Payne Pritchett
SA42

TWR-19322

SPACE SHUTTLE

Solid Rocket Motors
Morton Thiokol, Inc

RSRM NOZZLE FIXED HOUSING COOLDOWN TEST FINAL REPORT

May 1989

Prepared for:

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
GEORGE C. MARSHALL SPACE FLIGHT CENTER
MARSHALL SPACE FLIGHT CENTER, ALABAMA 35812

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MORTON THIOKOL, INC.

Aerospace Group

Space Operations

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TITLE

RSRM NOZZLE FIXED HOUSING COOLDOWN TEST FINAL REPORT

May 1989

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Composite Structures

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Systems Safety

Reliability 26 June 89

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Certification Planning

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FORM TC NO. 1810

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1.0 INTRODUCTION

Flight 5 aft segments with nozzles were exposed to -17 °F temperatures while awaiting shipment to KSC in February, 1989. No records have been found which show that any previous nozzles were exposed to air temperatures as low as those seen by the Flight 5 nozzles. Thermal analysis shows that the temperature of the fixed housing,and forward and aft exit cone components dropped as low as -10 °F.

Structural analysis of the nozzles at these low temperatures show the forward and aft exit cone adhesive bonds to have a positive margin of safety, based on a 2.0 safety factor.

These analyses show the normal and shear stresses in the fixed housing bond as low values. However, the hoop and meridinal stresses were predicted to be in the 4000 psi range; the failure stress allowable of EA913NA adhesive at -7 °F. If the bonds did break in directions perpendicular to the surfaces, called bond crazing, no normal bond strength would be lost.

Testing was conducted in two phases, showing that no degradation to the adhesive bonds occurred while the Flight 5 nozzles were subjected to subzero temperatures. This report documents the results of these tests, as outlined in ETP-0471. Phase I testing cooled a full-scale RSRM insulated fixed housing to -13 °F, with extensive bondline inspections. Phase II testing cooled the witness panel adhesive tensile buttons to -13 °F, with failure strengths recorded before, during, and after the cooldown.

2.0 SUMMARY AND CONCLUSIONS

Results of tests documented in this report verify the flight 5 nozzle adhesive bondlines were not degraded by the subzero temperatures.

The first phase of the test (Phase I) subjected an insulated nozzle fixed housing to -13 °F temperature for one day, then let it warm back to 75 °F in steps over several more days. The test article was subjected to temperature cycles that represented the most severe that the Flight 5 nozzles experienced. The results of Phase I show that no defects were induced into the phenolics or the adhesive bond by the cold temperature cycle. This conclusion is based on X-ray, pulse echo, and alcohol wipe inspection of the test article.

The second phase of the test (Phase II) used the witness panel tensile buttons from the Flight 5 Nozzle Fixed Housing bonding process. These buttons are configured such that high perpendicular stresses are induced in the adhesive when cooled. These stresses are about 50 percent higher in the buttons at -13 °F than those in the actual hardware at the same temperature. The analyses which predicts the stresses in the Nozzle Fixed Housing bond, and in the tensile button bond is documented in

TWR-19352 (see Reference 1). The major conclusions from this test program are summarized below:

- o The results of the tests performed in Phase I of ETP-0471 (see Reference 2) show that the adhesive bond of the fixed housing hardware is not damaged by thermal cooldown to -13 °F, and subsequent reheating.
- o The result of the tests performed in Phase II of ETP-0471 show that the bond strength of EA-913NA is not degraded by the cooling to -13 °F, and reheating.
- o Based on tests completed, it is concluded that the adhesive bonds in the nozzle of Flight 5 were not degraded by the cold temperatures, and are acceptable for flight.

3.0 RECOMMENDATIONS

The following recommendations should be considered:

- o Add lower bound temperature limits to flight hardware process planning of nozzle components for storage and shipping.
- o Monitor the ambient temperatures for all nozzle components during outdoor moves and shipment.

4.0 DISCUSSION

4.1 Test Article Description

Phase I. An RSRM Nozzle Fixed Housing was used: Insulated, 1U52862-09, S/N 0000004. The article includes the D6AC steel housing bonded to the phenolic insulator with EA-913NA adhesive.

The article was placed forward end up in Bay 2, as shown in Figure 1, at the T-51 test facility. This bay has four CO_2 jets. The plan called for jets 1 and 4 to be used during the test. A stuck valve in jet 4 during the initial cooldown cycle required that it be turned off, and jet 3 turned on to allow repair to the valve in jet 4.

Phase II. This phase used the witness panel buttons from the Flight 5 Nozzle Fixed Housing bond process. The panels consisted of a steel plate with 12 tensile buttons attached with EA-913NA adhesive. These panels were made at the same time the bonding of the insulation to the fixed housing took place, with adhesive from the same batch.

The configuration of witness panels is shown in Figure 2. They consisted of steel plates with 12 buttons bonded on each. The buttons were parallel ply glass cloth phenolic (GCP) with a threaded steel tab. The thickness of the adhesive bond between the GCP and the steel plate is controlled by a steel spacer. The spacers also controlled the bond area, which is 0.5 $in.^2$ for these buttons.

The testing took place in the mechanical test lab, Room 26 of M-54. The cold box used CO_2 for cooling, and is equipped with a Baldwin mechanical test machine.

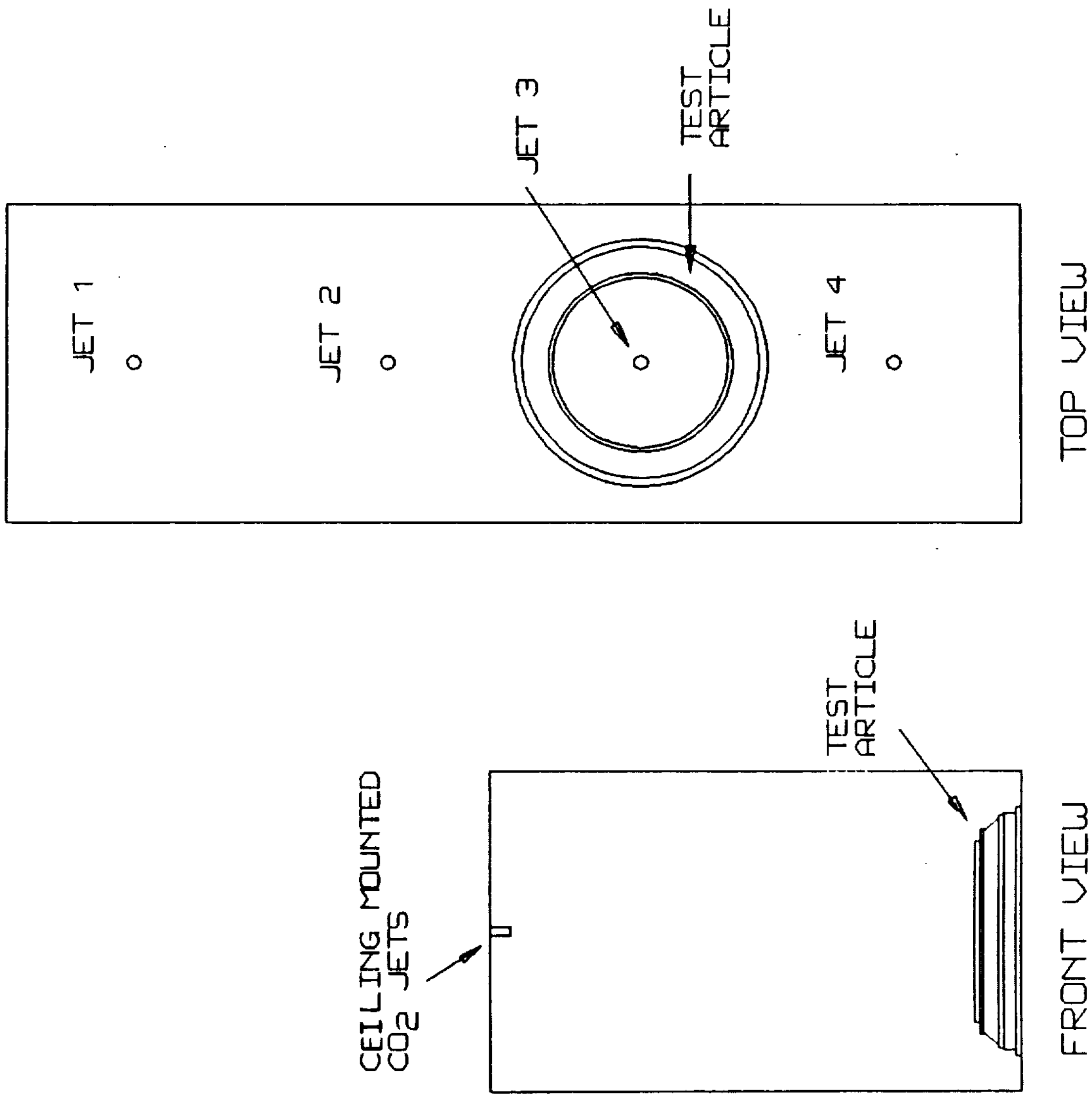


Figure 1 Test Article Position in Bay 2 of the T-51 Facility

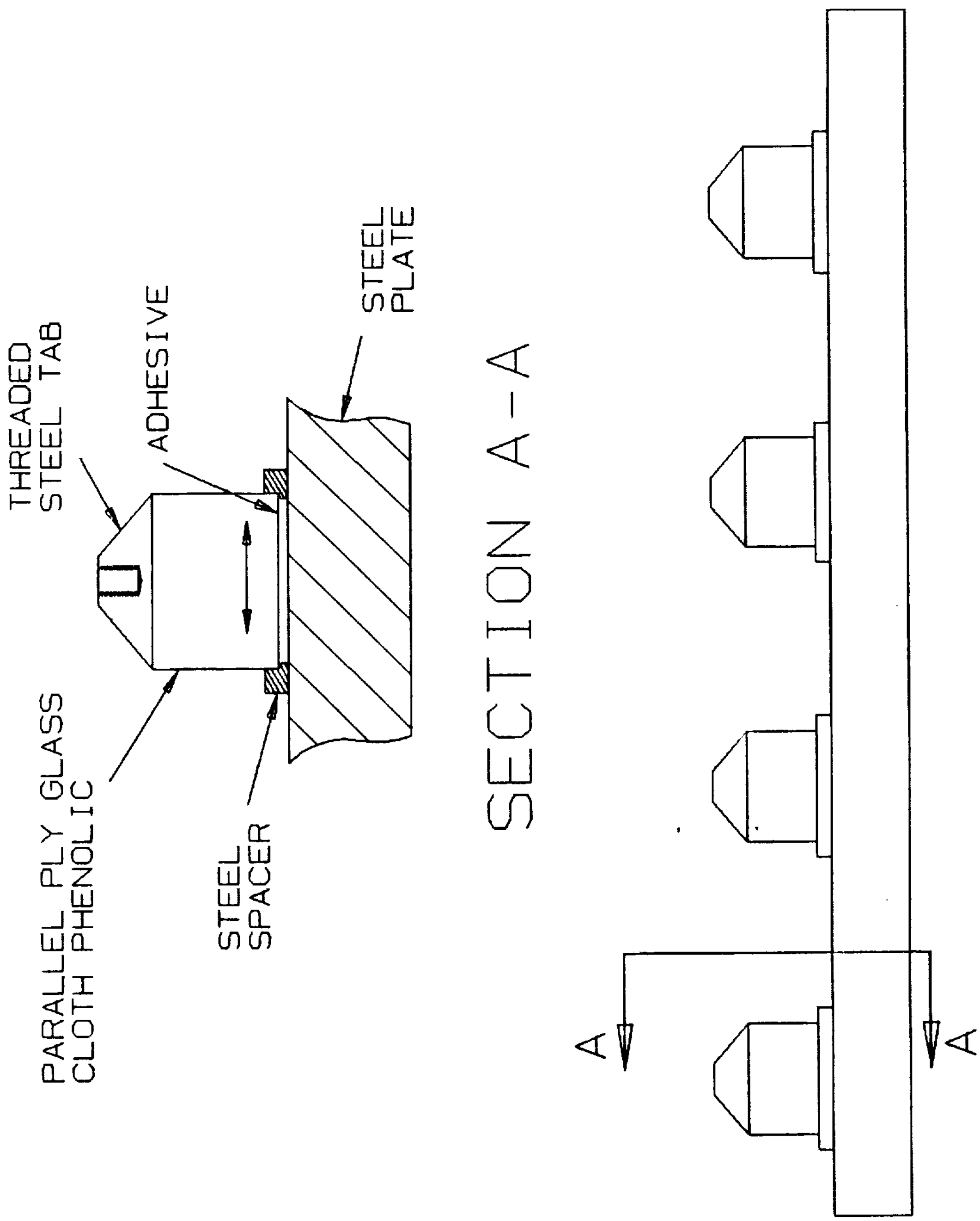


Figure 2 Witness Panel Button Configuration

4.2 Loading Description

Phase I. The fixed housing was subjected to the ambient air temperature cycle shown in Figure 3. The cooling rate, 10 °F/hour, is the same as seen by the Flight 5 nozzles. The predicted temperature-time profile for the Flight 5 nozzles is shown in Figure 4.

As previously mentioned, jet 4 had a stuck valve during the initial cooldown cycle, and required repair. Figure 3 shows the time frame in which jet 4 was turned off, and jet 3 turned on. This might be a consideration in the evaluation of the loads on the housing, as jet 3 was directly above the housing.

Phase II. The witness panel tensile buttons were subjected to the same cooling rate as the fixed housing in Phase I. Before cooling, three buttons from each of the two panels were pulled to failure at 75 °F at 0.05 inch per minute (ipm) to establish a baseline adhesive strength.

The remaining nine buttons on each panel were then cooled to -13 °F, and allowed to stabilize at that temperature. Four buttons per panel were then pulled at 0.05 ipm at -13 °F. The five buttons left on each panel were then allowed to warm back to 70 °F. These were then tested at 70 °F for comparison to the strengths before cooldown.

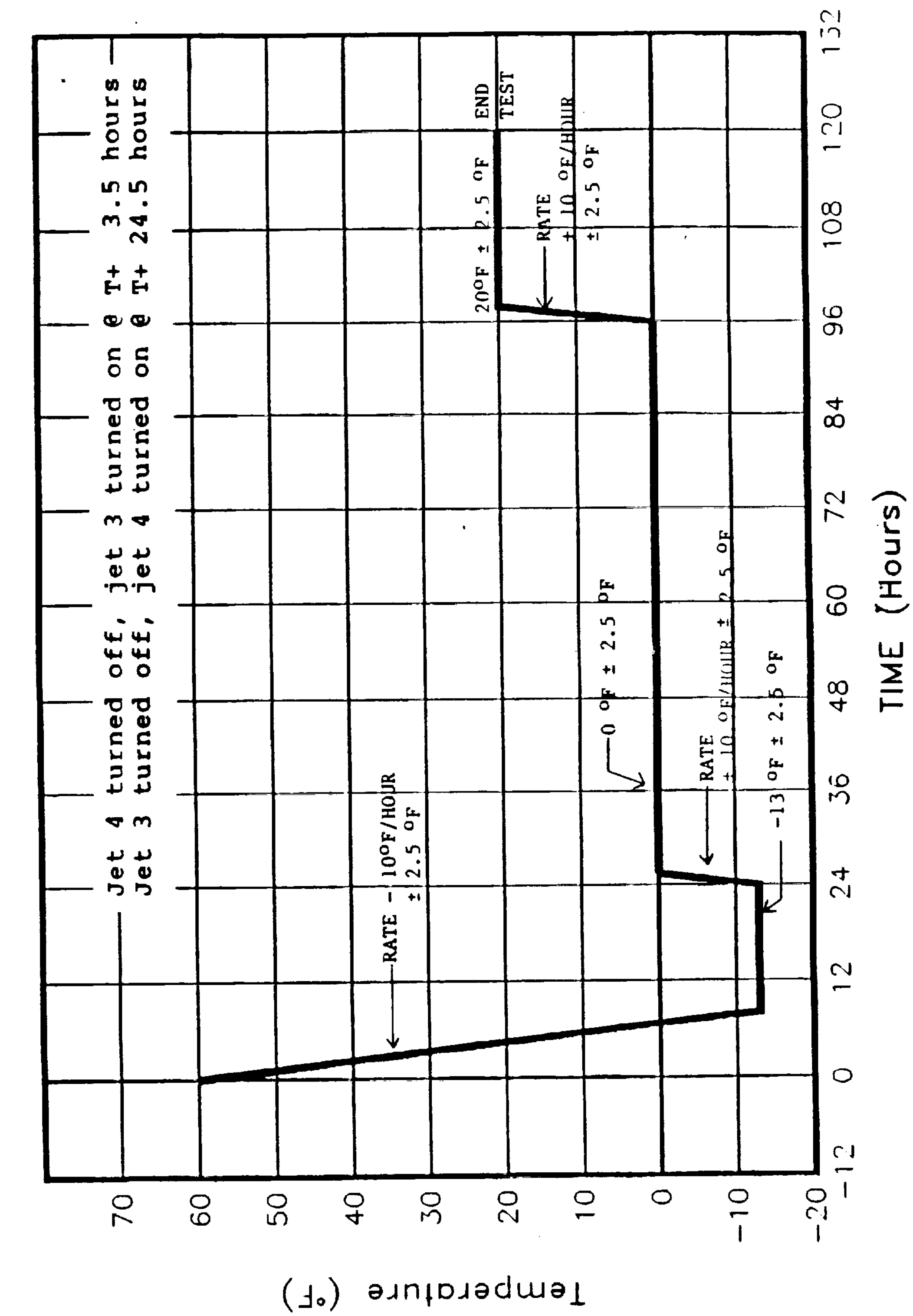


Figure 3 Phase I Imposed Thermal Cycle on Full-Scale Fixed Housing

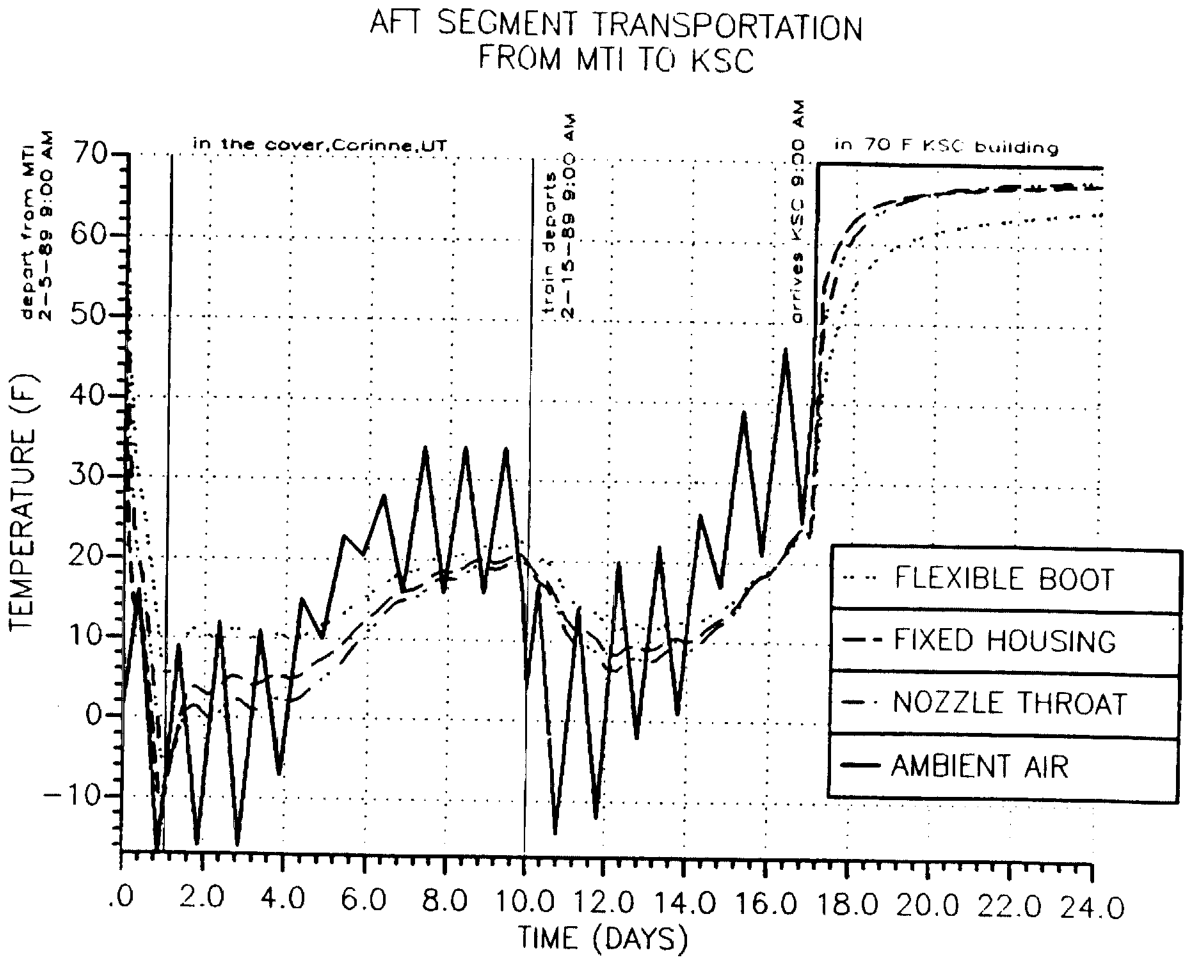


Figure 4 Predicted Worst Case Ambient Air Temperatures Seen by Flight 5 Nozzles

4.3 Pretest Inspection Descriptions

Phase I. The insulated fixed housing steel-to-adhesive bondline was inspected by ultrasonic pulse-echo type inspection. This inspection detected no flaws in this portion of the bond prior to the cooldown.

Phase II. The buttons were visually examined for obvious defects prior to the start of testing. No significant defects were reported.

4.4 Test Monitoring Description Phase I

4.4.1 Article Surface Temperature

Three thermocouples were placed on the phenolic side of the article which monitored surface temperature. Figure 5 shows the axial location of the gages, which were placed at zero, 120 and 240 degrees. Readings were taken at 10 minute intervals from the start of the test.

The surface temperature readings are shown in Figure 6. Notice that the temperature at gage 3, located at 240 degrees, keeps dropping after the driver air temperature is held constant at -13 °F. This is believed to be caused by jet number 3 blowing -100 °F CO_2 directly above this location. This temperature reached a minimum of -27 °F at that time. The thermocouple was located on the surface of the carbon near the aft end. It is unknown how low a temperature was reached on the metal surface and bond at the forward end of the assembly.

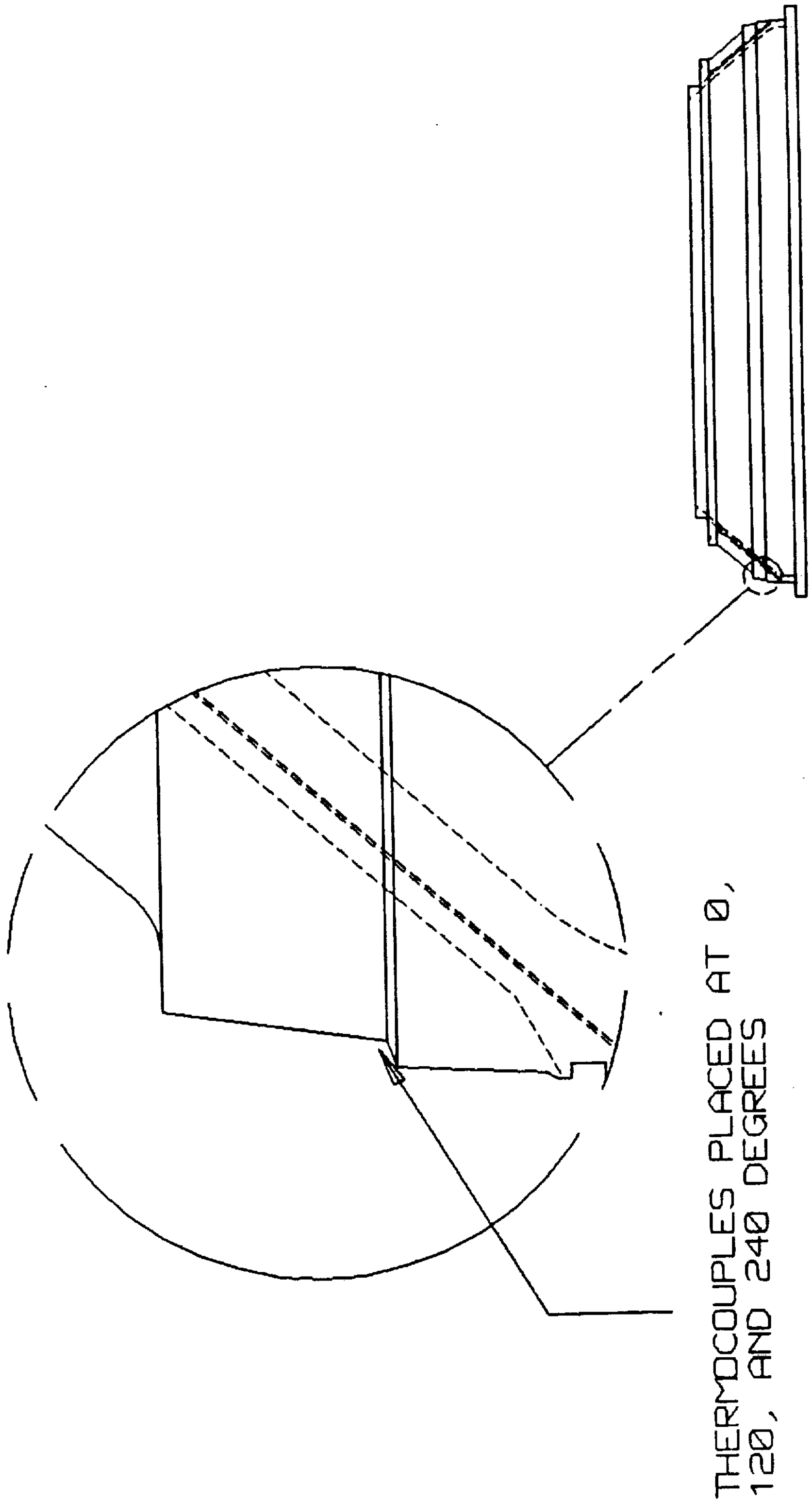


Figure 5 Locations of Thermocouples on the Surface of the Fixed Housing for Phase I Test

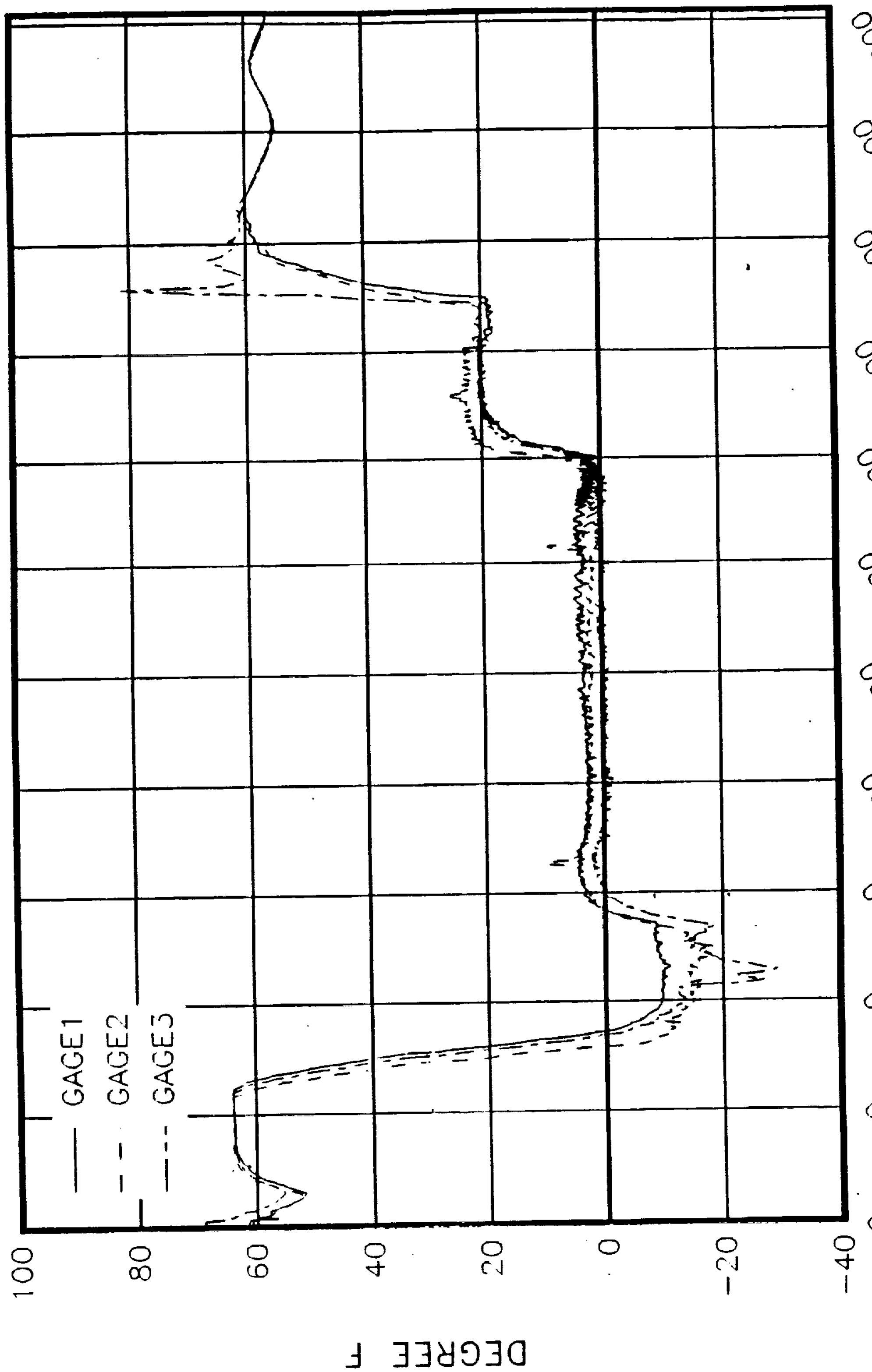


Figure 6 Fixed Housing Surface Temperature Measurements for Phase I Test

The high temperature spike at the end of the test at the same location is because the door to the bay was opened at that time, and the side of the housing with that thermocouple was in direct sunlight.

4.4.2 Ambient Air Temperature

The driver air temperature was monitored by a single thermocouple probe located within the coldbox. This temperature did not deviate from the planned thermal cycle by any significant amount.

4.4.3 Acoustic Emission

Six acoustic emission gages were placed on the steel housing, as shown in Figure 7. The results from these measurements are summarized in Memo 7313-FY89-M153, which is included as Appendix A of this report. These gages heard quite a lot of noise during the test. The noise seemed to fall in two dB ranges: 40 to 60, and 80 to 100. For reference, the noise that is made when a 0.5 mm pencil lead breaks is the 90 dB level.

The source mechanism generating the noise is not currently defined. The current AE database does not include carbon/phenolic material. Alcohol wipe and visual inspection of the part found no evidence of matrix crazing or other macroscopic damage. Microscopic cracking is not precluded.

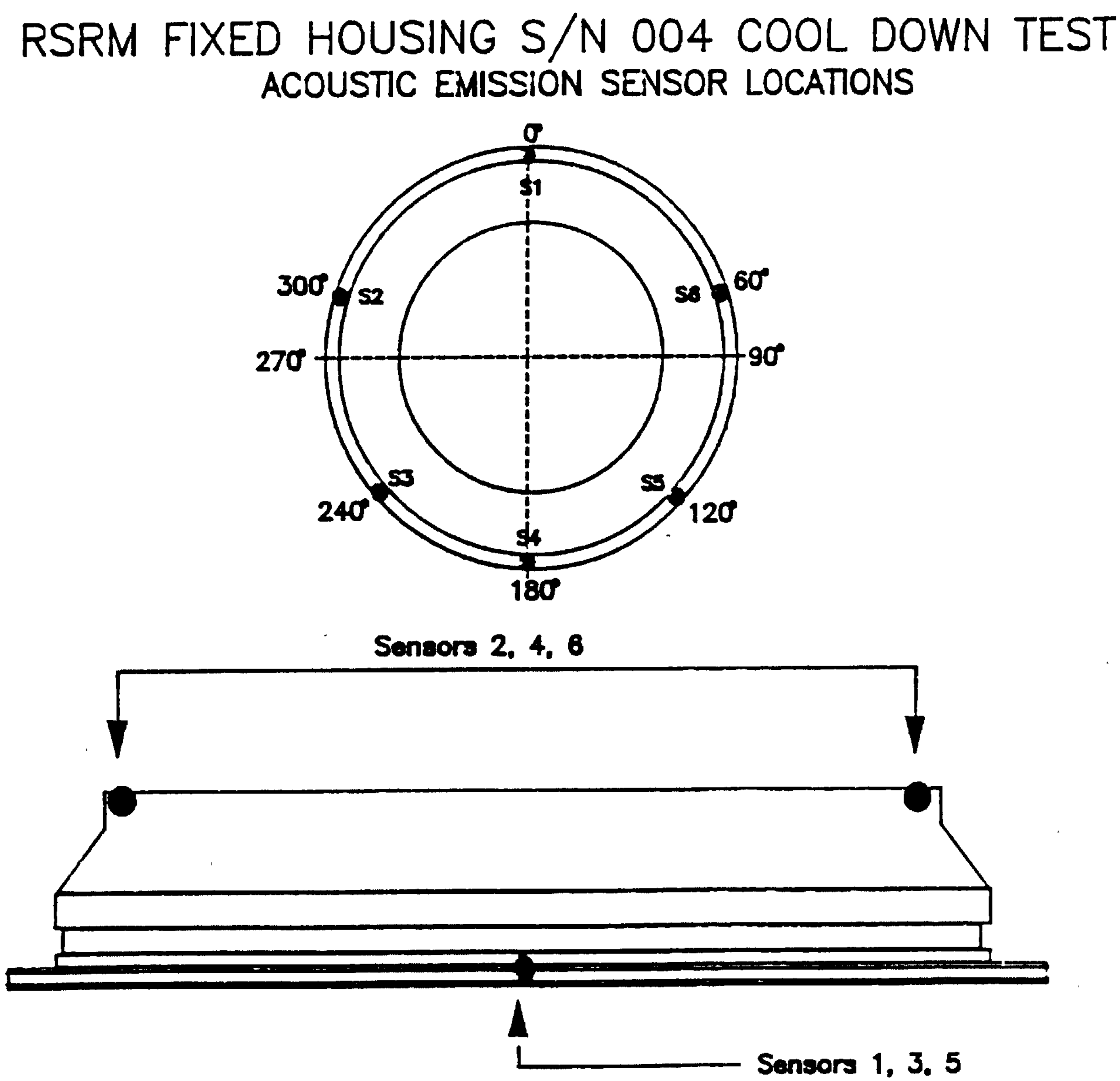


Figure 7 Locations of Acoustic Emission Sensors on the Surface of the Fixed Housing for Phase I Test

4.5 Test Monitoring Description Phase II

4.5.1 Ambient Air Temperature

The air temperature was monitored by two thermocouples within the coldbox.

4.5.2 Pull to Failure Testing

The pull-to-failure testing was performed with a Baldwin test machine contained within the coldbox. The results of these tests are summarized in Table I. The raw data are found in Appendix B of this report.

4.6 Post-Test Inspection Descriptions Phase I

4.6.1 Ultrasonic Inspection

A pulse-echo type ultrasonic inspection was conducted in the same manner as the pretest inspection. The inspection took place on the steel housing side of the article, covering the steel-to-adhesive bond at one inch intervals axially, and every three degrees circumferentially. The region which then produced the majority of noise was inspected completely. This inspection detected no steel-to-adhesive unbonds.

Table I

Pull-to-Failure Testing Results of Nozzle Fixed Housing Witness Panel Buttons

Nozzle Panel	Temperature (°F)	Average Max Stress (psi)
5A	75, Pre-Cooling	3519
5A	-13	5092
5A	69, Post-Cooling	3730
5B	75, Pre-Cooling	3134
5B	-13	3606
5B	69, Post-Cooling	3612

4.6.2 Phenolic X-ray

X-ray shots were taken of the phenolics after the ultrasonic inspection was complete. Shots were taken every 30 degrees, except for the 60 degree region from which the acoustic emissions were high, which was shot every three degrees.

The clarity of the glass to adhesive bond was unexpected, and very clear. The film examined showed no defects in this bond, or in the phenolic.

4.6.3 Phenolic Machining and Alcohol Wipe

The decision was made to machine the phenolics down to the bond in small increments. Alcohol wipes were made after each cut to visually look for delaminations in the phenolics. Cuts to 0.150 inch deep were used until the carbon phenolic was within 0.050 inch of the carbon-to-glass interface. The cut depths were reduced to 0.050 inch per pass, until the bond was exposed.

This process revealed no indication of delaminations or unbonds at any interfaces. The bond was very much intact, with relatively few voids in the adhesive, which are inherent to the bonding process. No crazing of the bond was evident by visual inspection.

4.7 Post-Test Inspection Descriptions Phase II

4.7.1 Failure Surface Visual Inspection

Visual inspection of the failure surfaces of the test buttons show that failures all initiated in the glass cloth phenolic. This indicates that the cold temperatures did not degrade the adhesive to the point that it was weaker than the cross-ply strength of the glass cloth phenolic.

5.0 TEST RESULTS

Phase I. All indications from the ultrasonic inspections and the post-test X-rays show that the steel-to-CCP bondline is completely intact. The test objectives were met by proving that the cold temperatures did not damage or degrade the adhesive bond systems on the Flight 5 RSRM nozzles.

Phase II. As shown in Table I, the strength of the adhesive did not decrease after the cooldown and reheat cycle. In fact, the values of stress increased slightly. There were not enough samples tested to statistically show that the cooling process increases bond strengths. Most of the failures were within the glass cloth phenolic, and propagated out onto the glass-to-adhesive interface.

The raw data are presented in Appendix B. The data for the 75 °F baseline tests is presented on page B-3. The data at -13 °F is presented on page B-4, and the data from samples cooled to -13 °F and tested at 75 °F are presented on page B-5. Thermocouple readings during specimen cooldown and reheat are presented on pages B-6 and B-7.

The test objectives for this phase of testing were met by showing:

1) the bond strength is relatively high at the low temperature of -13 °F, and

2) the process of cooling the adhesive with high induced stresses, then reheating, does not degrade the bond strength.

6.0 REFERENCES

1) Bolieau, D. J., TWR-19352, "Structural Analysis of Cold Temperature Effects on the RSRM Nozzle Adhesive Bonds", Morton Thiokol, Inc., April, 1989.

2) Bolieau, D. J., ETP-0471, "SRM Nozzle Fixed Housing Adhesive Bond Cooldown Test", Morton Thiokol, Inc., February, 1989.

APPENDIX A

Memo, 7313-FY89-M153:

Summary of Acoustic Emmision Results

18 April 1989
7313-FY89-M153

TO: Don Bolieau
Composite Structures

CC: F. C. Brasfield, S. R. Graves, P. Karner, M. Martersteck

FROM: T.J. Lewis, NDT Laboratory, Ext-9038

SUBJECT: Acoustic Emission Test Results from SRM Nozzle Fixed Housing Adhesive Bond Cooldown Test.

REFERENCE:
1) D.J. Bolieau, "SRM Nozzle Fixed Housing Adhesive Bond Cooldown Test", Morton Thiokol Test Plan Number ETP-0471, February 1989.

2) M.Buechler, G.F. Hawkins, R.A.Meyer, "Acoustic Emission and Microstructural Evaluation of Carbon-Carbon Composites", Annual Program Report by The Aerospace Corporation to The Air Force Rocket Propulsion Laboratory, Report Number TR-85-062, August 1985.

Summary

The acoustic emission data indicates that the area located between 120 to 180 degrees on the fixed housing should be evaluated post-cold test using other NDT methods to determine if the source of AE activity is critical to the structure.

Introduction

The test objective as stated in reference 1 is to demonstrate that the fixed housing can withstand thermal cooldown to a minimum of -10 degrees F without evidence of failure. This will be verified by nondestructive test methods during cold soak and post-test. The NDT method of acoustic emission monitored the test article during the cold soak. Pre-and post-test ultrasonic inspection of the metal-to-glass bond indicated no major separations of this bond. A post-test x-ray inspection will evaluate the test article for anomalous conditions throughout the part.

Test Results

The AE sensors were located on the part as shown in Figure 1. These locations were used so that 100 percent of the part would be monitored. Pre-test calibration showed that with this coverage and instrument settings a significant AE wave would be detected anywhere on the test article.

The temperature of the test article at 0 degrees was monitored for a comparison of AE to temperature. Figure 2 shows the relative temperature of the test article versus time. Figure 3 shows the cumulative AE from all sensors versus time. By comparing Figures 2 and 3, the data shows that the largest increase in AE activity occurs during the initial cooldown period. After reaching the temperature hold at -10 degrees F the test article has few emissions. A small increase in AE occurs as the temperature increases. Once into the temperature hold at 0 degrees the test article has a linear increase in AE versus time. This is probably due to background noise in the chamber. After the load hold, during the rise in temperature AE activity increased slightly.

The most AE active areas of the test article are shown in Figure 4 which is the cumulative AE events recorded at each sensor location during the entire test. The most active areas are Channels 4 and 5 which are located at 120 and 180 degrees.

To take a closer look at each location Figures 5 through 10 show the AE activity versus time on each sensor. The sensors located at 120 and 180 degrees were most active during the cooldown. All channels show a rollover once the -12 degree F hold occurred. During the increase of temperature to 0 degrees the sensors located at 0, 60, 120, and 240 degrees detected AE activity. All sensors show a small linear increase during the temperature hold at 0 degrees F. As stated previously, this is probably due to background noise from the chamber. During the final temperature increase, the sensor located at 0, 180, and 240 degrees had a small number of emissions. During the test there was a concern that the AE from 120 to 180 degrees was due to the CO2 jet aimed at that location on the part. It was traced down that the jet directly over the part was only in use for less than one day of the test. The active area was the most active area of the test article on every day of the test. For the majority of the test the CO2 jet used was equidistant to both sides of the part.

The amplitude of the AE signals recorded during this test are shown in Figure 11. During the real time data evaluation this number of high amplitude events became a concern. Past experience on graphite structure has shown that an increase in the test article. Due to this lack of information a literature review was performed. The most useful paper was reference 2. The material studied was PK nozzle material during thermal loading. This information shows that the carbon-carbon material studied was very active and high amplitude. There was no information available in my literature search about carbon-phenolic's AE signature during defect growth or during loading to failure. Since literature was not available and MTI's AE database has no samples of carbon-phenolic, we have only assumptions on the AE signature of this material based on carbon-carbon data which are unproven without sample data.

To further investigate I contacted one of the authors of the carbon-carbon paper, Dr. Gary Hawkins of Aerospace Corporation. He stated, " The AE event amplitude produced during his work with carbon-carbon nozzle components was an order of magnitude higher than graphite material". The data recorded during the test of the fixed housing is within the range described by Dr. Hawkins.

Conclusions

The test article had AE activity during thermal loading. The area of highest activity was located between 120 and 180 degrees. Most of the activity is associated with a change in temperature, with the first decrease in temperature producing the most activity. The AE during the increase in temperature could be similar to the AE activity observed during the reduction of pressure in composite cases. This activity is the rubbing noise generated by a separation as the load is removed from the part. The high amplitude of events recorded during the test is probably normal to this material type and not representative of major damage. The only information that would indicate possible damage is the high concentration of AE activity at one location on the test article and the AE during the increase in temperature. Since only limited data is available on AE of carbon-carbon, and none on carbon-phenolic and this data is not specific on how the AE signature relates to flaw growth I can only speculate that the AE data from this test is not representative of flaw growth. However, if there is flaw growth in the test article it would have occurred at the location between 120 and 180 degrees. A full NDT inspection of this specific area would give further information about the criticality of this area. If the NDT inspections reveals no flaw growth, or defects present then the AE activity is probably due to matrix cracking or other micro damage which is not critical to the structure.

Ted Lewis

Ted Lewis
NDT Engineer

RSRM FIXED HOUSING S/N 004 COOL DOWN TEST
ACOUSTIC EMISSION SENSOR LOCATIONS

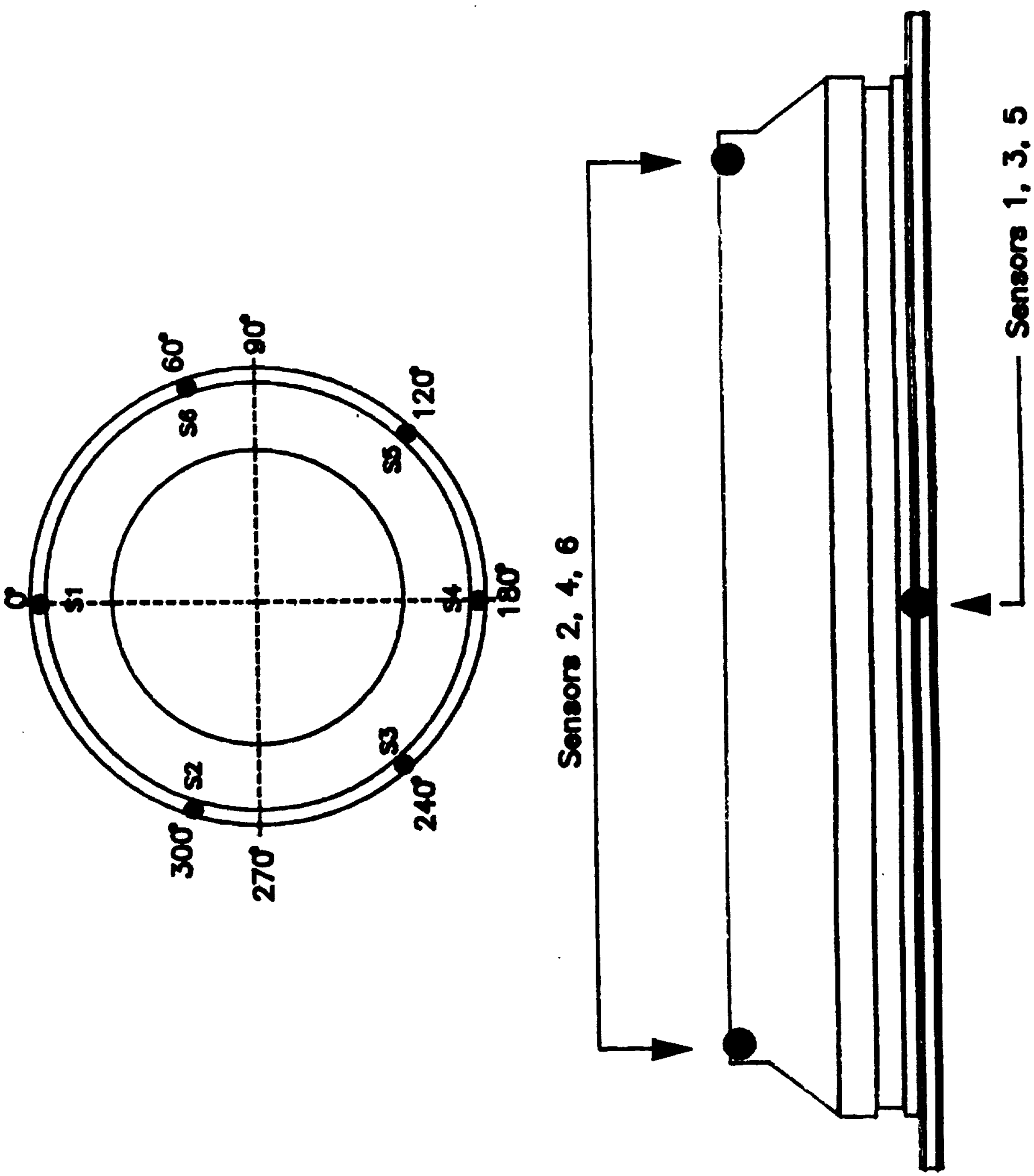


FIGURE 1

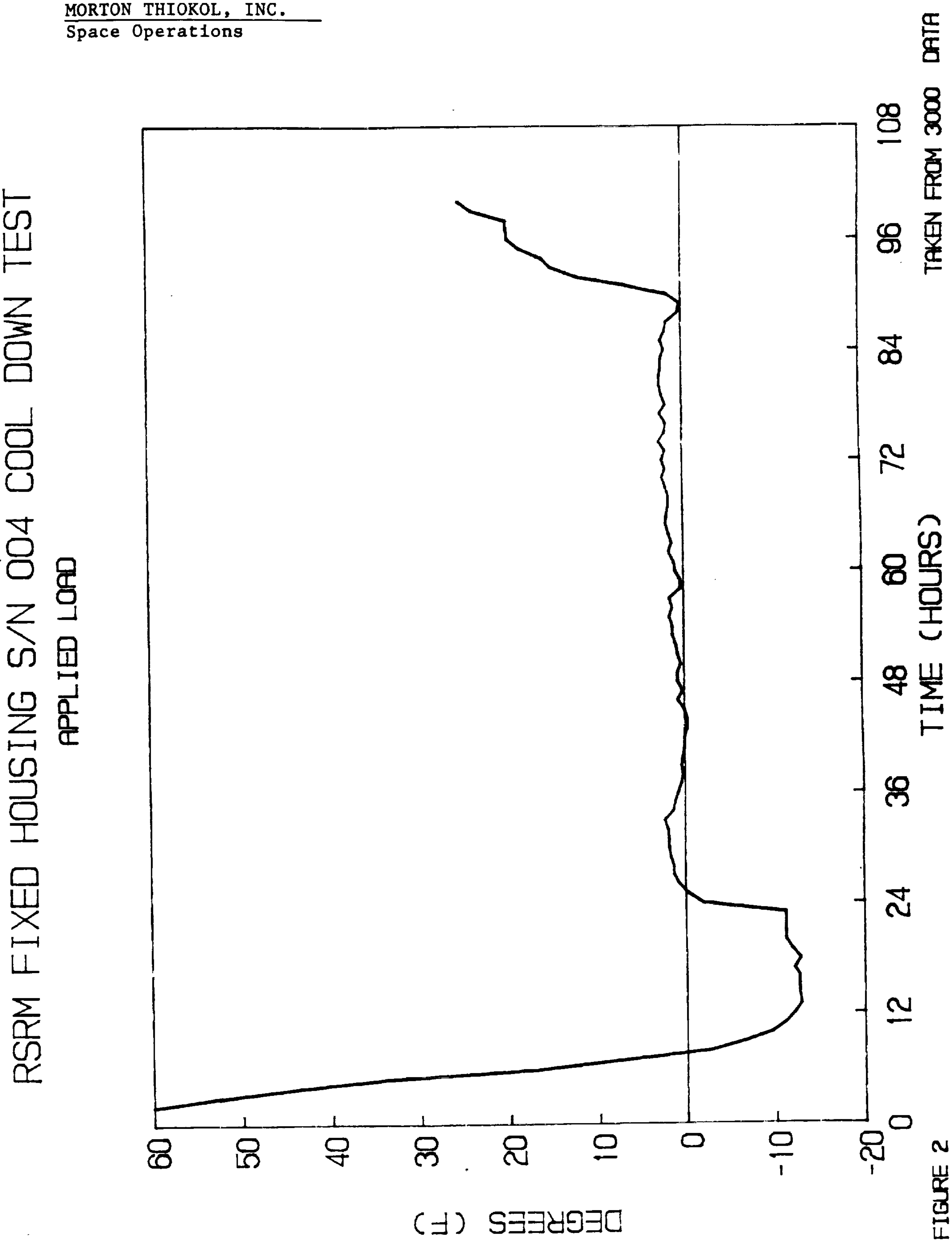

RSRM FIXED HOUSING S/N 004 COOL DOWN TEST
APPLIED LOAD
DEGREES (F)
TIME (HOURS)
TAKEN FROM 3000 DATA
60
50
40
30
20
10
0
-10
-20
0
12
24
36
48
60
72
84
96
108

FIGURE 2

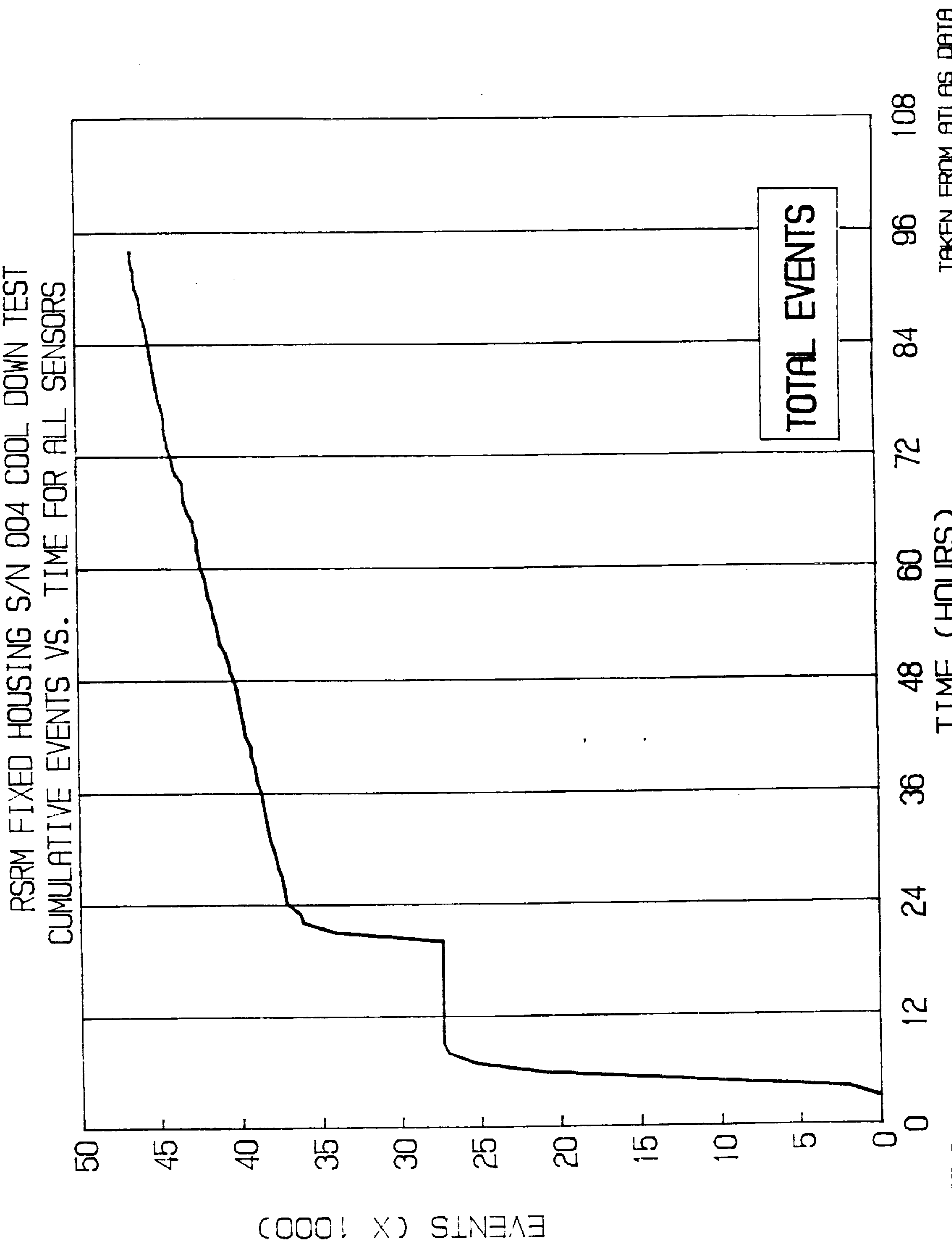

RSRM FIXED HOUSING S/N 004 COOL DOWN TEST
CUMULATIVE EVENTS VS. TIME FOR ALL SENSORS
TOTAL EVENTS
EVENTS (X 1000)
0
5
10
15
20
25
30
35
40
45
50
TIME (HOURS)
0
12
24
36
48
60
72
84
96
108
TAKEN FROM ATLAS DATA

FIGURE 3

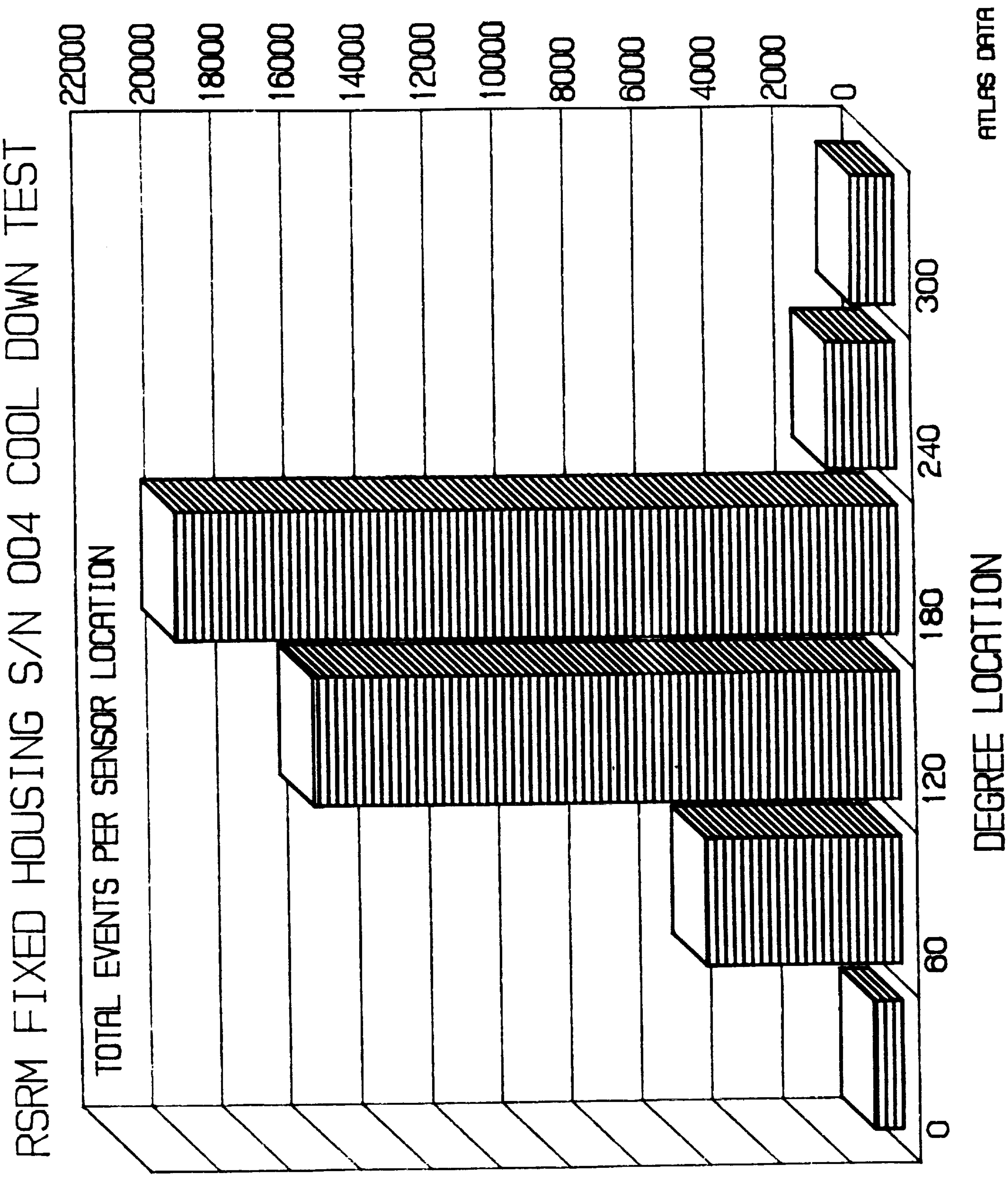

RSRM FIXED HOUSING S/N 004 COOL DOWN TEST
TOTAL EVENTS PER SENSOR LOCATION
22000
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
0
60
120
180
240
300
DEGREE LOCATION
ATLAS DATA

FIGURE 4

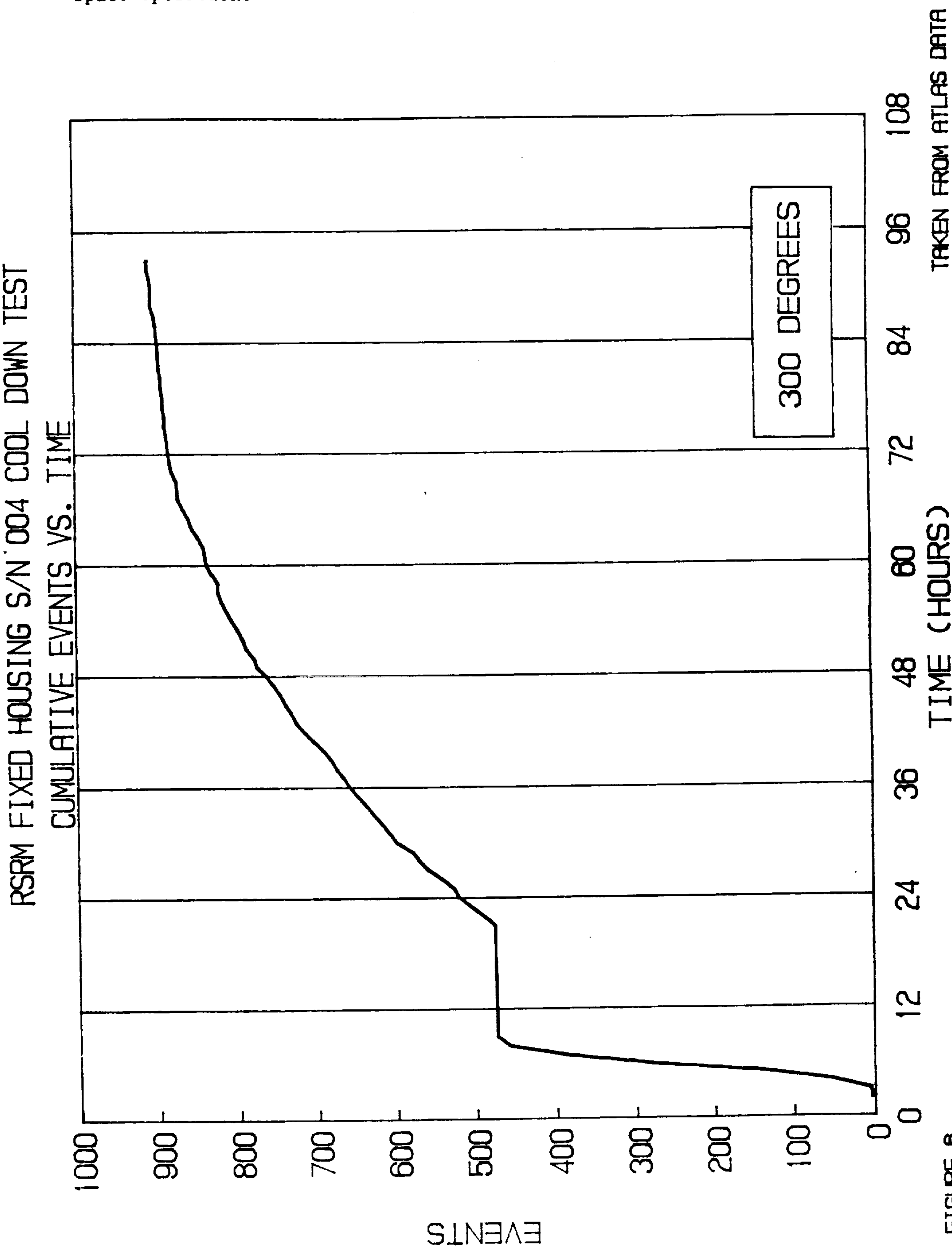

RSRM FIXED HOUSING S/N 004 COOL DOWN TEST
CUMULATIVE EVENTS VS. TIME
300 DEGREES
EVENTS
0
100
200
300
400
500
600
700
800
900
1000
TIME (HOURS)
0
12
24
36
48
60
72
84
96
108
TAKEN FROM ATLAS DATA

FIGURE 8

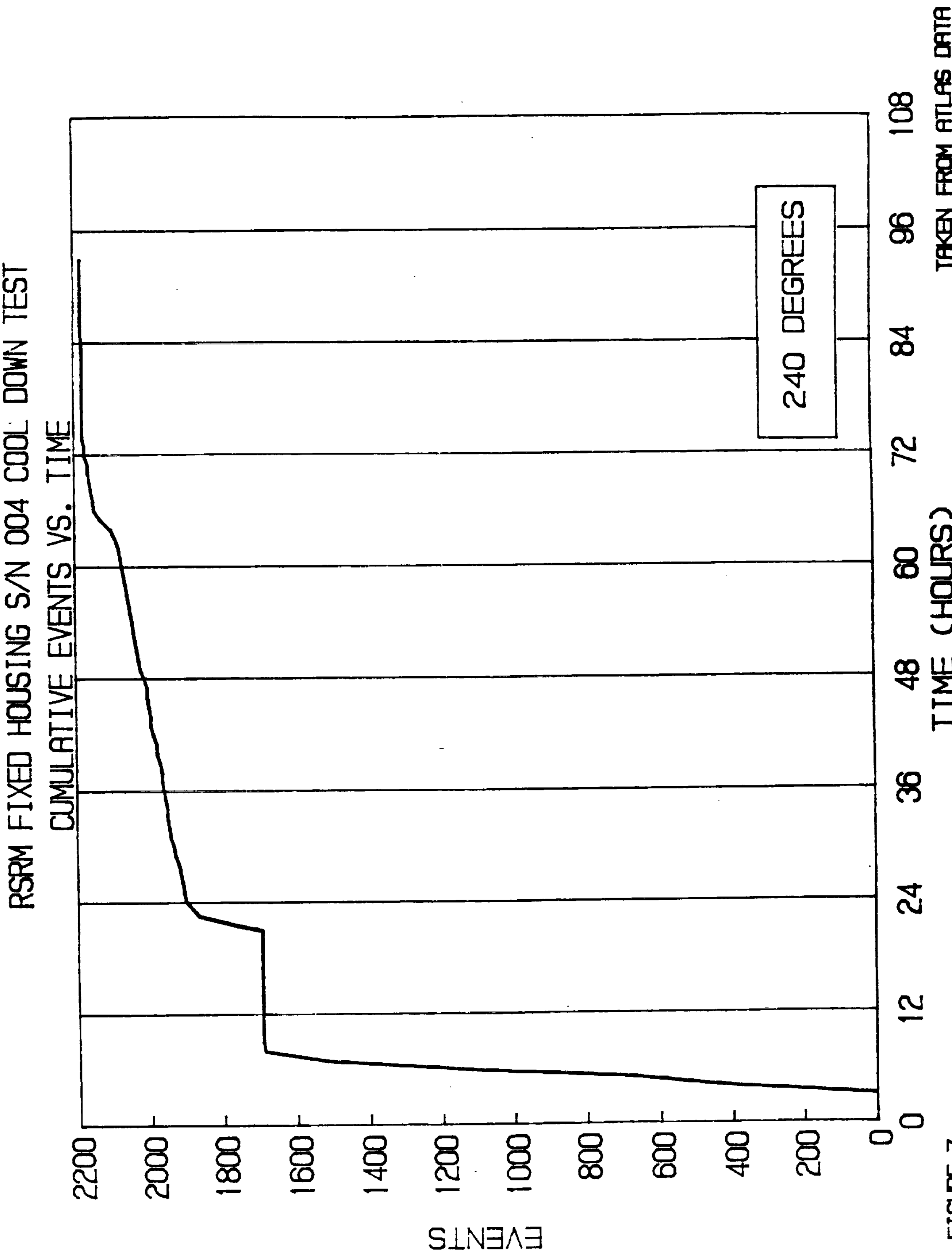

RSRM FIXED HOUSING S/N 004 COOL DOWN TEST
CUMULATIVE EVENTS VS. TIME
240 DEGREES
EVENTS
TIME (HOURS)
TAKEN FROM ATLAS DATA
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
0
12
24
36
48
60
72
84
96
108

FIGURE 7

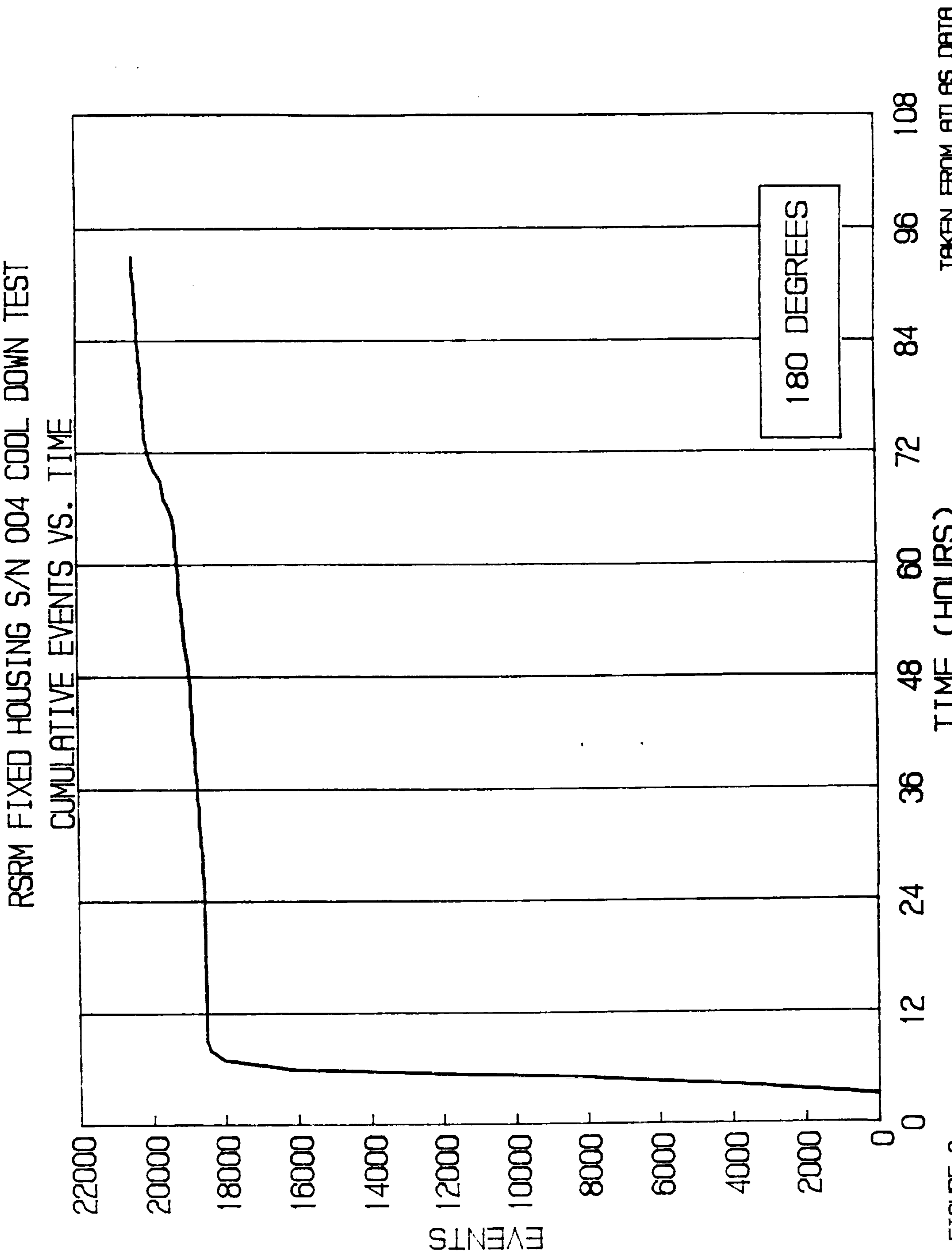

RSRM FIXED HOUSING S/N 004 COOL DOWN TEST
CUMULATIVE EVENTS VS. TIME
180 DEGREES
EVENTS
22000
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
0
12
24
36
48
60
72
84
96
108
TIME (HOURS)
TAKEN FROM ATLAS DATA

FIGURE 8

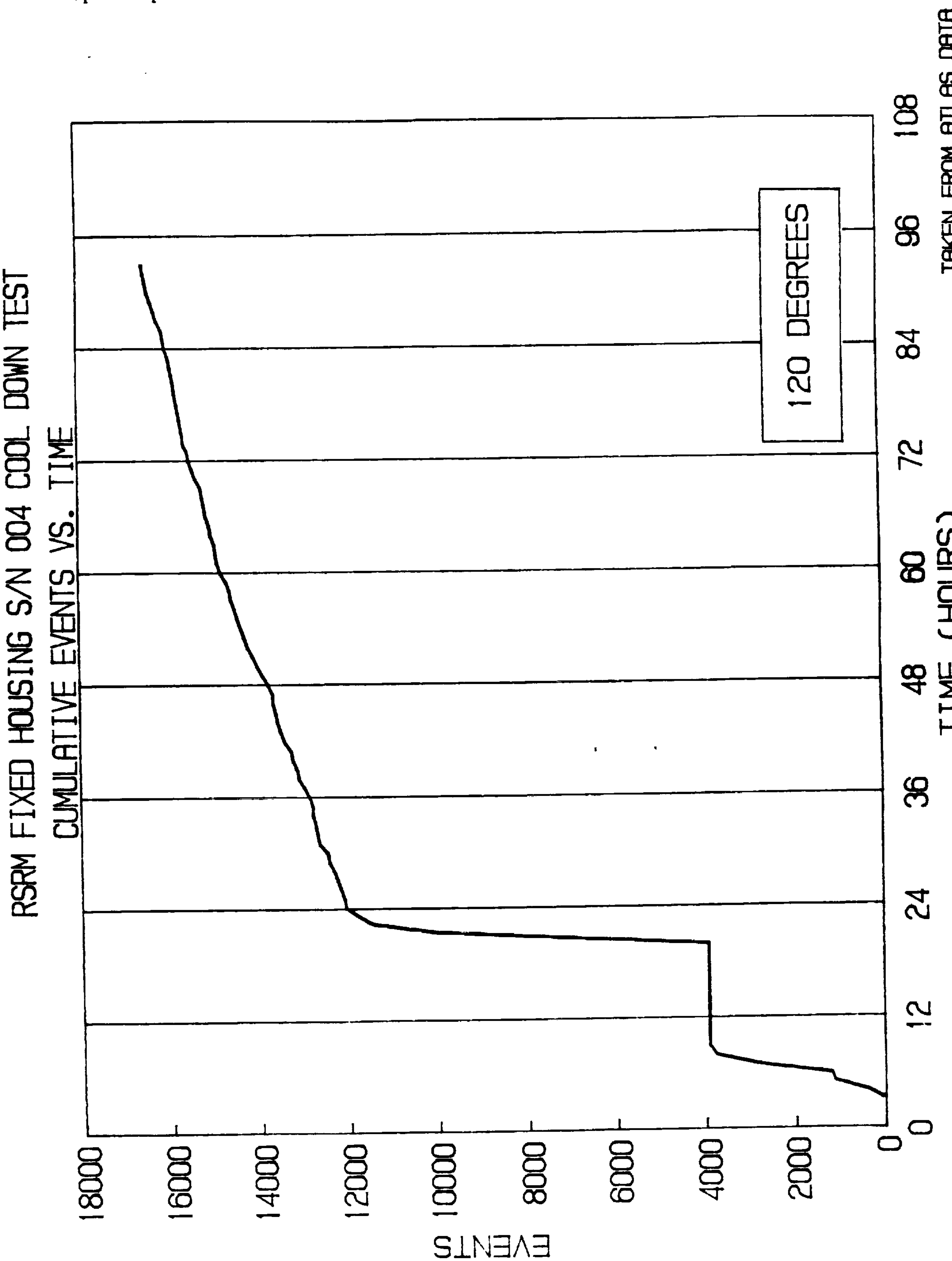

RSRM FIXED HOUSING S/N 004 COOL DOWN TEST
CUMULATIVE EVENTS VS. TIME
120 DEGREES
EVENTS
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
0
12
24
36
48
60
72
84
96
108
TIME (HOURS)
TAKEN FROM ATLAS DATA

FIGURE 9

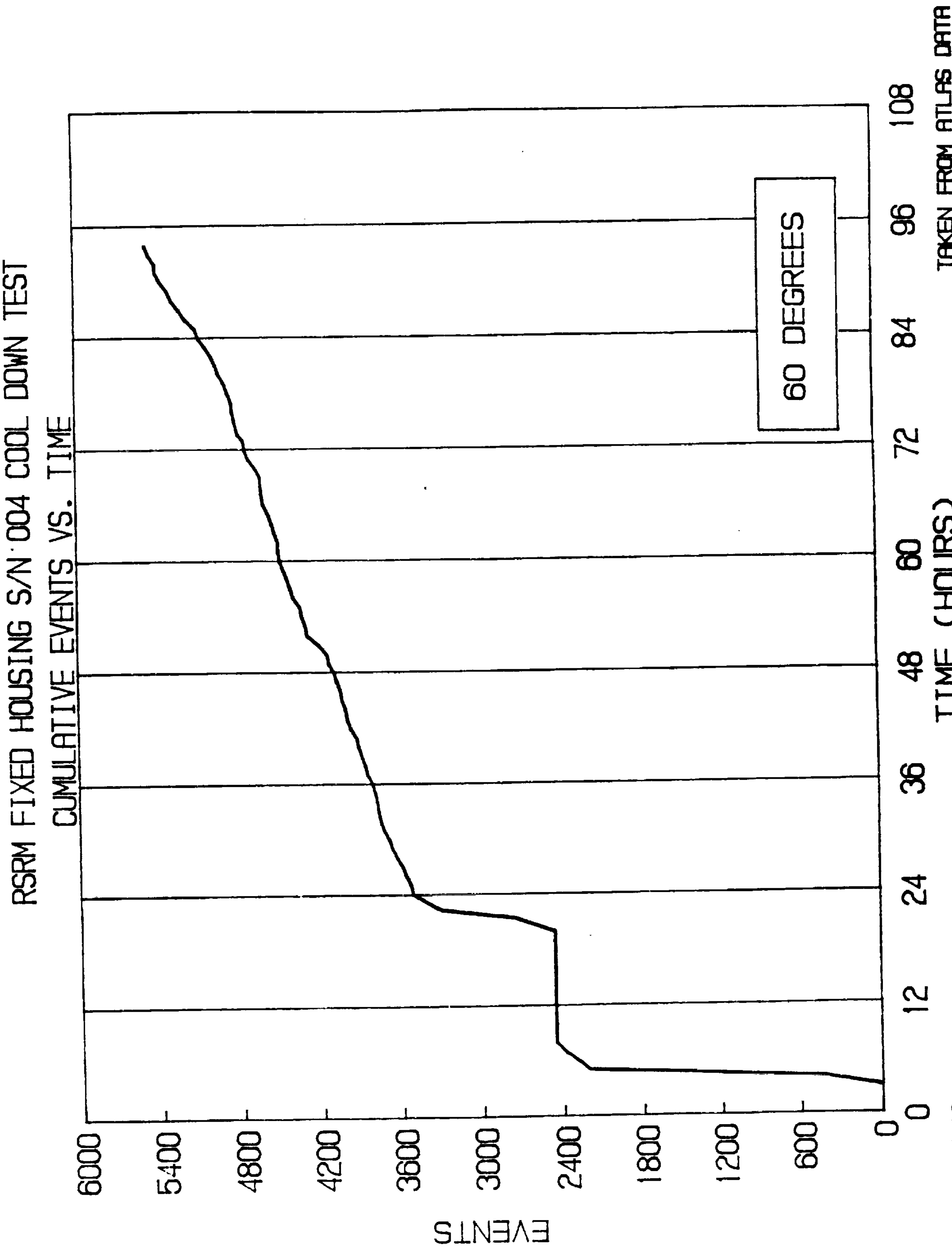
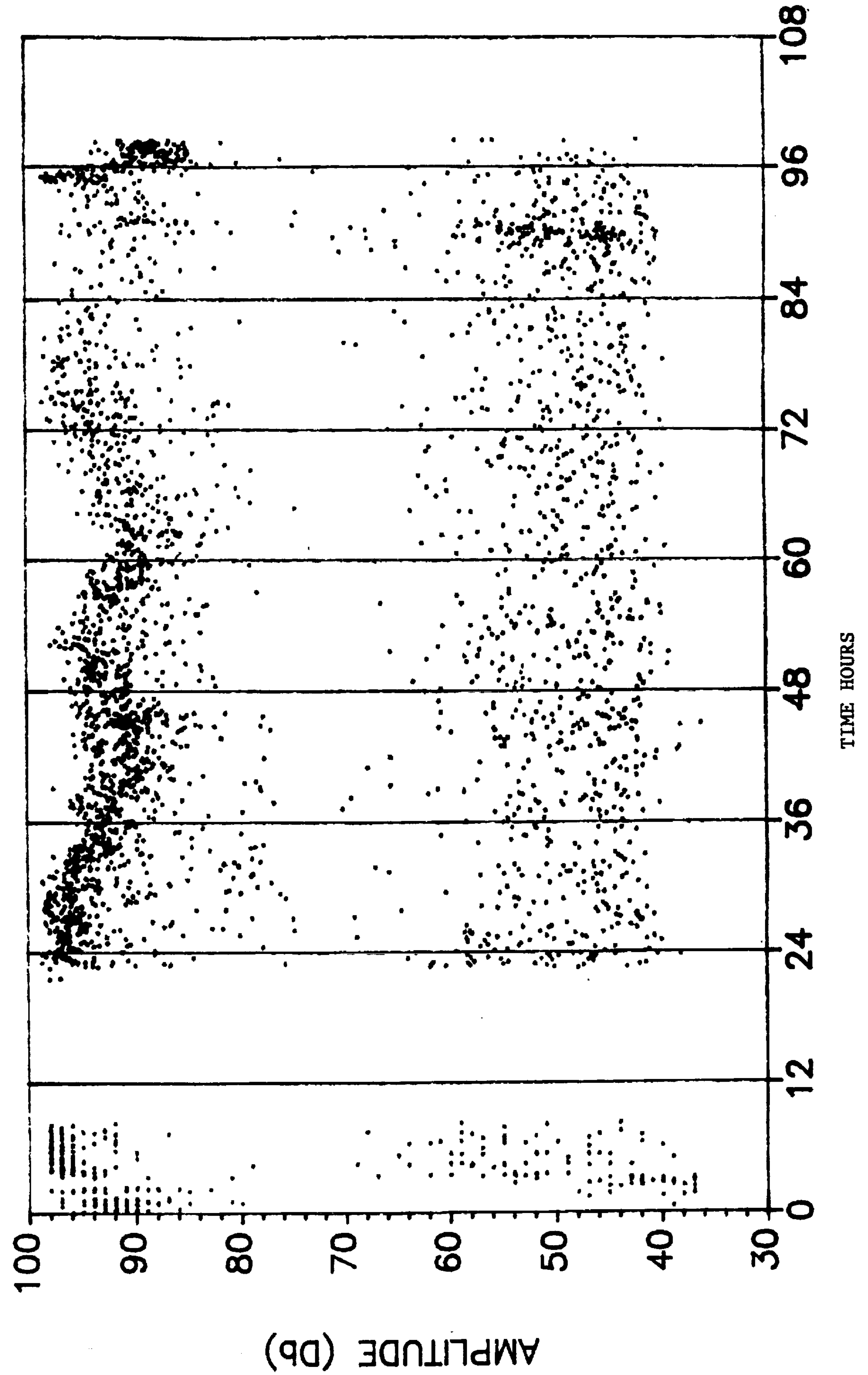

RSRM FIXED HOUSING S/N 004 COOL DOWN TEST
CUMULATIVE EVENTS VS. TIME
60 DEGREES
EVENTS
6000
5400
4800
4200
3600
3000
2400
1800
1200
600
0
0
12
24
36
48
60
72
84
96
108
TIME (HOURS)
TAKEN FROM ATLAS DATA

FIGURE 10

RSRM FIXED HOUSING S/N 004 COOL DOWN TST
MAXIMUM AMPLITUDES VS. TIME
FIGURE 11



APPENDIX B

Work Request No. 574534,

R & D Laboratories Report

CL-CC-89-2339(?)

574534

LABORATORY WORK REQUEST

TO: MECHANICAL PROPERTIES TESTING
DAVE SUISSE

FROM	EXTENSION	COST CENTER	PROJECT NO.	TASK	SUBTASK
CHUCK OLSEN JR	3597	L410	4B102	10	05
ORGANIZATION	**MAIL STOP**	**WORK ORDER NO.**		**USER**	**PCN**
SRM COMPOSITES	L40	B110			

SAMPLE INFORMATION

SAMPLE DESCRIPTION		DATE
S/N 14 FHI PVWP S/N 15 FHI PVWP	☐ RAW MATERIAL ☒ INPROCESS ☐ POST PROCESS	4/4/89

PART NO./STOCK NO.	SERIAL NO./LOT NO.	ASSEMBLY PART NO.	ASSEMBLY SERIAL NO.
7L76840			

MIX	GRINO	SAMPLED BY

TEST REQUIRED OR DESCRIPTION OF WORK REQUIRED, INCLUDE REASON FOR REQUEST

1. TEST 3 BUTTONS ON EACH PANEL; TEMP 70°F ± 5°, 0.05 IPM
2. * COOL BOTH PANELS TO -13°F ± 5; HOLD FOR 3 Hrs MIN.
3. TEST 5 BUTTONS ON EACH PANEL; TEMP -13 ± 5°, 0.05 IPM
4. WARM BOTH PANELS TO 70 ± 5° — Just Recover after each test
5. TEST REMAINING 4 BUTTONS ON EACH PANEL AT 70 ± 5°,
6. 0.05 IPM.
7. * MAXIMUM RATE OF TEMP CHANGE SHALL BE 10°F/hr ± 5° AFTER 20°F IS REACHED.
8. * ACOUSTIC EMISSION INSTRUMENTATION MUST BE INSTALLED BEFORE COOL

REPORT RESULTS TO	SEND COPY TO	RESULTS DESIRED BY (SPECIFIC DATE)
C. OLSEN JR	DON BOLIEAU SEND	ASAP
		AUTHORIZED SIGNATURE OR INSPECTION STAMP: [signature]

FOR LABORATORY USE ONLY

SPECIAL INSTRUCTIONS

ACCORDING TO TERRY WILLIAMS ACOUSTIC EMISSION IS NOT FEASIBLE ON THIS TEST.
4 APR 89

RESULTS OF LABORATORY ANALYSIS

CAN ACOUSTIC EMISSION ALSO RECORD TEMP.

DRILL 2 HOLES FOR THERMOCOUPLES

condition hold time changed to 1 1/2 HRS / DAVE SUISSE 11:45 AM TH.

DISPOSITION

☐ ACCEPT ☐ REJECT ☐ RESAMPLE

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DATE AND TIME COMPLETED	TIME REQUIRED	DATE REPORTED	SIGNATURE

MORTON THIOKOL, INC.
Space Operations

			Failure Mode Key	
LWR # :	574534	1 = Adhesive/Metal	5 = Cohesive/Rubber	9 = Void
Work Order:	B1101	2 = Cohesive/Adhesive	6 = Adhesive/Rubber	10 = Failure Comment
Originator:	C. OLSEN JR.	3 = Adhesive/Phenolic	7 = Cohesive/Liner	TB = Tab Broke
		4 = Cohesive/Phenolic	8 = Adhesive/Liner	B = Button Side
				P = Panel Side

Date: 04-04-89 Test Machine: BALDWIN Temperature: 75 Deg. F
Technician: LD. WALTERS Test Type: Tensile Adhesion Crosshead Speed: .05 in/min

Spec No.	Segment ID.	Panel ID. Serial	Dia (in)	Cross Section (in2)	Max Load (lbs)	Max Stress (psi)	1	2	3	4	5	6	7	8	9	10
1	#2	5A 14 FHI PUMP	0.79789	0.500	1774	3548		10	90							P
2	#4	5A 14 FHI PUMP	0.79789	0.500	1750	3499		10	87	3						P
3	#5	5A 14 FHI PUMP	0.79789	0.500	1755	3509		15	70	15						P
Average (PSI):						3519		12	82	6						
Standard Deviation:						25.8										
Coeff. of Var:						0.7										

Date: 04-04-89 Test Machine: BALDWIN Temperature: 75 Deg. F
Technician: LD. WALTERS Test Type: Tensile Adhesion Crosshead Speed: .05 in/min

Spec No.	Segment ID.	Panel ID. Serial	Dia (in)	Cross Section (in2)	Max Load (lbs)	Max Stress (psi)	1	2	3	4	5	6	7	8	9	10
4	#2	5B 15 FHI PUMP	0.79789	0.500	1501	3003		15	70	15						P
5	#4	5B 15 FHI PUMP	0.79789	0.500	1481	2961		5	75	20						P
6	#5	5B 15 FHI PUMP	0.79789	0.500	1719	3438			8	92						
Average (PSI):						3134		7	51	42						
Standard Deviation:						264.4										
Coeff. of Var:						8.4										

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MORTON THIOKOL, INC.
Space Operations

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			P = Panel Side

Failure Mode Key

Date: 04-06-[redacted] Test Machine: SATEC Temperature: -13 Deg. F
Technician: TOM MYERS Test Type: Tensile Adhesion Crosshead Speed: .05 in/min

Spec No.	Segment ID.	Panel ID. Serial	Dia (in)	Cross Section (in2)	Max Load (lbs)	Max Stress (psi)	Failure Mode Analysis 1	2	3	4	5	6	7	8	9	10
7	#7	14 PHI PVWP	0.79789	0.500	2555	5110		85	15							
8	#10	14 PHI PVWP	0.79789	0.500	2795	5590		85	15							
9	#12	14 PHI PVWP	0.79789	0.500	2840	5680				100						
10	#13	14 PHI PVWP	0.79789	0.500	2230	4460		50	50							
11	#15	14 PHI PVWP	0.79789	0.500	2310	4621		50	45						5	
Average (PSI):						5092		54	25	20					1	
Standard Deviation:						551.3										
Coeff. of Var:						10.8										

Date: 04-06-89 Test Machine: SATEC Temperature: -13 Deg. F
Technician: TOM MYERS Test Type: Tensile Adhesion Crosshead Speed: .05 in/min

Spec No.	Segment ID.	Panel ID. Serial	Dia (in)	Cross Section (in2)	Max Load (lbs)	Max Stress (psi)	Failure Mode Analysis 1	2	3	4	5	6	7	8	9	10
12	#7	15 PHI PVWP	0.79789	0.500	1900	3800			50	50						
13	#10	15 PHI PVWP	0.79789	0.500	2025	4050			50	50						
14	#12	15 PHI PVWP	0.79789	0.500	1560	3120			40	60						
15	#13	15 PHI PVWP	0.79789	0.500	1925	3850			70	30						
16	#15	15 PHI PVWP	0.79789	0.500	1605	3210		40	40	15					5	
Average (PSI):						3606		8	50	41					1	
Standard Deviation:						414.5										
Coeff. of Var:						11.5										

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MORTON THIOKOL, INC.
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				P = Panel Side

[redacted] 04-06-89 Test Mac[redacted] SATEC Temperature: +69 Deg. F
Technician: TOM MYERS Test Type: Tensile Adhesion Crosshead Speed: .05 in/min

Spec No.	Segment ID.	Panel ID. Serial	Dia (in)	Cross Section (in2)	Max Load (lbs)	Max Stress (psi)	Failure Mode Analysis 1	2	3	4	5	6	7	8	9	10
17	#18	15 PHI PVWP	0.79789	0.500	1805	3610			50	50						
18	#20	15 PHI PVWP	0.79789	0.500	1900	3800		15	70	15						
19	#21	15 PHI PVWP	0.79789	0.500	1565	3130			35	65						
20	#23	15 PHI PVWP	0.79789	0.500	1955	3910			45	55						
Average (PSI):						3612		4	50	46						
Standard Deviation:						344.7										
Coeff. of Var:						9.5										

Date: 04-06-89 Test Machine: SATEC Temperature: +70 Deg. F
Technician: TOM MYERS Test Type: Tensile Adhesion Crosshead Speed: .05 in/min

Spec No.	Segment ID.	Panel ID. Serial	Dia (in)	Cross Section (in2)	Max Load (lbs)	Max Stress (psi)	Failure Mode Analysis 1	2	3	4	5	6	7	8	9	10
21	#18	14 PHI PVWP	0.79789	0.500	1880	3760		20	72	5					3	
22	#20	14 PHI PVWP	0.79789	0.500	1915	3830			95	5						
23	#21	14 PHI PVWP	0.79789	0.500	1770	3540		10	70	20						
24	#23	14 PHI PVWP	0.79789	0.500	1895	3790			95	5					2	
Average (PSI):						3730		8	83	9					1	
Standard Deviation:						129.8										
Coeff. of Var:						3.5										

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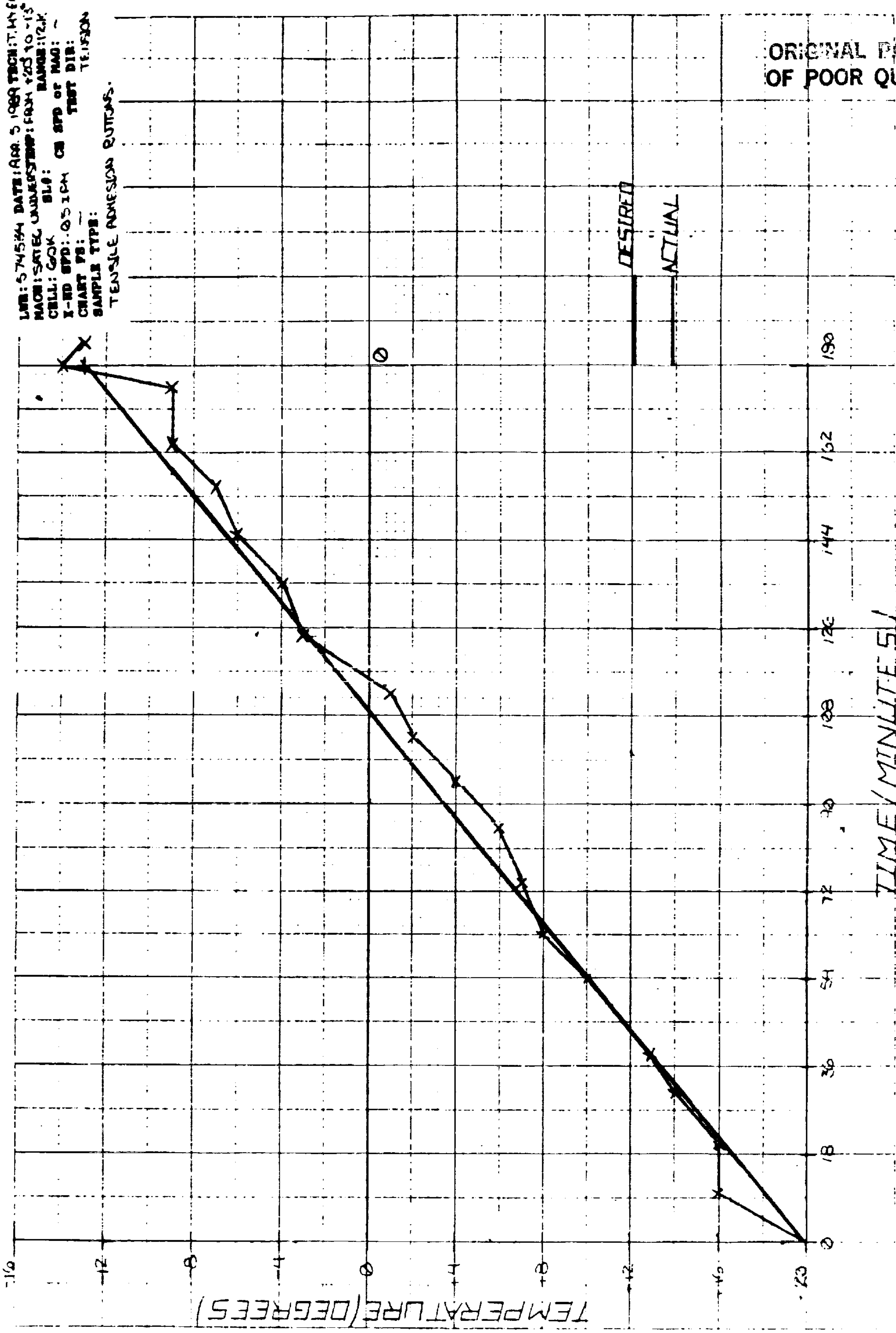

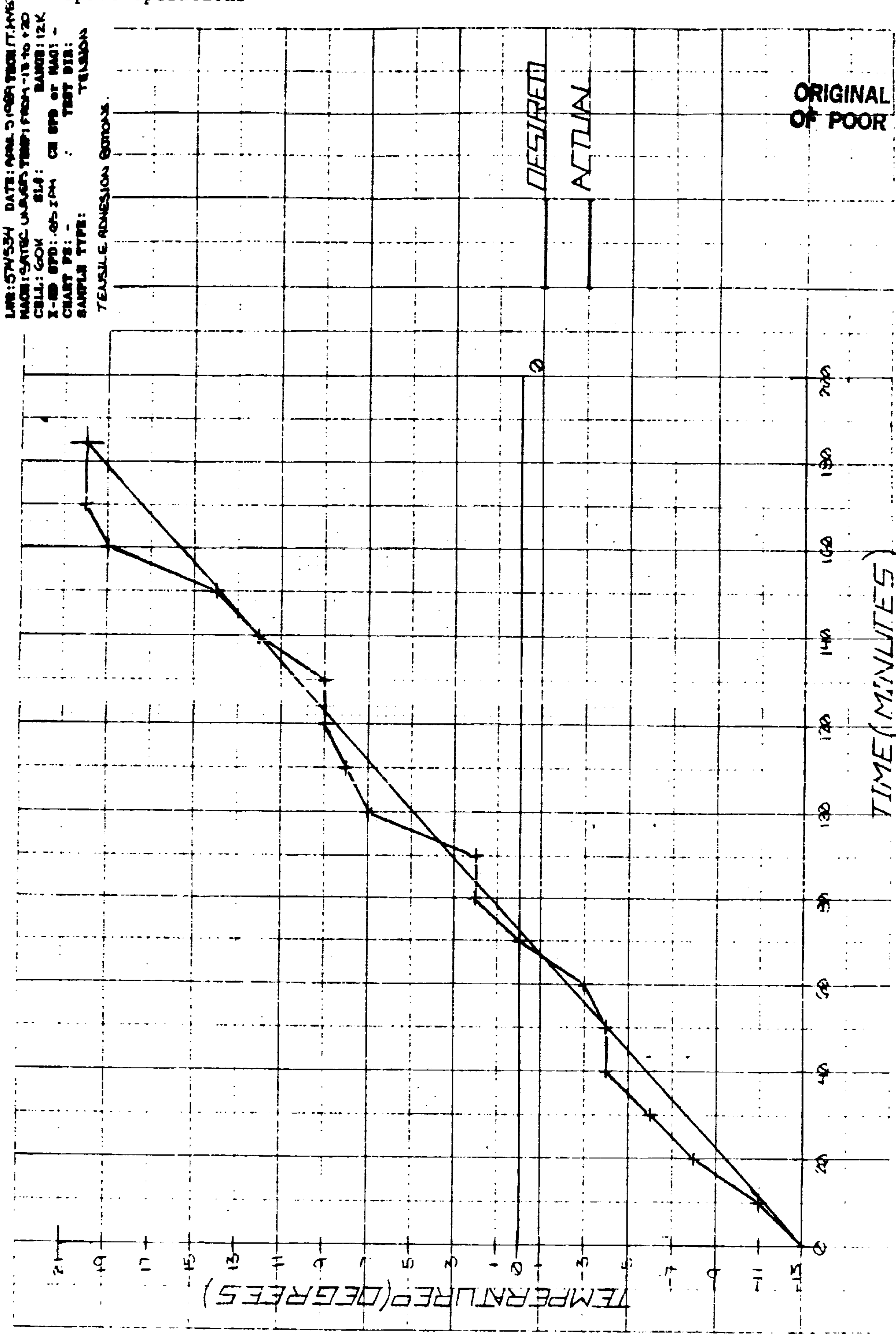
DESIRED
ACTUAL
TIME (MINUTES)
TEMPERATURE (DEGREES)