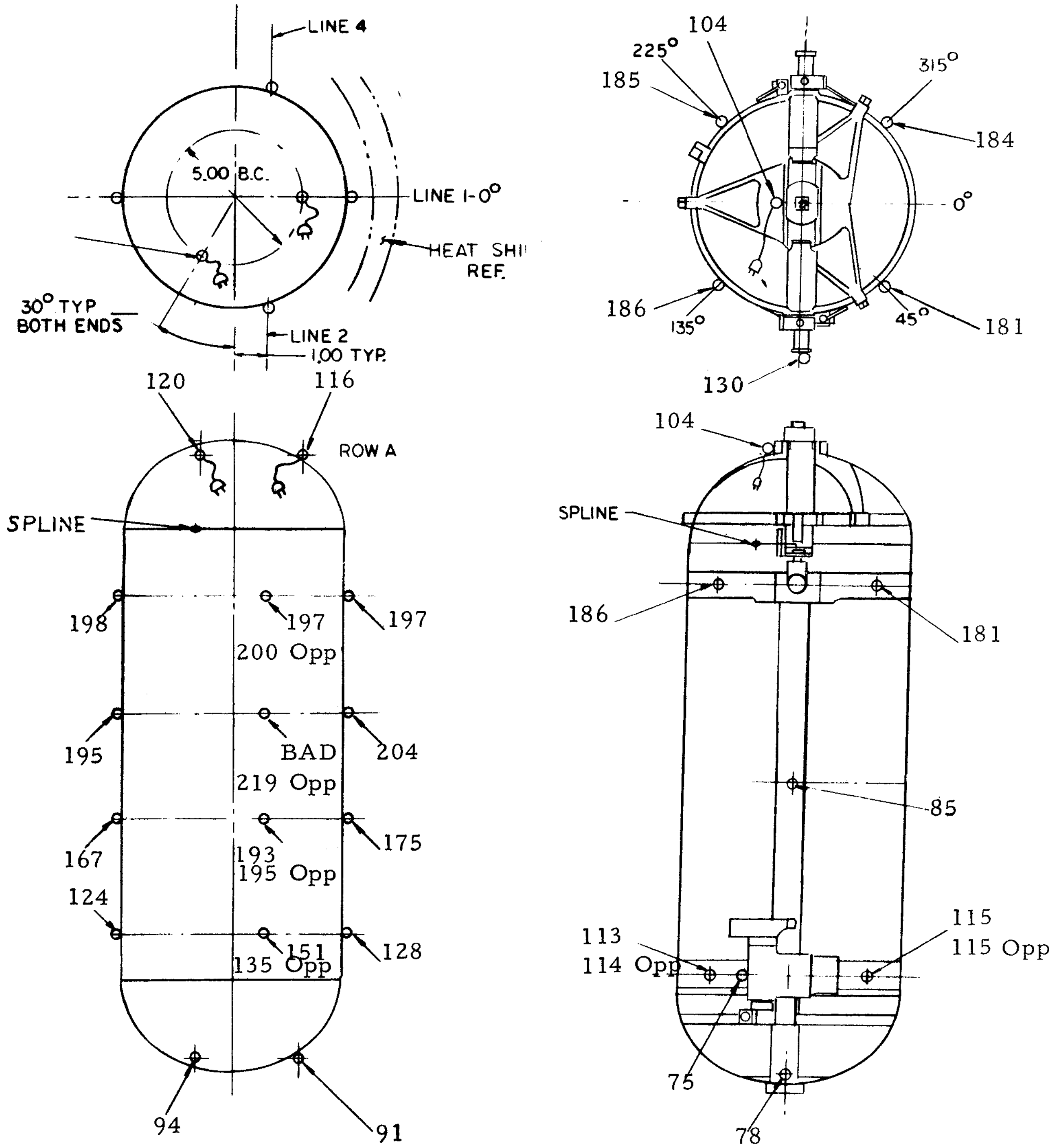


Figure 16. ACA Cask and Band Equilibrium Temperatures for Cask Cooling Run 2 (25.1 lb/min at 84°F).

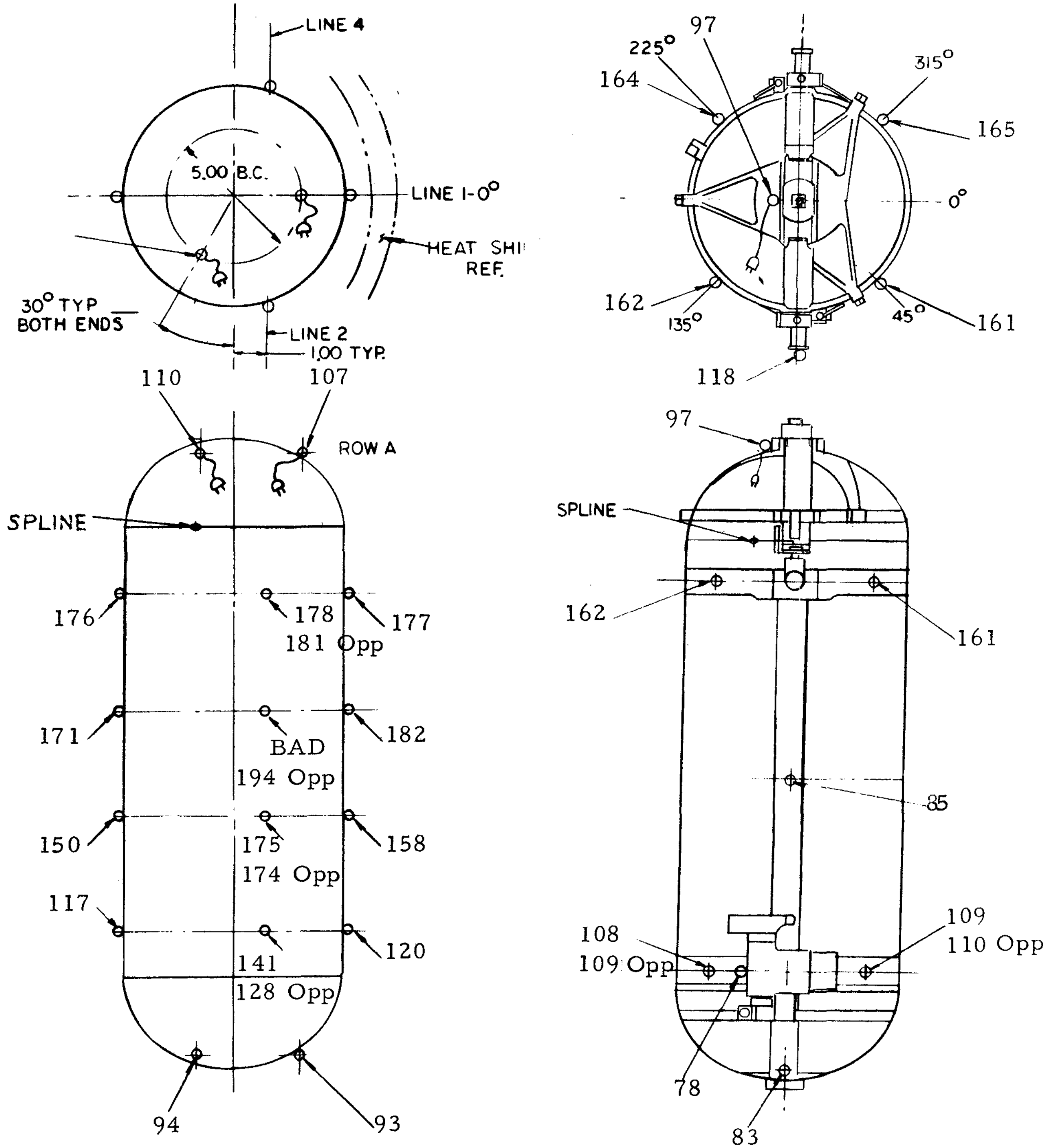


Figure 17. ACA Cask and Band Equilibrium Temperatures for Cask Cooling Run 3 (33.5 lb/min at 93°F).

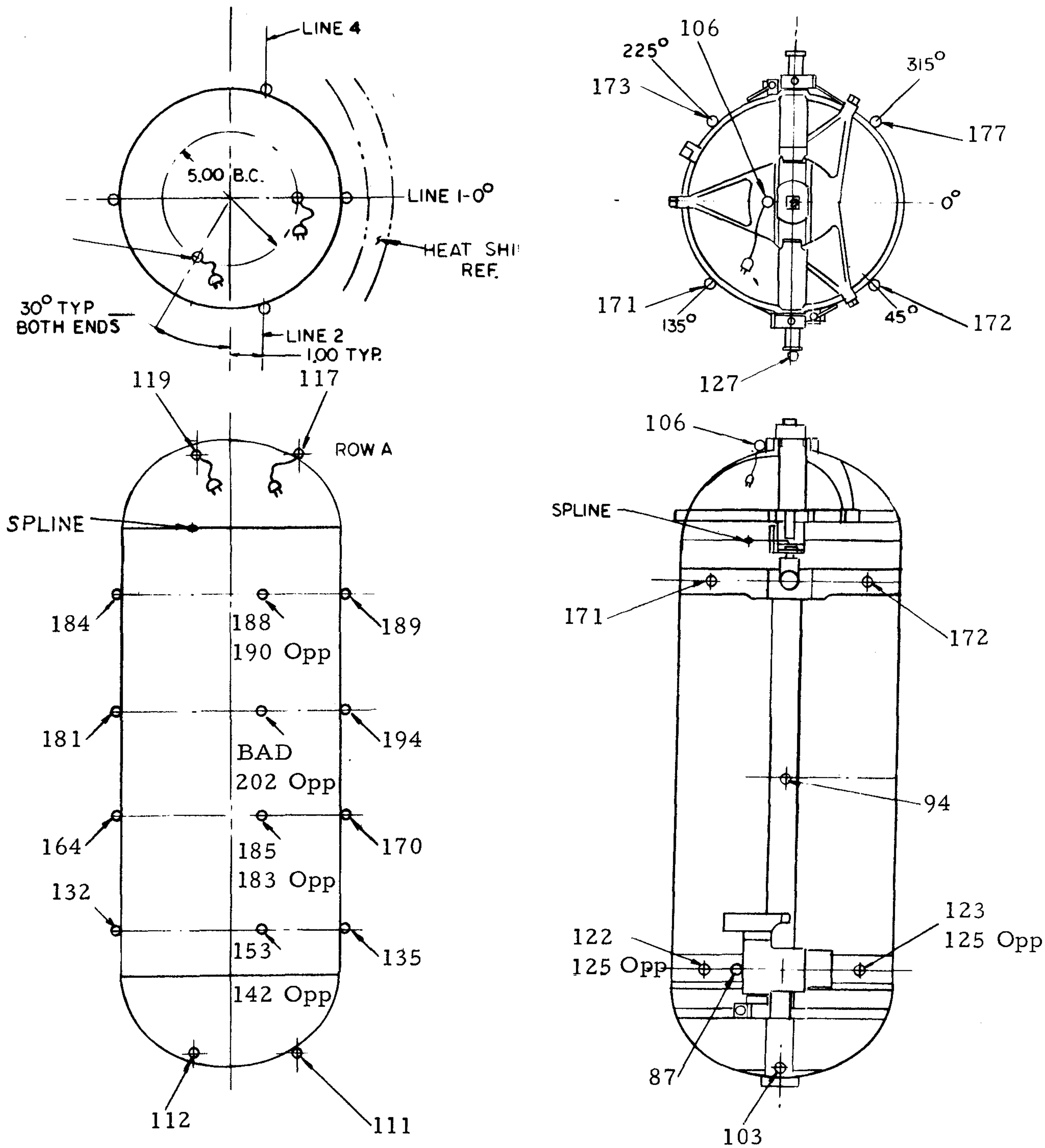


Figure 18. ACA Cask and Band Equilibrium Temperatures for Cask Cooling Run 4 (34 lb/min at 132°F).

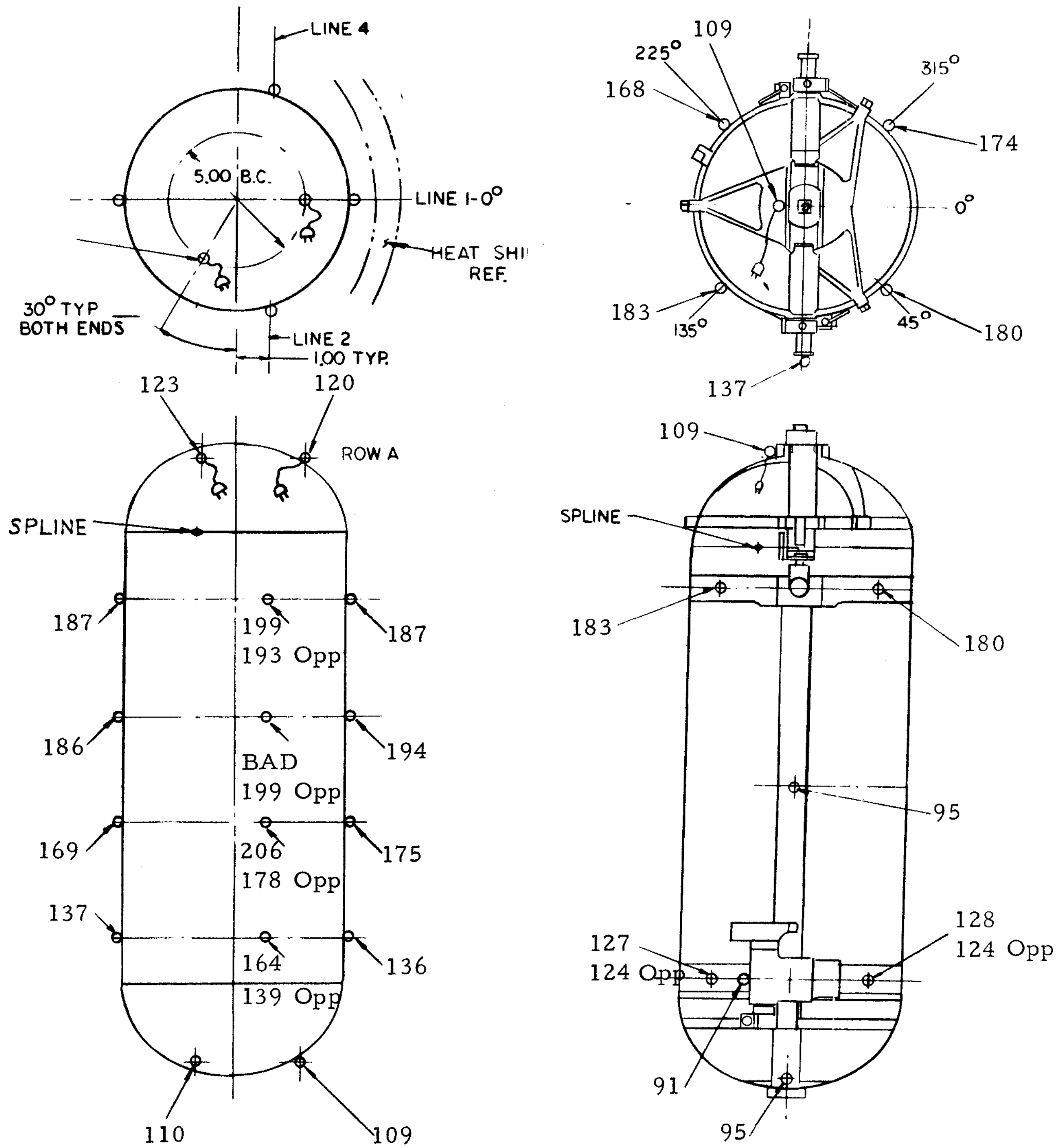


Figure 19. ACA Cask and Band Equilibrium Temperatures for Cask Cooling Run 5 (34 lb/min at 132°F).

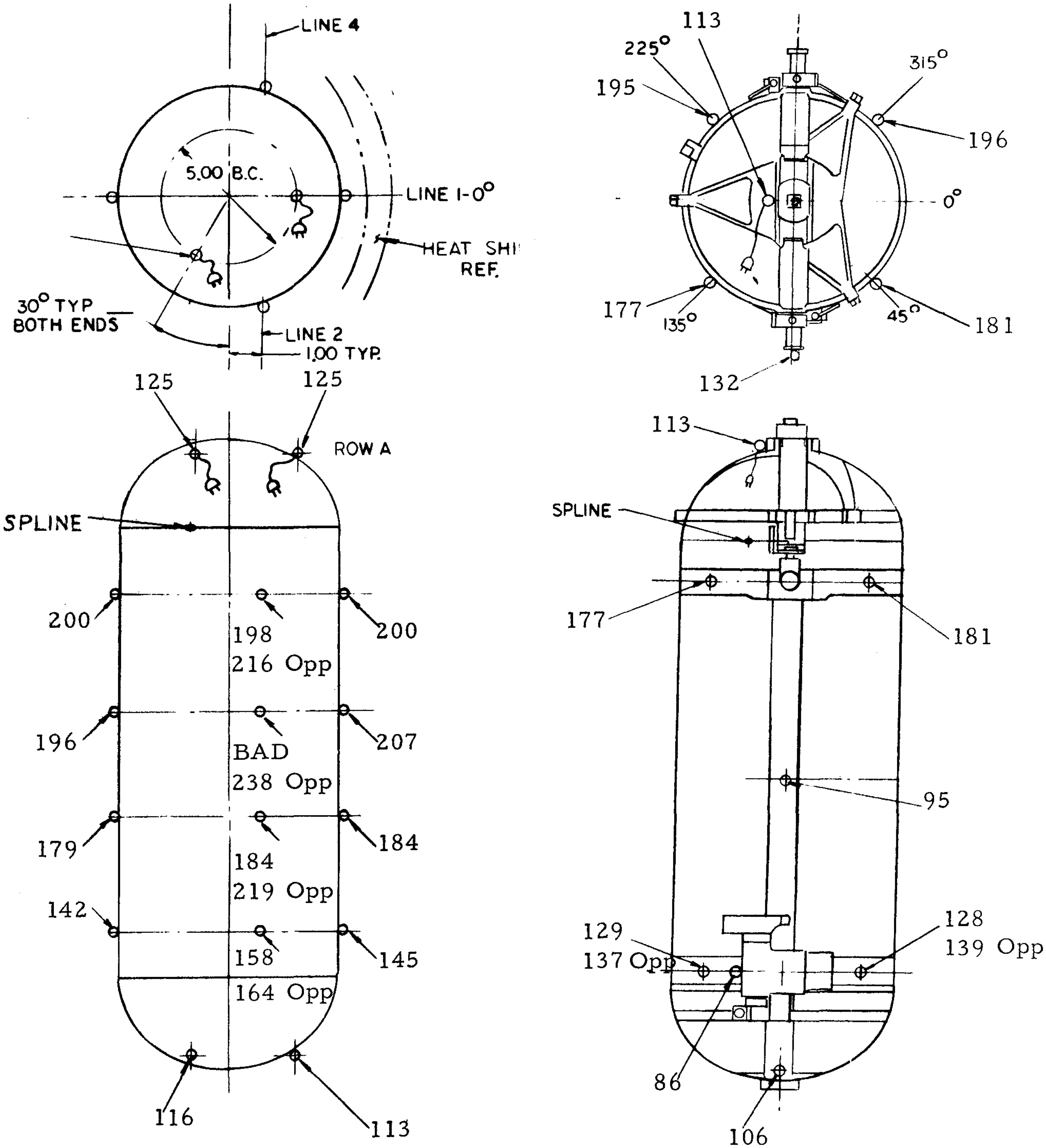


Figure 20. ACA Cask and Band Equilibrium Temperatures for Cask Cooling Run 6 (25 lb/min at 130°F).

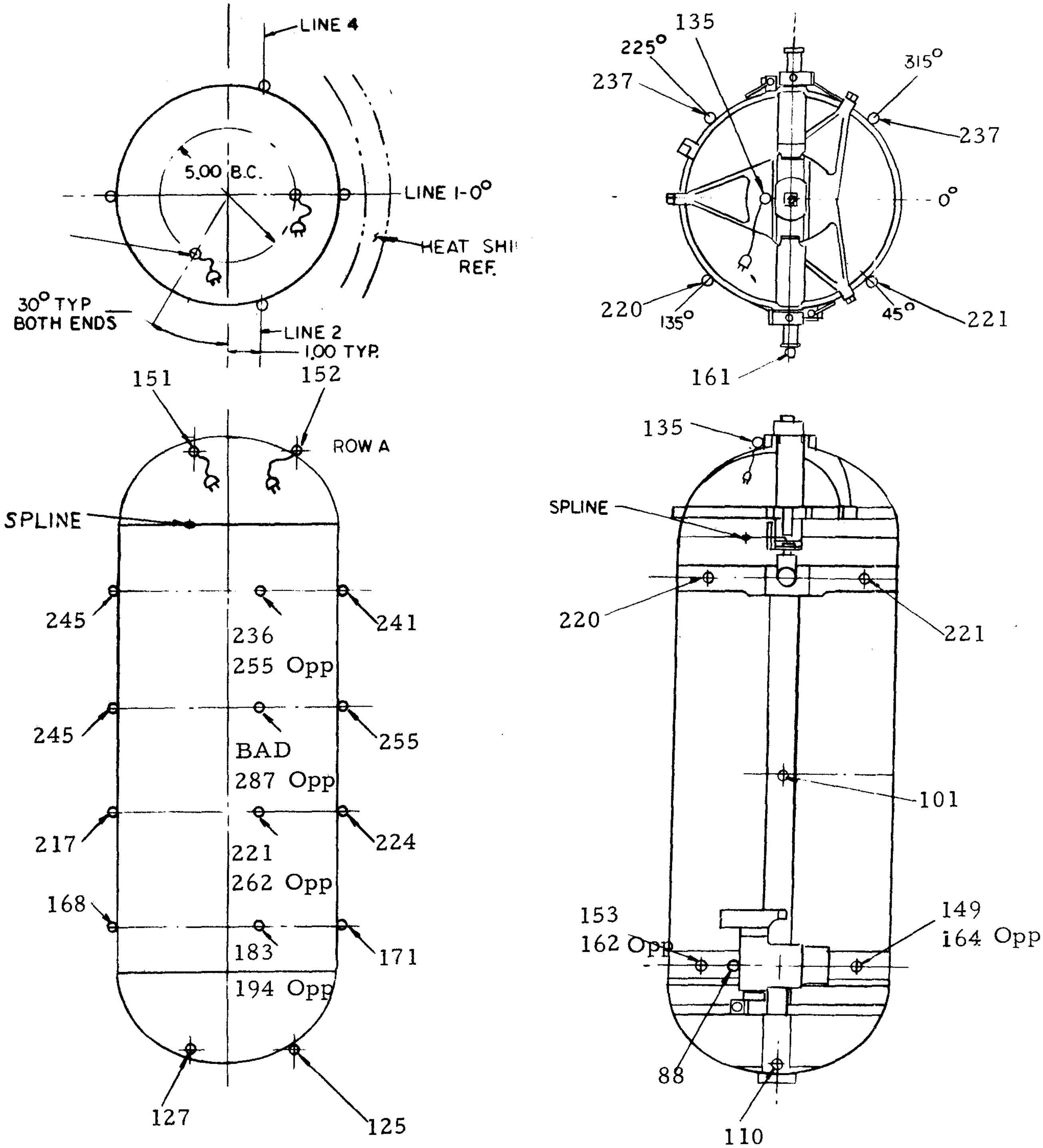


Figure 21. ACA Cask and Band Equilibrium Temperatures for Cask Cooling Run 7 (15 lb/min at 130°F).

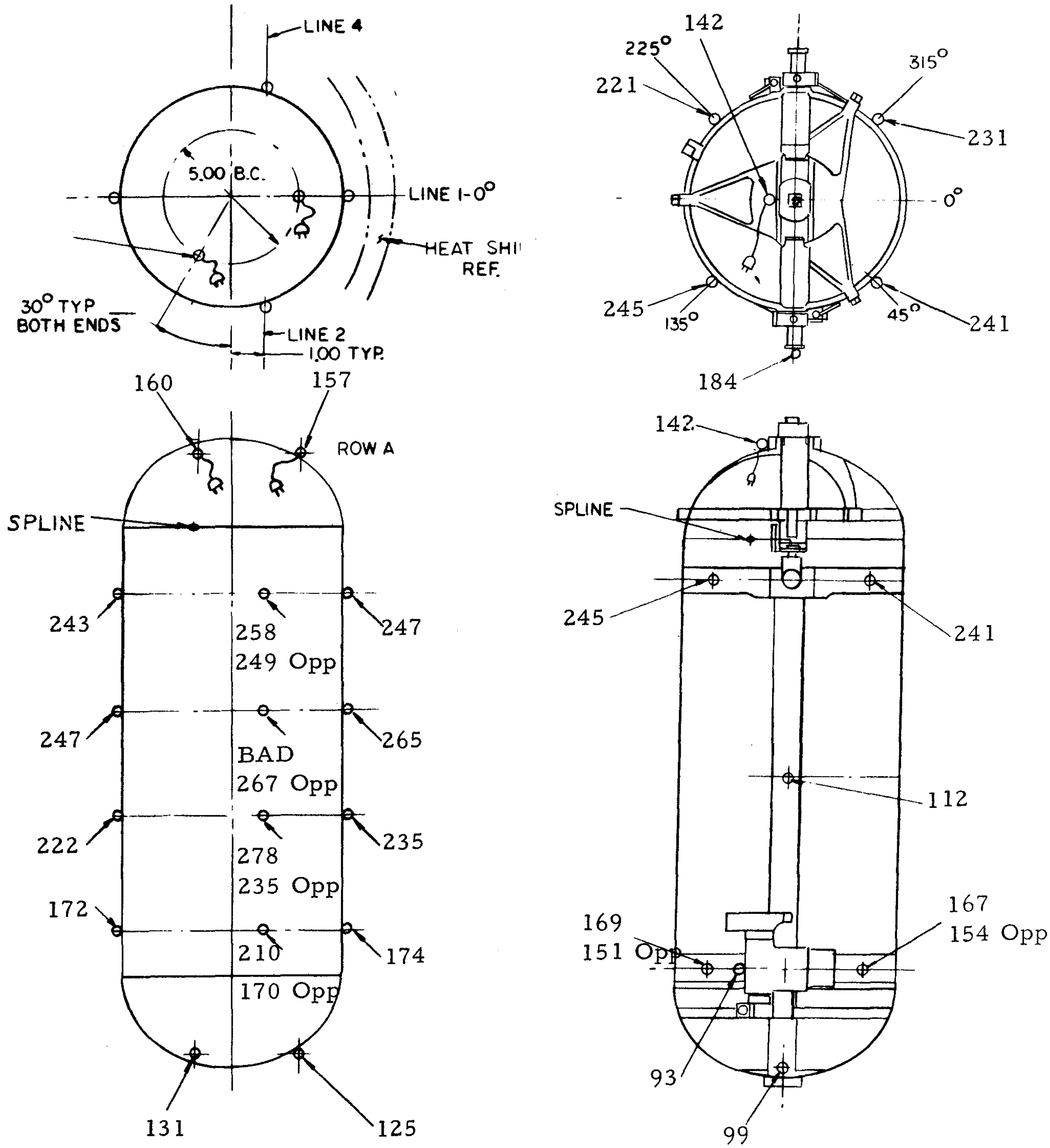


Figure 22. ACA Cask and Band Equilibrium Temperatures for Cask Cooling Run 8 (15 lb/min at 130°F).

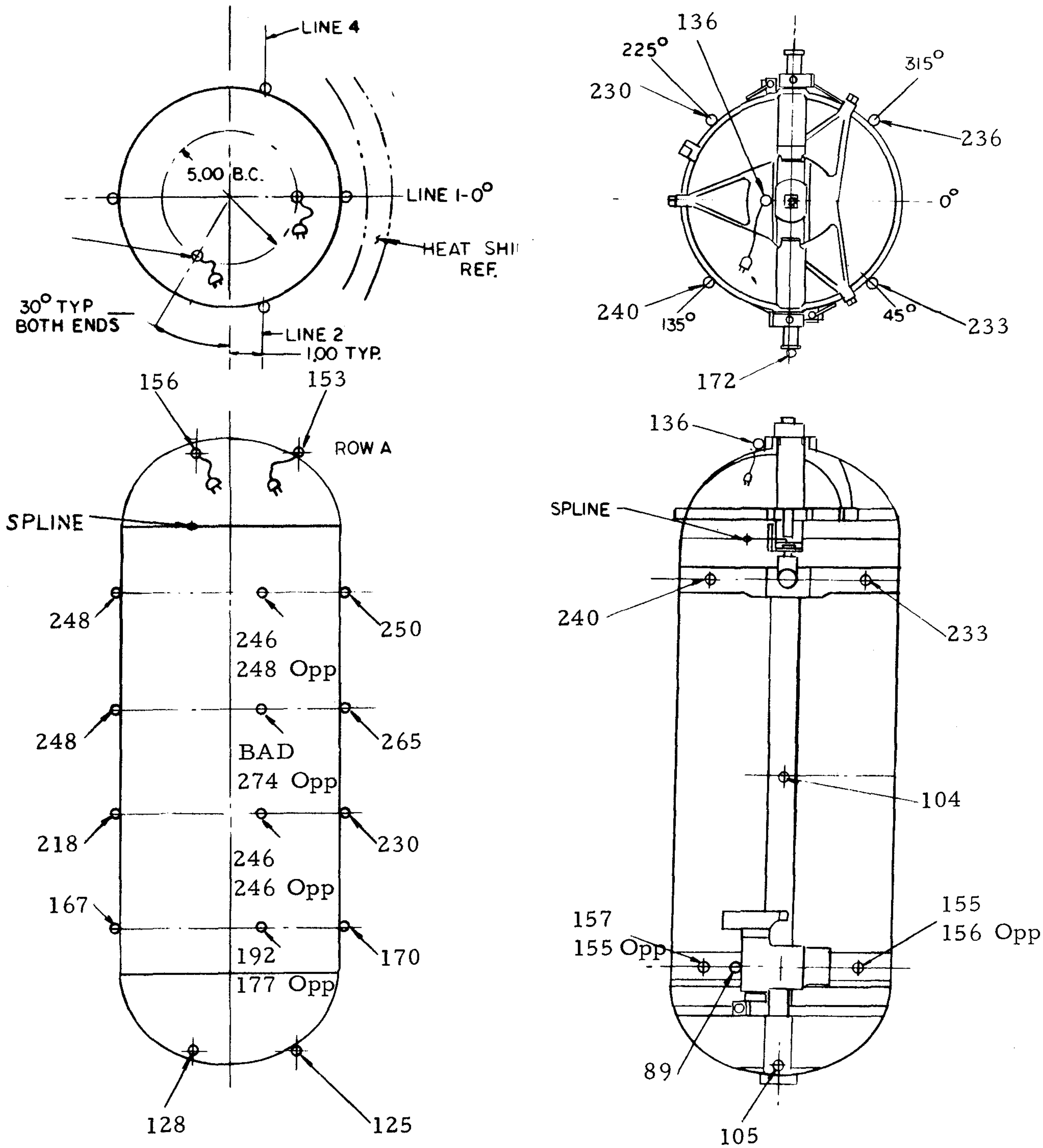


Figure 23. ACA Cask and Band Equilibrium Temperatures for Cask Cooling Run 9 (15 lb/min at 133°F).

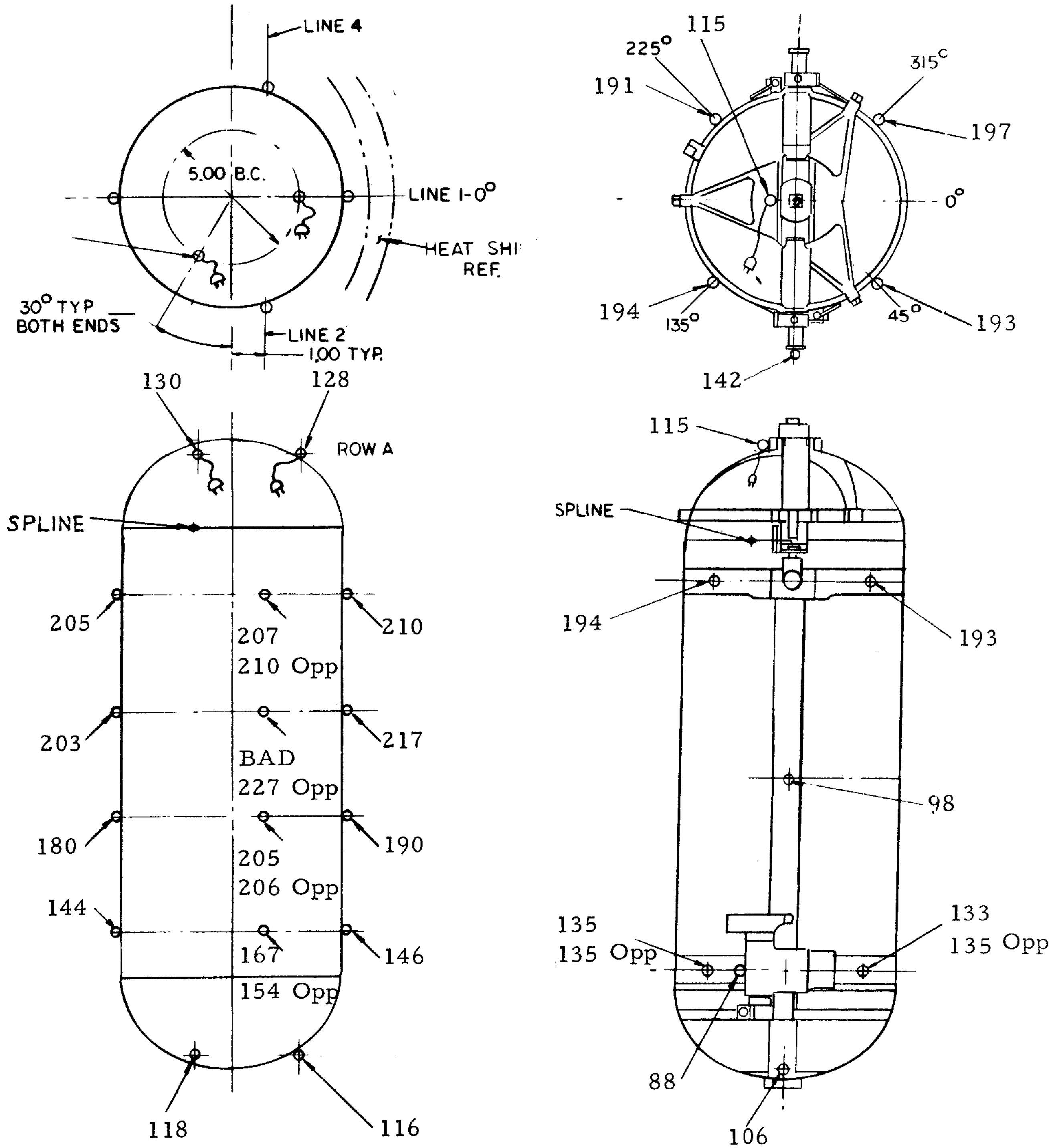


Figure 24. ACA Cask and Band Equilibrium Temperatures for Cask Cooling Run 10 (25 lb/min at 132°F).

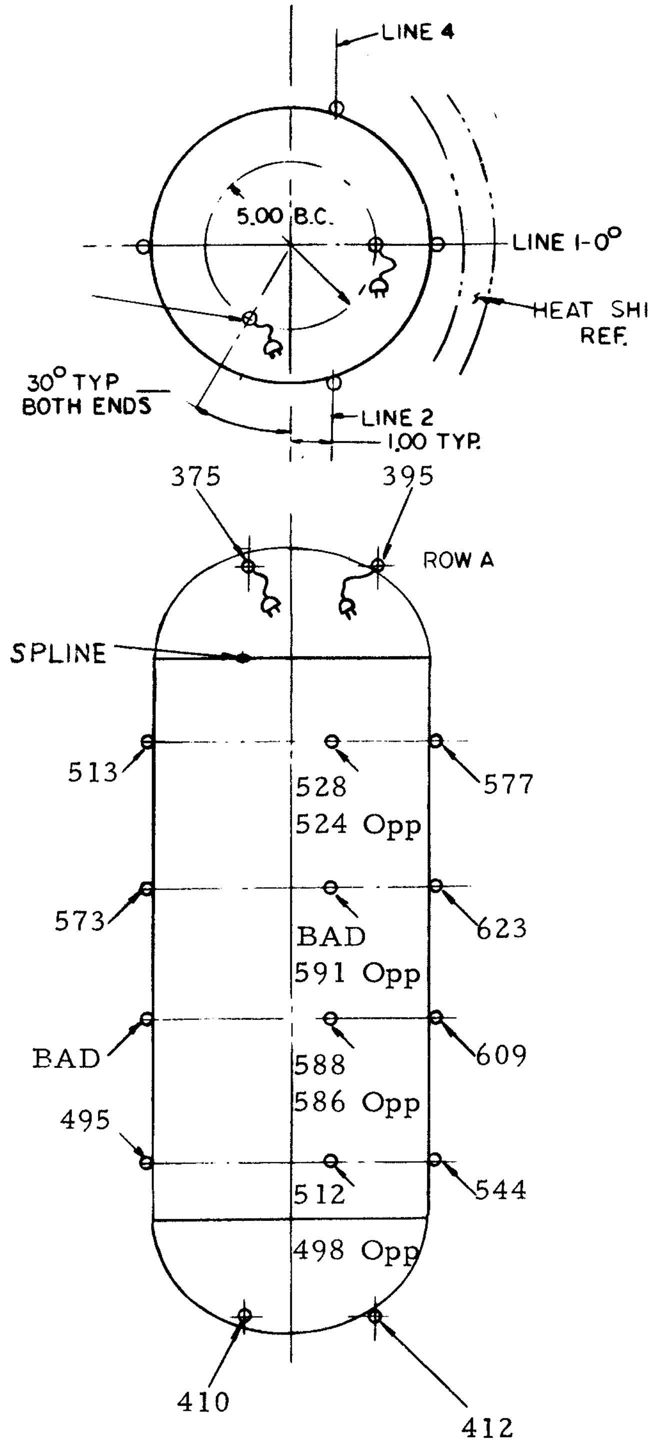


Figure 25. ALSEP Cask Equilibrium Temperatures for Free Convection Run 11.

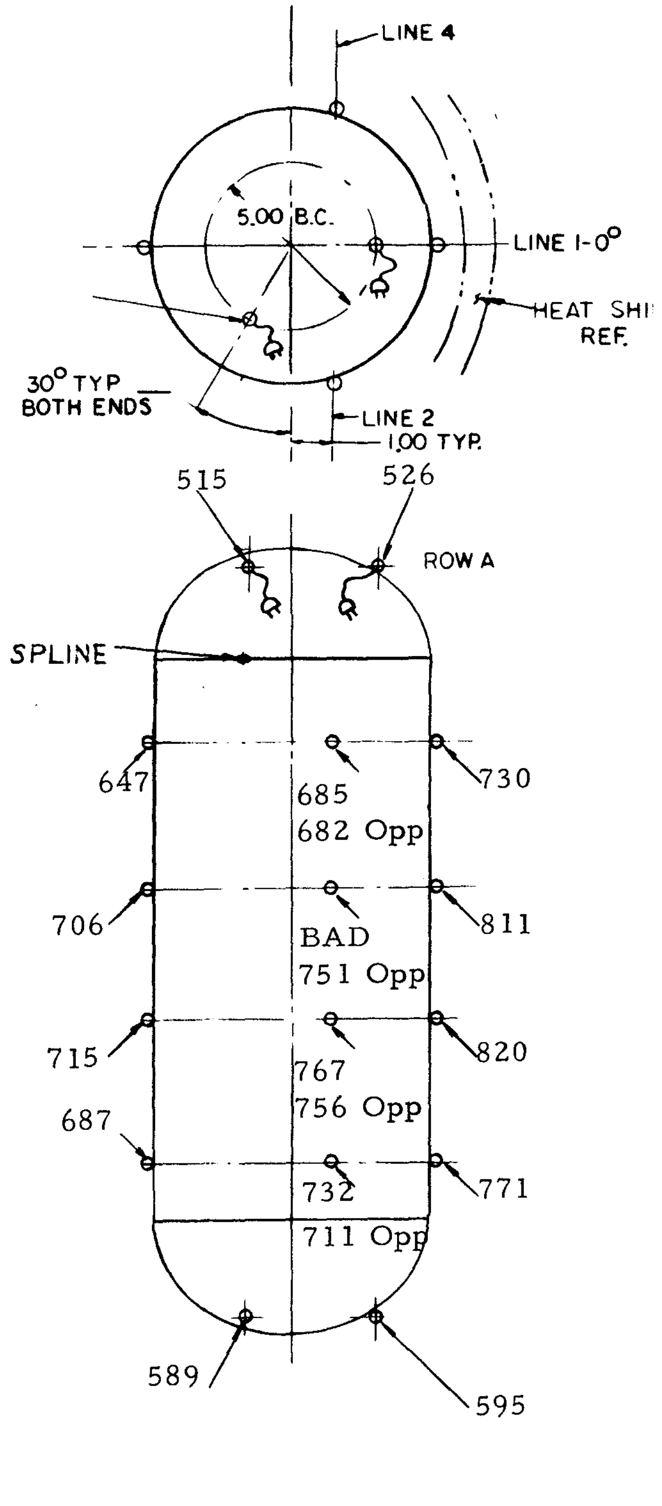


Figure 26. ALSEP Cask Equilibrium Temperatures for Thermal Vacuum Run 12 (SLA on with sun).

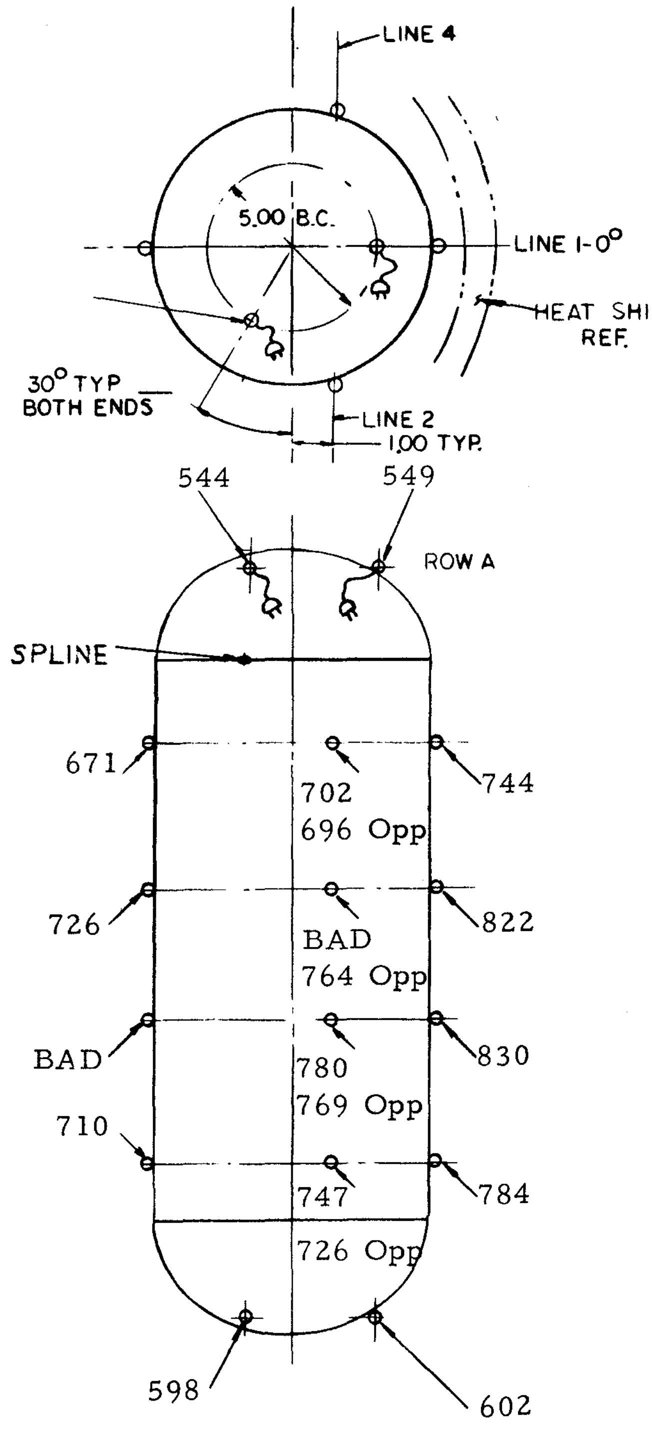


Figure 27. ALSEP Cask Equilibrium Temperatures for Thermal Vacuum Run 13 (SLA off with sun).

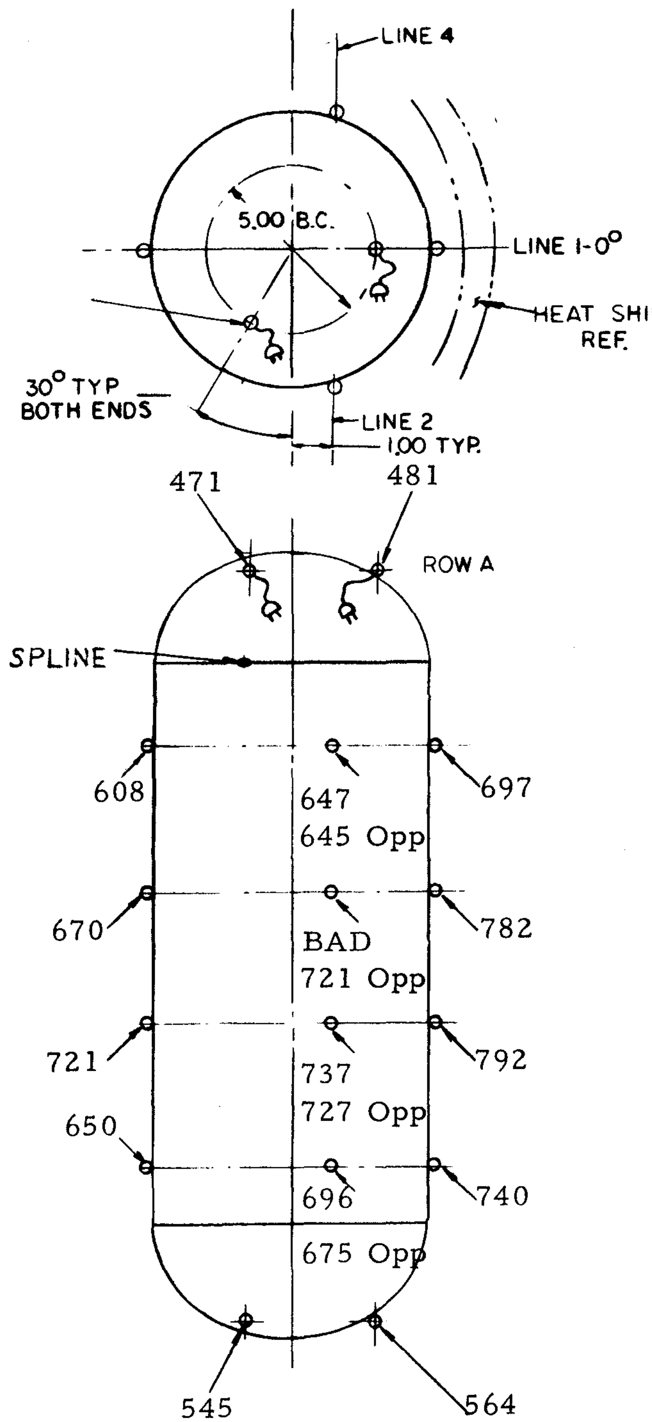


Figure 28. ALSEP Cask Equilibrium Temperatures for Thermal Vacuum Run 14 (SLA off, no sun).

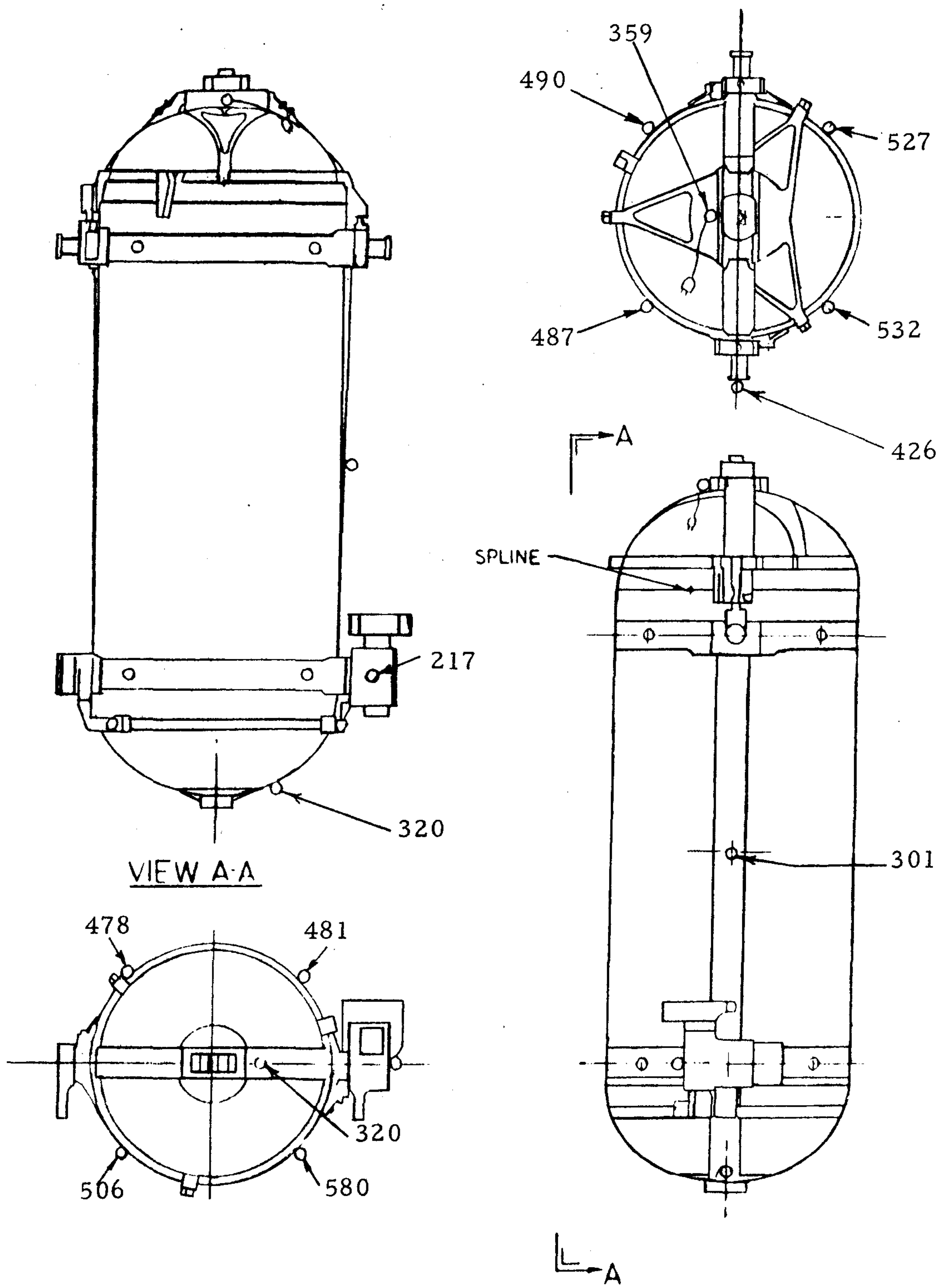


Figure 29. ALSEP Cask Band Equilibrium Temperatures for Free Convection Run 11.

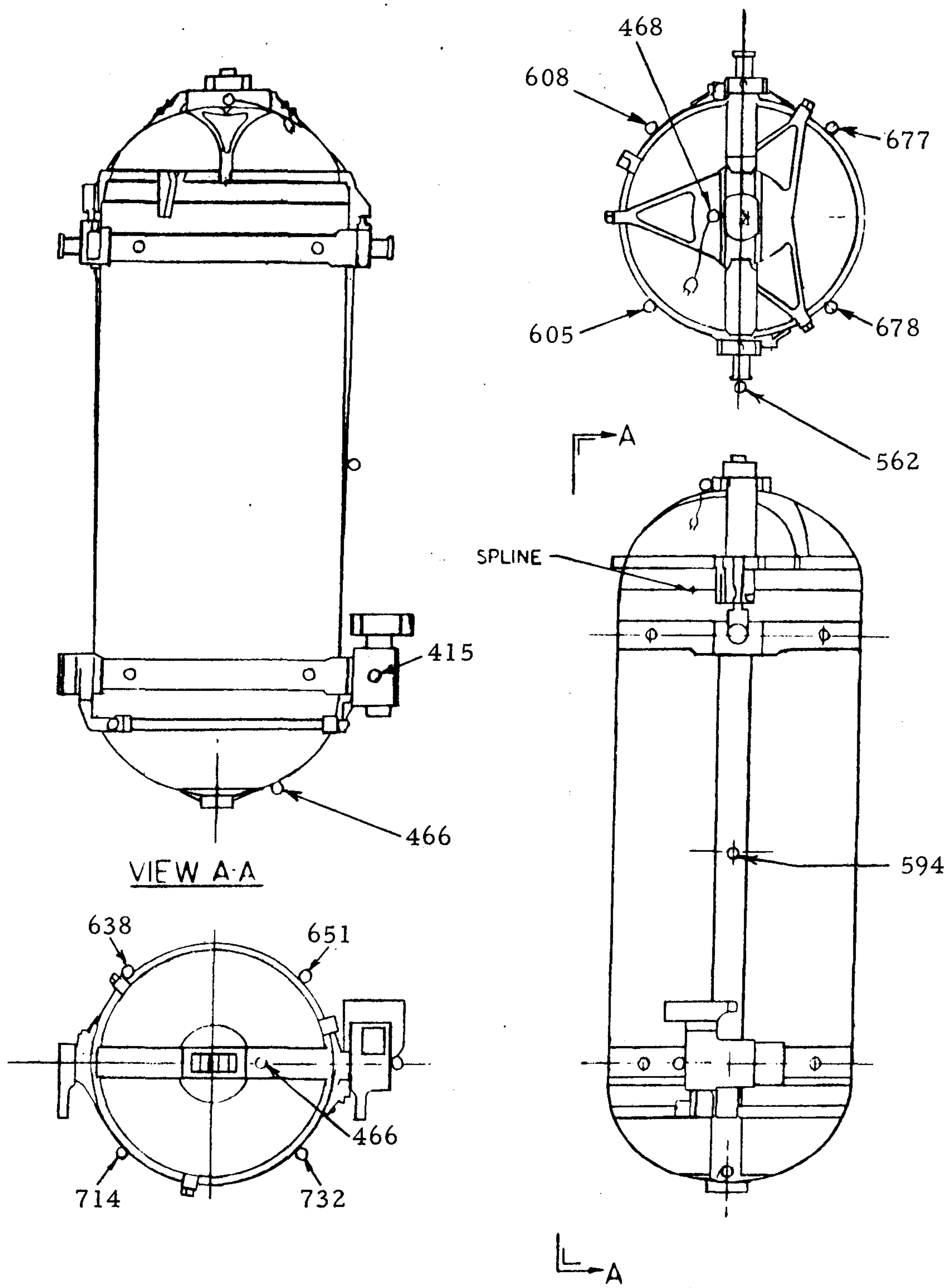


Figure 30. ALSEP Cask Band Equilibrium Temperatures for Thermal Vacuum Run 12 (SLA on with sun).

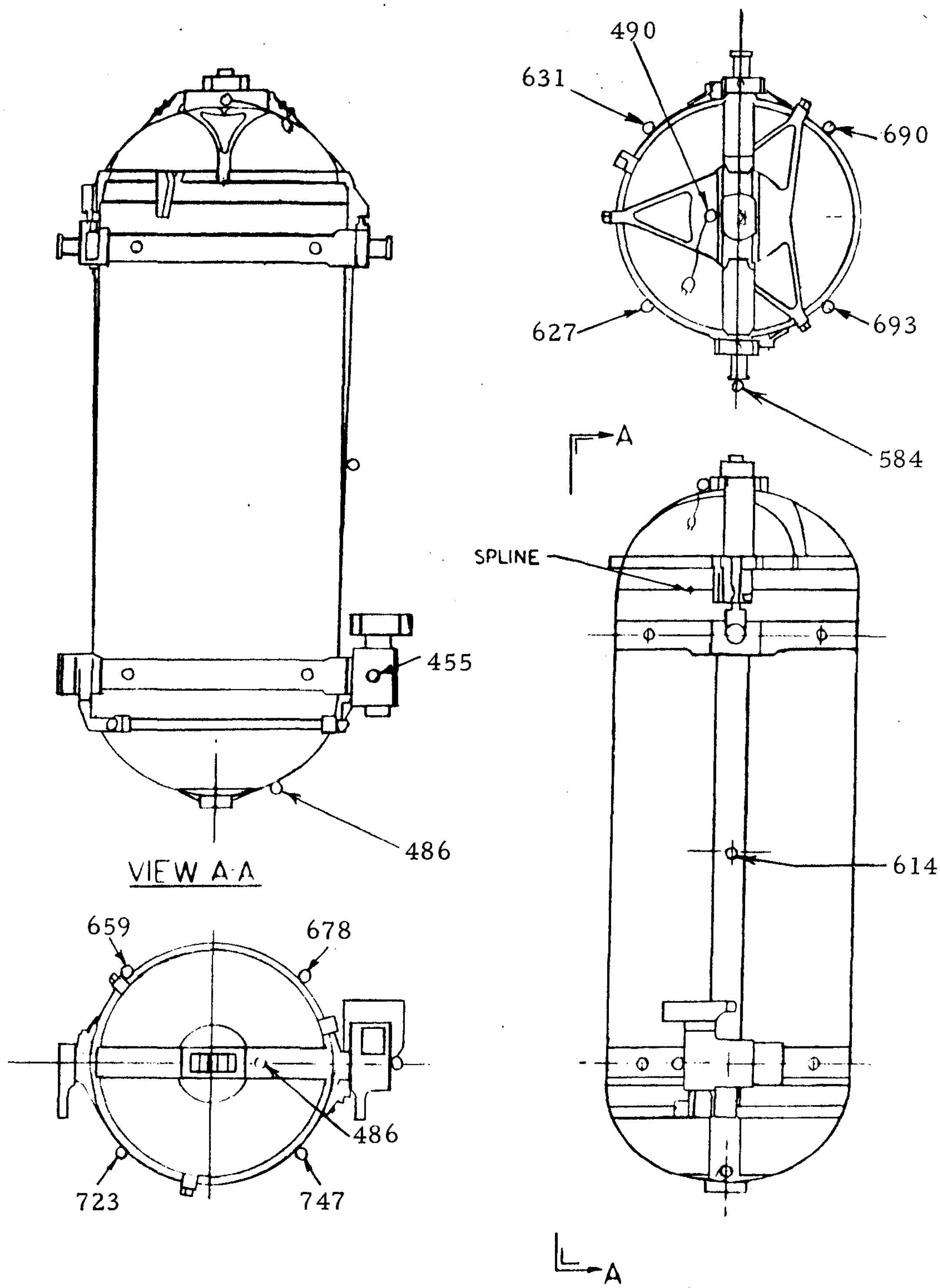


Figure 31. ALSEP Cask Band Equilibrium Temperatures for Thermal Vacuum Run 13 (SLA off with sun).

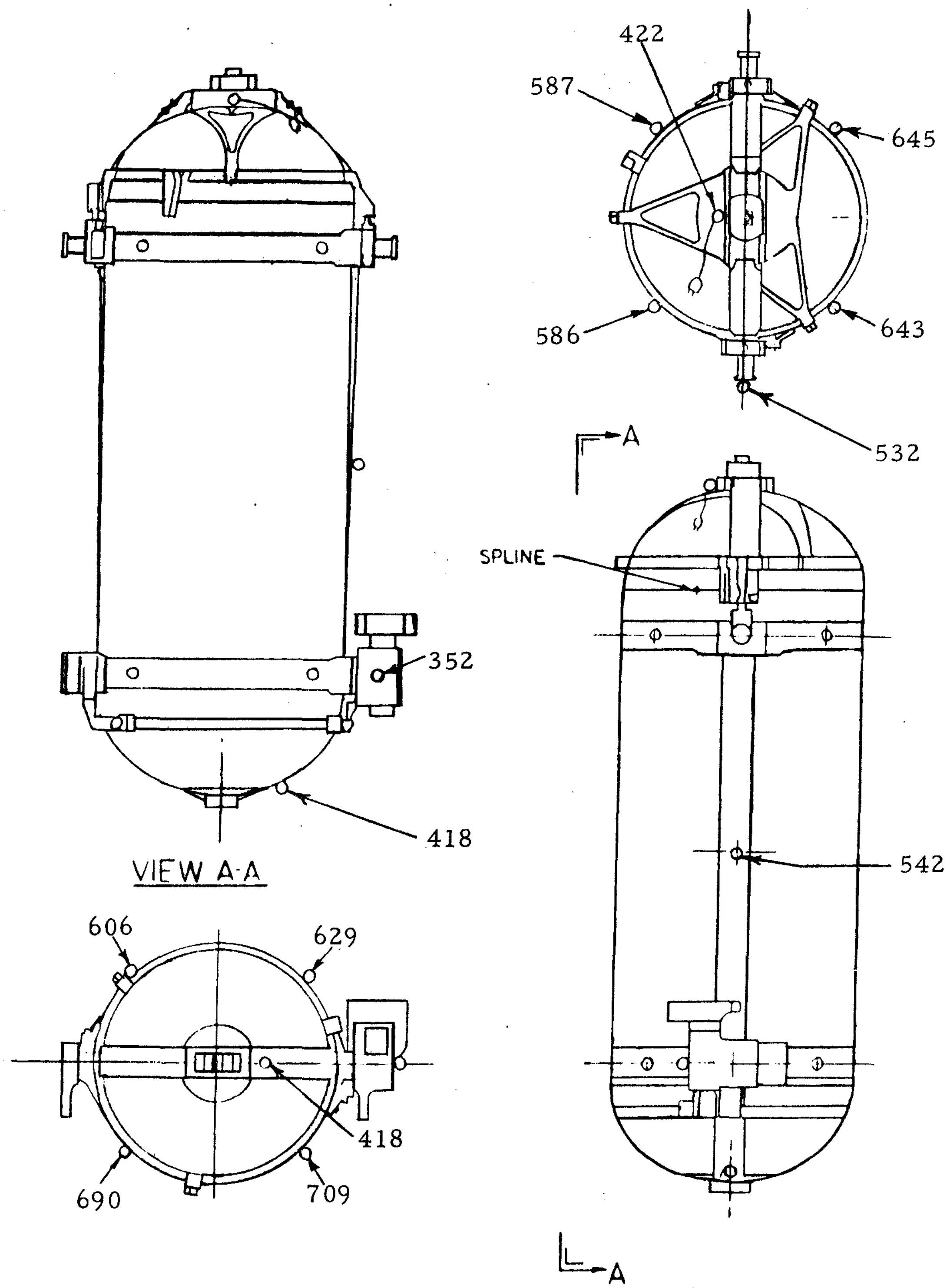


Figure 32. ALSEP Cask Band Equilibrium Temperatures for Thermal Vacuum Run 14 (SLA off, no sun).

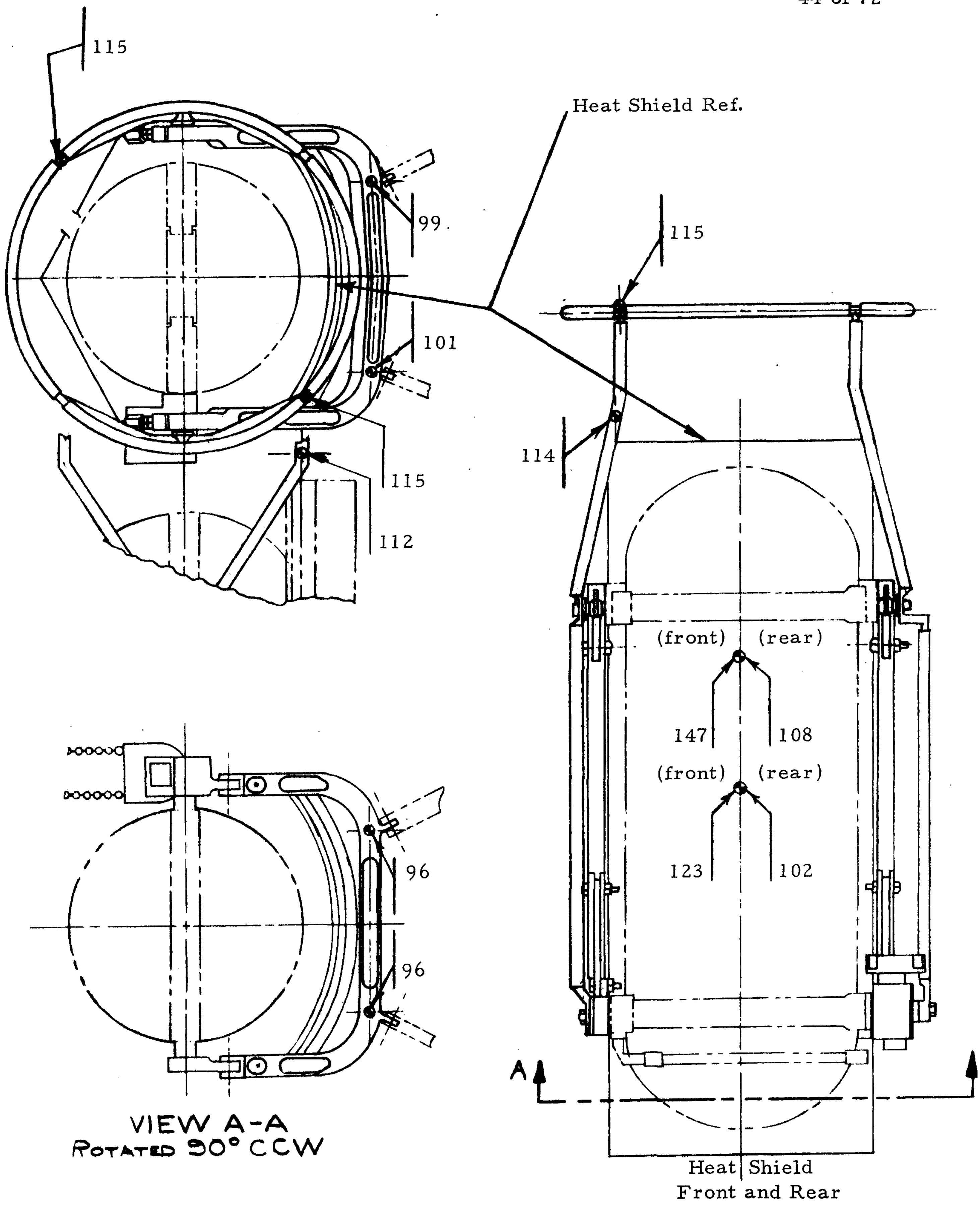


Figure 33. ALSEP Cask Support Structure Equilibrium Temperatures for Free Convection Run 11.

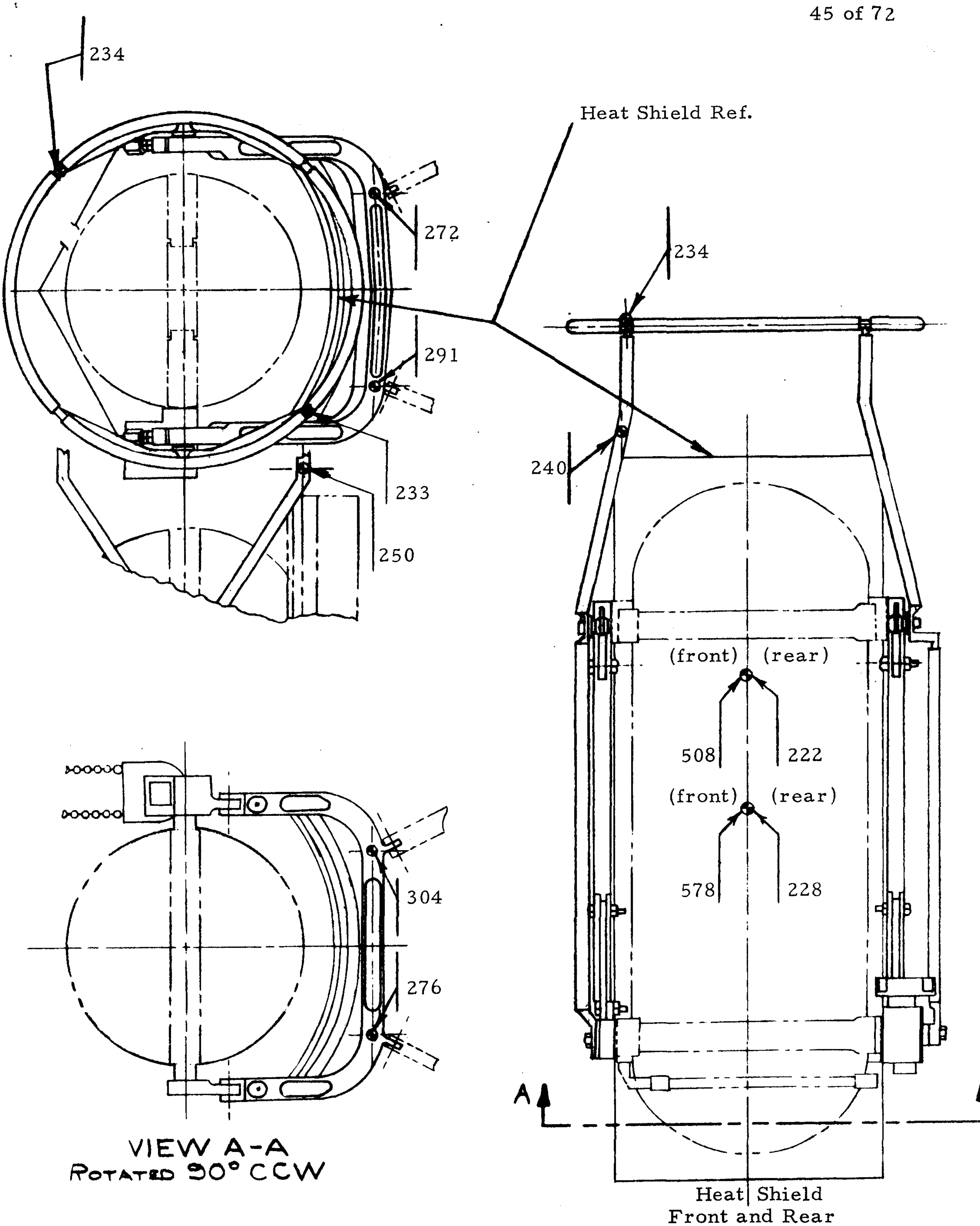


Figure 34. ALSEP Cask Support Structure Equilibrium Temperatures for Thermal Vacuum Run 12 (SLA on with sun).

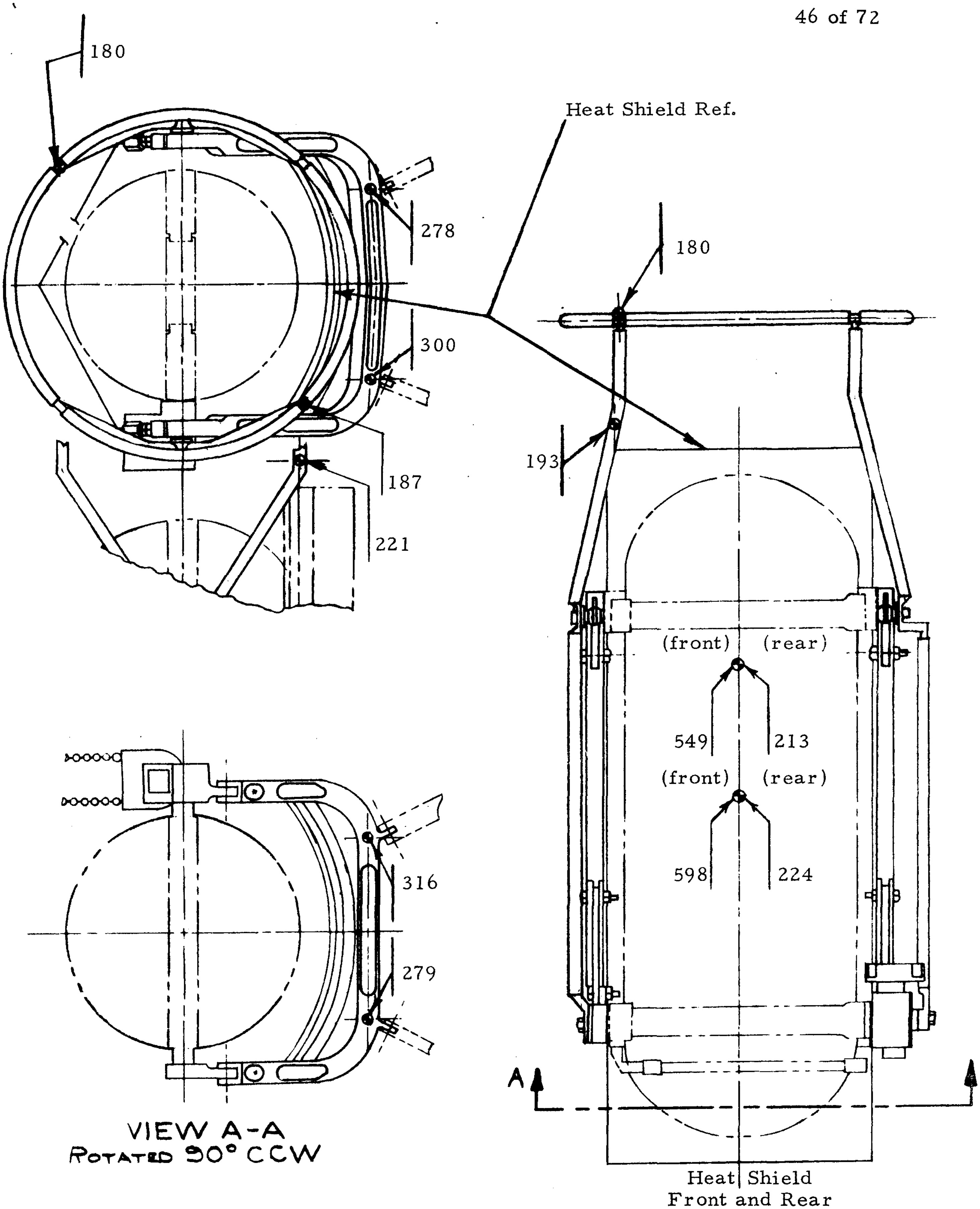


Figure 35. ALSEP Cask Support Structure Equilibrium Temperatures for Thermal Vacuum Run 13 (SLA off with sun).

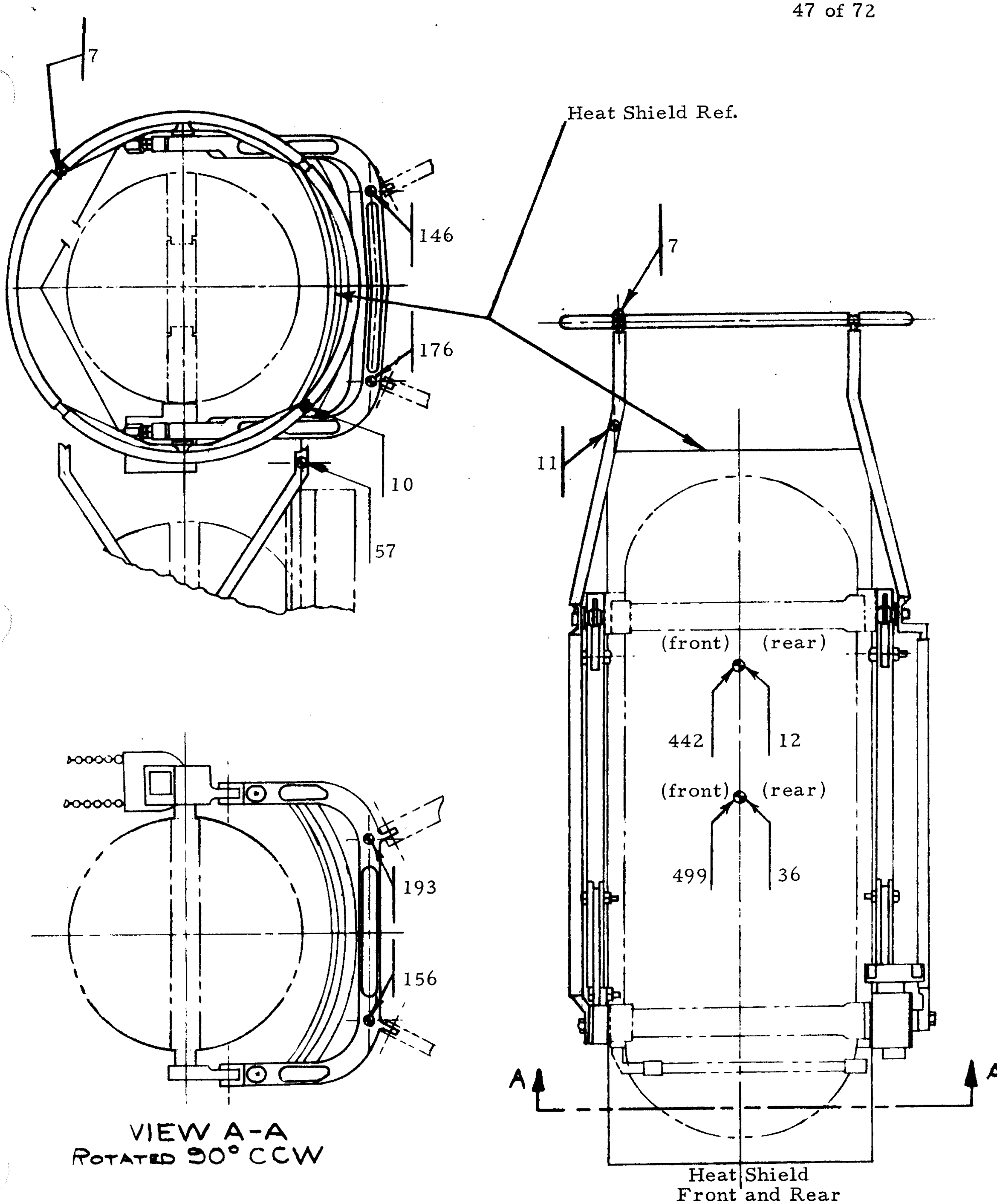


Figure 36. ALSEP Cask Support Structure Equilibrium Temperatures for Thermal Vacuum Run 14 (SLA off, no sun).

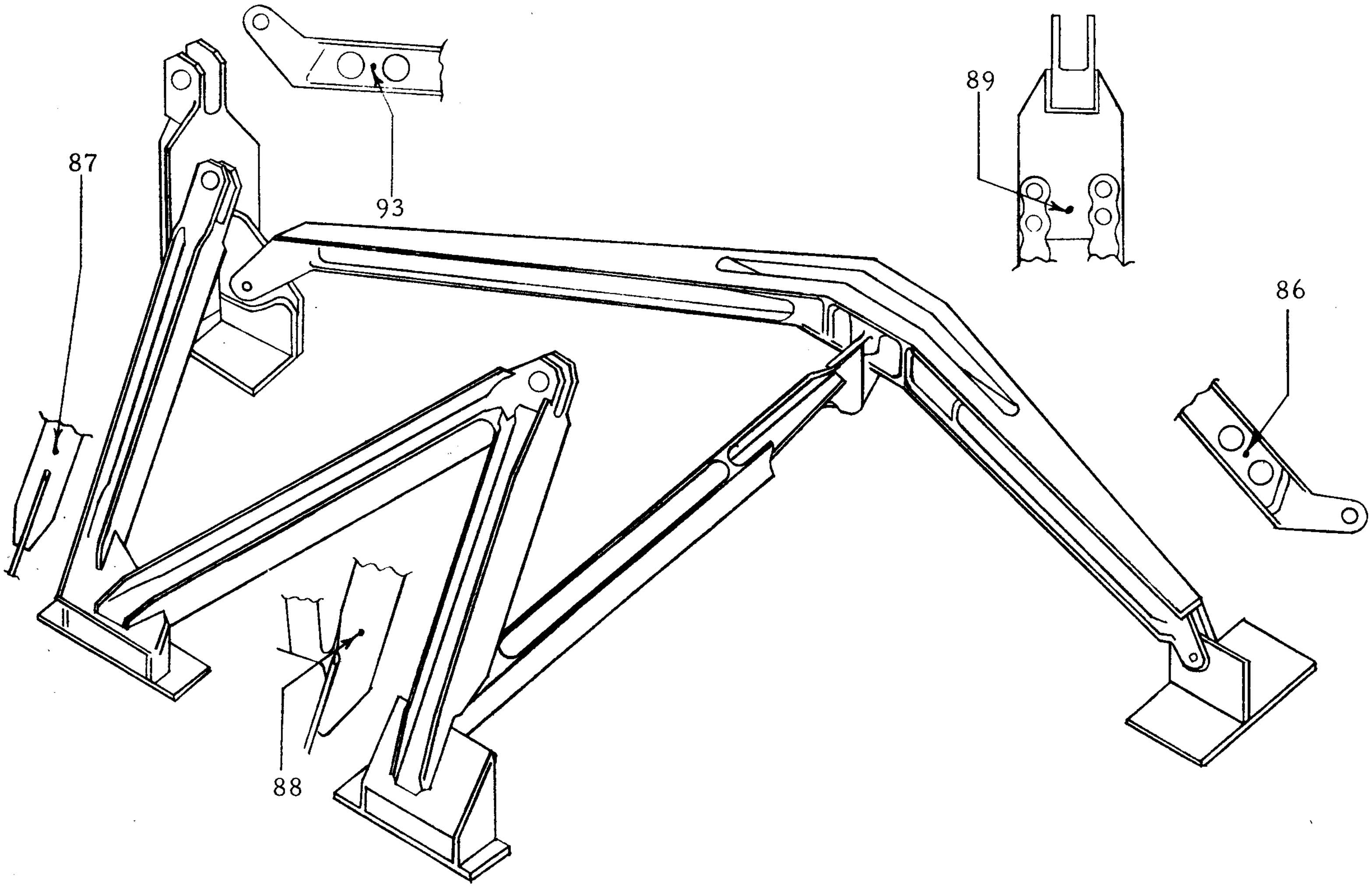


Figure 37. Grumman Strut Equilibrium Temperatures for Free Convection Run 11.

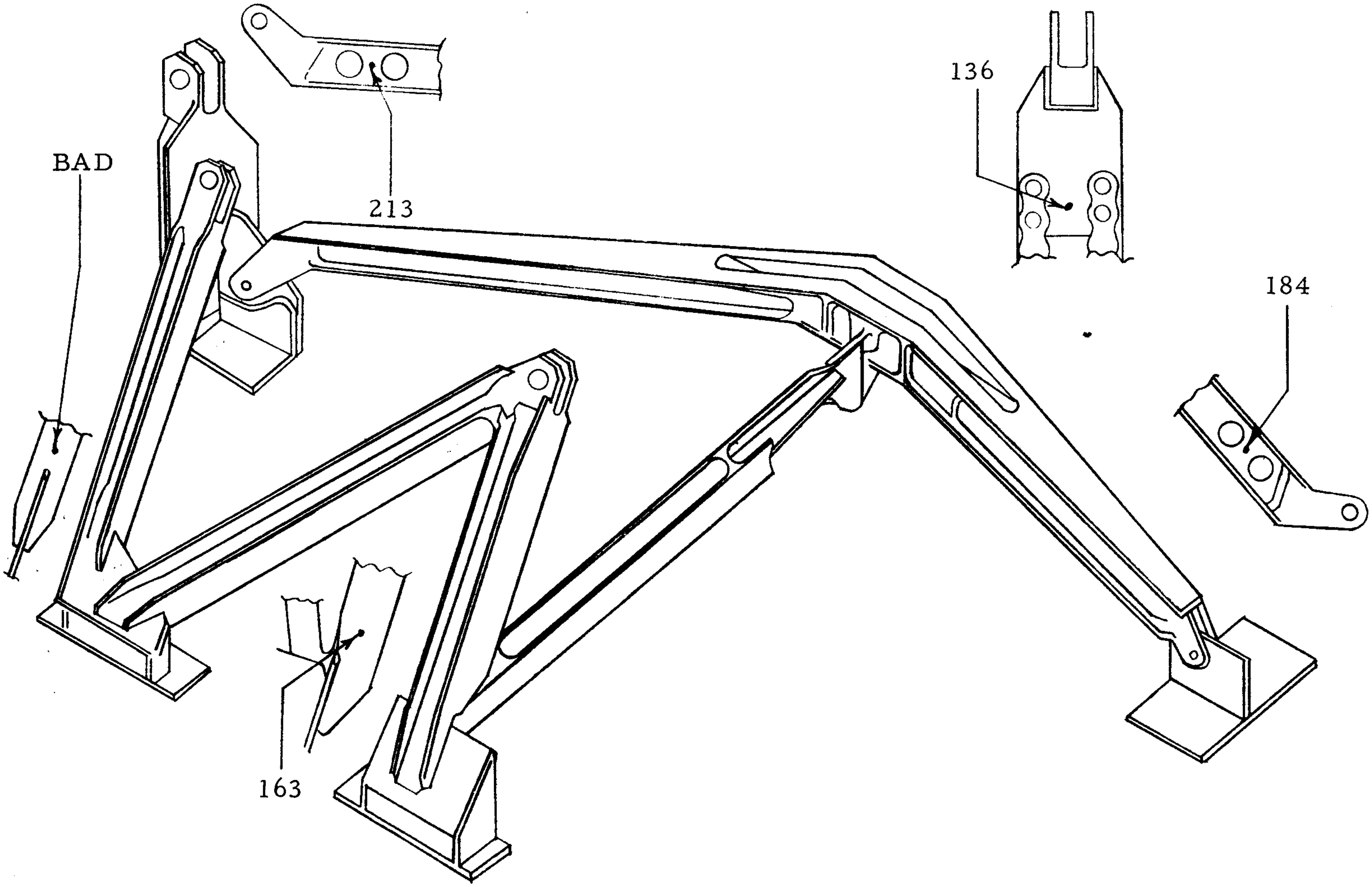


Figure 38. Grumman Strut Equilibrium Temperatures for Thermal Vacuum Run 12 (SLA on with sun).

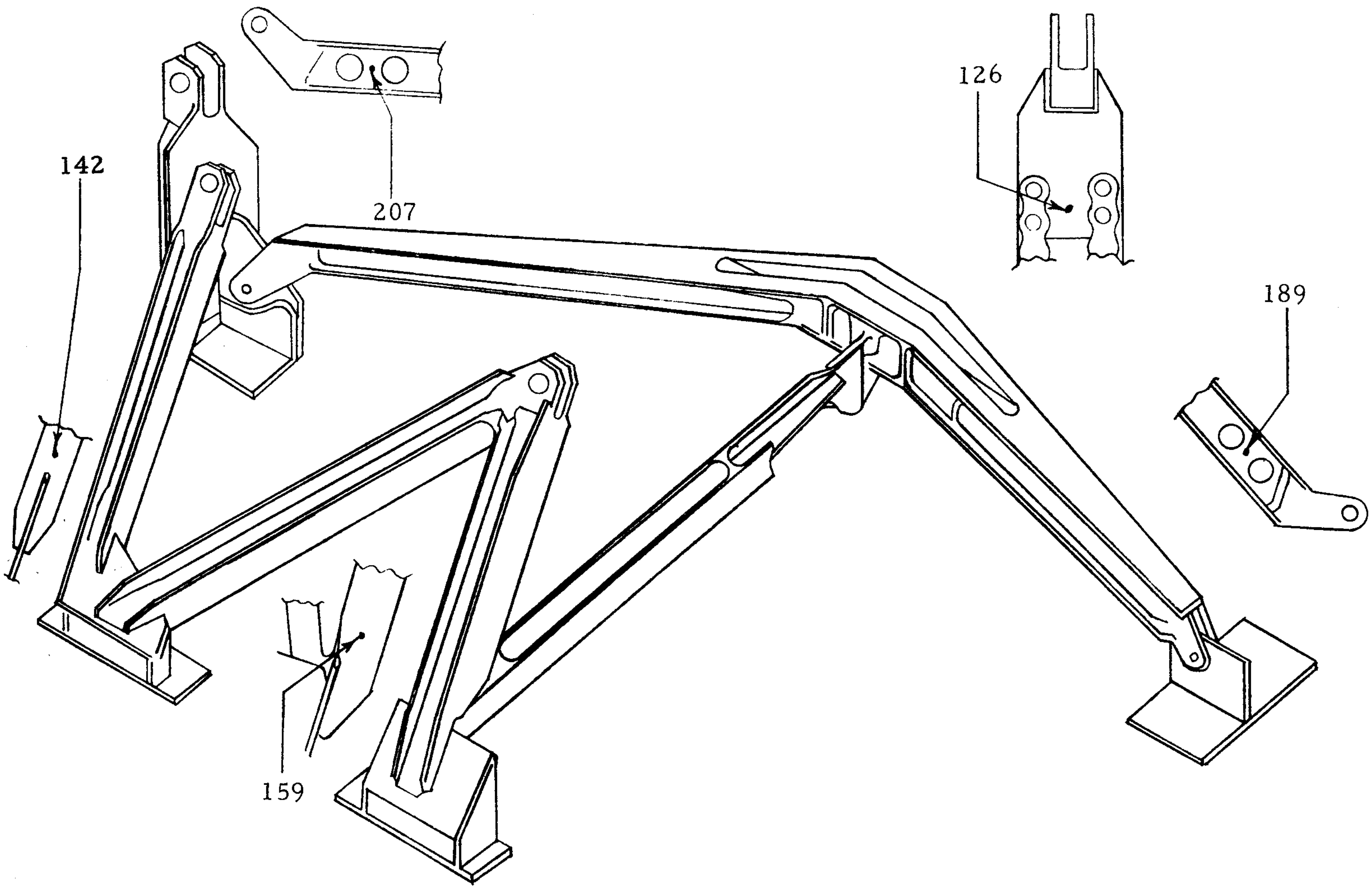


Figure 39. Grumman Strut Equilibrium Temperatures for Thermal Vacuum Run 13 (SLA off with sun).

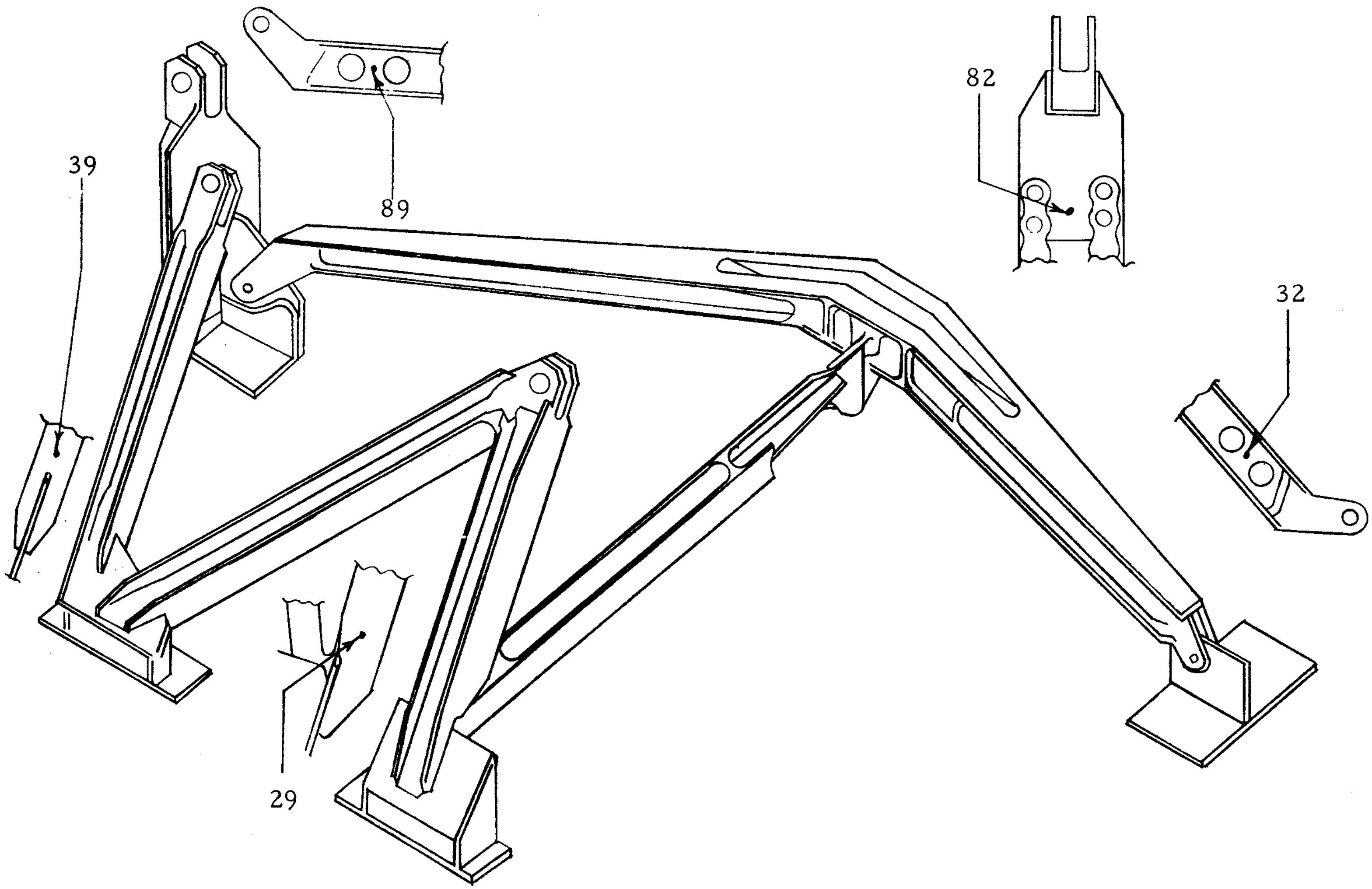


Figure 40. Grumman Strut Equilibrium Temperatures for Thermal Vacuum Run 14 (SLA off, no sun).

Figure 41. Grumman Thermal Blanket (7A) Equilibrium Temperatures for Free Convection Run 11.

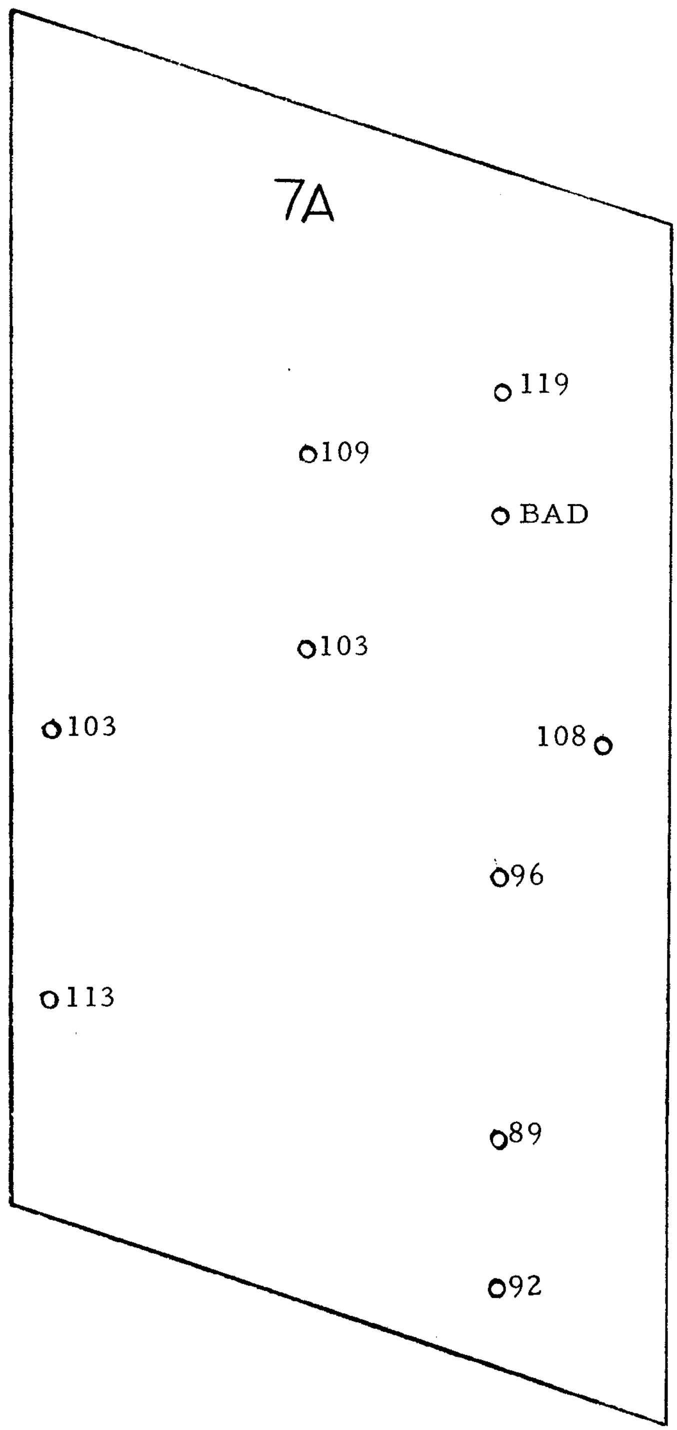


Figure 42. Grumman Thermal Blanket (7A) Equilibrium Temperatures for Thermal Vacuum Run 12 (SLA on with sun).

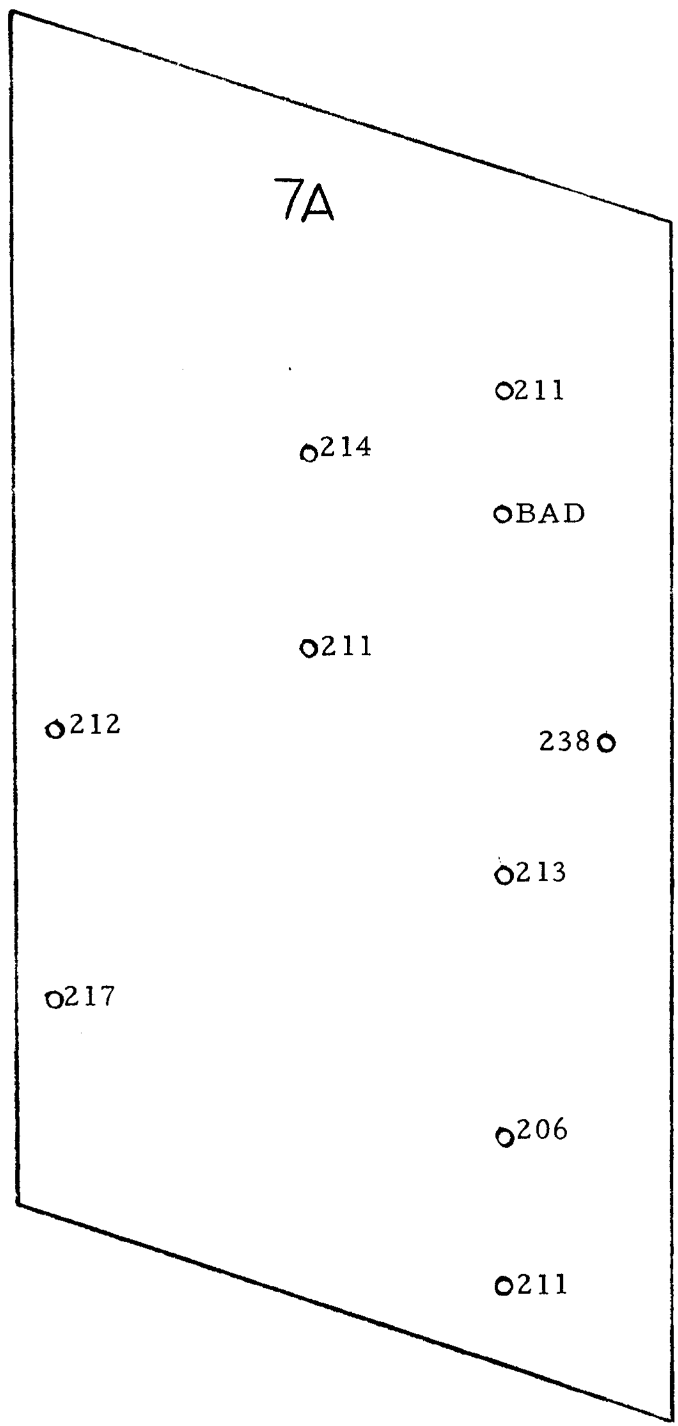


Figure 43. Grumman Thermal Blanket (7A) Equilibrium Temperatures for Thermal Vacuum Run 13 (SLA off with sun).

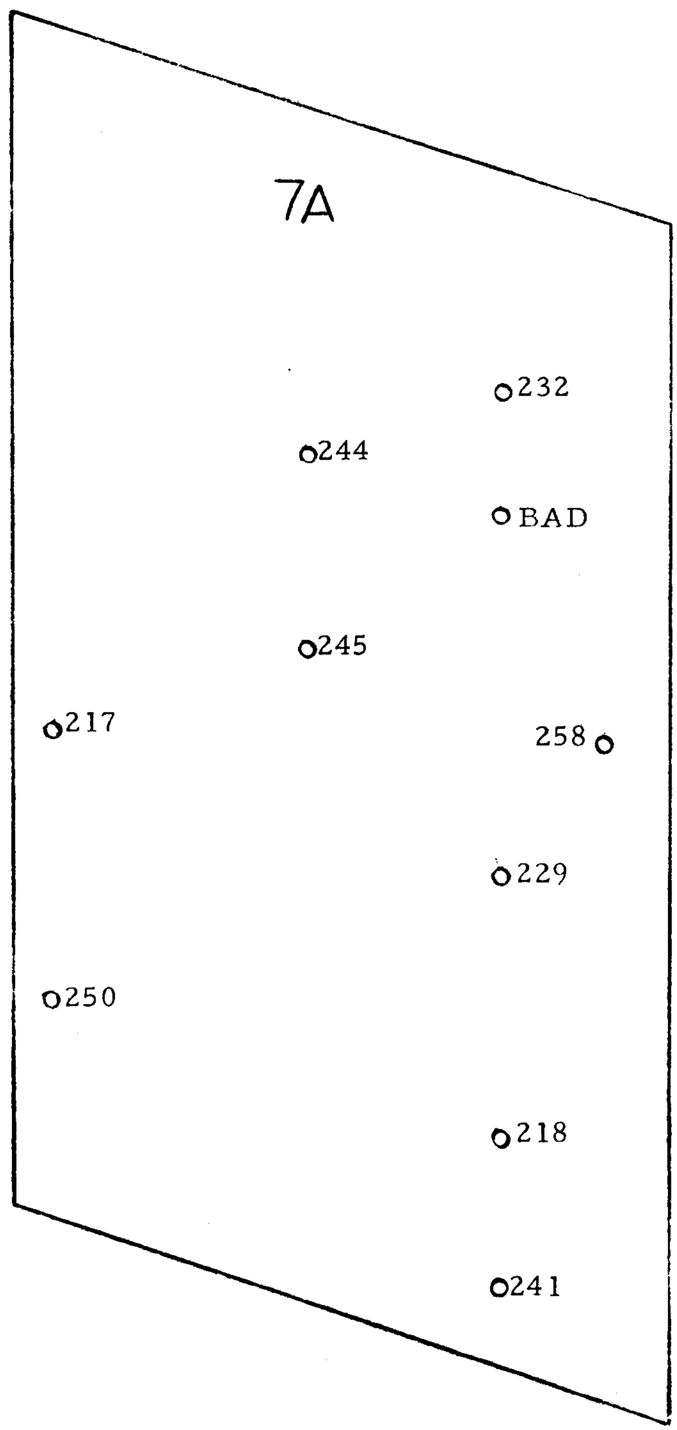
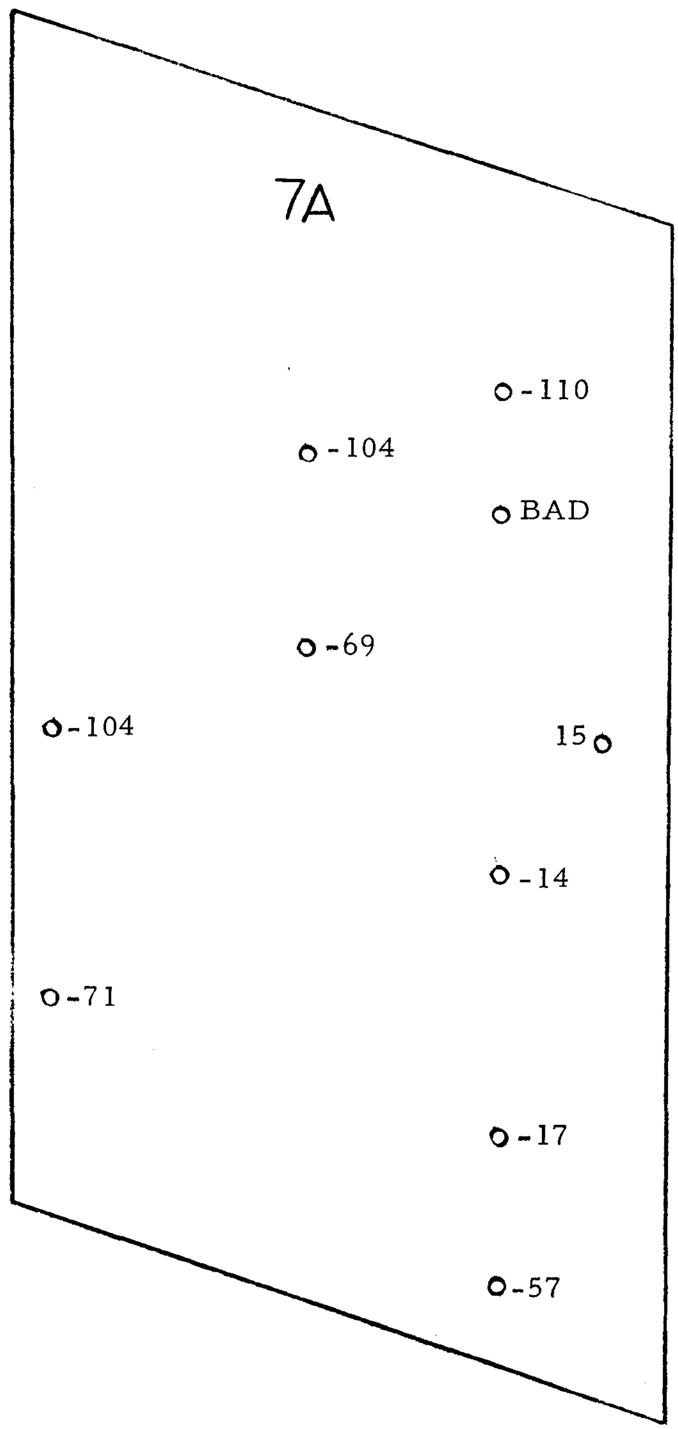


Figure 44. Grumman Thermal Blanket (7A) Equilibrium Temperatures for Thermal Vacuum Run 14 (SLA off, no sun).



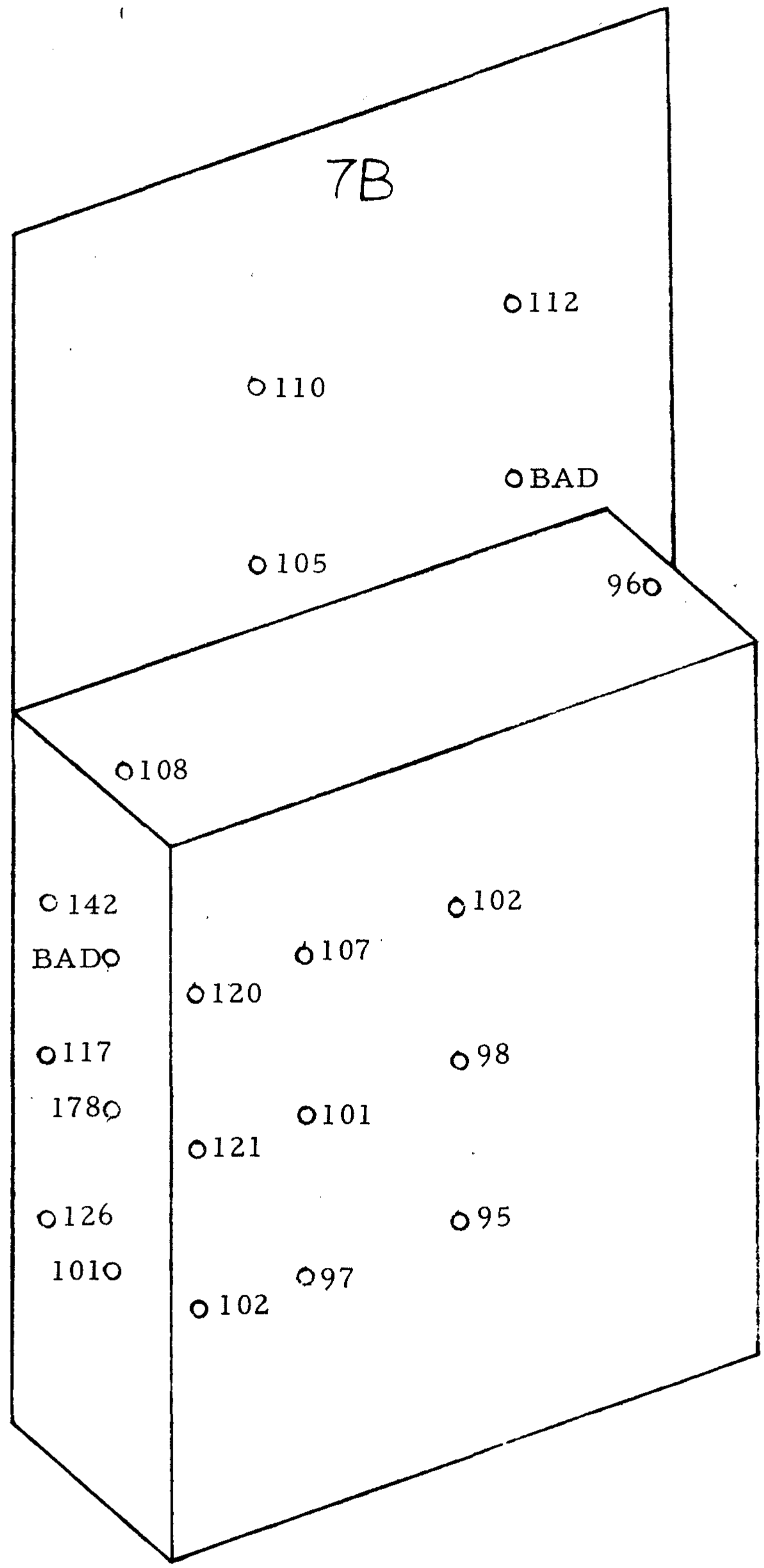


Figure 45. Grumman Thermal Blanket (7B) Equilibrium Temperatures for Free Convection Run 11.

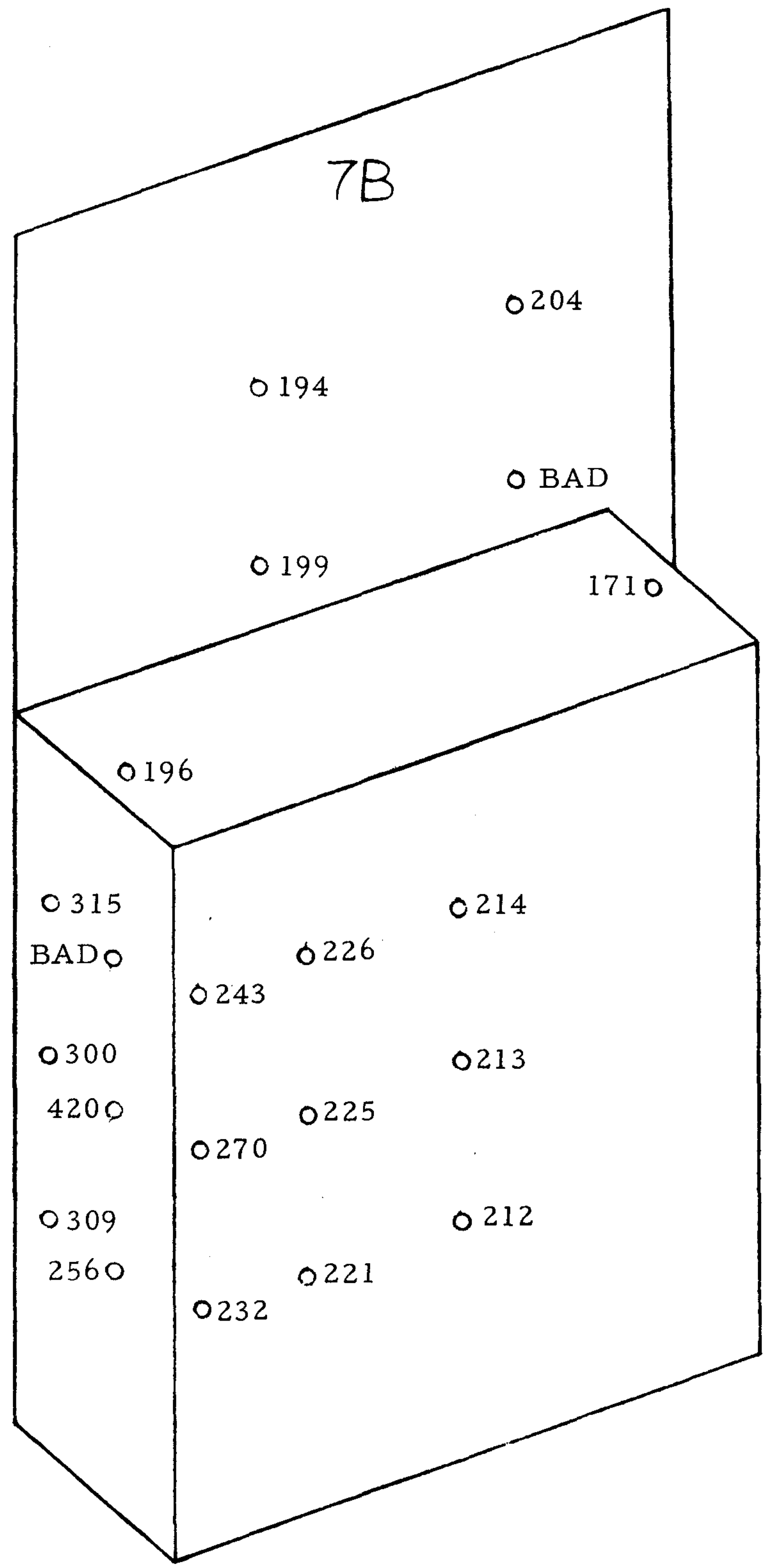


Figure 46. Grumman Thermal Blanket (7B) Equilibrium Temperatures for Thermal Vacuum Run 12 (SLA on with sun).

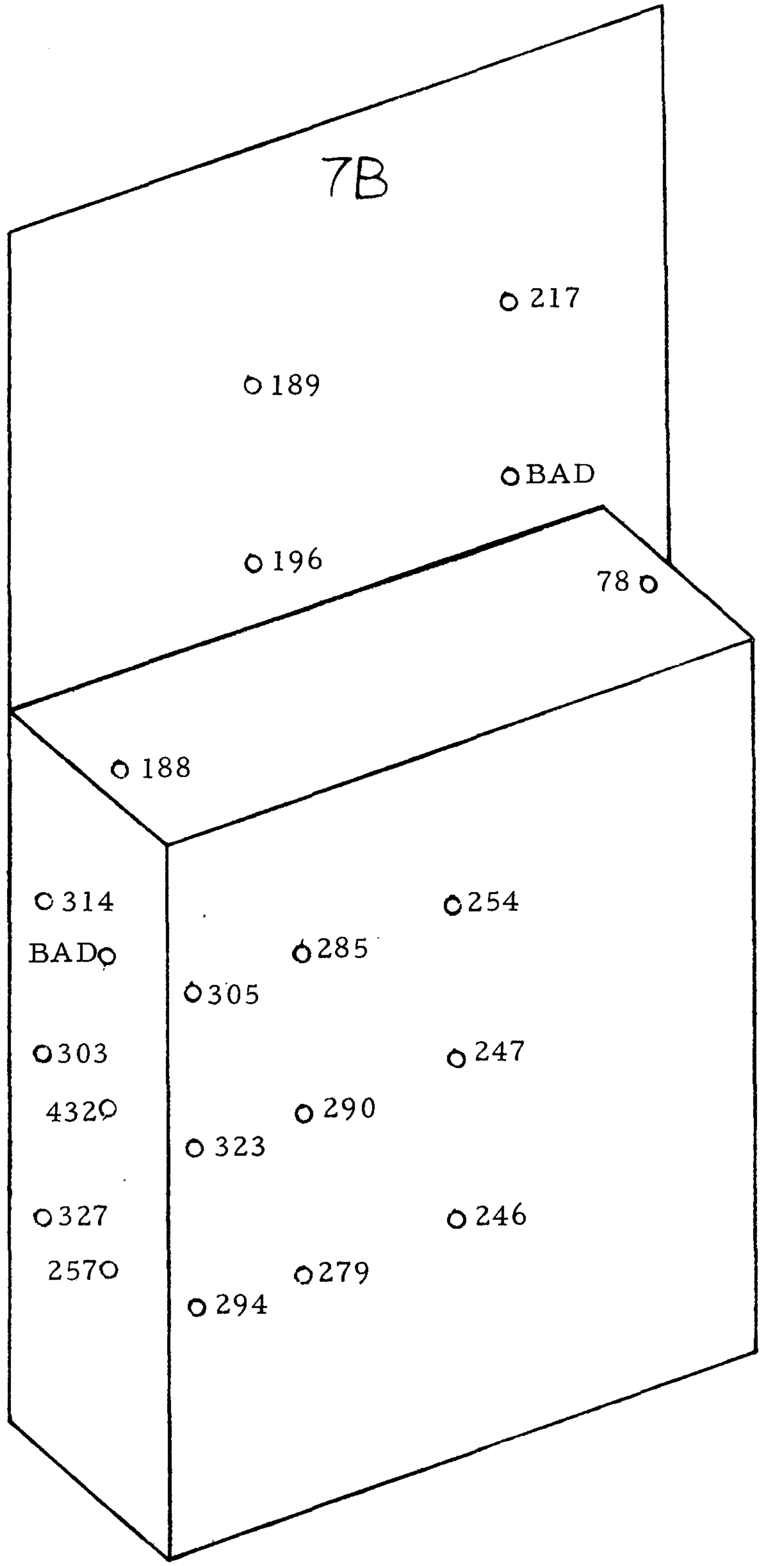


Figure 47. Grumman Thermal Blanket (7B) Equilibrium Temperatures for Thermal Vacuum Run 13 (SLA off with sun).

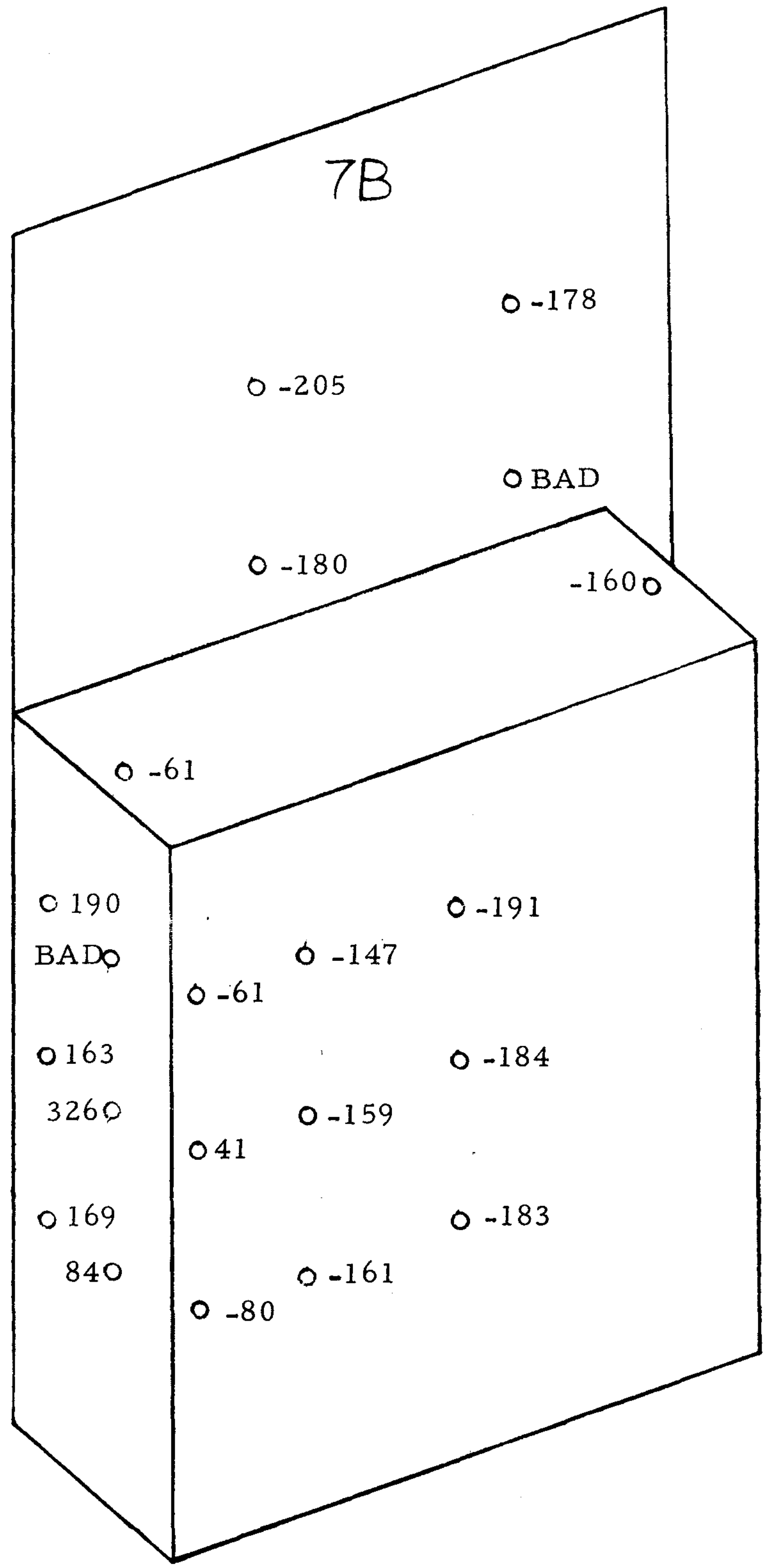
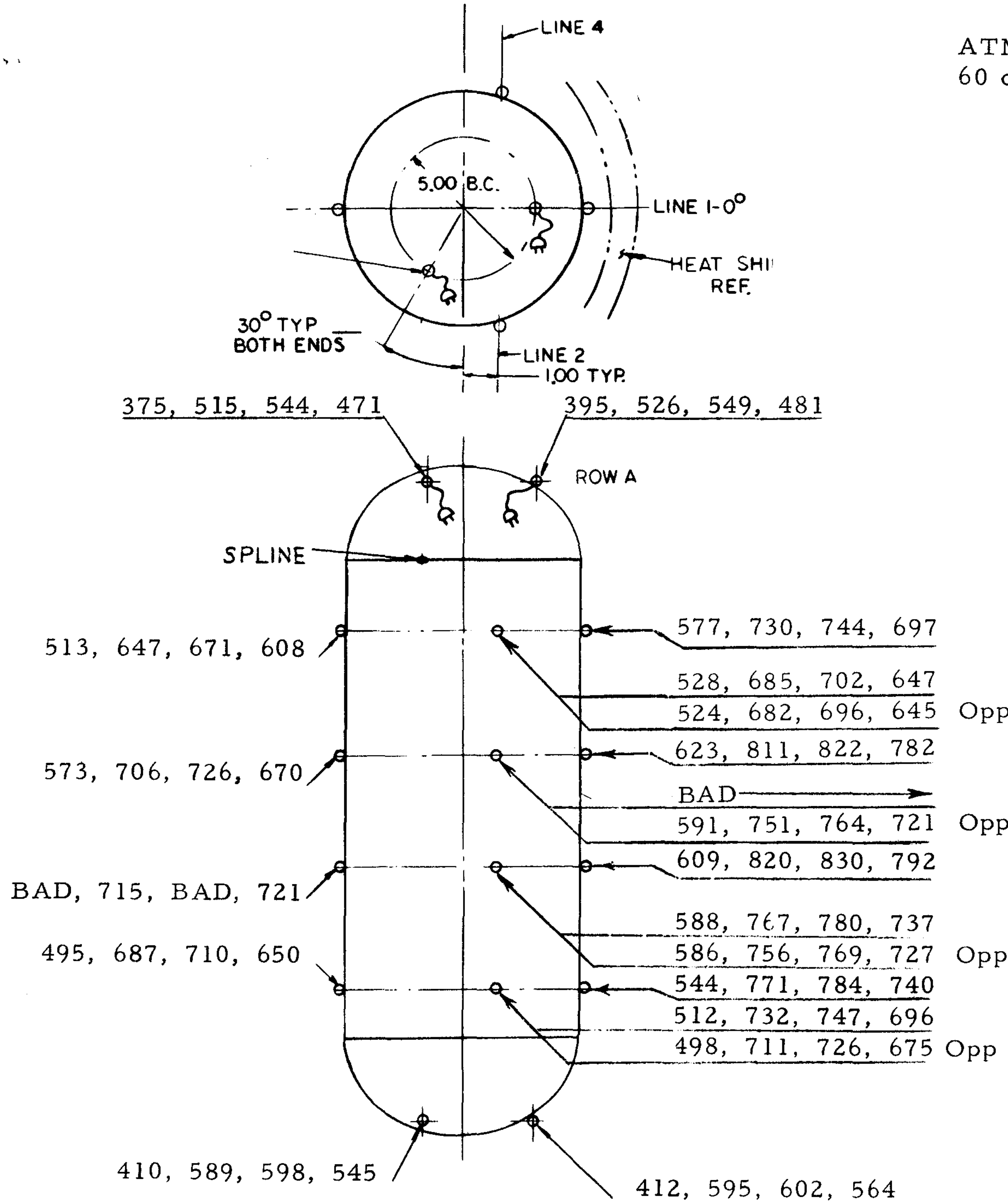


Figure 48. Grumman Thermal Blanket (7B) Equilibrium Temperatures for Thermal Vacuum Run 14 (SLA off, no sun).



Note: Temperatures are presented for the following test sequence.

A. free convection
B. SLA on with sun
C. SLA off with sun
D. SLA off, no sun

Figure 49. ALSEP Cask Equilibrium Temperatures for Free Convection and Thermal Vacuum Runs (#11-14).

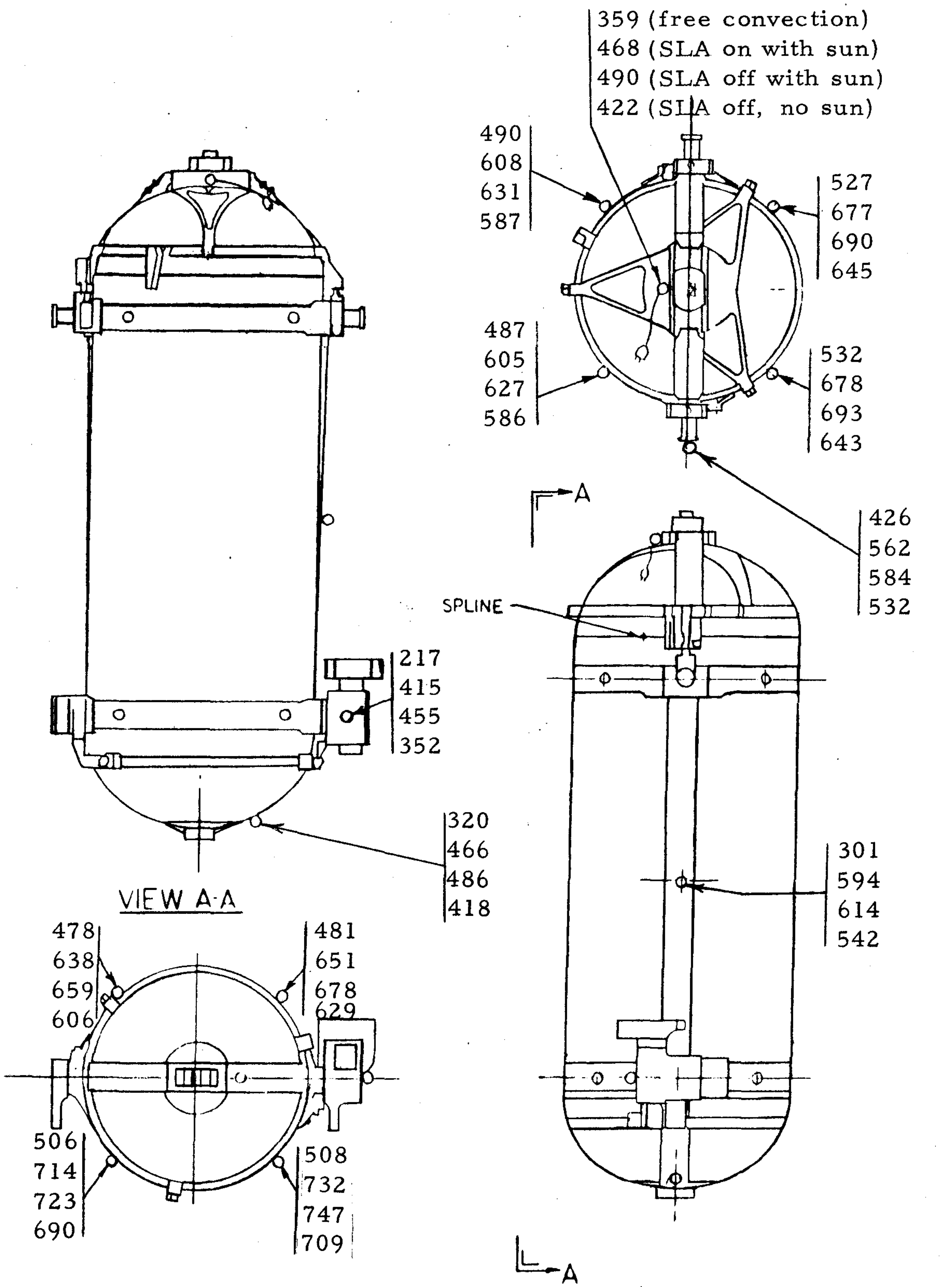


Figure 50. ALSEP Cask Band Equilibrium Temperatures for Free Convection and Thermal Vacuum Runs (#11-14).

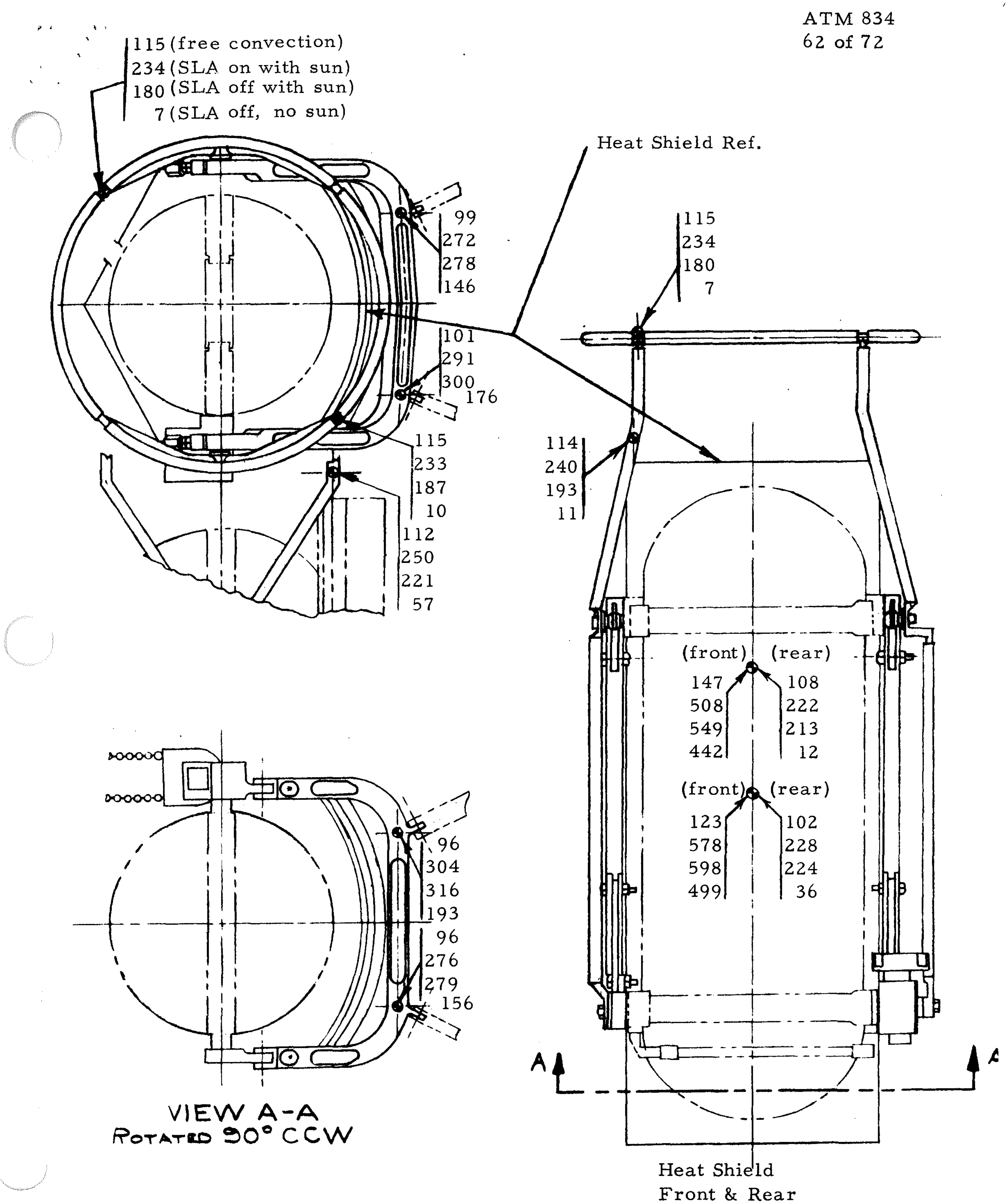


Figure 51. ALSEP Cask Support Structure Equilibrium Temperatures for Free Convection and Thermal Vacuum Runs (#11-14).

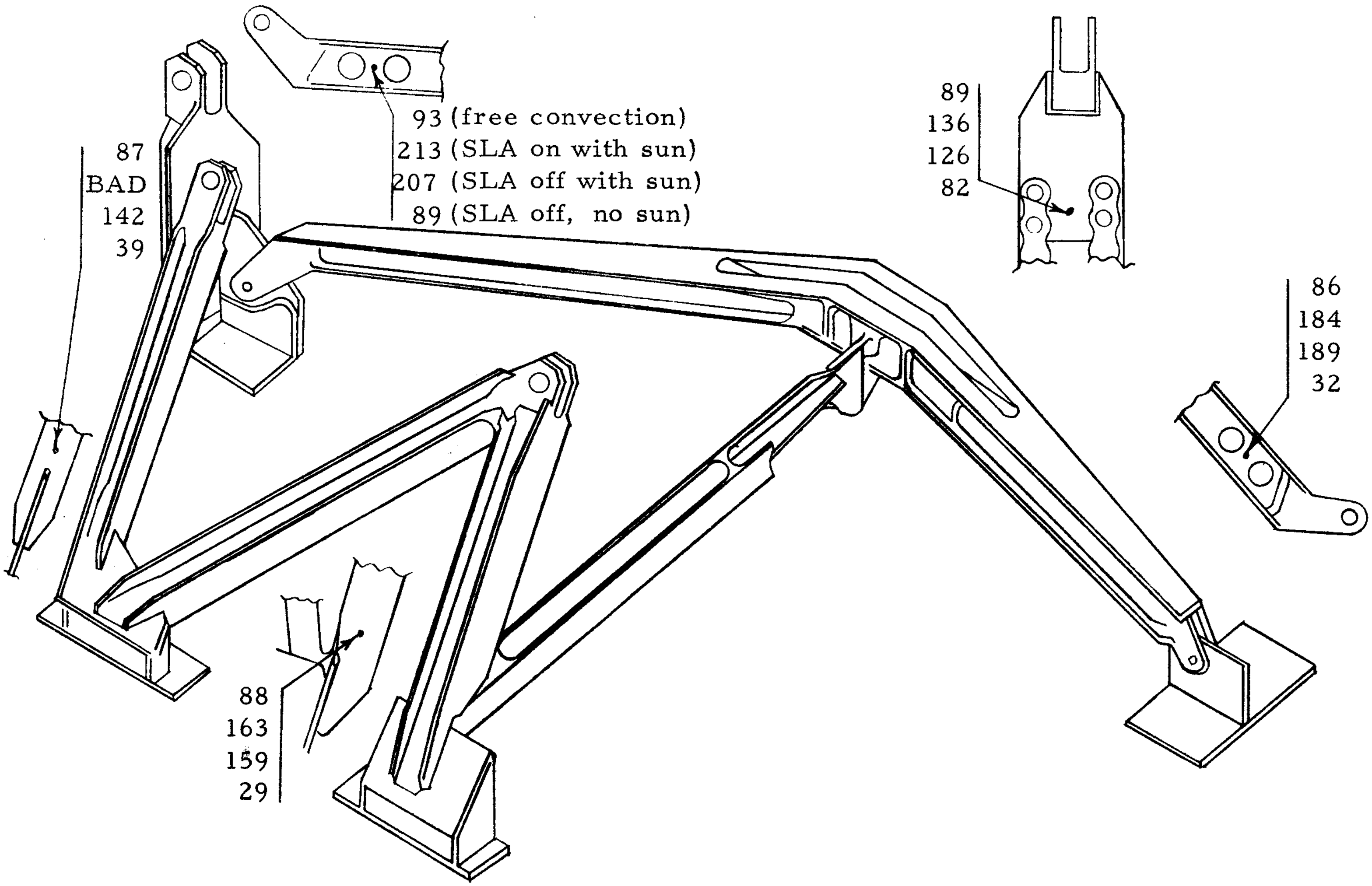
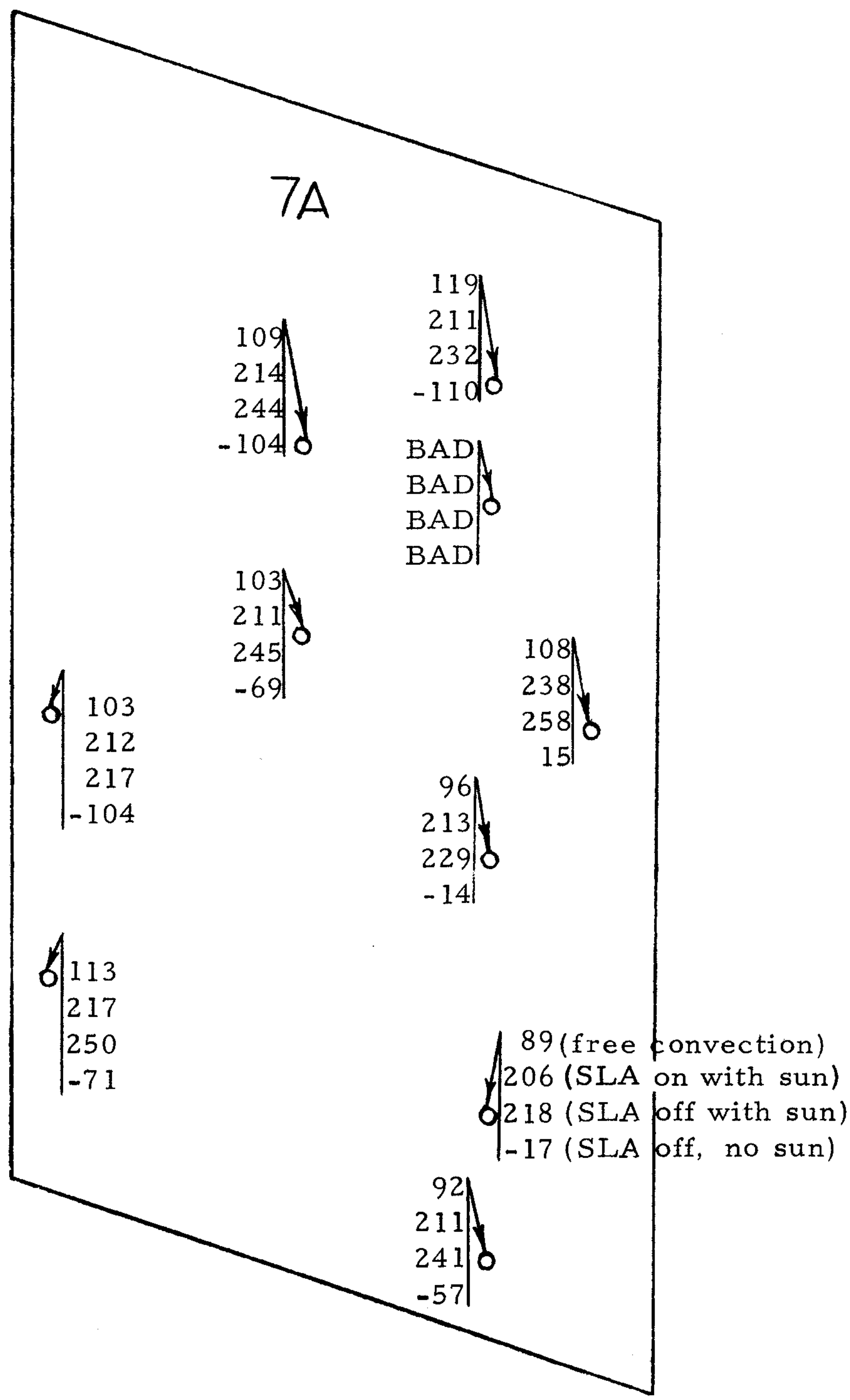


Figure 52. Grumman Strut Equilibrium Temperatures for Free Convection and Thermal Vacuum Runs (#11-14).

Figure 53. Grumman Thermal Blanket (7A) Equilibrium Temperatures for Free Convection and Thermal Vacuum Runs (#11-14).



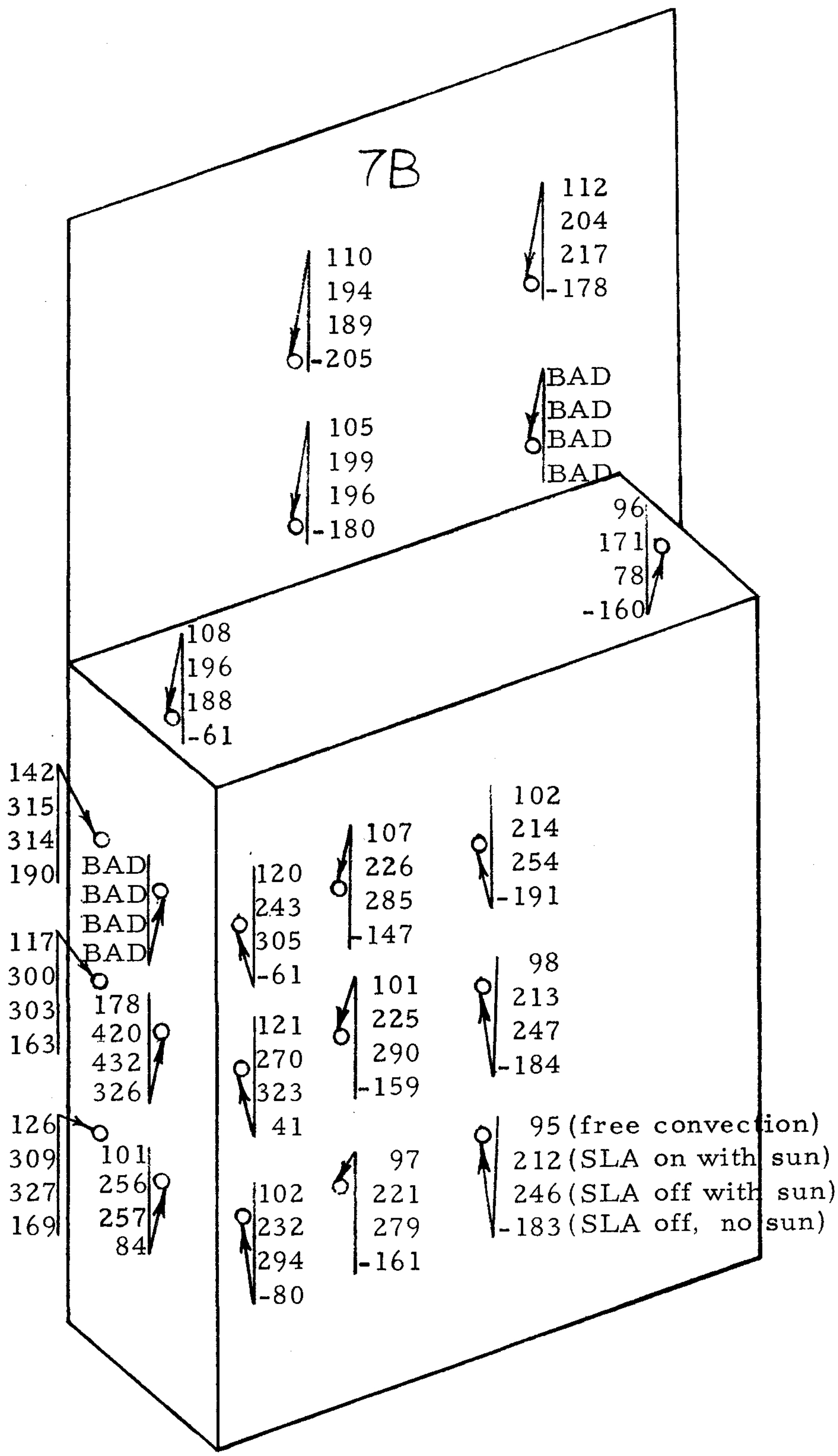
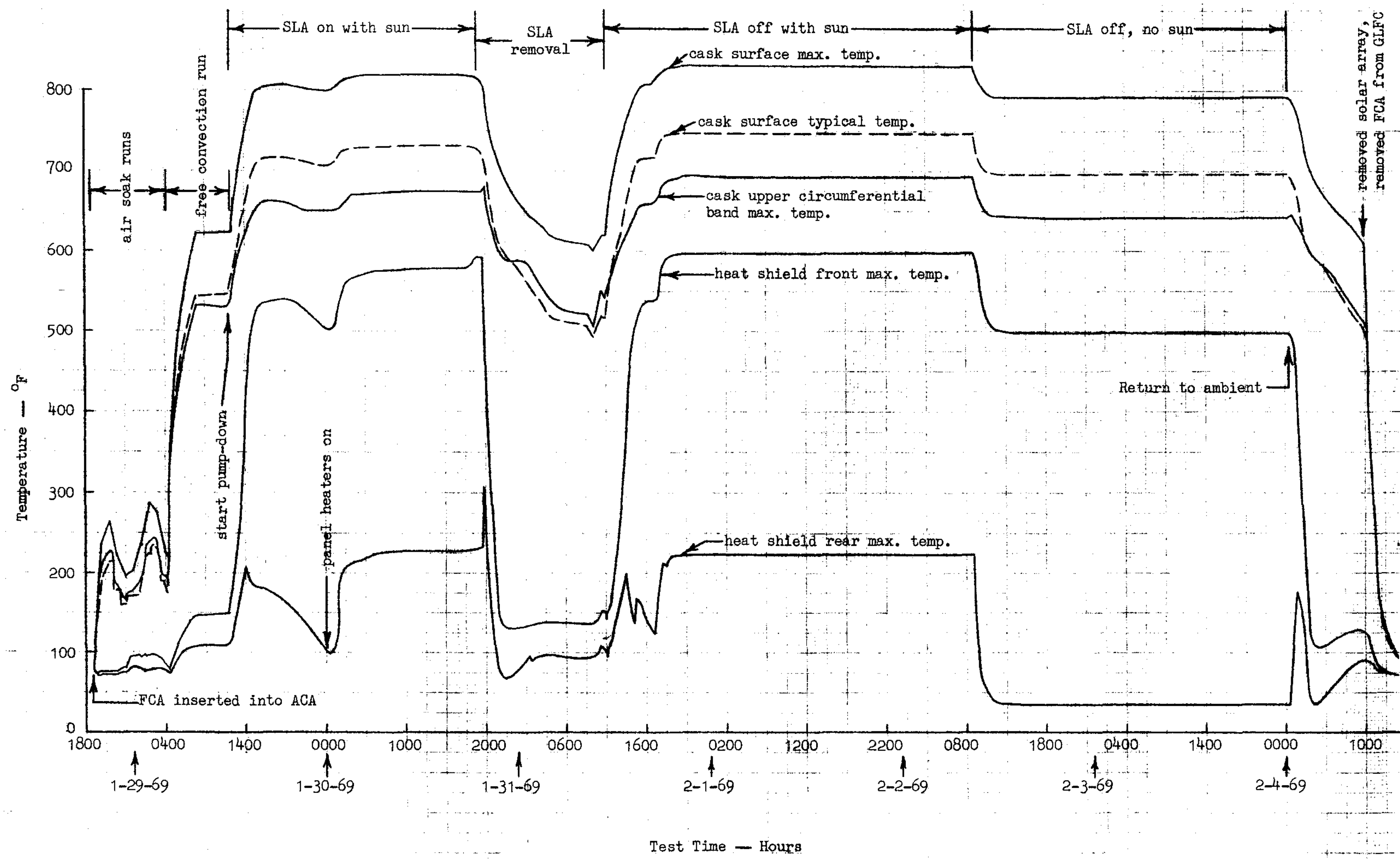


Figure 54. Grumman Thermal Blanket (7B) Equilibrium Temperatures for Free Convection and Thermal Vacuum Runs (#11-14).

Figure 55. Summary of Air Soak and Thermal/Vacuum Test Results



Run No.	Date of Run	Time of Run	Mass Flowrate, lb/min	Inlet Supply Temperature, ^{o}F	$P_{nozzle\ entrance}$, psig	J1, $\frac{micro\text{-}in}{in}$	J2, $\frac{micro\text{-}in}{in}$	J3, $\frac{micro\text{-}in}{in}$	J4, $\frac{micro\text{-}in}{in}$	J5, $\frac{micro\text{-}in}{in}$	J6, $\frac{micro\text{-}in}{in}$
1	1/28	2110	15.1	80	.117	1836	1772	1516	1460	1600	1310
2	1/28	2210	25.1	84	.321	1830	1770	1536	1466	1606	1310
3	1/28	2300	33.5	93	.621	1826	1770	1550	1472	1608	1316
4	1/28	2340	34	132	.635	1800	1748	1546	1453	1600	1313
5	1/29	0030	34	132	.635	1790	1750	1550	1450	1600	1310
6	1/29	0110	25	130	.355	1794	1908	1538	1729	1590	1308
7	1/29	0200	15	130	.126	1785	1905	1488	1702	1564	1280
8	1/29	0240	15	130	.126	1802	1876	1495	1663	1570	1250
9	1/29	0310	15	133	.128	1804	1900	1490	1666	1567	1254
10	1/29	0350	25	90	.36	1800	1904	1512	1685	1577	1258

Table 1 Summary of Band Strain Gage Readings for Runs 1 through 10.

Table 2 Summary of Parameters Related to Air Soak Test Conditions.

Run	Geometric Configuration	Mass Flow Rate, lbs/min		Flow Temp., °F		Nozzle Exit Vel., fpm		Vel. 2' Downstream, fpm	Vel. 4' Downstream, fpm	$P_{Nozzle\ Entrance}$ psig		Pump Speed, RPM		Heater Voltage
		Pred.	Test	Pred.	Test	Pred.	Test	Test	Test	Pred.	Test	Pred.	Test	
1	*Standard	15	15.1	Amb.	80	7391	6800	670	580	.115	.117	450	437	---
2	Standard	25	25.1	Amb.	84	12318	11100	1300	1000	.321	.321	800	778	---
3	Standard	35	33.5	Amb.	93	17246	14950	1700	1450	.628	.626	1200	1210	---
4	Standard	35	34	130	132	19061	15300	1750	1480	.70	.635	1200	1205	190
5	Nozzle Offset 2" Left	35	34	130	132	19061	15000	1350	980	.695	.635	1200	1205	190
6	Nozzle Offset 2" Right	25	25	130	130	13615	11700	1200	950	.354	.355	800	805	190
7	Nozzle Offset 2" Right	15	15	130	130	8169	7300	680	580	.128	.126	450	450	150
8	Nozzle Offset 2" Left	15	15	130	130	8169	7300	580	360	.128	.126	450	450	150
9	Standard	15	15	130	130	8169	7300	750	640	.128	.128	450	450	150
10	Standard	25	25	130	132	13615	11750	1300	1150	.354	.36	800	810	175

*Standard is designated as being directly under the axial center line of the GLFC.

Run No.	Date of Run	Time of Run	Mass Flowrate, lb/min	Inlet Supply Temp., °F	$P_{nozzle\ entrance}$, psig	ACA Upper Dome Band Temp., °F	ACA Upper Trunnion Temp., °F	*ACA Upper Circumferential Band Temp., °F	ACA Axial Band Temp., °F	ACA Trunnion Gearbox Temp., °F	*ACA Lower Circumferential Band Temp., °F	ACA Lower Dome Band Temp., °F	*Cask Upper Dome Temp., °F	*Cask Temp., °F	*Cask Lower Dome Temp., °F	*ACA Guard Ring Temp., °F	*ACA Guard Strut Temp., °F	*ACA Upper Yoke Temp., °F	*ACA Lower Yoke Temp., °F	*ACA Heat Shield Back Temp., °F	*ACA Heat Shield Front Temp., °F	*GAEC Struts Temp., °F	*Latch Plate Temp., °F	*EFCS Temp., °F	LM Thermal Blanket Temp. Behind Cask, °F	LM Door Thermal Blanket Temp., °F
1	1/28	2110	15.1	80	.117	125	161	228 222	91	75	136 133	77	146 142	266 145	102 98	77 77	77 76	74 74	73 73	74 74	77 75	75 74	—	—	77	78
2	1/28	2210	25.1	84	.321	104	130	186 181	85	75	115 113	78	120 116	219 124	94 91	77 77	77 76	75 74	73 73	74 74	77 77	75 74	—	—	76	77
3	1/28	2300	33.5	93	.621	97	118	165 161	85	78	110 108	83	110 107	194 117	94 93	79 78	79 79	77 76	76 76	76 76	81 80	76 75	—	—	78	78
4	1/28	2340	34	132	.635	106	127	177 171	94	87	125 122	103	119 117	202 132	112 111	87 85	87 86	81 80	78 78	81 80	94 93	79 76	—	—	81	81
5	1/29	0030	34	132	.635	109	137	183 168	95	91	128 124	95	123 120	206 136	110 109	91 84	91 84	81 79	78 77	80 80	96 95	78 76	—	—	80	81
6	1/29	0110	25	130	.355	113	132	196 177	95	86	139 129	106	125 125	238 142	116 113	84 84	85 84	80 78	76 75	78 78	93 92	77 74	—	—	79	79
7	1/29	0200	15	130	.126	135	161	237 220	101	88	164 119	110	152 151	287 168	127 125	86 86	87 86	81 78	75 75	79 79	95 93	77 74	—	—	80	80
8	1/29	0240	15	130	.126	142	184	245 221	112	93	169 151	99	160 157	278 170	131 125	92 84	91 85	81 79	76 76	80 80	98 96	78 74	—	—	80	81
9	1/29	0310	15	130	.128	136	172	240 230	104	89	157 155	105	156 153	274 167	128 125	86 86	87 86	81 80	76 76	81 80	96 94	78 74	—	—	80	80
10	1/29	0350	25	132	.360	115	142	197 191	98	88	135 133	106	130 128	229 144	118 116	86 85	87 85	81 80	77 77	81 80	95 94	78 75	—	—	80	81
Free Convection Case (No Purge)			—	80	—	348	399	498 409	266	190	485 462	315	— —	560 480	402 397	95 —	95 85	85 80	80 80	94 85	125 100	— —	676 650	1230 1032	— —	— —
Channel No.			—	—	—	350	351	352-5	356	357	358-361	362	363-4	365-380	381-2	383-4	385-6	387-8	389-390	391, 393	392, 394	395-9	—	—	—	—
Thermocouple No.			—	—	--	1	2	3-6	7	8	9-12	13	14-15	16-31	32-33	34-35	36-37	38-39	40-41	42&44	43&45	46-50	—	—	—	—

*Indicates temp. range, high/low

Table 3 Summary of Qualification Air Soak Test Results.

Table 4 Summary of Qualification Test Results for Air Soak and T/V Testing.

				← Cask Cooling Air Flow Tests →										Free Convection Test	SLA on with Sun Test	SLA off with Sun Test	SLA off w/o Sun Test
Avg. No.	Location	Channel No.	Units	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Run 7	Run 8	Run 9	Run 10	Run 11	Run 12	Run 13	Run 14
1	GLFC Cylinder Barrel (Line 1-4)	365-380	°F	215	178	161	173	177	189	227	231	228	191	554	731	748	701
2	GLFC Line 1, Facing Heat Shield	365, 369, 373, 377	°F	214	176	159	172	173	184	223	230	229	191	588	783	795	753
3	GLFC Line 3, 180° from Heat Shield	367, 371, 375, 379	°F	207	171	154	165	170	179	219	221	220	183	527	689	702	662
4	Both GLFC End Caps	363, 364, 381, 382	°F	100	92	94	111	110	115	126	128	126	117	398	556	573	515
5	Bendix Bands	352-356, 358-362	°F	160	136	126	138	140	148	176	179	177	152	464	636	655	596
6	Aft Circumferential Bands	352-355	°F	224	184	163	173	176	187	229	235	235	194	509	642	660	615
7	Fwd Circumferential Bands	358-361	°F	134	114	109	124	126	133	157	160	156	134	493	684	702	659
8	Bendix Heat Shield	391&393 392&394	°F °F	75	76	78	87	88	85	86	89	87	88	105 135	225 546	219 574	24 471
9	Bendix Astronaut Protective Guard	383-386	°F	77	77	79	86	87	84	86	88	86	86	114	239	195	21
10	Bendix Support Yokes	387-390	°F	74	74	76	79	79	77	77	78	78	79	98	286	293	168
11	Grumman Struts	395-399	°F	74	74	76	78	78	76	76	76	76	77	89	174	165	54
12	Grumman Blanket (P7a)	235-244	°F	77	76	78	81	80	79	80	80	80	80	104	215	237	-56
13	Grumman Blanket (P7b)	245-264	°F	78	77	78	81	81	79	80	81	80	81	113	243	264	-51
14	Exit Nozzle Air	401	°F	77	82	91	130	130	128	129	128	128	130	-----	-----	---	---
15	GLFC	374, 376	°F	235	194	174	184	192	201	242	256	246	205	587	762	775	732
16	Nozzle Throat (P1)	402	mv	-.01	-.02	-.044	-.044	-.042	-.025	-.012	-.011	-.011	-.026	-----	-----	---	---
17	Upstream (P3)	403	psig	.13	.37	.71	-----	-----	.41	.14	.14	.14	.41	-----	-----	---	---
18	Nozzle Entrance (P2)	404	psig	.117	.321	.624	.637	.638	.358	.13	.127	.1295	.362	-----	-----	---	---
19	Exit Nozzle Air (velocity)	405	fpm	7410	12370	17170	18310	18310	13750	8270	8240	8240	13840	-----	-----	---	---
20	Exit Nozzle Air (flowrate)	406	lb/min	15.11	25.08	34.9	33.7	33.6	25.5	15.2	14.97	15.16	25.55	-----	-----	---	---
21	Thermal Resistance Patch	---	°F	77	78	80	85	84	82	83	84	84	85	109	228	226	35

Table 5 Compairson of Prototype and Qualification Test Results.

Group No.	Measurement Locations	Forced Convection, 15 lb/min @ 130°F (on pad)		Free Convection (on pad)		SLA on			SLA off with sun		SLA off without sun	
		Proto	Qual	Proto	Qual	with sun Proto	with sun Qual	w/o sun Proto	Proto	Qual	Proto	Qual
1	Bands, Axial	109 134	--- 104	388 484	--- 301	592 626	--- 594	564 596	588 627	--- 614	552 592	--- 542
2	Band, Upper Circumferential	167 206	230 240	470 512	487 532	578 666	605 678	559 646	581 664	627 693	540 635	586 645
3	Band, Lower Circumferential	133 142	155 157	475 499	478 508	633 692	638 732	612 674	634 686	659 747	598 662	606 709
4	Band, Upper Dome	64 115	--- 136	65 321	--- 359	407 426	--- 468	369 399	--- 403	--- 490	--- 366	--- 422
5	Band, Lower Dome	33 113	--- 105	363 373	--- 320	414 497	--- 466	469 483	485 509	--- 486	460 473	--- 418
6	Band, Dome Circ. Upper	116 178	--- ---	345 417	--- ---	417 505	--- ---	374 476	421 487	--- ---	334 452	--- ---
7	Band, Dome Circ. Lower	127 131	--- ---	148 152	--- ---	--- ---	--- ---	--- ---	573 675	--- ---	574 637	--- ---
8	Cask Upper Dome	141 146	153 156	386 397	375 395	507 519	515 526	482 498	489 502	544 549	453 472	471 481
9	Cask Lower Dome	--- 115	125 128	--- 385	--- 412	--- 538	--- 595	--- 508	--- 523	--- 602	--- 496	--- 564
10	Cask Row A	192 206	--- ---	510 546	--- ---	656 717	--- ---	631 692	653 688	--- ---	612 660	--- ---
11	Cask Row B	222 234	246 250	530 571	513 577	647 671	647 730	618 645	679 733	671 744	639 705	608 697
12	Cask Row C	218 233	248 274	576 609	573 623	646 793	706 811	616 772	723 787	726 822	698 764	670 782
13	Cask Row D	164 194	218 246	527 587	586 609	692 805	715 820	666 785	621 799	769 830	658 777	721 792
14	Cask Row E	157 167	167 192	506 536	498 544	660 717	678 771	630 693	662 713	710 784	621 689	650 740
15	EFCS Surface	1094 1257	--- ---	1182 1309	1032 1230	1243 1313	--- ---	1218 1318	1213 1311	--- ---	1209 1307	--- ---
16	Capsule Liner	--- 492	--- ---	--- 651	--- ---	--- 848	--- ---	--- 782	--- 772	--- ---	--- 740	--- ---
17	Capsule Latch Plate	441 518	--- ---	643 705	--- ---	817 863	--- ---	806 855	815 859	--- ---	793 840	--- ---
18	Trunnion, Upper	109 113	--- 172	323 339	--- 426	560 584	--- 562	532 555	563 578	--- 584	523 545	--- 532
19	Trunnion, Lower	--- 106	--- ---	--- 378	--- ---	--- 590	--- ---	--- 559	--- 583	--- ---	--- 552	--- ---
20	Diagonal, Long	79 91	--- ---	103 171	--- ---	378 553	--- ---	318 516	355 562	--- ---	291 498	--- ---
21	Diagonal, Short	84 88	--- ---	144 155	--- ---	483 505	--- ---	439 460	483 515	--- ---	416 436	--- ---
22	Dome Release Mechanism	105 130	--- 135	321 364	--- 359	397 460	--- 468	360 430	394 446	--- 490	433 400	--- 422
23	Struts, Upper	82 106	--- ---	96 173	--- ---	250 478	--- ---	212 433	186 466	--- ---	56 410	--- ---
24	Struts, Lower	76 83	--- ---	93 131	--- ---	312 410	--- ---	234 354	265 393	--- ---	198 328	--- ---
25	Dome Band Attach, Upper	125 134	--- ---	383 400	--- ---	501 536	--- ---	473 510	492 523	--- ---	450 490	--- ---
26	Dome Band Attach, Lower	127 140	--- ---	152 205	--- ---	584 718	--- ---	493 670	--- 532	--- ---	537 691	--- ---
27	Cradle, Upper	82 90	--- ---	95 173	--- ---	314 478	--- ---	241 433	267 467	--- ---	207 411	--- ---
28	Cradle, Lower	76 83	--- ---	93 131	--- ---	312 410	--- ---	234 354	264 391	--- ---	200 329	--- ---
29	Brace	84 88	--- ---	144 155	--- ---	483 505	--- ---	444 466	481 519	--- ---	416 437	--- ---
30	Thermal Shield, Front	82 91	94 96	88 135	123 147	371 587	508 578	310 546	404 604	549 598	284 531	442 499
31	Thermal Shield, Rear	77 82	--- 81	88 102	102 108	223 314	222 228	98 237	131 286	213 224	17 193	12 36
32	Gearbox	--- 87	--- 89	--- 215	--- 217	--- 450	--- 415	--- 408	--- 445	--- 455	--- 390	--- 352
33	Astroguard	--- ---	--- 86	--- ---	--- 115	--- ---	233 234	--- ---	--- ---	180 187	--- ---	7 10
34	ACA Yoke, Lower	--- ---	--- 76	--- ---	96 101	--- ---	272 304	--- ---	--- ---	278 316	--- ---	146 193
35	BxA/GAEC I/F Struts	73 74	--- ---	76 79	--- ---	192 256	--- ---	122 146	149 201	--- ---	63 93	--- ---
36	GAEC Struts @ LM	71 75	74 78	74 78	86 93	125 236	136 213	67 134	85 175	126 207	42 80	29 89
37	Lanyard Mechanism	--- 84	--- ---	--- 155	--- ---	--- 434	--- ---	--- 385	--- 451	--- ---	--- 395	--- ---

Note: Temperatures in °F are listed in columns of two and represent low-high temperature ranges.

TABLE 6

ALSEP/CASK/LM INTERFACE SPECIFICATION REQUIREMENTS VERSUS QUALIFICATION TEST RESULTS

		Interface Specification	Specification Requirement	Test Results
1.	MAXIMUM FUEL CASK SURFACE TEMPERATURE	BxA/GE	≤ 835°F	830°F
2.	MAXIMUM FUEL CASK CIRCUMFERENTIAL TEMP GRADIENT	BxA/GE	≤ 150°F	105°F
3.	MAXIMUM HEAT LEAK TO LM	BxA/GAEC	≤ 100 Btu/hr	33 Btu/hr
4.	MAXIMUM LM SKIN SURFACE TEMPERATURE (EXCEPT ASTRONAUT THERMAL DOOR)	BxA/GAEC	≤ 270°F	258°F
5.	ASTRONAUT THERMAL DOOR TEMPERATURE	BxA/GAEC	≤ 450°F	432°F
6.	MAXIMUM CASK THERMAL SHIELD TEMPERATURE	BxA	≤ 600°F	598°F
7.	MINIMUM AVERAGE FUEL CASK SURFACE TEMPERATURE DURING CASK COOLING	BxA/GE	≥ 125°F	161°F
8.	MAXIMUM AVERAGE FUEL CASK SURFACE TEMPERATURE DURING CASK COOLING	BxA/MSC	≤ 350°F	194°F to 287°F*
9.	ASTRONAUT PROTECTION GUARD	BxA/MSC	≤ 250°F	105°F**

*For Flowrate range between 15 to 35 lb/min
**Corrected for IR solar simulation level to actual one sun condition