TWR-17639

SPACE SHUTTLE

Solid Rocket Motors
Thiokol Corporation

Space Shuttle Technical Evaluation Motor No. 3 (TEM-3) Final Test Report

July 1989

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(NASA-CR-183740) TECHNICAL EVALUATION MOTOR 3 (TEM-3) Final Test Report (Thiokol Corp.) 227 p CSCL 21H

N89-28567

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ORIGINAL PAGE
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Technical Evaluation Motor 3
(TEM-3)
Final Test Report

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ABSTRACT

A primary objective of the technical evaluation motor program is to recover the case, igniter and nozzle hardware for use on the redesigned solid rocket motor flight program.

Two qualification objectives were addressed and met on TEM-3. The Nylok thread locking device of the 1U100269-03 leak check port plug and the 1U52295-04 safe and arm utilizing Krytox grease on the barrier-booster shaft O-rings were both certified.

All inspection and instrumentation data indicate that the TEM-3 static test firing conducted 23 May 1989 was successful. The test was conducted at ambient conditions with the exception of the field joints (set point of 121°F, with a minimum of 87°F at the sensors), igniter joint (set point at 122°F with a minimum of 87°F at sensors) and case-to-nozzle joint (set point at 114°F with a minimum of 87°F at sensors).

Ballistics performance values were within specification requirements. Nozzle performance was nominal with typical erosion. The nozzle and the case joint temperatures were maintained at the heaters controlling set points while electrical power was supplied. The water and the CO_2 quench systems prevented damage to the metal hardware. All other test equipment performed as planned, contributing to a successful motor firing.

All indications are that the test was a success, and all expected hardware will be refurbished for the RSRM program.

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FIGURES

TABLES

ACRONYMS

Al	aluminum
AP	ammonium perchlorate
B-B	barrier-booster
CCP	carbon-cloth phenolic
CP	circular perforated
CTPB	carboxyl terminated polybutadiene polymer
DR	discrepancy reports
EPDM	ethylene propylene diene monomer
ET	external tank
FWC	filament wound case
HPM	high performance motor
JPS	joint protection system
LSC	linear shaped charge
NBR	acrylonitrile butadiene rubber
OBR	outer boot ring
OD	outer diameter
PBAN	polybutadiene acrylic acid acrylonitrile terpolymer binder
S&A	safe and arm
SBRE	surface burn rate error
sccs	standard cubic centimeters per second
SII	shuttle igniter initiator
SRB	solid rocket booster
SRM	solid rocket motor
TEM	technical evaluation motor
TVC	thrust vector control
1-L	first longitudinal

1
INTRODUCTION

The solid rocket motor (SRM), used in pairs, is the primary space shuttle propulsive element, providing impulse and thrust vector control (TVC) from SRM ignition to solid rocket booster (SRB) separation. The space shuttle technical evaluation motor (TEM-3) test was a full-scale full-duration test of a high performance motor (HPM) configuration SRM. This test report includes a presentation and discussion of TEM-3 performance and of test result concurrence with the objectives outlined in the latest revision of CTP-0103. A major focus of this report is placed on the test objectives, anomalies, and motor performance.

TEM-3 was successfully fired on 23 May 1989 at Morton Thiokol, Utah-based operations, test bay T-97. The test was conducted in accordance with the requirements of CTP-0103, "Space Shuttle Technical Evaluation Motor No. 3 (TEM-3) Static Fire Test Plan, Rev C." Postfire inspection procedures followed TWR-16474, Vol I through Vol IX.

1.1 TEST ARRANGEMENT AND FACILITIES

The TEM-3 static test arrangement was in accordance with Drawing 2U129760 as shown in Figure 1.1-1. T-97 is equipped with a water deluge system and a CO_2 quench. An aft skirt ring/actuator support ring assembly was installed in place of the aft skirt. The ring provided mounting provisions for the fixed links which were used in place of TVC actuators.

1.2 TEST ITEM DESCRIPTION

The TEM-3 static test motor consists of HPM configuration motor segments fabricated and loaded with propellant prior to January 1986. These segments (forward from SRM 31B; forward center from SRM 29A; aft center from SRM 27A; aft from SRM 30B) have been kept in open storage since that time (Table 1.2-1). The test article was not configured to approximate the RSRM flight motors. The HPM static test motor consisted of a lined, insulated, segmented rocket motor case loaded with solid propellant; ignition system complete with electro-mechanical safety and arming (S&A) device, initiators and loaded igniter; and an aft skirt/actuator support ring assembly in place of the aft skirt to provide mounting provisions for the fixed links that were used in place of the TVC actuators. The motor was instrumented to provide data to satisfy the test objectives. An overall view of the test article is shown in Figure 1.2-1.

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Figure 1.1-1. TEM-3 Static Test Arrangement

Table 1.2-1. Original Segment Assignment

Segment	HPM	Cast Date	Storage History
Forward	31B	16 Jan 1986	Stored at Thiokol since cast
Forward Center	29A	19 Nov 1985	Stored at Thiokol since cast
Aft Center	27A	3 Sep 1985	Stored at KSC (36 months stacked--27 Nov 1985 to 3 Jan 1989)
Aft	30B	10 Dec 1985	Stored at Thiokol since cast

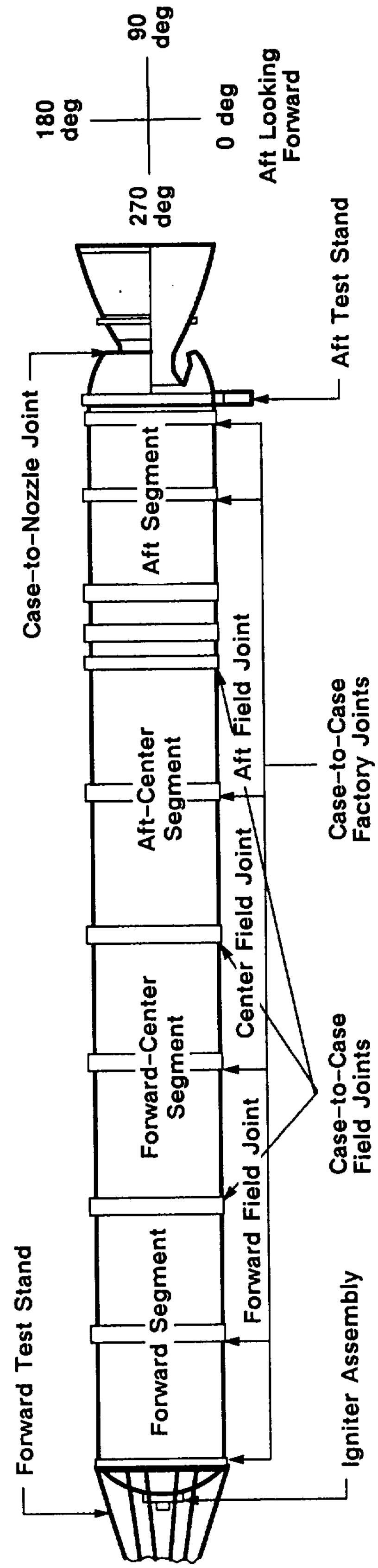

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Figure 1.2-1. TEM-3 Static Test Motor

1.2.1 Case/Seals

The case consists of 11 individual segments: the forward dome, six cylinder segments, the external tank (ET) attach segment, two stiffener segments, and the aft dome. The 11 segments are preassembled into four subassemblies before propellant casting. These four subassemblies are the forward segment assembly, the forward center and aft center segment assembly, and the aft segment assembly. These individual casting segments are joined by means of HPM tang and clevis field joints which are held in place by pins. The case-to-nozzle joint is formed by bolting the nozzle fixed housing into the aft dome with 100 axial bolts. The assembled case was approximately 116 ft in length and 12 ft in diameter (Figure 1.2-1).

Factory joints were configured with the following:

--HPM tang and clevis hardware design

--HPM insulation overlaid and cured over the interior of the joint (Figure 1.2.1-1).

Field joints were configured with the following:

--Tang and clevis with RSRM-type long pins, custom shims, and RSRM-type hatband pin retainers.

--Standard HPM insulation configuration with putty joint filler.

--Fluorocarbon clevis O-rings (STW4-3339)

--Field joint heaters.

--No joint protection system (JPS)

The case-to-nozzle was configured with the following:

--Standard HPM nozzle joint insulation with putty joint filler (STW4-3266).

--Primary and secondary O-rings were fluorocarbon (STW4-3339). New RSRM O-ring was used for primary.

--Nozzle joint heater.

--One hundred axial bolts installed using torque.

The igniter was configured with the following:

--S&A device utilizing Krytox grease to lubricate barrier-booster (B-B) shaft O-rings

--SRM igniter modified for CO_2 quench port

The igniter-to-forward dome joint was configured with the following:

--Igniter joint heater

--Putty joint filler (STW4-3266).

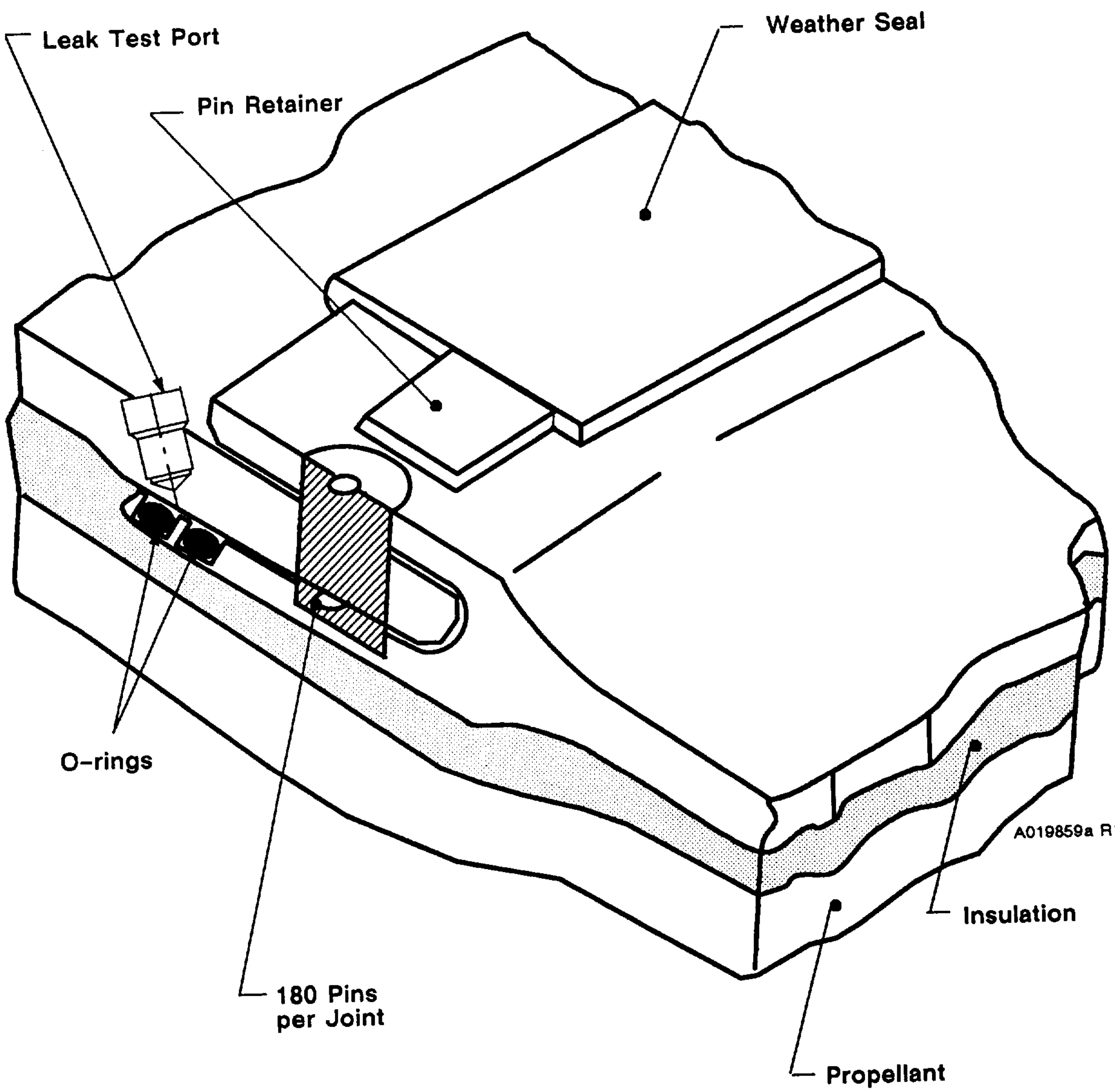

Figure 1.2.1-1. Factory Joint Seal

Corrosion protection consisted of full external paint and a thin film of grease (including O-rings, sealing surfaces and pinholes.)

1.2.2 Propellant/Liner

The HPM propellant (same as RSRM), TP-H1148, is a composite-type solid propellant, formulated of polybutadiene acrylic acid acrylonitrile terpolymer binder (PBAN), epoxy curing agent, ammonium perchlorate (AP) oxidizer and aluminum (Al) powder fuel. A small amount of burning rate catalyst (iron oxide) is added to achieve targeted propellant burn rate of 0.368 in./sec at 625 psia and 60°F.

The propellant grain design consists of an 11-point star with a smooth bore-to-fin cavity transition region that tapers into a circular perforated (CP) configuration in the forward segment. The two center segments are double-taper CP configurations, and an aft segment is a triple-taper CP configuration with a cutout for the partially submerged nozzle (Figure 1.2.2-1).

The liner material is an asbestos-filled carboxyl terminated polybutadiene polymer (CTPB) which bonds the propellant to the case insulation in the SRM.

1.2.3 Insulation/Inhibitor

The internal insulation system includes chamber insulation and propellant stress relief flaps. The insulation material for the chamber and stress relief flaps is an asbestos-silica filled acrylonitrile butadiene rubber (NBR). NBR is used for the basic case wall insulation and for the forward end inhibitors on the center and aft segments. The aft dome insulation system uses NBR with inboard layers of carbon-fiber-filled EPDM. The carbon-fiber-filled EPDM is installed to reduce the erosion of the insulator near the submerged nozzle and under the stress relief flaps in the center segments.

The castable inhibitors on the aft end of the forward and center segments are the HPM configuration per STW5-3223. The castable inhibitor material is a CTPB polymer.

1.2.4 Nozzle/TVC

The nozzle assembly is the pre 51-L partially-submerged convergent/divergent movable design with an aft pivot point flexible bearing (Figure 1.2.4-1).

An aft skirt/actuator support ring assembly was used instead of the aft skirt to provide mounting provisions for the fixed links that were used in place of the TVC actuators.

1.2.5 Ignition System

The SRM ignition system shown in Figure 1.2.5-1 was a modified HPM igniter assembly. It contained a single nozzle, steel chamber, external and internal insulation, and solid propellant

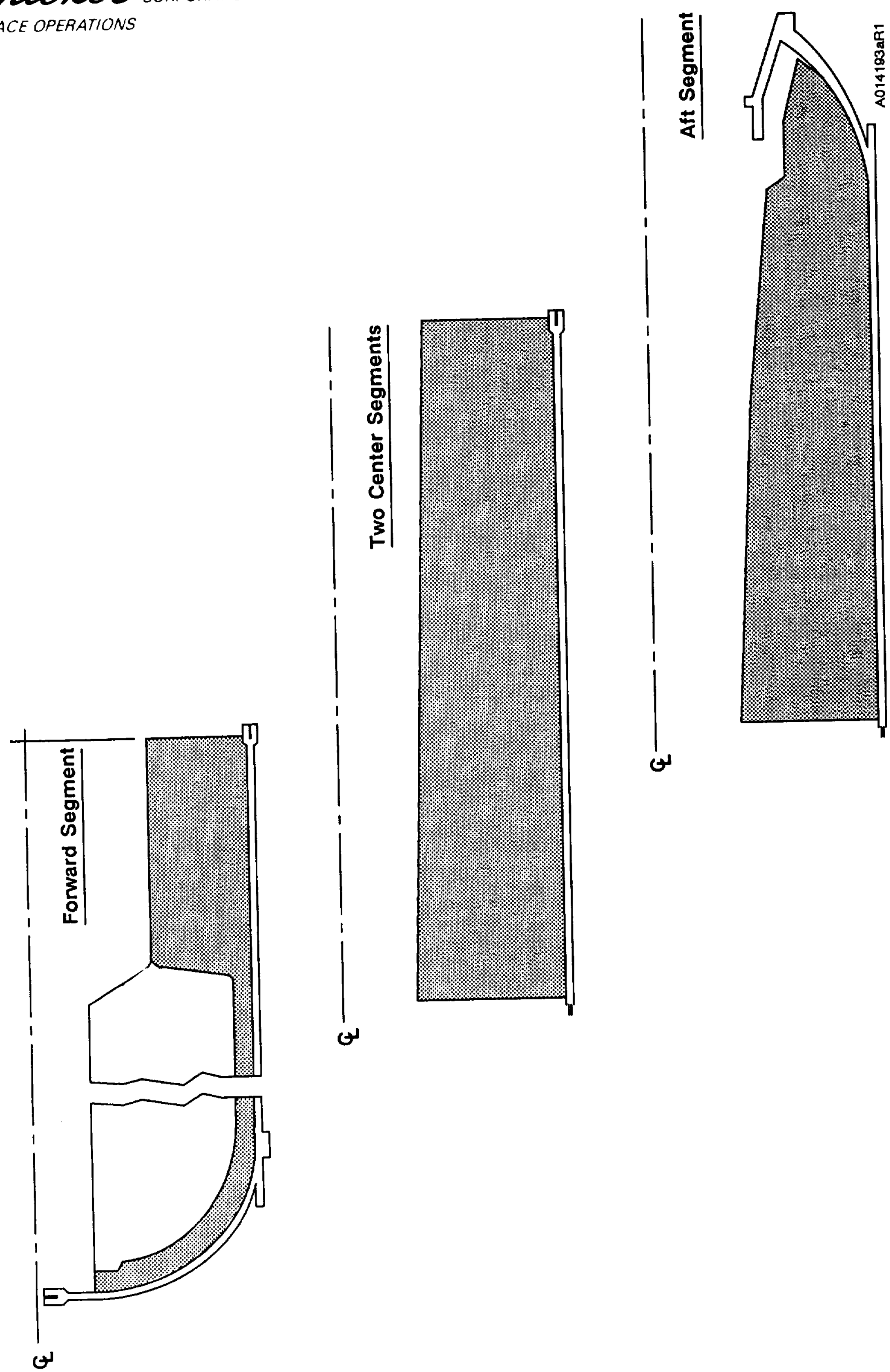

Figure 1.2.2-1. HPM Propellant Grain Design Configuration

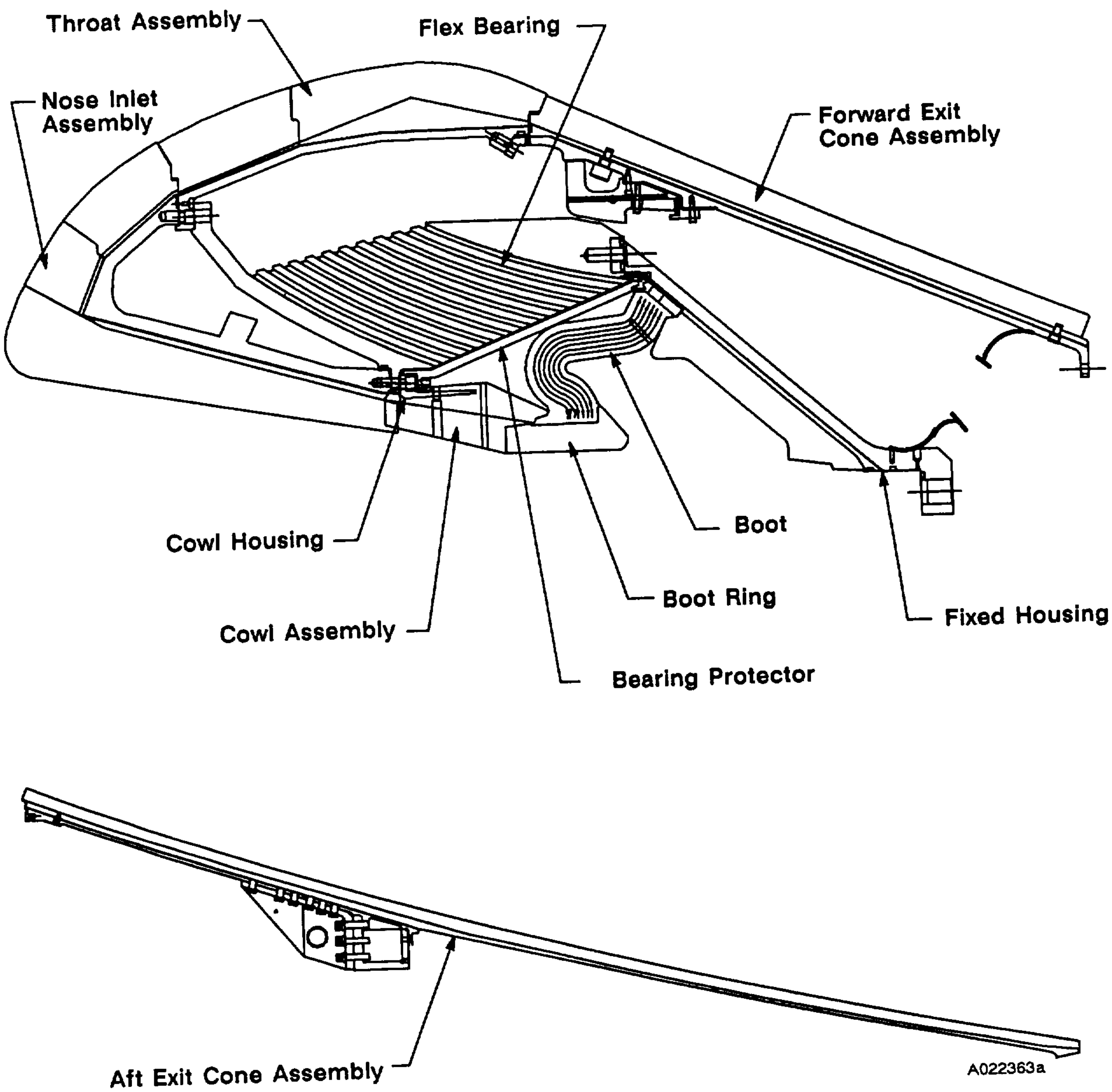

Figure 1.2.4-1. HPM Nozzle

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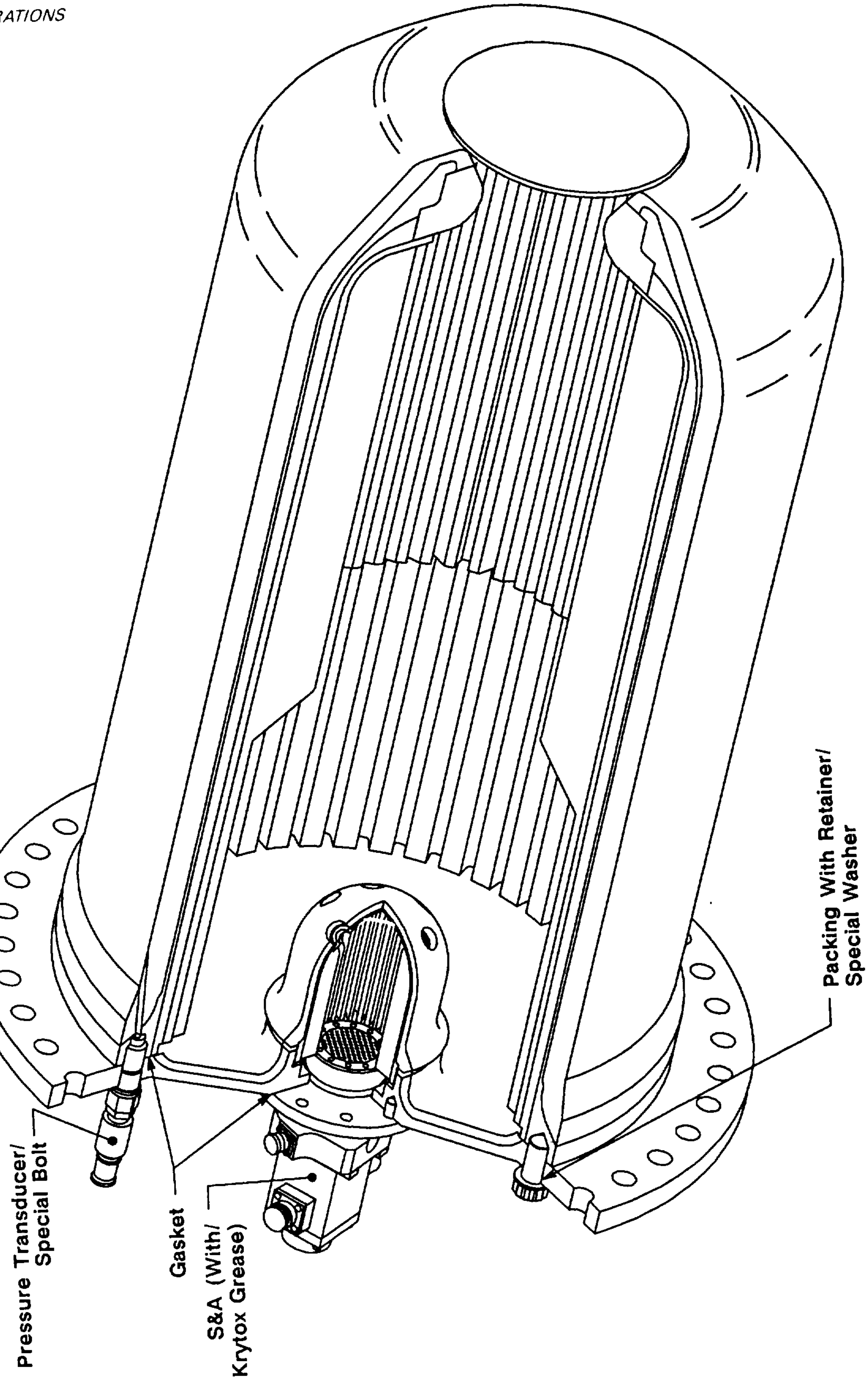

Figure 1.2.5-1. Standard HPM Igniter System

igniter containing a case-bonded 40-point star grain. The forward mounted solid rocket type igniter was modified with a CO_2 quench port. The ignition system produced a short and predictable motor ignition which minimizes thrust imbalance. An S&A device utilizing Krytox grease to lubricate the B-B shaft O-rings was installed on the igniter.

1.2.6 JPS/Weather Seal

The JPS installed on each field joint, the igniter, and the case-to-nozzle joint consisted of heaters and sensors only. The heaters consist of primary and redundant chemically etched, foil circuits which are superimposed upon one another and laminated in Kapton and FEP Teflon. The underside of the heater's Kapton surface is coated with a pressure-sensitive adhesive. This adhesive provides bonding to the case during assembly. An additional cork piece and Kevlar strap was installed just forward of the existing cork piece and Kevlar strap. The lead wires extend from the heaters and are terminated in electrical connectors. No systems tunnel or linear shaped charge (LSC) was installed on TEM-3.

1.2.7 Leak Check Port Plugs

Leak check port plugs with the Nylok locking feature (1U100269-03) were installed in the leak check ports of all three field joints and the case-to-nozzle joint.

The TEM-3 drawing tree is included in Appendix A.

2

TEST OBJECTIVES

The TEM-3 test objectives were derived from objectives in TWR-15723, Rev C. Instrumentation was selected to provide data to satisfy the test objectives.

TEM-3 Test Objectives:

Development

A Recover case, nozzle, and igniter hardware for RSRM flight program.

B Obtain additional data on the effect of three-year open storage of loaded SRM case segments upon motor ignition and performance.

C Obtain additional data on the performance of electrical strip heaters on the igniter, field, and case-to-nozzle joints.

D Obtain additional data on the low-frequency chamber pressure oscillations in the motor forward end.

E Obtain data on nozzle fixed link force oscillations.

F Evaluate the effects of known cracks in the aft segment stiffener stubs.

Qualification objectives of this test are as follows:

G Certify the Nylok thread locking device of the 1U100269-03 leak check port plug (CPW1-3600A, Para 3.3.6.10).

H Certify for use on RSRM the 1U52295-04 S&A device which utilizes Krytox grease on the barrier-booster shaft O-rings (CPW1-3600A, Para 3.2.1.2, 3.2.1.2.4.a, 3.2.1.5.a).

3

EXECUTIVE SUMMARY

3.1 SUMMARY

All of the objectives that can be addressed to date have been met. All inspection and instrumentation data indicate that the TEM-3 static test firing was successful. Data was gathered at instrumented locations during pretest, test, and post-test operations. The information assembled from the test procedures has supplied valuable knowledge and understanding about the performance of the HPM SRM design components utilized in TEM-3.

3.1.1 Case Performance

No anomalies associated with case or joint hardware occurred during the TEM-3 static test. During the post-test cooldown, the deluge system allowed a portion of the aft case to become overheated and discolored. Later assessment of this occurrence indicate that the motor case had not been adversely affected. All case hardware will be refurbished for use on the RSRM flight program. Assembly procedures proved adequate, and valuable motor chamber pressure oscillation data was gathered during the test. Chamber pressure was contained. Additional case performance evaluation can be found in Section 7.1 of this report.

3.1.1.1 Field Joints. All results were as expected. No apparent metal damage was found during inspection.

3.1.1.2 Case-to-Nozzle Joint. The sealing surfaces were inspected and found to be in good condition, no evidence of damage, corrosion, or excessive grease coverage was observed.

3.1.1.3 Internal Nozzle Joints. The sealing surfaces of the aft exit cone-to-forward exit cone joint were visually inspected and found to be in good condition, no evidence of damage, corrosion, or excess grease coverage was observed.

In-groove inspection of the O-rings found no erosion, heat effects, or damage. The remaining TEM-3 internal nozzle joints have not been disassembled as of 20 Jun 1989. More information will become available as case refurbishment proceeds; any anomalies will be documented according to refurbishment specification procedures.

3.1.2 Case Internal Insulation Performance

The final weight of TEM-3 aft segment slag was 2,895 lb. Center aft segment slag has not been determined by Quality at this time. The water deluge and CO_2 quench operated correctly. Additional insulation performance evaluation can be found in Section 7.2 of this report.

3.1.2.1 Case-to-Case Field Joints

Forward Field Joint. Evidence of hot gas impingement into the forward field joint opening was observed between the clevis insulation and joint putty. At the 132 deg location a terminated gas path flowed radially into the joint up to the inboard corner of the ramp surface. The clevis insulation showed heavy heat effects, as the NBR was fibrous and loose at the gas path entry point. Another soot path was observed at the 180 deg location; it terminated at the inboard corner of the ramp surface. This soot path showed no contact or heat effects on either the tang or clevis insulation.

Center Field Joint. This joint performed very well with no indications of any soot or gas paths in the joint.

Aft Field Joint. This joint also appeared typical with the putty showing good tack and mostly cohesive failure. A small soot path which terminated at the inboard ramp corner was observed at the 174 deg location.

3.1.2.2 Case-to-Case Factory Joints. A walkthrough inspection revealed nominal factory joints with no abnormal erosion.

3.1.2.3 Case-to-Nozzle Joint. There was a small blowhole through the putty in the case-to-nozzle joint at the 115 deg location. Erosion in the aft dome insulation surfaces appeared normal, with total circumferential soot travel of 148 deg.

3.1.3 Seals Component/Leak Check Performance

Additional Seals/Leak Check performance evaluation can be found in Section 7.3 of this report.

3.1.3.1 Field Joints. There was no evidence of hot gas past the putty to any primary O-ring. No corrosion was found on the joint metal surfaces and no metal damage was found on the sealing surfaces.

3.1.3.2 Case-to-Nozzle Joint. A 0.4-in. wide putty blowhole which allowed pressurization of the primary O-ring was found at 115 deg. Maximum erosion depth on the primary O-ring was 0.074 inch. No damage was found to the secondary O-ring at the eroded location of the primary O-ring.

The sealing surfaces were visually inspected and found to be in good condition, no evidence of damage, corrosion, or excess grease coverage was observed.

3.1.3.3 Igniter Joints. Inspection at the B-B, sealing surfaces, gasket, and SIIs showed no anomalies. The outer and inner joints have not been disassembled.

3.1.3.4 Internal Nozzle Joints. The sealing surfaces of the aft exit cone-to-forward exit cone joint were visually inspected and found to be in good condition, no evidence of damage, corrosion, or excess grease coverage was observed. No erosion or heat effects were observed on the O-rings.

The remaining TEM-3 internal nozzle joints had not been disassembled as of 20 Jun 1989.

3.1.3.5 Leak Test. The leak tests performed on TEM-3 were not required to satisfy the objectives of the certification test plan. These tests were performed merely to verify that the joints were properly assembled and the O-rings will perform properly. It is concluded the seals are acceptable for the TEM-3 joints. A complete discussion is included in Section 7.3 of this report.

3.1.3.6 Nylok Locking Device for the Leak Check Plugs. The plugs were successfully installed and removed from the motor, demonstrating the effectiveness of the Nylok thread locking material. The certification objective was met.

3.1.3.7 Krytox Grease Certification in the Igniter S&A

The postfire leak test and subsequent disassembly data established that the Krytox-certification S&A device fired on TEM-3 performed as expected.

3.1.4 Nozzle Assembly Performance

The overall appearance of the TEM-3 nozzle phenolics was good, no abnormal erosion characteristics were observed.

Nozzle Joint 1 (aft exit cone-to-forward exit cone field joint) was disassembled, and no anomalies were observed. There was 100 percent backfill to the primary O-ring.

The nozzle was demated from the aft dome, and although the overall condition of the joint was good, one blowpath through the putty was observed. In addition, there was some erosion of the primary O-ring at the blowpath location. The nozzle is currently being stored, pending future internal joint disassembly, phenolic washout, and liner sectioning. Additional nozzle performance information can be found in Section 7.4 of this report.

3.1.4.1 Nozzle TVC Performance. The nozzle was held rigid using fixed links with no TVC.

3.1.5 Igniter Performance

The igniter assembly is expected to be disassembled in August 1989. It will be inspected at that time and any anomalies will be documented according to refurbishment specifications. All indications are that the igniter performed as designed with no anomalies. Performance was well within the HPM data base.

3.1.5.1 Igniter Performance. The igniter temperature control system maintained the igniter temperature within the specified temperature range. The installation and components were inspected postfire, revealing no anomalies.

3.1.6 JPS/Factory Joint Weather Seal

Additional JPS performance evaluation can be found in Section 7.6 of this report.

3.1.6.1 Joint Heaters. The field joint heater temperature control system operated as predicted, maintaining the temperature at the controlling RTD at 121°F with a maximum deviation of +0.5° to -0.3°F until T-2 hr. At that time, the forward field joint heater lost electrical power and that joint temperature began to drop. The nozzle heater, igniter heater, and both other field joint heaters continued operation as planned. At the time of motor ignition all joint temperatures, including the forward, were well above the 75°F minimum launch commit temperature of the RSRM program.

3.1.7 Instrumentation

Instrumentation on TEM-3 was very limited. Measurements were taken to determine ballistic data, joint temperatures, nozzle/axial and radial deflections, case temperatures, and force on the nozzle fixed links. Of the 57 data channels, 55 produced satisfactory data. Additional instrumentation information can be found in Section 5 of this report.

3.1.8 Ballistics/Mass Properties Performance

The TEM-3 ballistic performance was typical and within expected limits. The three-year storage of loaded SRM case segments did not appear to affect motor performance. Ignition interval, pressure rise rate and impulse gate limits were met. The TEM-3 ballistic performance compared closely with HPM historical data. Table 3.1.8-1 lists the predicted and reconstructed values for the performance of TEM-3 against the CPW1-3300 Specification Table 2 values. All the values were within the limits. Slag weight was 2,895 lb (aft segment). Figure 3.1.8-1 shows the predicted and measured head-end pressure. Section 7.7 contains a complete summary and discussion of the performance results from TEM-3.

The TEM-3 motor exhibited chamber pressure oscillations similar to previously tested space shuttle HPMs. The first longitudinal (1-L) mode oscillations experienced by TEM-3 were typical for an HPM, and significantly lower than the RSRM static test motors. A possible cause for the increased oscillations from HPM to RSRM is the change in the joint insulation. The clevis side base thickness in the insulation has decreased, and late in burn time the NBR inhibitor is supported by this insulation. This would allow more flexibility in the inhibitor and cause increased pressure oscillation. Investigation into this theory may be performed on future TEM motors.

Table 3.1.8-1. TEM-3 Performance Summary* With CPW1-3300 CEI Specification Limits

	Vacuum Spec Limits (60°F)	TEM-3 Predicted (60°F)	Delivered (60°F)
Web Time (sec)	106.1 - 117.2	111.7	112.0
Action Time (sec)	115.4 - 131.4	123.7	123.2
MOP Head-End (psia)	858.7 - 978.1	918.0	916.0
Maximum Seal Level Thrust (Mlbf)**	2.87 - 3.25	3.07	3.05
Web Time Average Head-End Pressure (psia)	625.8 - 695.8	660.9	662.6
Web Time Average Vacuum Thrust (Mlbf)**	2.45 - 2.72	2.595	2.596
Web Time Total Impulse (Mlbf*sec)**	286.1 - 291.8	289.9	290.7
Action Time Impulse (Mlbf*sec)**	293.3 - 299.2	297.6	297.5
I_{sp} Average Delivered (lbf*sec/lbm)**	265.3 - 269.0	268.2	268.2
Ignition Interval (sec), Time to Reach 563.5 psia	0.170 - 0.340	0.232	0.227
Maximum Pressure Rise Rate (psi/10-ms)	x < 109.0	90.5	88.5

Loaded Propellant Weight of 1,109,773 lb

*TEM-3 performance based on the following as cast motor segments: Forward: SRM-31B, center forward: SRM-29A, center aft: SRM-27A, aft: SRM-30B

**All thrust and impulse values based on reconstructed thrust. No actual thrust measurements on TEM-3 static test

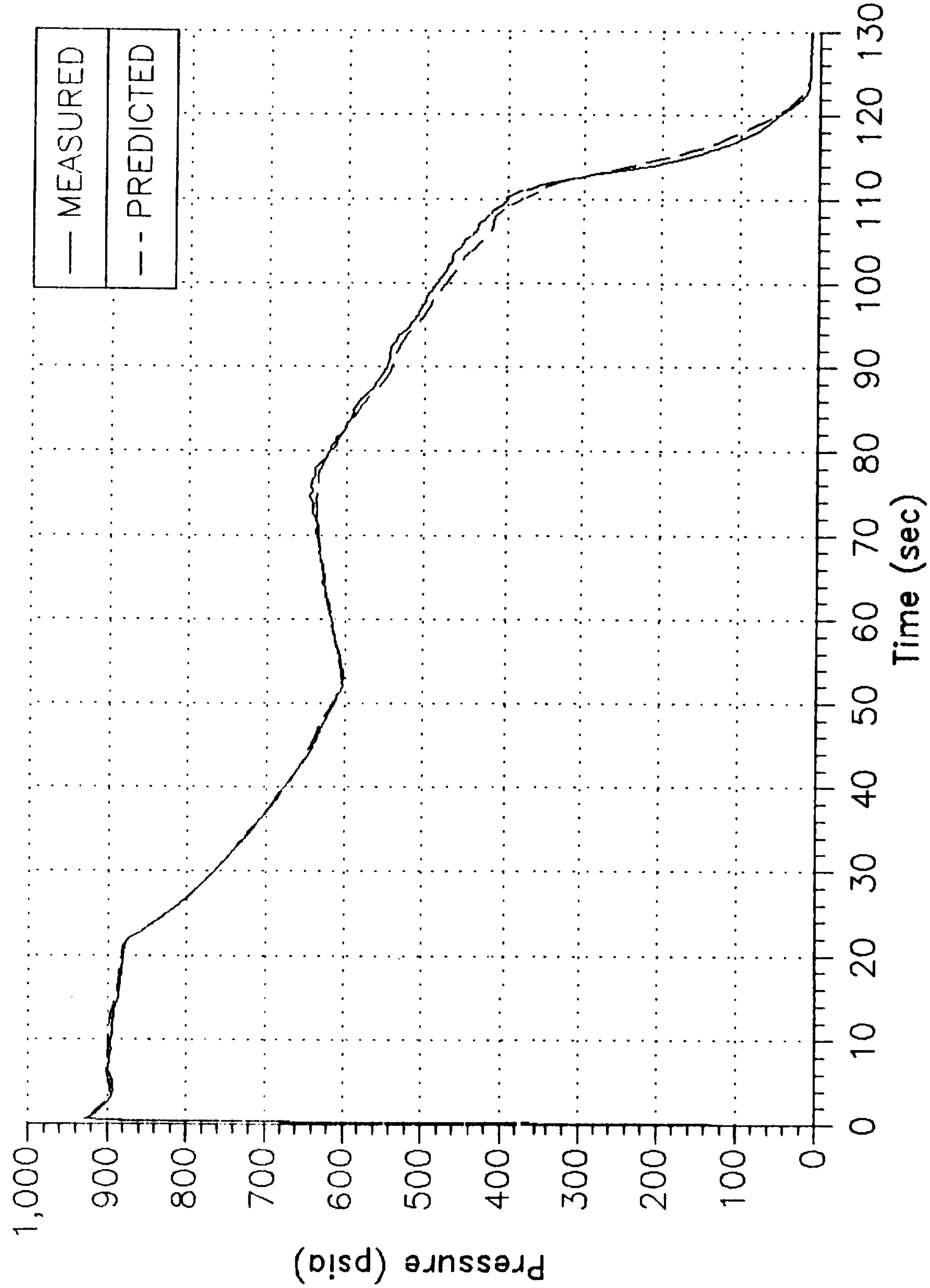

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Figure 3.1.8-1. TEM-3 Predicted and Measured Pressure at 70°F

3.1.12.1 Temperature Data. Temperature data were nominal. Ambient temperature at the time of ignition was 75°F and PMBT was 70°F.

3.2 CONCLUSIONS

This section shows TEM-3 static test compliance with TWR-15723 Rev C, Vol II (D&V Plan), July 1988. The following comments are drawn from the test with a one-to-one correlation to the test objectives listed in Section 2.

	Test Objectives: Development	Results: (Reference Section)
A	Recover case, nozzle and igniter hardware for RSRM flight program.	Case, nozzle, and igniter hardware were recovered for use on RSRM flight program. (Sections 7.1, 7.4, 7.5)
B	Evaluate the effect of three-year open storage of loaded SRM case segments upon motor ignition and performance.	There was no effect on motor ignition and performance due to three-year open storage. (Sections 7.2, 7.4, 7.7)
C	Obtain additional data on the performance of electrical strip heaters on the igniter, field and case-to-nozzle joints.	Data on the performance of electrical strip heaters was obtained. (Section 7.6)
D	Obtain additional data on the low-frequency chamber pressure oscillations in the motor forward end.	Data was gathered and low-frequency chamber pressure oscillations are being investigated. (Section 7.7)
E	Obtain data on nozzle fixed link force oscillations.	Data was collected on nozzle fixed link force oscillations. (Section 7.4)
F	Evaluate the effects of known cracks in the aft segment stiffener stubs.	Use of an aft segment with cracked stiffener stubs had no effect on test hardware (visual inspection). More information will become available during refurbishment, any anomalies will be documented according to refurbishment specifications. (Section 7.1)
G	Certify the Nylok thread locking device of the 1U100269-03 leak check port plug (CPW1-3600A, Para 3.3.6.10).	The plugs were successfully installed and removed from the motor, and demonstrated the effectiveness of the Nylok thread locking material. The certification objective was met. (Section 7.3)

Test Objectives: Development		Results: (Reference Section)
H	Certify for use on RSRM the 1U52295-04 S&A device which utilizes Krytox grease on the barrier-booster shaft O-rings (CPW1-3600A, Para 3.2.1.2, 3.2.1.2.4.a, 3.2.1.5.a)	The postfire leak test and subsequent disassembly data established that the Krytox-certification S&A device fired on TEM-3 performed as expected. (Section 7.3)

3.3 RECOMMENDATIONS

3.3.1 Slag Prediction

The slag accumulation theory associated with the AP particle size distribution should be further investigated.

3.3.2 Chamber Pressure Oscillation

The magnitude of chamber pressure oscillations should be observed on future motors.

3.3.3 Nozzle Instrumentation

Continued instrumentation of nozzle components is important to adequately monitor nozzle response. Development of methods to more directly monitor the thermostructural response of the phenolic parts should be pursued.

4

APPLICABLE DOCUMENTS

The latest revisions of the following documents, unless otherwise specified, are applicable to this report.

Specification

CPW1-3600	Prime Equipment Contract End Item Detail Specification (CEI)
CTP-0103 Rev C	Space Shuttle Technical Evaluation Motor No. 3 (TEM-3) Static Fire Test Plan
TWR-15723 Rev C	Development and Verification Plan (D&V Plan)
TWR-16474 Vol I-IX	Technical Evaluation Motor Postfire Engineering Evaluation Plan
STW4-3266	Putty and Caulking or Glazing Compounds, Other
STW7-2632	Space Shuttle SRM Supplier Configuration Management Requirements (Chemical Raw Materials)
STW7-2787	Leak Testing, Igniter Assembly Seals Space Shuttle Project Solid Rocket Motor
STW7-2831 Rev NC	Inspection and Process Finalization Criteria, Insulated Components, Space Shuttle Solid Propellant Rocket Motor
STW7-2853	Leak Test, Pressure Transducer Assemblies, Space Shuttle Project Solid Rocket Motor
STW7-2913	Procedure, Leak Test of Barrier-Booster Redundant Seals
STW7-3301	Procedure, Individual Acceptance Test, Barrier-Booster Assembly with 8U52742 Test Console
STW7-3499	Leak Check Plug Preparation and Installation
STW7-3633	Leak Testing, Safe and Arm Joint, Space Shuttle Project Redesigned Solid Rocket Motor
STW7-3682	Leak Testing, Case-Field and Nozzle-to-Case Joint, Test Evaluation Motor (TEM) Program
STW7-3688	Grease Application and O-ring Installation for Field and Case-to-Nozzle Joints Space Shuttle TEM Program
STW7-3745	Putty, Aft Segment and Nozzle Assembly Joint, Application of
STW7-3746	Putty Vacuum Seal, Field Joint Assembly, Application of

5
INSTRUMENTATION

5.1 INTRODUCTION

Instrumentation on TEM-3 was very limited. Measurements were taken to determine ballistic data, joint temperatures, nozzle/axial and radial deflections, case temperatures, and force on the nozzle fixed links. Of the 57 data channels, 55 produced satisfactory data. Instrumentation was installed on the test article per Drawing 7U76876. Figure 5.1-1 illustrates instrument locations. Appendix B contains the instrumentation list, Appendix C contains the data plots.

5.2 OBJECTIVES

TEM-3 was instrumented to support the following development objectives from Section 2:

B Evaluate the effect of three-year open storage of loaded SRM case segments upon motor ignition and performance.

C Obtain additional data on the performance of electrical strip heaters on the igniter, field, and case-to-nozzle joints.

D Evaluate low-frequency chamber pressure oscillations in the motor forward end.

E Obtain data on nozzle fixed link force oscillations.

5.3 CONCLUSIONS/RECOMMENDATIONS

Overall, the TEM-3 instrumentation performed very well. Instrumentation installation was successfully completed and performed as expected. Valuable performance data was collected.

All instrumentation test objectives were met.

5.4 INSTRUMENTATION RESULTS/DISCUSSION

There were 57 channels of instrumentation installed on TEM-3, including pressure, force, displacement, and temperature gages. Normal T-97 test stand measurements and countdown timing data was recorded. Fifty-five of fifty-seven instrumentation channels operated correctly.

Five pressure transducers were installed to measure motor chamber and igniter pressures. Three gages were dedicated for chamber pressure, one gage for igniter pressure and an AC coupled gage for pressure oscillation measurement.

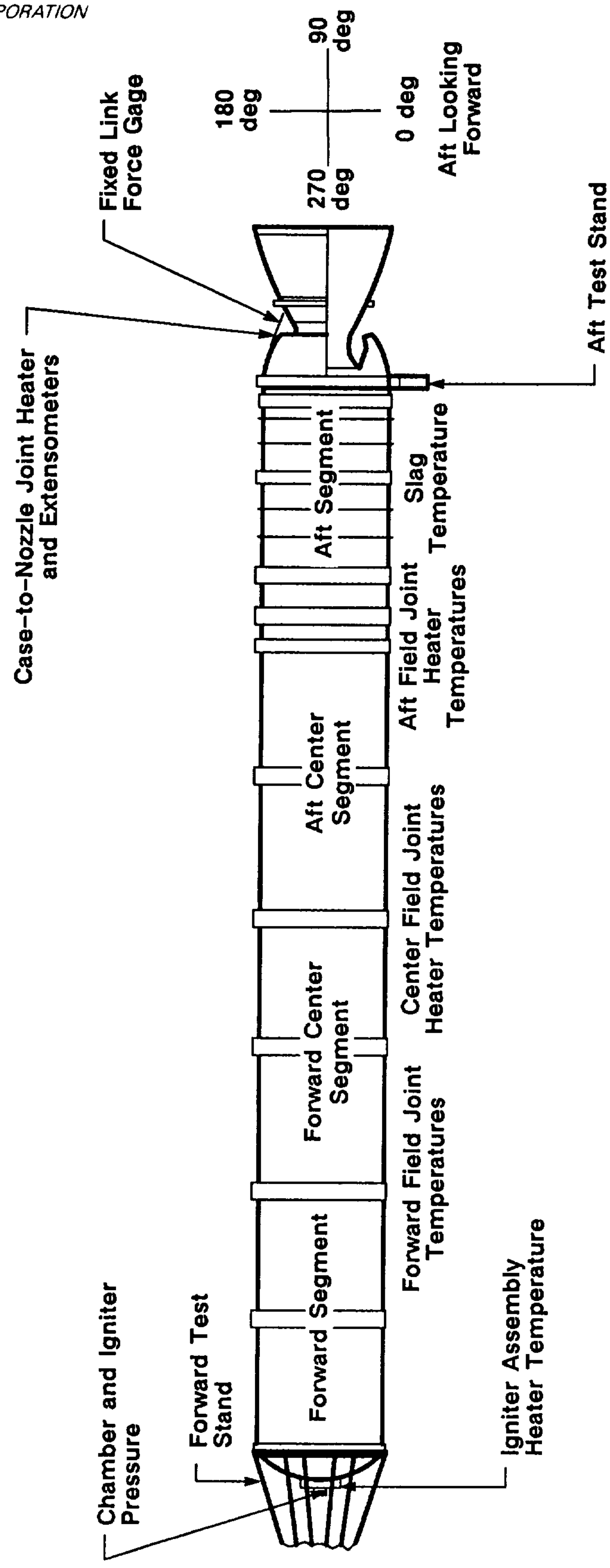

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Figure 5.1-1. TEM-3 Instrumentation Locations

Twelve extensometers were installed to measure nozzle deflection in the radial direction and four extensometers were used to measure nozzle deflection in the axial direction. Two nozzle actuation extensometers (D208 and D211) were anomalous. The set screw which secures the cable to the shaft was loose.

Case joint temperatures were measured with the built-in RTDs on the heater assemblies. RTDs were added to the igniter assembly and case-to-nozzle joint to monitor these joint temperatures. Eighteen thermocouples were bonded on the bottom of the case to measure case temperature.

6

PHOTOGRAPHY

Photographic coverage was required to document the test, test configuration, instrumentation, and any anomalous conditions which may have occurred. The TEM-3 photographs and video tapes are available from the Thiokol Photo Lab.

6.1 STILL PHOTOGRAPHY

Still color photographs of the test configuration were taken before, during, and after the test. Photographs were taken of joints each 45 deg minimum and at anomalous conditions. A large number of photographs were taken during disassembly.

6.2 MOTION PICTURES

Color motion pictures of the test were taken with four video, two documentary, nine high-speed cameras, and two still-sequence cameras. Documentary motion pictures are recorded on Roll 7947 and high-speed motion pictures on Roll 7948. Cameras are listed in Table 6.2-1. The camera setup is shown in Figure 6.2-1.

Table 6.2-1. Photography and Video Coverage

Camera	Station	Location	Type	Coverage
1	7	Thrust block	HS	Igniter port
2	1	No forward barricade	HS	Center forward and center joints
3	1	No forward barricade	Vid	Overall motor and plume
4	2	No aft barricade	HS	Center aft and C/N joints
5	2	No aft barricade	Doc	Aft case, nozzle and plume
6	2	No aft barricade	HS	Nozzle, 200 ft plume
7	3	So aft barricade	Doc	Overall motor and plume
8	3	So aft barricade	Vid	Aft case, nozzle, plume, deluge
9	4	So center barricade	Vid	Aft joint, nozzle, plume
10	4	So center barricade	HS	Nozzle, 200 ft plume
11	4	So center barrivade	HS	Center aft and C/N joints
12	5	So forward barricade	HS	Center forward and center joints
13	7	Thrust block	HS	Igniter port
14	7	Thrust block	Vid	Top of case, nozzle and plume
15	7	Thrust block	HS	Top of case, nozzle and plume

HS--(9 each) at 300 pps
Doc--(2 each) at 24 pps
Video--(4 each) at real-time

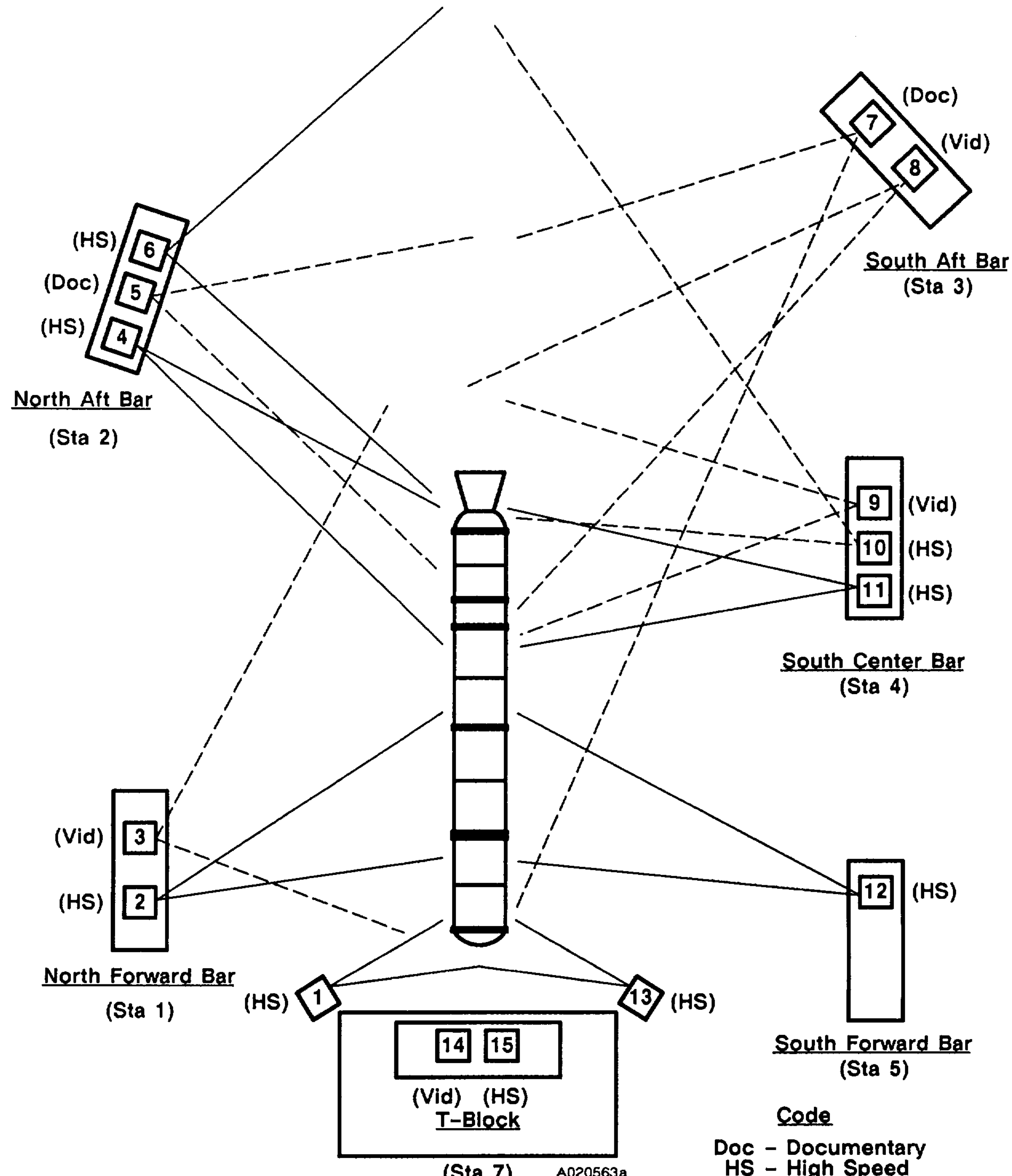

Figure 6.2-1. Photography Coverage—TEM-3

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7

TEST RESULTS

7.1 CASE PERFORMANCE

7.1.1 Introduction

No anomalies associated with case or joint hardware occurred in the TEM-3 static test. All case hardware was recovered for use on the RSRM flight program. Assembly procedures proved adequate, and chamber pressure was contained. Remaining inspections include factory joint demate and refurbishment. More information will become available as case refurbishment proceeds; any anomalies will be documented according to refurbishment specification procedures.

7.1.2 Objectives

The objectives from Section 2 regarding case performance are:

A Recover case, nozzle, and igniter hardware for RSRM flight program.

F Evaluate the effects of known cracks in the aft segment stiffener stubs.

7.1.3 Conclusions/Recommendations

All sealing surfaces were visually inspected and found to be in good condition with no evidence of damage, corrosion, or excess grease coverage. No apparent metal damage was found during the joint inspections, except several pinhole metal slivers.

The cracked stubs in the stiffener segment performed adequately, as expected. A complete inspection will be performed as the segment undergoes refurbishment, any anomalies will be documented according to refurbishment specifications.

7.1.3.1 Motor Deluge System. The deluge spray system was activated at T+105 sec, approximately 18 sec before the end of motor burn. After the motor test, the motor was being sprayed and cooled. During a routine motor walkthrough, it was noticed that an area of discolorization was growing on the motor case in a region shielded from the water spray. The strap holding the spray curtain to the case was cut, allowing the curtain to fall and the spray to cool the discolored area.

It was later determined that the spray curtain had been improperly located on the test motor. The spray curtain was designed to be placed beyond the aft dome factory joint, but had been connected to the aft stiffener ring (see Figure 7.1.3.1-1).

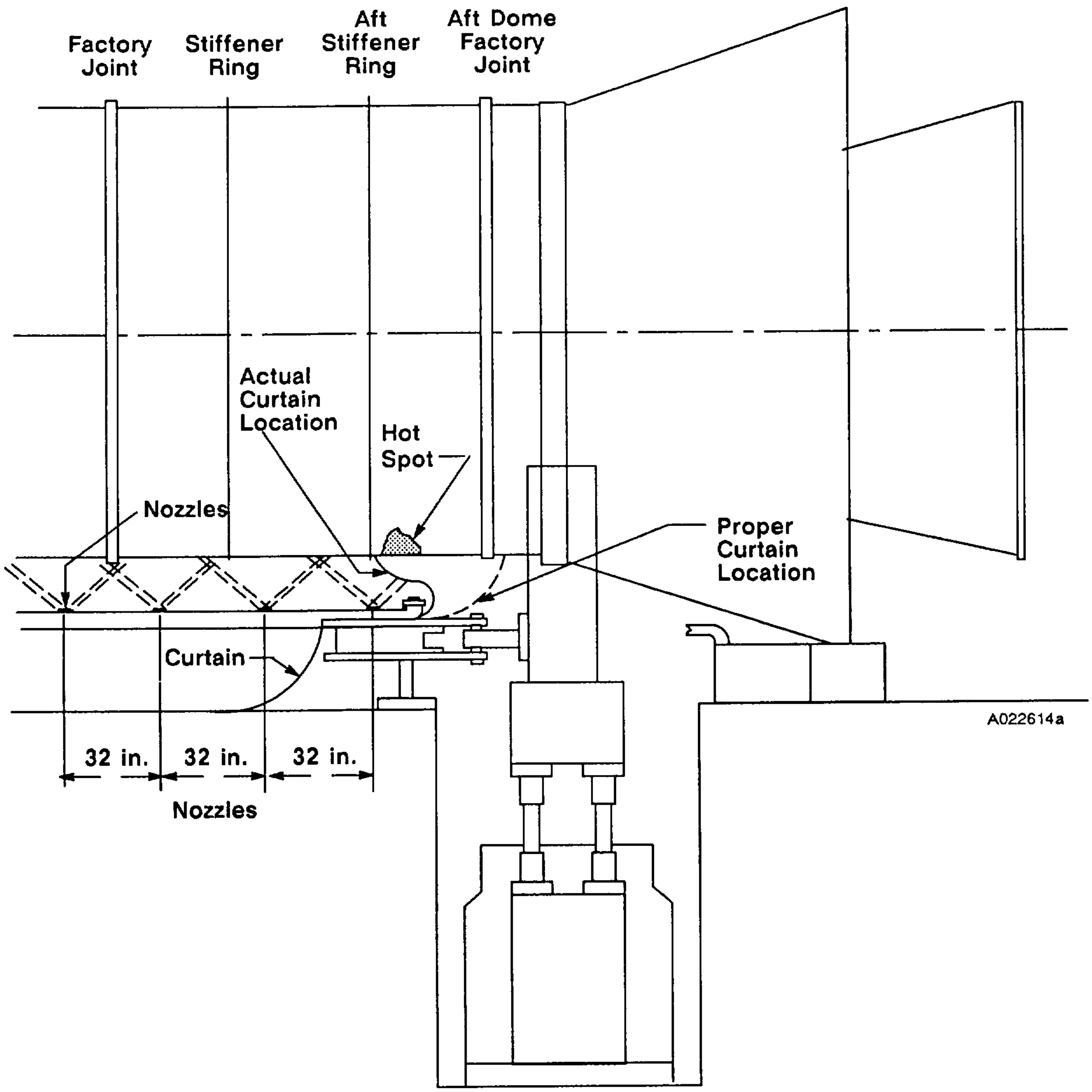

Figure 7.1.3.1-1. Location of AFt Spray Curtain

Post-test assessment of the motor case showed that the steel case was not affected by the increased temperatures during cooldown.

7.1.4 Results/Discussion

7.1.4.1 Forward Field Joint. No corrosion was observed on either the tang or clevis. No apparent metal damage was found during the inspection, except a pinhole sliver found at the 298 degree clevis pinhole. The grease on the O-ring and sealing areas was as prescribed in STW7-3688.

7.1.4.2 Center Field Joint. No corrosion was observed on either the tang or clevis. No apparent metal damage was found during the inspection, except a pinhole metal sliver found at the 258 deg clevis pinhole. The grease on the O-ring and sealing areas was as prescribed in STW7-3688.

7.1.4.3 Aft Field Joint. The condition of the joint was nominal. No corrosion was observed on either the tang or clevis. A pinhole metal sliver was found in the 172 deg pinhole. Otherwise, no apparent metal damage was found during the inspection. The grease on the O-ring and sealing areas was as prescribed in STW7-3688. A small amount of foreign material had fallen onto the joint during or after disassembly.

7.1.4.4 Case-to-Nozzle Joint. The sealing surfaces were visually inspected and found to be in good condition, with no evidence of damage or corrosion. Grease coverage on the joint was nominal and per STW7-3688.

7.1.4.5 Internal Nozzle Joints. The aft exit cone-to-forward exit cone joint was disassembled on 31 May 1989. The sealing surfaces were visually inspected and found to be in good condition with no evidence of damage, corrosion, or excess grease coverage.

7.1.4.6 Cracked Stiffener Stubs. Post-test inspection revealed no inboard cracks in the locations where the stiffener stubs were cracked through the outboard web.

7.2 CASE INTERNAL INSULATION PERFORMANCE

7.2.1 Introduction

7.2.1.1 Segment History. The TEM-3 motor consisted of segments which had been designated for flight prior to the Challenger incident. These segments had been insulated and cast with propellant approximately three years prior to their use for TEM-3. In reviewing the history of the segments, no significant discrepancy reports (DR) were found which would affect the operation of the TEM motors. No edge unbonds were documented on any field joint prior to test.

7.2.1.2 Insulation Configuration/Putty Application. Since TEM motors were fabricated prior to the Challenger incident, all joints were of the HPM design. The motor consisted of three field joints: forward, center, and aft. These field joints were fabricated of asbestos-silica filled NBR, as shown in Figure 7.2.1.2-1. Prior to mate at T-97, the joints were inspected per STW7-2831 Rev NC, the flight motor insulation inspection criteria for the HPM joints. Putty was applied to the clevis joint per STW7-3746, as shown in Figure 7.2.1.2-2, and the joint was mated. After mate, the joint (Figure 7.2.1.2-3) was inspected from the bore for discontinuities and tamped as described in Section 7.2.1.3.

The case-to-nozzle joint, shown in Figure 7.2.1.2-4, was also fabricated as an HPM joint and inspected per STW7-2831. The putty was layed up per STW7-3745. Figure 7.2.1.2-5 shows the putty layup used throughout the HPM program. Two nominal thicknesses of putty are referenced, 0.25 in. and 0.125 in. It was not possible to use both thicknesses for the TEM-3 case-to-nozzle joint since the nominal 0.125-in. thick putty is not currently stocked. Only 0.25-in. putty strips were used. The TEM-3 nozzle was mated to the aft segment with no apparent anomalies. The total weight of putty used was 27.2 lb. Because of inaccessibility the case-to-nozzle joint was not inspected and tamped as were the field joints.

7.2.1.3 Pre-test Operations

Joint Putty Tamping. After all field joints were mated, chocks pulled, and final leak check performed, a bore inspection was done to assess putty flow after mate. This did not include the case-to-nozzle joint, which is inaccessible for this operation. The putty in the joint was inspected for grease, discontinuities, bubbles, blowholes, etc. Some bubbles, or possible bubbles, were observed in the forward and center field joints, including a popped bubble found in the center joint. All locations were documented for each joint, and the bubbles were tamped to close off any gas paths through the putty.

7.2.2 Objectives

The test objective from Section 2 regarding insulation performance was:

B Evaluate the effect of three-year open storage of loaded SRM case segments upon motor ignition and performance.

7.2.3 Conclusions/Recommendations

No anomalous conditions resulting from the three-year open storage of the segments were documented. All insulated surfaces and joint regions functioned properly.

Joint filler putty was used in all three field joints. The case-to-nozzle joint used STW4-3266 Canadian Inmont putty. The field joint O-ring seals were not exposed to the motor environment, but there was a small blowhole through the putty in the case-to-nozzle joint.

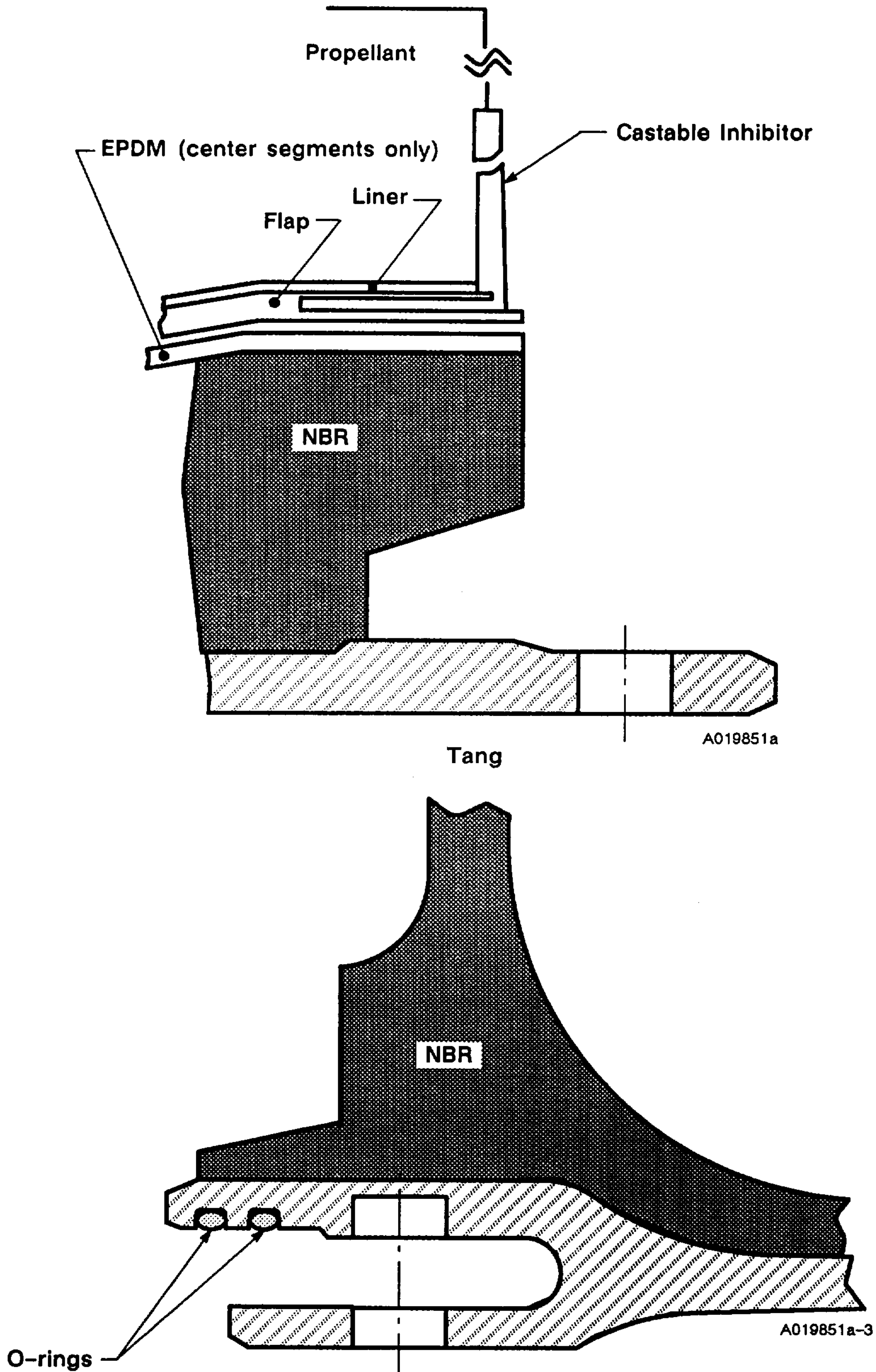

Figure 7.2.1.2-1. HPM Field Joint

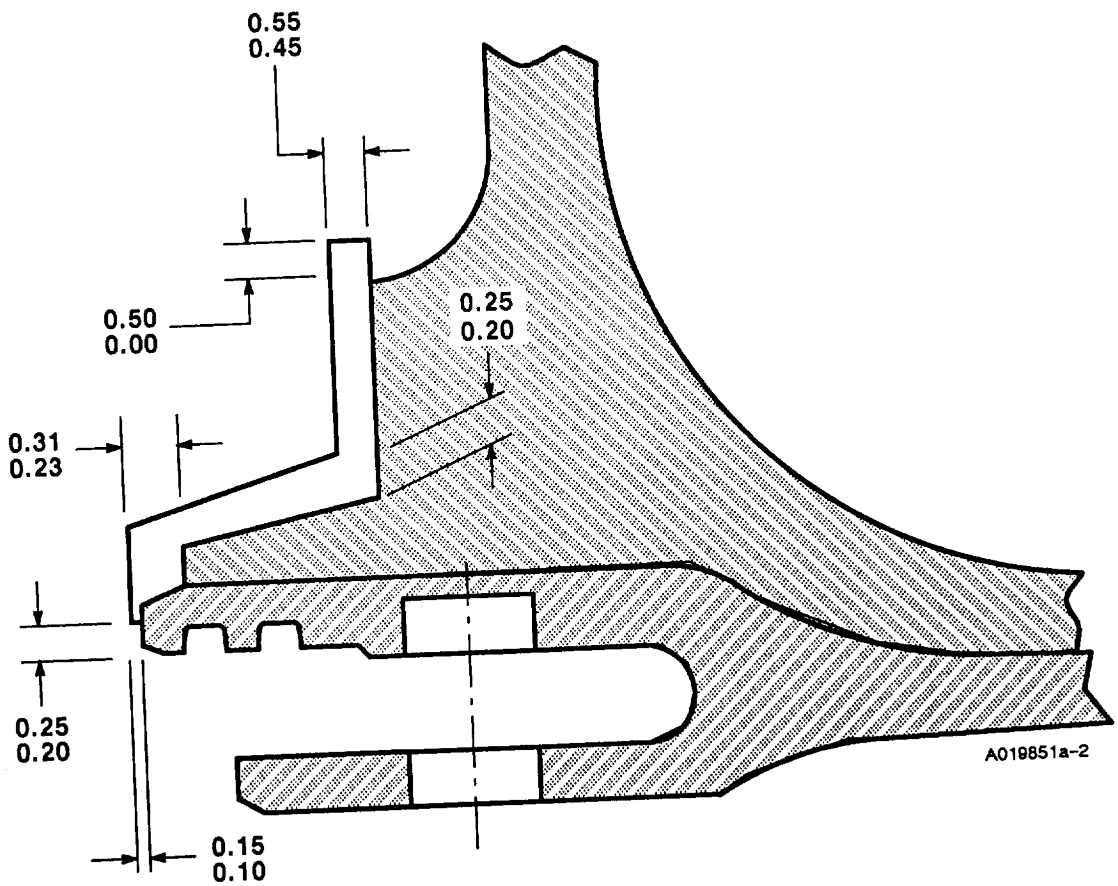

Figure 7.2.1.2-2. Clevis Joint Filler Putty Layup

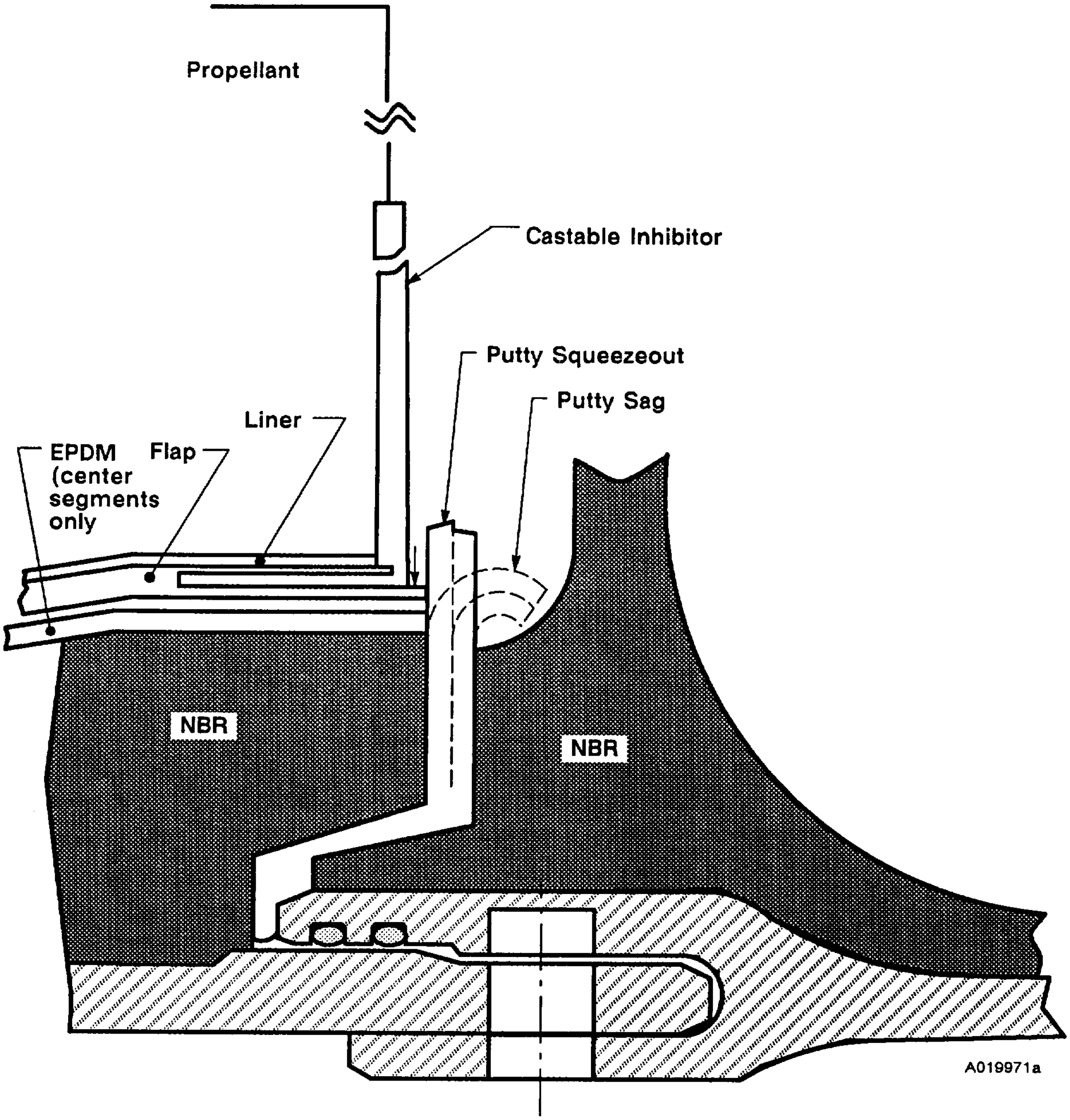

Figure 7.2.1.2-3. Assembled HPM Field Joint

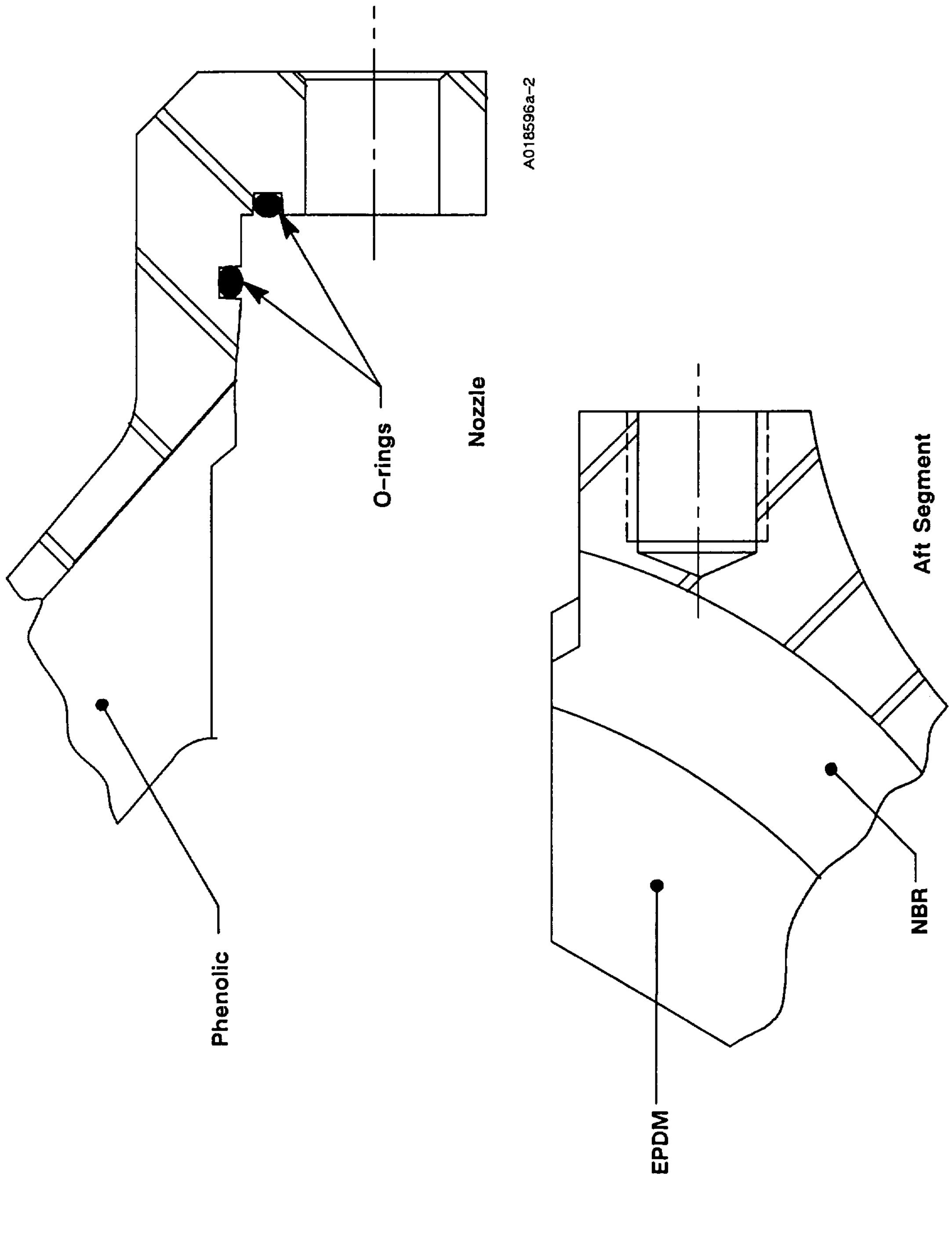

Figure 7.2.1.2-4. HPM Case-to-Nozzle Joint

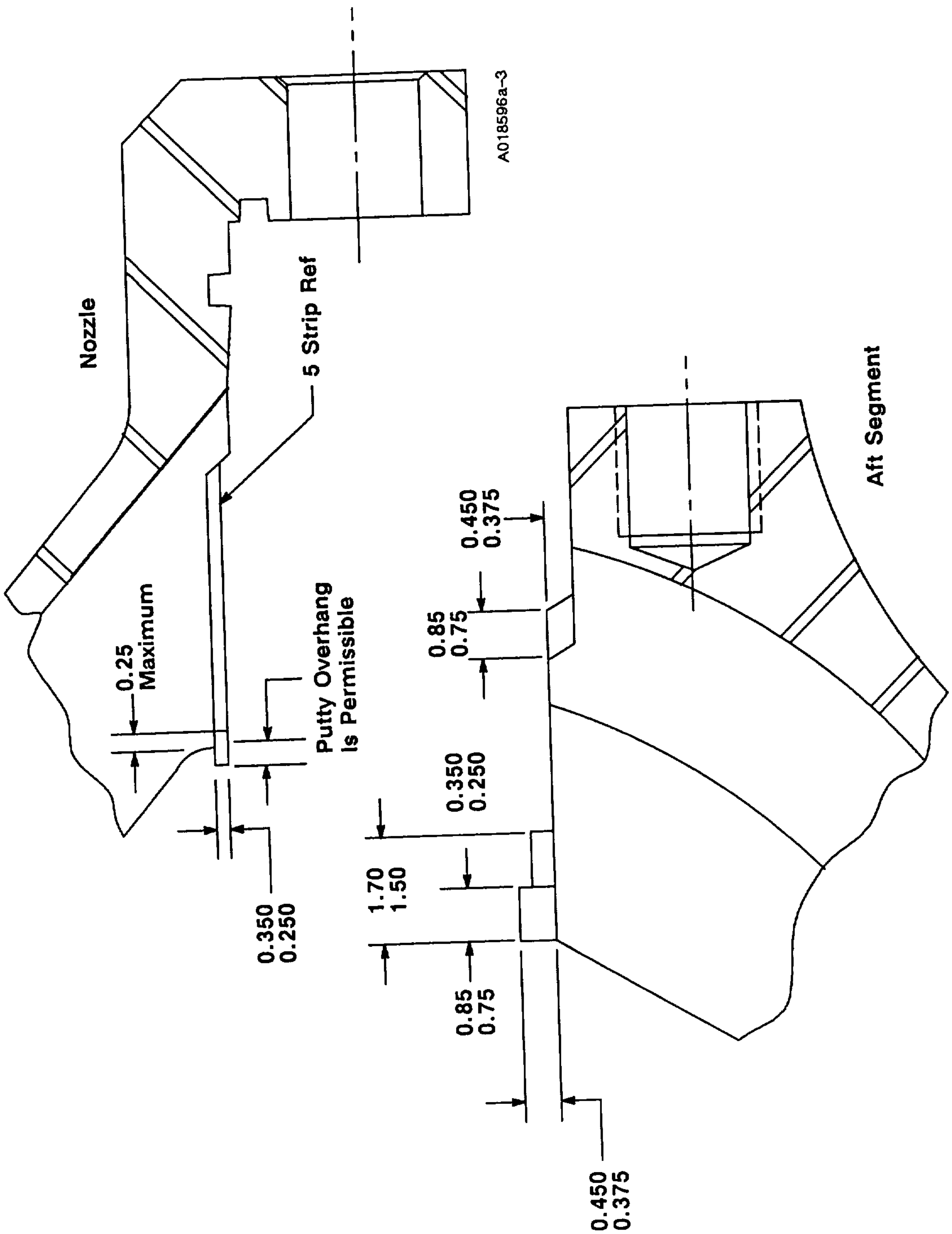

Figure 7.2.1.2-5. Putty Layup

During the external quick-look inspection, a brown discoloration was observed just aft of the aft stiffener stub. This brown spot was attributed to higher case temperatures due to an above average slag accumulation and the deluge system spray curtain being mislocated. Case hardware was not damaged. Planning has been modified to ensure proper placement of the curtain during future static tests.

Instrumentation was not provided to gain insulation parameters so operation and exposure values were not obtainable during the firing.

7.2.4 Results/Discussion

At the time of aft segment demate, a walkthrough was made of the entire motor; at this time the case wall insulation was inspected for any anomalies such as blistering, tears, and unusual erosion. A quick-look was also done on the two remaining field joints, the case-to-nozzle joint, and the igniter. Since the remaining joints were demated and inspected subsequent to the walkthrough, these joints will be covered in their respective sections.

The overall appearance of the interior acreage insulation looked nominal. Factory joints were also nominal, with no abnormal erosion. The SRM igniter showed normal heat-affected interior and exterior insulation. The 11-point star burnback pattern was symmetrical and largely visible full circumference on the aft region of the forward segment where the propellant fins were located. This indicates that most of the propellant liner remained as is normal. Very little char or heat-affected insulation was observed on this segment. The aft-center segment showed soot and charred insulation full length, with no blistering or anomalous conditions. The aft segment also showed soot and charred insulation throughout.

As expected, the slag pool was larger than normal. It extended the full length of the aft segment and 89 in. into the center aft segment. Measurements were taken by Design Engineering at this time, and by Quality at the H-7 facility. The two sets of measurements do not agree (Table 7.2.4-1). One explanation for this is that Design Engineering measurements were to the extreme edge of the slag pool while Quality measurements were only of the main bulk of the slag material.

7.2.4.1 Forward Field Joint. Evidence of hot gas impingement into the forward field joint opening was observed between clevis insulation and the joint putty. This clevis insulation surface (Figure 7.2.4.1-1) was heavily heat affected, but not charred, for approximately 0.60 in. radially, from 45 to 180 to 278 deg, except in a small region around the 132 deg location. Overall, the putty had good tack and failed cohesively during demate full circumference, except in the circumferential region where the 0.60-in. radial heat effects existed.

Table 7.2.4-1. TEM-3 Slag Measurements

Location	Circumference Measurements (in.) Design Engineering	Quality Assurance
Aft Segment		
Stiffener-to-Dome Joint	60	37
Stiffener-to-Stiffener Joint	63	38
Stiffener-to-ET Attach Joint	70	38
Total Slag Weight		2,895 lb
Center Aft Segment	Measurement (in.)	
Longitudinal Length of Slag From Tang End	89	*
Width at Tang End	34	*
Width at Termination End	18	*
Total Slag Weight		*

*Has not been measured by Quality at this time.

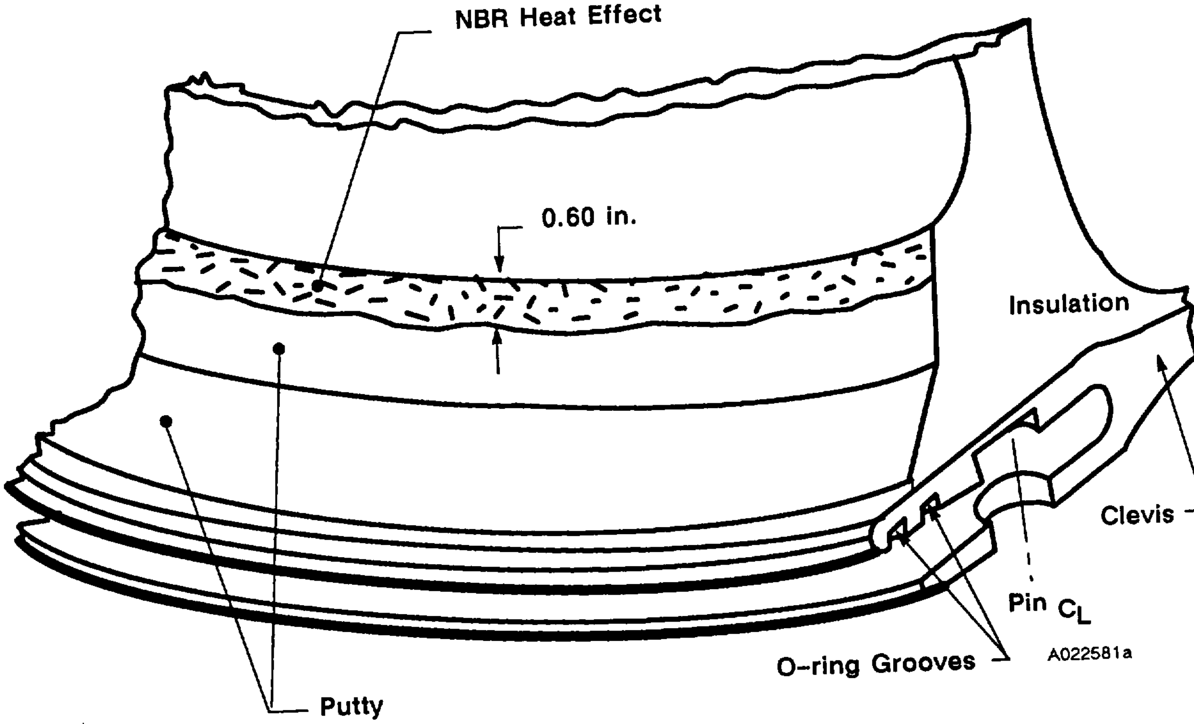

Figure 7.2.4.1-1. Forward Field Joint

At the 132 deg location a terminated gas path flowed radially into the joint to the inboard corner of the ramp surface. It then flowed for a total of 8 in. circumferentially between 129 and 136 deg (Figure 7.2.4.1-2). This gas path appeared to have occurred between the putty and the clevis insulation. The clevis insulation showed heavy heat effects, as the NBR was fibrous and loose at the gas path entry point. Where the gas flowed circumferentially, the NBR had become brown and the Hypalon paint covering the insulation had bubbled. Evidence showed that the gas attempted to flow radially past the inboard corner of the ramp surface at the 133 deg location, but terminated 0.30 in. past this point.

A soot path that terminated at the inboard corner of the ramp surface was observed at the 180 deg location. This soot path showed no contact or heat effects on either the tang or clevis insulation and appeared to have occurred between the layered putty strips. The putty underneath and adjacent to the soot path showed no signs of heat effects.

Portions of the forward segment castable inhibitor were remaining on the forward segment, and 100 percent of the stress relief flap was still intact. The FEP film underneath the flap showed no indications of heat effect. The NBR inhibitor had no tears or delaminations. Measurements of the remaining NBR inhibitor are given in Table 7.2.4.1-1. All of these inhibitor observations are consistent with HPM experience.

7.2.4.2 Center Field Joint. This joint performed very well, with no indications of any soot or gas paths in the joint. Putty failure due to disassembly was mostly cohesive, except for a region located near the inboard edge of the tang insulation from 50 to 180 to 310 deg which exhibited an approximate 15 percent adhesive failure.

The center forward segment castable inhibitor was completely missing and the stress relief flap had been eroded up to the bulb region from approximately 60 to 180 to 300 deg. Full flap was remaining from 310 to 0 to 50 deg. The underlying ethylene propylene diene monomer (EPDM) was exposed and heat-affected where the flap was missing. The NBR inhibitor showed no tearing or delaminations and was present for the full circumference. Measurements for the NBR inhibitor are given in Table 7.2.4-1. All observations were within TEM and HPM experience.

7.2.4.3 Aft Field Joint. This joint also appeared typical with the putty showing good tack and mostly cohesive failure during demate, except for a region along the inboard edge of the tang insulation from 130 to 180 to 216 deg. This area showed 30 percent adhesive failure, but no evidence of gas or soot penetration was observed. A small soot path measuring 1.4 in. circumferentially by 0.50 in. radial was observed at the 174 deg location. The underlying putty or NBR showed no indications of heat effects or charring. This soot path appeared to have occurred between putty plies.

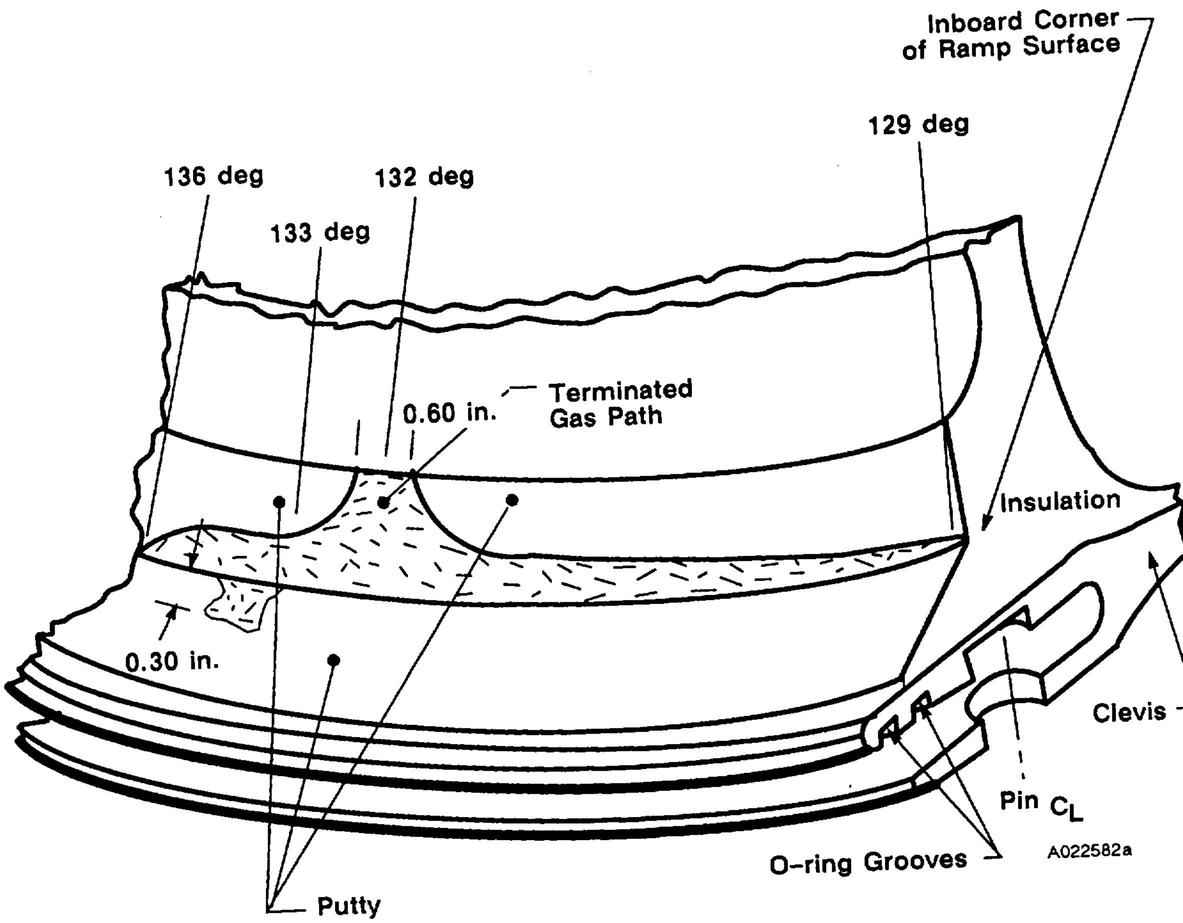

Figure 7.2.4.1-2. Forward Field Joint

Table 7.2.4.1-1. TEM-2 NBR Inhibitor Height Measurements

Circumference Location (deg)	Inhibitor Height (in.)
Forward Center Segment	
0	27.2
90	27.0
180	23.5
270	24.5
Aft Center Segment	
0	16.0
90	16.5
180	16.0
270	16.5
Aft Segment	
0	6.5
90	8.0
180	7.0
270	8.0

[redacted]

The castable inhibitor was completely missing as was the stress relief flap up to the bulb region for the full circumference. The EPDM insulation underneath the flap region was exposed for the full circumference, evidence of heat effect and erosion was observed. The NBR inhibitor was still remaining for the full circumference, measurements are given in Table 7.2.4-1. Nothing was observed out of TEM or HPM flight history.

7.2.4.4 Case-to-Nozzle Joint. The TEM-2 case-to-nozzle disassembly inspection indicated that the amount of putty used in the layup process (22.6 lb) was smaller than expected. TEM-1 and TEM-2 displayed a large blowhole through the putty to the primary O-ring. To prevent recurrence, the amount of putty used for TEM-3 (27.2 lb) was closer to the upper limit of 30 lb. The TEM-3 case-to-nozzle joint assembly showed a gas path that was much smaller in circumferential width (Figure 7.2.4.4-1). The excess putty reduced the gas path size, as expected, but the smaller channel size increased gas impingement on the primary O-ring. The blowhole width just forward of the primary O-ring measured 0.40 in. circumferentially, while the previous motors ranged from 4.6 in. on TEM-1 to 5 in. on TEM-2. The TEM-3 blowhole occurred at 115.2 deg, total circumferential soot traveled approximately 148 deg. Although the fill volume was smaller than TEM-2 (256 deg total circumferential sooting), the actual primary O-ring erosion was greater because of the direct impingement caused by the smaller gas path.

Other than the one blowhole, the rest of the joint looked good. Putty tack was good with 100 percent cohesive failure. Erosion in the aft dome insulation surfaces appeared normal.

7.3 SEALS/LEAK CHECK

7.3.1 Introduction

Leak Check

After each pressure vessel joint is assembled, a leak test is performed to determine the integrity of the seals. The leak test usually consists of a joint volume determination and a pressure decay test. The volume and pressure information, combined with temperature and time data, is collected during the test, used in the calculation of a leak rate, and expressed in terms of standard cubic centimeters per second (SCCS). Each leak test has a maximum leak rate allowed.

Some specifications require only a maximum pressure decay over time. This method has been determined as sufficient based on the small, constant volumes and the equivalent leak rates, which are conservative when using all worst-case variables.

Table 7.3.1-1 comprises a list of the joints tested for TEM-3, the leak test specifications, and the equipment used to test the joints. The case factory and nozzle internal joints were tested after the original assembly. This report does not discuss the results of those tests.

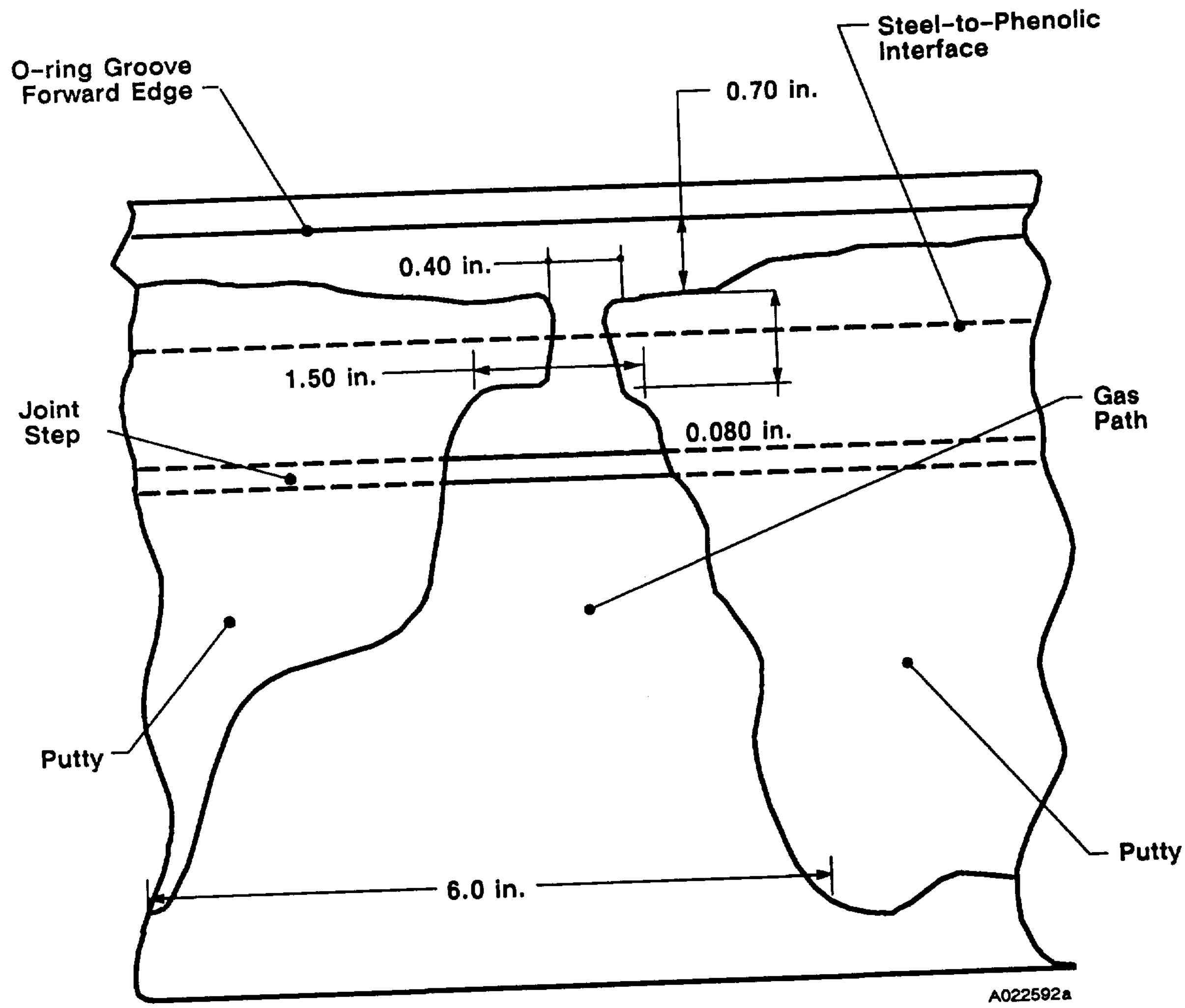

Figure 7.2.4.4-1. TEM-3 Case-to-Nozzle Joint Gas Path 132-deg Location on Fixed Housing Surface

Table 7.3.1-1. TEM-3 Seal Leak Testing

Joint	Specification	Equipment
Case Field Joints	STW7-3682	8U76902
Case-to-Nozzle Joint	STW7-3682	2U129714
Inner Gasket	STW7-2787	2U66170
Outer Gasket	STW7-2632	2U129718
Special Bolt Installation	STW7-3632	2U129718
S&A Joint	STW7-3633	8U76500
Transducer Assembly	STW7-2853	2U65686
Barrier-Booster	STW7-2913	2U65848

Seals

The field joint seals were 1U75150-11 for the forward and center, 7U75204-21 for the aft. The case-to-nozzle joint had a 1U75801-15 RSRM primary O-ring. The secondary O-ring was an RSRM 1U75801-16. All internal nozzle joints, except the forward-to-aft exit cone, and all factory joints were assembled prior to 51-L. RSRM O-rings were used for the forward-to-aft exit cone.

Nylok Locking Device for the Leak Check Plugs

Three 1U100269-03 leak check plugs were installed in the 0 deg ports on the field joints of TEM-3. The leak check plugs were prepared and installed per STW7-3499. The installation torques (running and final) and the removal torques (breakaway and removal) were taken to evaluate the effectiveness of the Nylok.

Krytox Grease Certification in the Igniter S&A

TEM-3 was used as one of a series of certification tests to evaluate the use of Krytox grease on the B-B shaft O-rings for RSRM flight. TEM-3 was specifically used to certify that Krytox grease does not adversely affect the barrier-booster shaft seals.

7.3.2 Objectives

The test objectives from Section 2 regarding seals/leak check are:

G Certify the Nylok thread locking device of the 1U100269-03 leak check port plug.

H Certify for use on RSRM the 1U52295-04 S&A Device which utilizes Krytox grease on the barrier-booster shaft O-rings.

7.3.3 Conclusions/Recommendations

7.3.3.1 Leak Check. The leak tests performed on TEM-3 were not required to satisfy the objectives of the certification test plan. These tests were performed merely to verify that the joints were properly assembled and the O-rings will perform properly. As discussed in the following section, it is concluded the seals are acceptable for the TEM-3 joints. No further conclusions or recommendations are reached.

Nylok Locking Device for the Leak Check Plugs

The plugs were successfully installed and removed from the motor, and demonstrated the effectiveness of the Nylok thread locking material. The certification objective was met.

7.3.3.2 Seals

Forward Field Joint. The condition of the joint was nominal. No hot gas or soot was observed past the putty.

Center Field Joint. The condition of the joint was nominal. No hot gas or soot was observed past the putty.

Aft Field Joint. The condition of the joint was nominal. No hot gas or soot was observed past the putty.

Case-to-Nozzle Joint. A 0.4-in. wide putty blowhole which allowed pressurization of the primary O-ring was found at 115 deg. Maximum eroded depth on the primary O-ring was 0.074 inch. No damage was found to the secondary O-ring at the eroded location of the primary O-ring.

The sealing surfaces were visually inspected and found to be in good condition with no evidence of damage, corrosion, or excess grease coverage.

Internal Nozzle Joints. The sealing surfaces of the aft exit cone-to-forward exit cone joint were visually inspected and found to be in good condition with no evidence of damage, corrosion, or excess grease coverage. No erosion or heat effects were observed on the O-rings.

The remaining TEM-3 internal nozzle joints have not been disassembled as of 20 June 1989.

7.3.3.3 Krytox Grease Certification in the Igniter S&A. The postfire leak test and subsequent disassembly data established that the Krytox-certification S&A device fired on TEM-3 performed as expected. No anomalous conditions were observed.

7.3.4 Results/Discussion

7.3.4.1 Leak Check. The case field joint leak test results are shown in Table 7.3.4.1-1. The TEM field joints were tested at lower pressures (185 psig) than RSRM field joints (1,000 psig) because of their configuration. These joints were tested with and without the assembly stands in place. This was done since previous HPM motors showed the potential for leaking after the stands were removed. The results of the leak tests for the field joints were nominal.

The field tests were performed with a variation of the 8U75902 ground support equipment leak test system. For testing of the TEM motors, the equipment was modified to include a pressure relief valve to preclude the possibility of over-pressurizing the joint.

The ignition system leak test results are shown in Table 7.3.4.1-2. The tests were performed with a variety of equipment as shown in Table 7.3.1-1. The equipment was identical to that used to test most of the RSRM joints. All results were within the limits.

The adapter plate of the igniter was of flight configuration and could not be used for a static test motor. Consequently, it was necessary to replace the adapter with one having a quench port. Because of this, the inner joint of the igniter was retested. This test was performed to the HPM

Table 7.3.4.1-1. TEM-3 Case Field Joint Leak Test Results

Pressure (psig)	Maximum Leak Rate (sccs)	Actual Leak Rates Prechock/Postchock (sccs)		
		Forward	Center	Aft
185	0.072	0.0148/0.0135	0.0134/0.0151	0.0217/0.0139
30	0.0082	0.0008/0.0010	0.0008/0.0004	0.0006/0.0008

7.3.4.1-2. TEM-3 Igniter and S&A Leak Test Results

Joint Seal	Allowable Leak Rate High/Low* (sccs)	Actual Leak Rate High/Low (sccs)
Inner	1 psi/10 min	N/A
Outer	0.10/0.0082	-0.0015/-0.0001
Transducer Installation	0.10/0.0082	0.0280/0.0000
OPT**	10 psi/10 min/ 10 min	2.0/0.0 4.0/0.0 3.0/0.0 3.0/0.0
Barrier-Booster	1 psi/10 min	0.0
S&A	0.10/0.0082	0.0052/-0.0001

N/A Not available
*High = 1,000 psig, low = 30 psig
**OPTs tested at 1,024 psig and 30 psig, leak rate units are psi/10 min

leak test requirements which allowed a maximum pressure drop of 1 psi in 10 minutes at a pressure of 50 psig. This differs from the RSRM requirements, which test the inner igniter seal at 1,000 and 30 psig and allow a maximum leak rate of 0.1 and 0.0082 sccs, respectively.

Table 7.3.4.1-3 lists the results of the TEM-3 case-to-nozzle joint leak test. This joint was tested at a maximum pressure of 185 psig. This differs from the RSRM case-to-nozzle joint leak tests which are performed at 920 psig. The TEM-3 case-to-nozzle leak test was performed after the first torque sequence, when the axial bolts are torqued to 25 ft-lb. This procedure prevented the occurrence of a metal-to-metal seal between the fixed housing and the aft dome when the axial bolts were fully torqued. All leak test results were within the allowable limits.

The 2U129714 equipment was used to test the TEM-3 case-to-nozzle joint. This is the new equipment used to test all RSRM case-to-nozzle joints, starting with 360L006A.

7.3.4.2 Nylok Locking Device for the Leak Check Plugs. A summary of the torque values are listed in Table 7.3.4.2-1. The maximum torque value allowed during installation is 70 in.-lb running torque, and 100 in.-lb final torque. All three plugs were successfully installed into their respective port per STW7-3499. Table 7.3.4.2-1 shows that the installation running torques were less than 70 in.-lb, and the final torque for each plug was 90 in.-lb.

Post-test removal of the leak check plugs showed the removal torques of the leak check plugs to be within the criteria established in MIL-F-18240. As shown in Table 7.3.4.2-1, the breakaway torque and running torque were within the allowable limits.

7.3.4.3 Seals

Forward Field Joint. The condition of the joint was nominal. No hot gas or soot was observed past the putty. There was no evidence of damage to the O-rings while in the groove. The grease on the O-ring and sealing areas was as prescribed in STW7-3688.

Center Field Joint. The condition of the joint was nominal. No hot gas or soot was observed past the putty. There was no evidence of damage to the O-rings while in the groove.

The grease on the O-ring and sealing areas was as prescribed in STW7-3688.

Aft Field Joint. The condition of the joint was nominal. No hot gas or soot was observed past the putty. A terminated void 0.50-in. deep was found at 174 deg in the putty. No soot or pressure reached the primary O-ring. There was no evidence of damage to the O-rings while in the groove. The grease on the O-ring and sealing areas was as prescribed in STW7-3688.

A small amount of foreign material had fallen onto the joint during or after disassembly.

Table 7.3.4.1-3. TEM-3 Case-to-Nozzle Leak Test Results

Pressure (psig)	Allowable Leak Rate (sccs)	Actual Leak Rate (sccs)
185	0.072	0.0046
30	0.0082	-0.0003

Table 7.3.4.2-1. Leak Check Plug Torque Summary

Port Location	Installation Torques (in.-lb) Running	Installation Torques (in.-lb) Final	Removal Torques (in.-lb) Breakaway	Removal Torques (in.-lb) Removal
Forward Field	<70	90	100	65
Center Field	<70	90	55	35
Aft Field	<70	90	70	22
Requirements	70 (max)	80-100	100 (max)	14 (min)

Case-to-Nozzle Joint. A blowhole through the putty which allowed pressure and soot to reach the primary O-ring was found at 115 deg, but no soot was found down stream of the primary O-ring. The blowhole was 0.4 in. wide at the opening. Soot was observed to have reached the primary O-ring from 32 to 198 deg. Heavy sooting was found on the forward side of the primary O-ring from 61 to 169 deg.

Inspection of the O-rings in the grooves showed erosion to the primary O-ring; the majority of the erosion damage centered around the 115 deg location. The secondary O-ring had no damage. Detailed inspection of the primary O-ring revealed a maximum erosion depth of 0.074 in., centered at 115 deg (Figures 7.3.4.3-1 and 7.3.4.3-2). The total eroded length measured 21.0 in. with a heat-affected length of 34.0 inches. Grease coverage on the joint was nominal and per STW7-3688.

Internal Nozzle Joints

Aft Exit Cone-to-Forward Exit Cone Joint. No erosion, heat effects, or damage were observed on the O-rings. RTV was in contact with the primary o-ring inner surface the full circumference of the joint. No RTV was found on or past the sealing crown of the primary O-ring. No evidence of hot gas or soot was observed past the RTV backfill.

The remaining internal nozzle joint had not been disassembled as of 20 Jun 1989. Further results will become available during refurbishment; any anomalies will be documented according to refurbishment specifications.

7.3.4.4 Krytox Grease Certification in the Igniter S&A. The S&A device was post-fire leak tested on 25 May 1989 and disassembled on 2 Jun 1989. The B-B was partially disassembled to allow the B-B rotor shaft O-rings, initiators/seals, and leak check plugs to be inspected.

The fired S&A device was subjected to a postfire leak test to provide additional information on the sealing capability of the primary rotor shaft seals. The test was performed using STW7-3301, except at a test pressure of 1,000 +100 -0.0 psi, as specified in CTP-0131. The test was performed with a one-minute stabilization period and a two-minute isolated test. No bubbles were observed. A video of the leak test was also made to provide a permanent visual record of the test.

The test unit was then taken to H-7 and disassembled for final inspection. The primary and secondary O-rings were in good condition, no evidence of blowby or heat effects were found on the qualification unit. The inspection of the primary O-ring regions showed little evidence of soot up to the O-ring gland. The secondary O-rings were in good condition, no evidence of damage was observed.

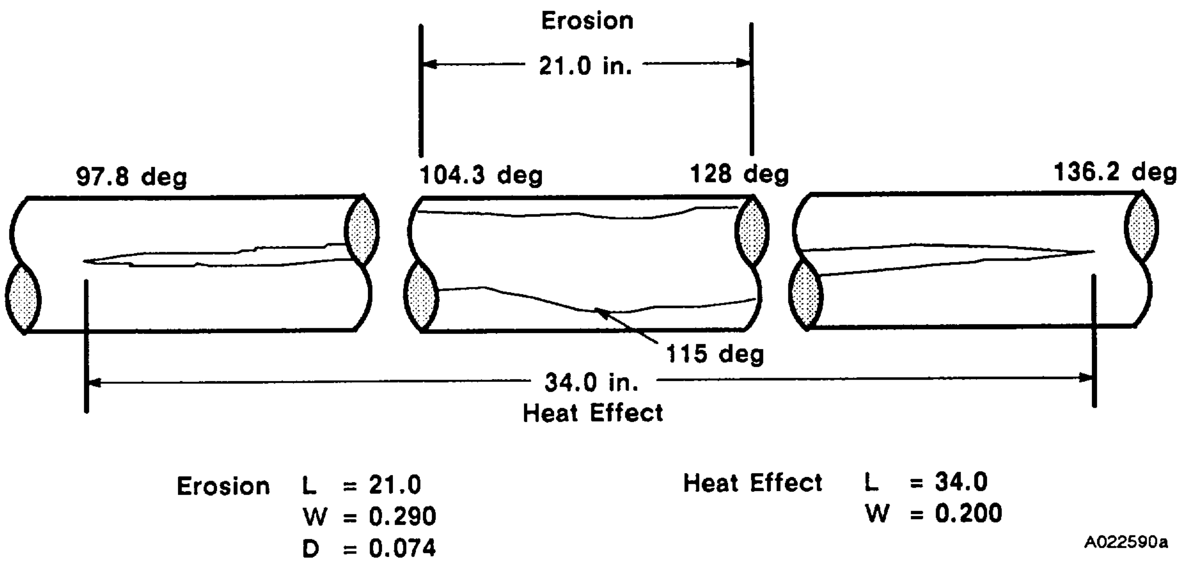

Figure 7.3.4.3-1. Case-to-Nozzle Joint Primary O-ring Erosion

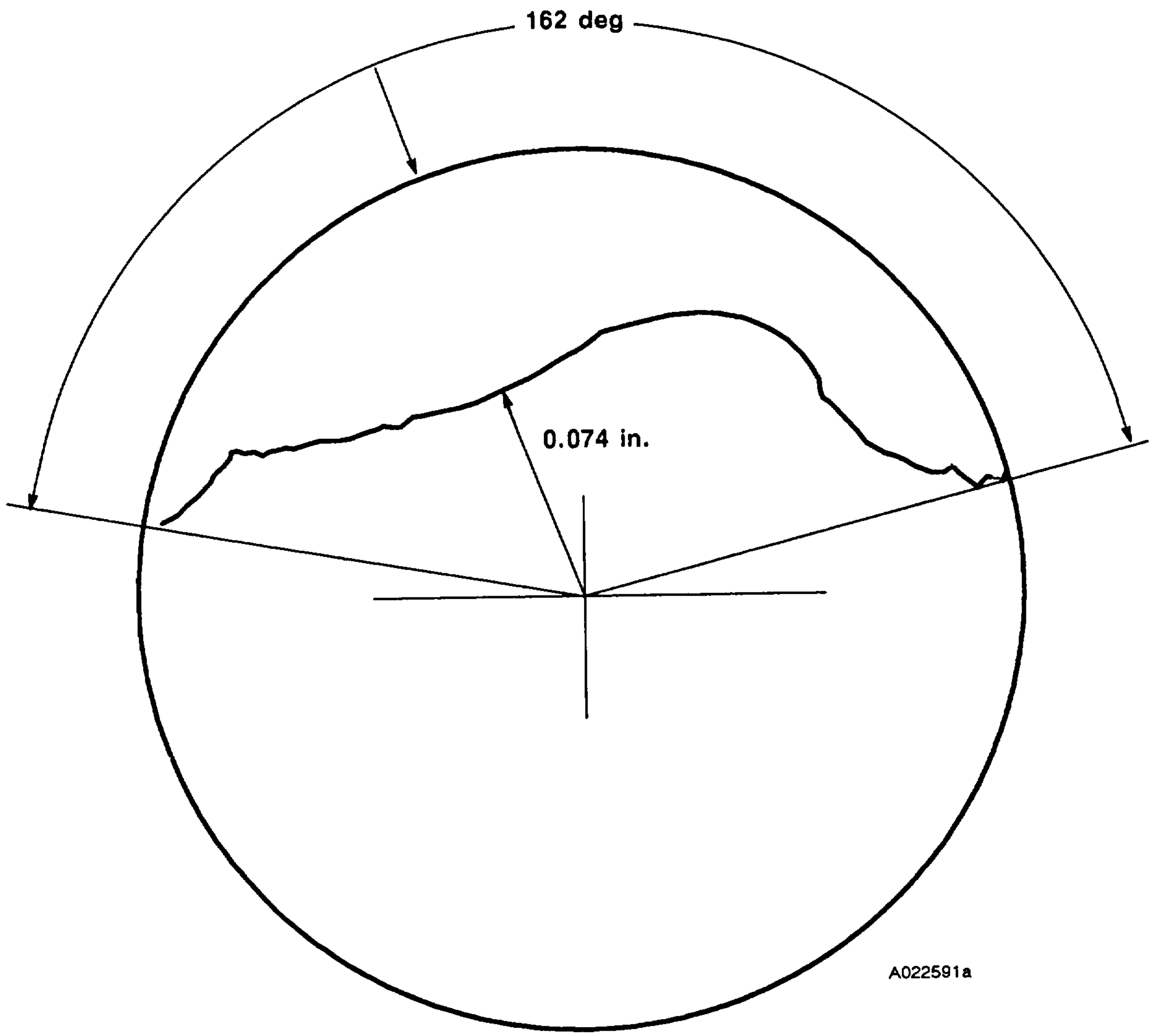

Figure 7.3.4.3-2. Case-to-Nozzle Joint Primary O-ring Erosion

The Teflon retainer used in the primary gland had a slight amount of deformation at the installation slit, the secondary retainer was in good condition.

The initiators were removed from the B-B and inspected. No evidence of blowby was found past the threads. The primary sealing surface of each initiator was inspected for threads protruding into the sealing region. Both initiators had satisfactory seal areas and threads.

Inspection of the leak check paths between the primary and secondary O-rings of the initiator showed no grease in either of the small leak check holes.

A complete inspection of the metal sealing surfaces found a possible anomaly (radial scratch) on the primary rotor shaft housing sealing surface. The subsequent use of a 5-mil brass shim stock showed no anomaly. Several small impressions were also found in the flange region, but none were in the sealing region of the S&A-to-adapter gasket.

7.4 NOZZLE PERFORMANCE

7.4.1 Introduction

The TEM-3 assembly was an HPM configured, partially-submerged, convergent/divergent movable design with an aft pivot point flexible bearing. The nozzle (Figure 7.4.1-1) incorporated the following features:

--HPM Forward Exit Cone with Snubbers
--HPM Fixed Housing
--HPM Outer Boot Ring (OBR)
--HPM Cowl Ring
--HPM Nose-Inlet Assembly
--HPM Throat Assembly
--HPM Aft Exit Cone Assembly
--RTV Backfill in Joint 1
--EA913 (with asbestos) and EA946 adhesives

The TEM-3 nozzle did not incorporate a nozzle plug.

7.4.2 Objectives

The test objectives regarding nozzle performance were:

A Recover case, nozzle, and igniter hardware for RSRM flight program

B Obtain data on nozzle fixed link force oscillations

7.4.3 Conclusions/Recommendations

The overall appearance of the TEM-3 nozzle phenolics was good, no abnormal erosion characteristics were observed.

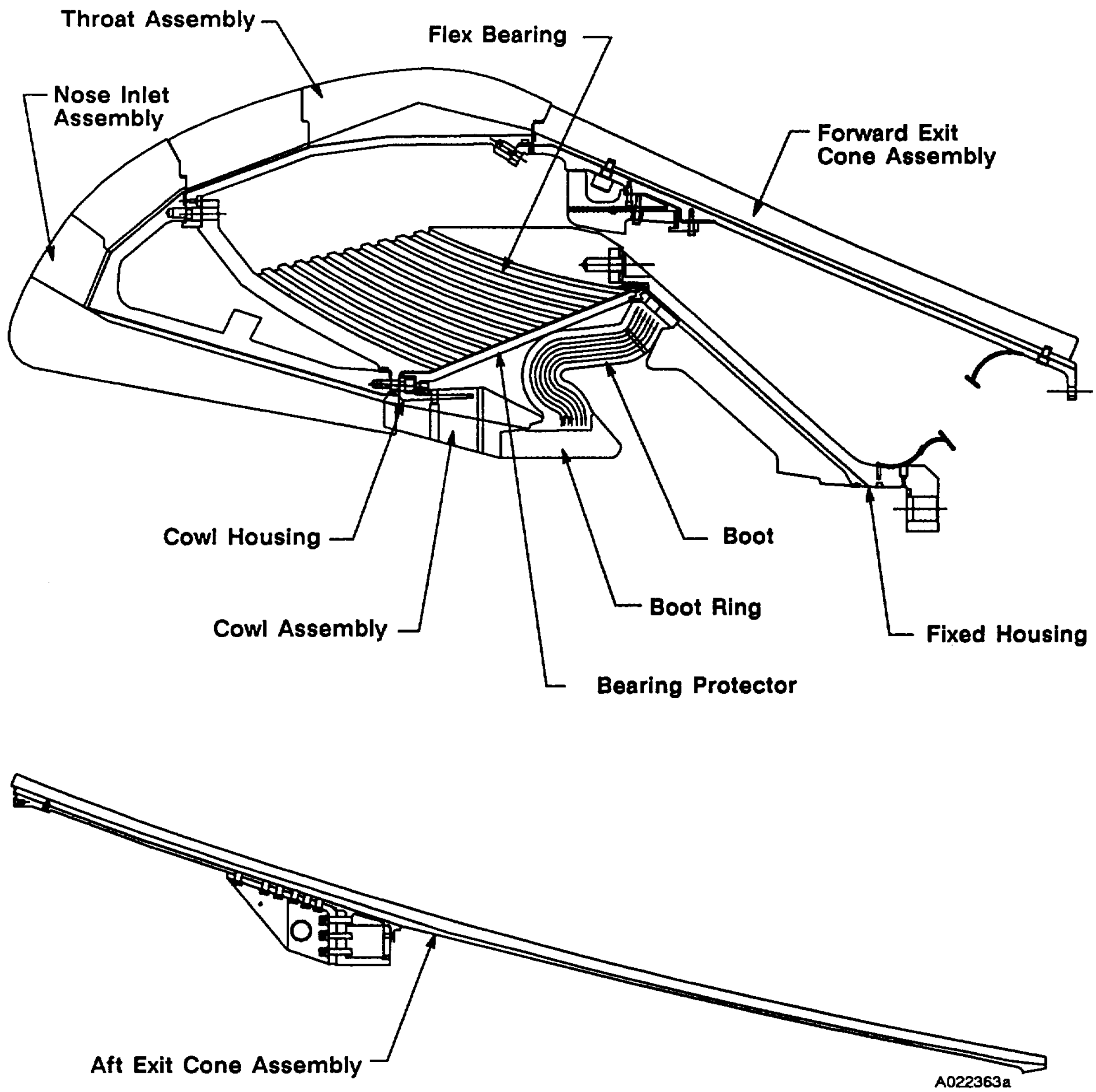

Figure 7.4.1-1. HPM Nozzle

Nozzle Joint 1 (aft exit cone-to-forward exit cone field joint) was disassembled, and no anomalies were observed. There was 100 percent backfill to the primary O-ring.

The nozzle was demated from the aft dome, and although the overall condition of the joint was good, one blowpath through the putty was observed. In addition, there was some erosion of the primary O-ring at the blowpath location. The nozzle is currently being stored, pending future internal joint disassembly, phenolic washout, and liner sectioning.

7.4.4 Results/Discussion

7.4.4.1 Nozzle. Overall erosion of the TEM-3 forward nozzle assembly and aft exit cone carbon-cloth phenolic (CCP) ablative liner was smooth and uniform.

7.4.4.2 Aft Exit Cone Assembly. The TEM-3 exit cone liner erosion was smooth and uniform. No surface ply lifting was observed. The protective unpainted cork on the outside of the aft exit cone adjacent to the compliance ring was heavily charred from 40 to 180 deg, due to wind blowing the tailoff flame in that direction. This also caused the compliance ring to have smoke discoloration in the same region. There was no heat effect to the paint on the compliance ring.

7.4.4.3 Forward Exit Cone Assembly. The TEM-3 forward exit cone liner erosion was nominal showing no major washing or pocketing.

Visual inspection of the forward exit cone showed a dimpled erosion pattern located circumferentially over the entire length of the cone, with a maximum radial depth of approximately 0.2 inch. A review of prior post-test and postflight forward exit cones, both SRM and other (PK) programs, showed that this type of erosion pattern frequently occurred on CCP forward exit cones.

No missing or damaged snubbers were observed.

7.4.4.4 Throat Assembly. Erosion of the throat and throat-inlet rings was smooth and uniform, and appeared typical of past motors. The throat post-fired mean diameter was 56.112 in. (erosion rate of 9.2 mil/sec based on an action time of 122.1 sec). Nozzle postburn throat diameters have ranged from 55.787 to 56.38 inches. This erosion is within the historical database.

7.4.4.5 Nose-Inlet Assembly. All regions of the TEM-3 nose-inlet assembly appeared to erode smoothly and uniformly.

Minor slag deposits were observed on the flow surface of the nose cap. The nose cap aft end showed minor typical wedgeouts and popped-up charred CCP material that has been noted on all previous post-test and postflight nozzles.

7.4.4.6 Cowl Ring. Erosion of the TEM-3 cowl ring was smooth and uniform and did not exhibit the typical erratic erosion found on post-test RSRM cowl rings.

All cowl vent holes appeared plugged with slag on the outer diameter (OD) of the ring. Typical post-burn axial surface cracks between plug and vent hole locations were observed around the circumference.

7.4.4.7 OBR. The TEM-3 OBR was intact and eroded smoothly and uniformly. Charred CCP material on the aft tip adjacent to the flex boot fractured and wedged out 360 deg circumferentially and was found lying in the flex boot cavity. Approximately 3 ft of the ring was missing and may be located in the aft segment. The fracture edges of the OBR aft end were sharp and showed no slag deposits. This indicates that the aft tip fractured off after motor operations. This is a typical observation found on post-test and postflight nozzles.

7.4.4.8 Fixed Housing Insulation. The TEM-3 fixed housing insulation erosion was smooth and uniform. Normal slag deposits were observed on the aft end of the CCP insulation around most of the circumference. No wedgeouts or popped-up material were observed.

7.4.4.9 Flex Boot. The TEM-3 flex boot erosion appeared typical of previous post-test and postflight flex boots. There were no abnormal erosion characteristics observed.

7.4.4.10 Nozzle Joint 1 (Aft exit cone-to-forward exit cone field joint). The overall condition of the TEM-3 aft-to-forward exit cone joint was good. The backfilled RTV extended below the joint char line and reached the high-pressure side of the primary O-ring 360 deg circumferentially. There were no blowholes through the RTV. No anomalous conditions were observed and no soot was found past the RTV.

Inspection of the O-rings, while still in the grooves, showed no damage, erosion, blowby or heat effect. Grease coverage appeared nominal. No corrosion or damage to the joint metal surface was observed.

7.4.4.11 Case-to-Nozzle Joint. A blowhole through the putty at 115 deg allowed pressure to reach the primary O-ring. The O-ring eroded approximately 25 percent over a 1-in. circumferential width. Pressure did not pass the secondary O-ring, and no metal damage or any heat-affected areas were observed. No corrosion was found on the joint metal surfaces and no metal damage was found on the sealing surfaces.

7.4.4.12 Nozzle Axial Deflection. The TEM-3 used -4 extensometers mounted in the axial direction to the fixed housing, as well as the standard configuration of 12 extensometers mounted to the kick ring. The 4 axial extensometer were mounted around the nozzle 90 deg apart, starting at 0 deg. The objective was to show that the simpler arrangement of 4 axial extensometers would provide adequate results for axial deflection and vector angle for fixed-nozzle TEM motors.

The axial deflection and vector angle were first determined using the data from the 12 standard extensometers. However, the extensometers were not zeroed out before the test, and the extensometer location dimensions were not available at the time of data reduction. But since the mounting brackets were the same ones used on the QM-8 motor, the initial offset value and location dimensions for each extensometer were estimated from the QM-8 data.

The maximum axial deflection was estimated by the set of 12 extensometers to be -0.73 in. (forward direction), occurring at approximately T+125 sec. The forward deflection was a result of the remaining boot cavity pressure. Figure 7.4.4.12-1 and 7.4.4.12-2 show the data from the axial extensometers located at 0 deg and 180 deg, respectively (pitch plane). Analysis showed that a vector angle of less than 2 deg in the yaw plane has a negligible effect on the extensometer readings in the pitch plane. Since the vector angle of a fixed-nozzle TEM motor is expected to be less than 2 deg, the pitch plane axial extensometers will give a direct reading for axial deflection. At T+125 sec, both showed a maximum deflection of -0.66 in., giving a difference of 0.07 in. between the two sets of extensometers.

The axial extensometer data at 270 deg (yaw plane) (Figure 7.4.4.12-3) showed a maximum deflection of -1.55 in., reflecting the vectoring in the yaw plane due to flex bearing compression. The axial extensometer data at 90 deg was lost during the test. The maximum vector angle at T+125 sec was calculated from the axial extensometer data in the yaw plane in conjunction with the pitch plane data and yielded a maximum vector angle of 1.18 deg. The maximum angle estimated by the data from the set of 12 extensometers was 1.33 deg, giving a difference of 0.15 deg between the two sets of extensometers.

7.5 IGNITER PERFORMANCE

7.5.1 Introduction

The SRM ignition system was a modified HPM igniter assembly containing a single nozzle, steel chamber, external and internal insulation, and a solid propellant igniter containing a case-bonded 40-point star grain. The ignition system was modified with a CO_2 quench port.

An S&A device utilizing Krytox grease to lubricate the B-B shaft O-rings was installed on the igniter. All indications are that operation was within specification limits. A postfire leak test at MEOP showed no leaks. Postfire disassembly showed no anomalies.

7.5.2 Objectives

The objectives from Section 2 regarding the igniter are:

A Recover case, nozzle, and igniter hardware for RSRM flight program.

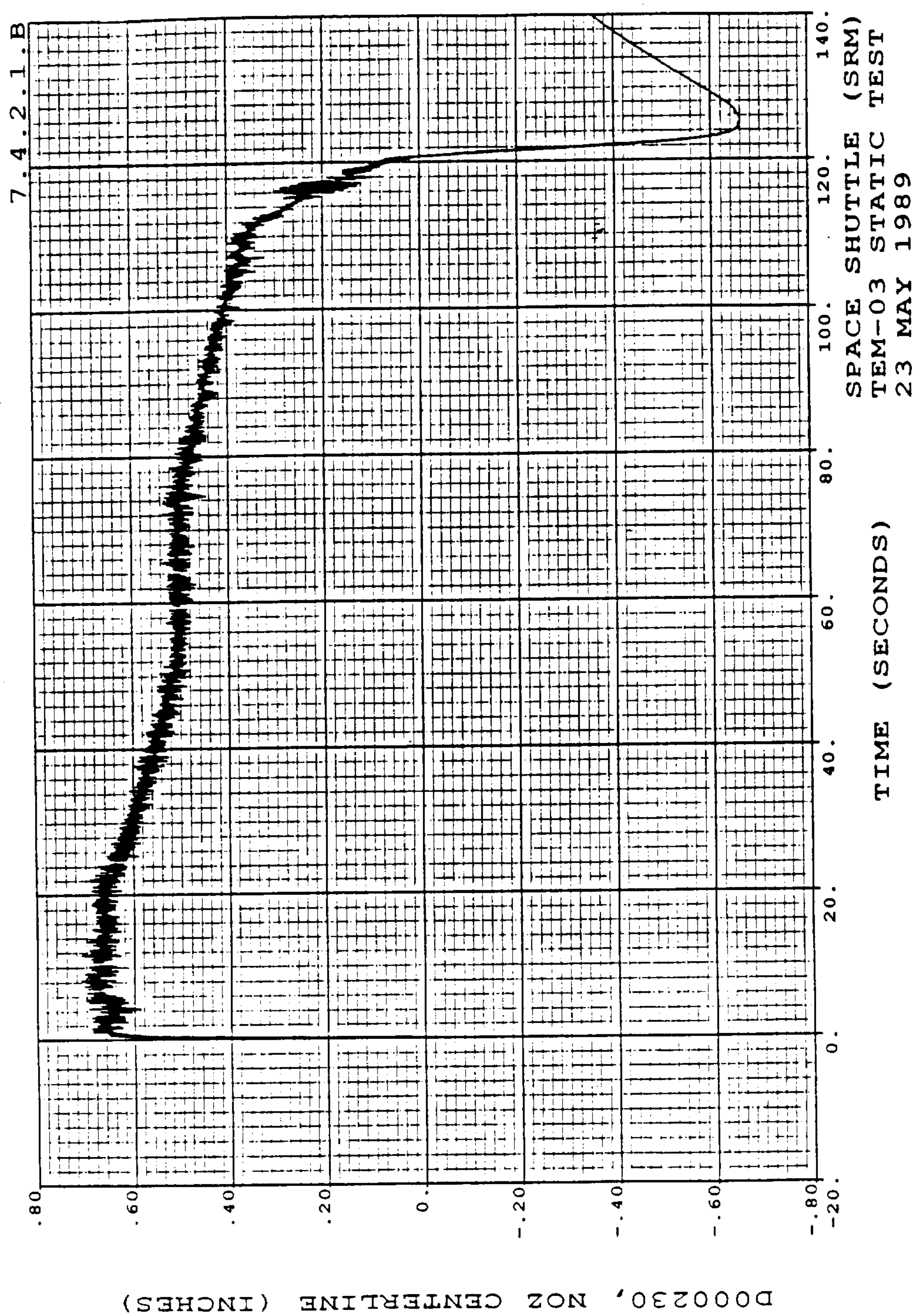

Figure 7.4.4.12-1. Nozzle Axial Extensometer Data (0 deg)

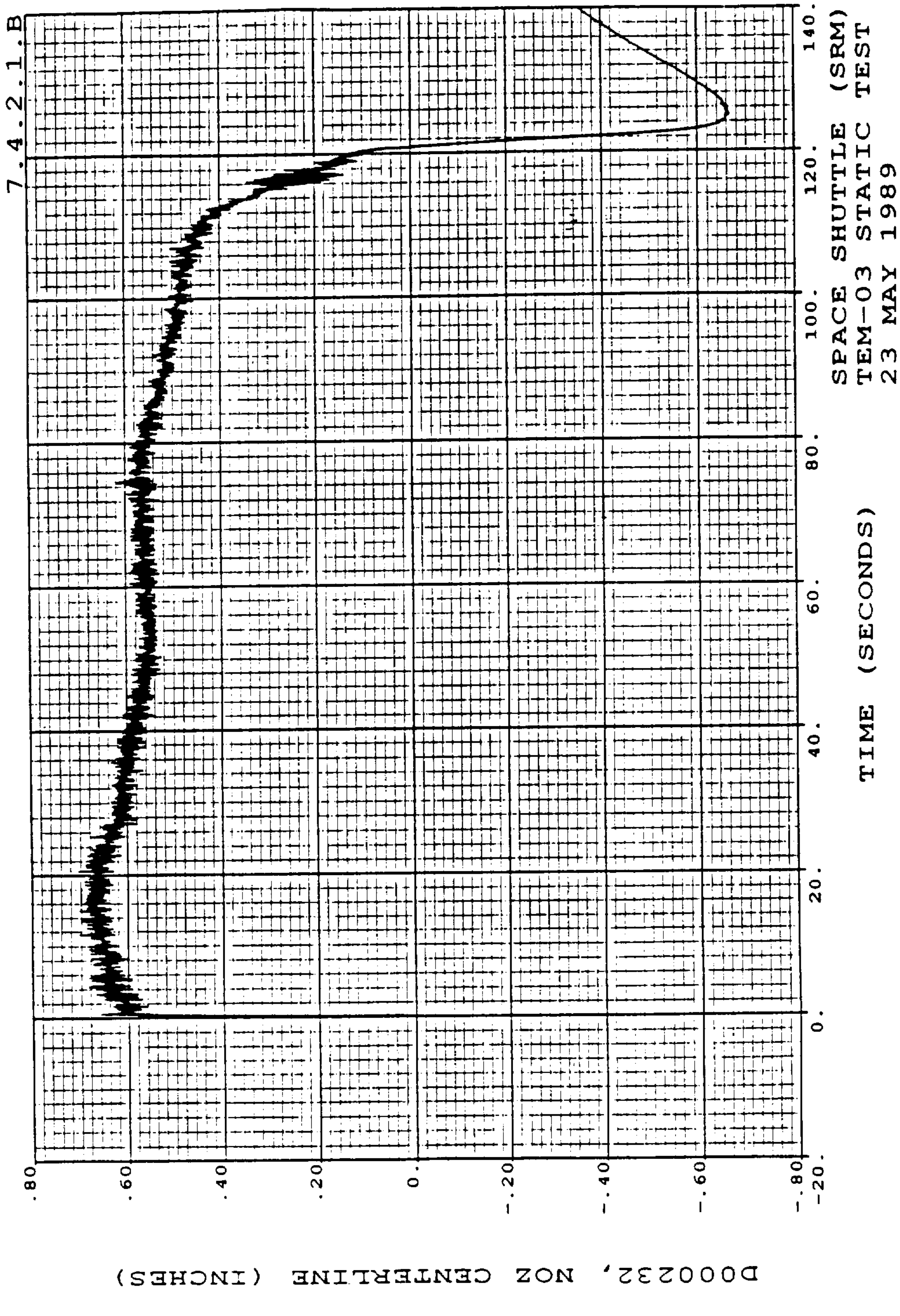

Figure 7.4.4.12-2. Nozzle Axial Extensometer Data (180 deg)

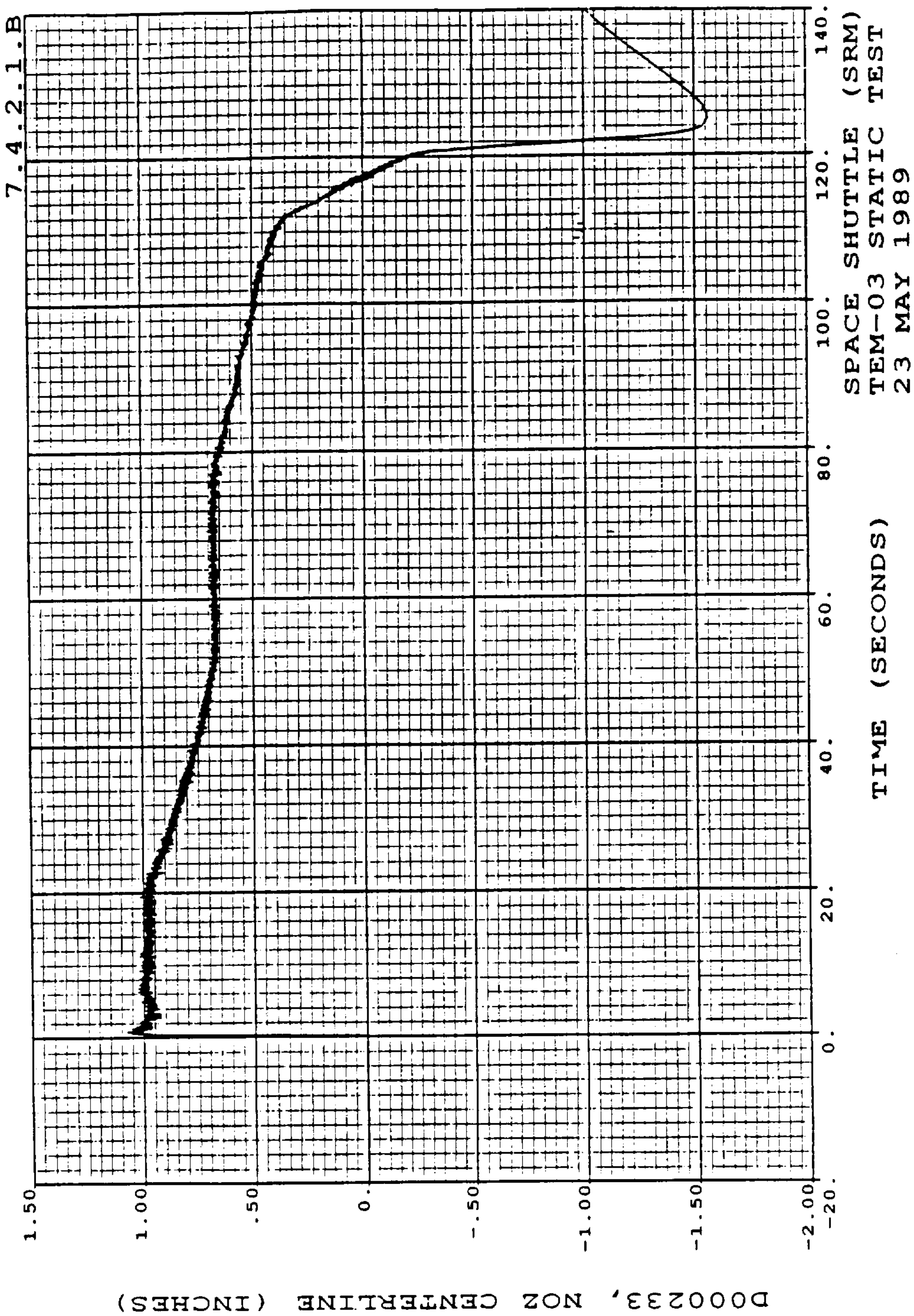

Figure 7.4.4.12-3. Nozzle Axial Extensometer Data (270 deg)

H Certify for use on RSRM the IU52295-04 S&A device which utilizes Krytox grease on the B-B shaft O-rings.

7.5.3 Conclusions/Recommendations

Igniter

At the time of disassembly the igniter will be inspected; any anomalies will be documented according to refurbishment specifications. All current indications are that the igniter performed well within the HPM data base and exhibited no anomalies (Figure 7.5.3-1).

7.5.4 Results/Discussion

Igniter

The igniter assembly is expected to be disassembled in August 1989 and will be inspected at that time. All indications are that the igniter performed as designed with no anomalies.

7.6 JPS

7.6.1 Introduction

The three field joints were protected by the JPS (Figure 7.6.1-1). The case-to-nozzle joint was heated by the nozzle heater (Figure 7.6.1-2). The igniter was heated by the igniter heater (Figure 7.6.1-3). Figure 7.6.1-4 identifies the heater mounting positions on the case. The JPS heaters were turned on prior to the test firing to ensure that the joint O-ring temperatures were within the specified launch commit temperature at the time of ignition.

7.6.2 Objectives

The objectives from Section 2 concerning the JPS are:

C Obtain additional data on the performance of electrical strip heaters on the igniter, field, and case-to-nozzle joints.

7.6.3 Conclusions/Recommendations

With the exception of the forward field joint heater, which lost power at approximately T-2 hours, the JPS performed per specification and maintained the field joint temperatures within the required temperature range up to the time of motor ignition.

7.6.4 Results/Discussion

7.6.4.1 Field Joint Heater Control System. The field joint heater control system operated as predicted and maintained the heater temperatures at the controlling RTD at 121°F with a maximum deviation of +0.5° to -0.3°F until T-2 hr. At that time the forward joint heater lost

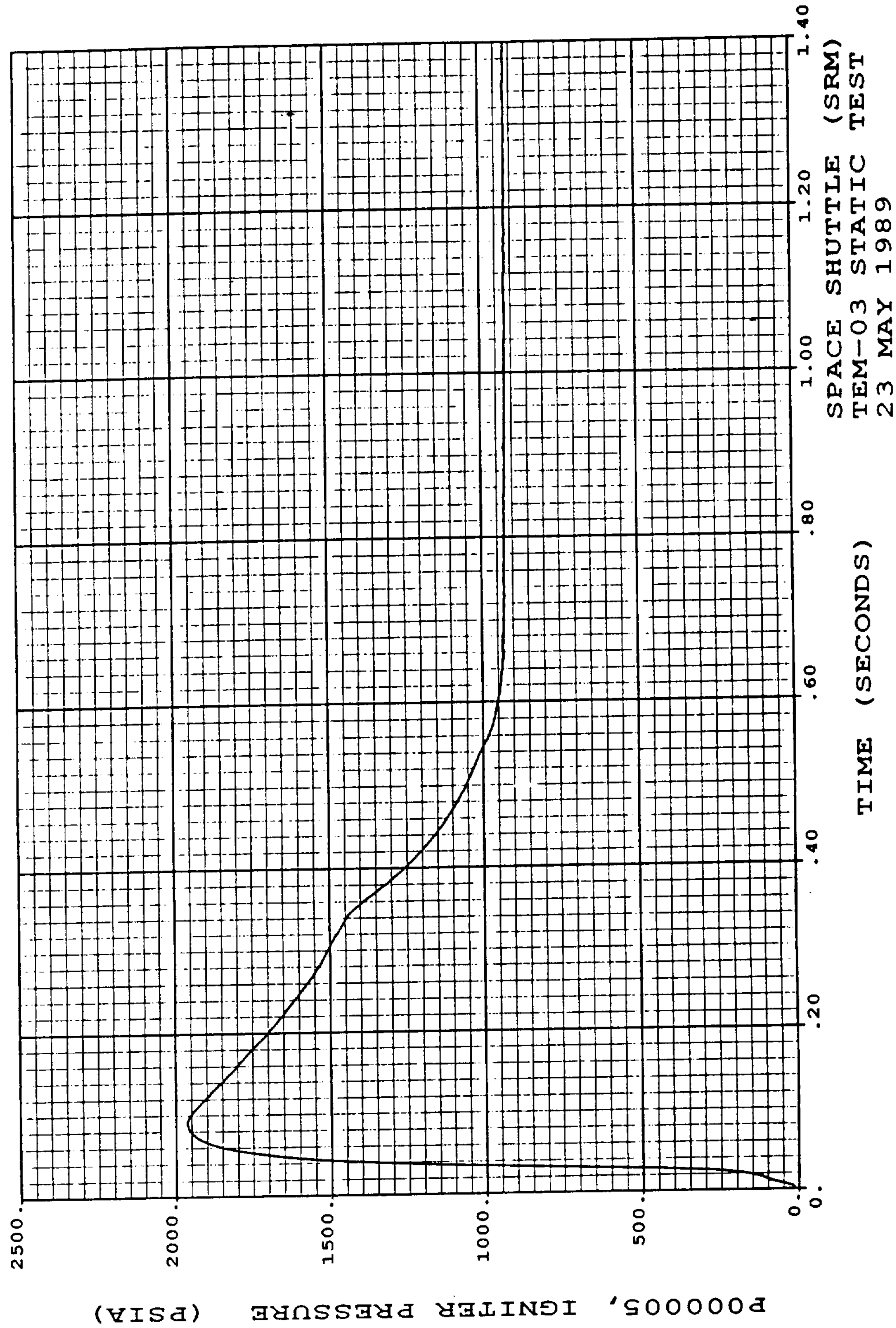

Figure 7.5.3-1. Igniter Pressure Versus Time

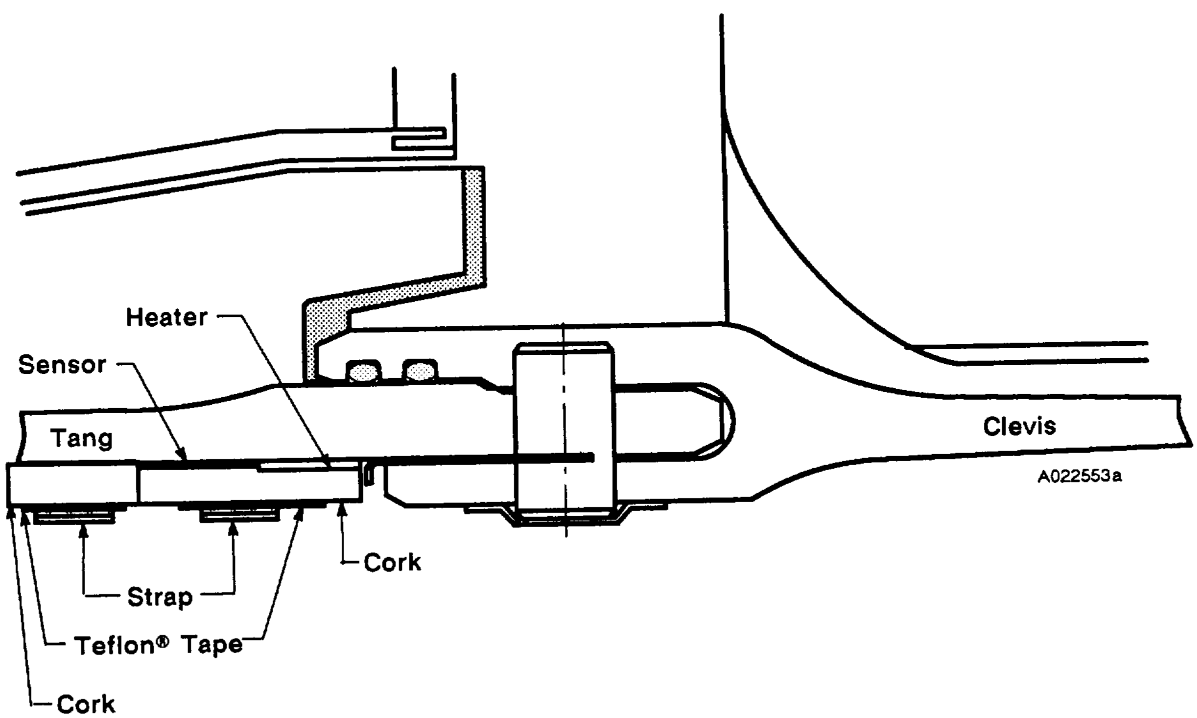

Figure 7.6.1-1. Field Joint Heater Configuration

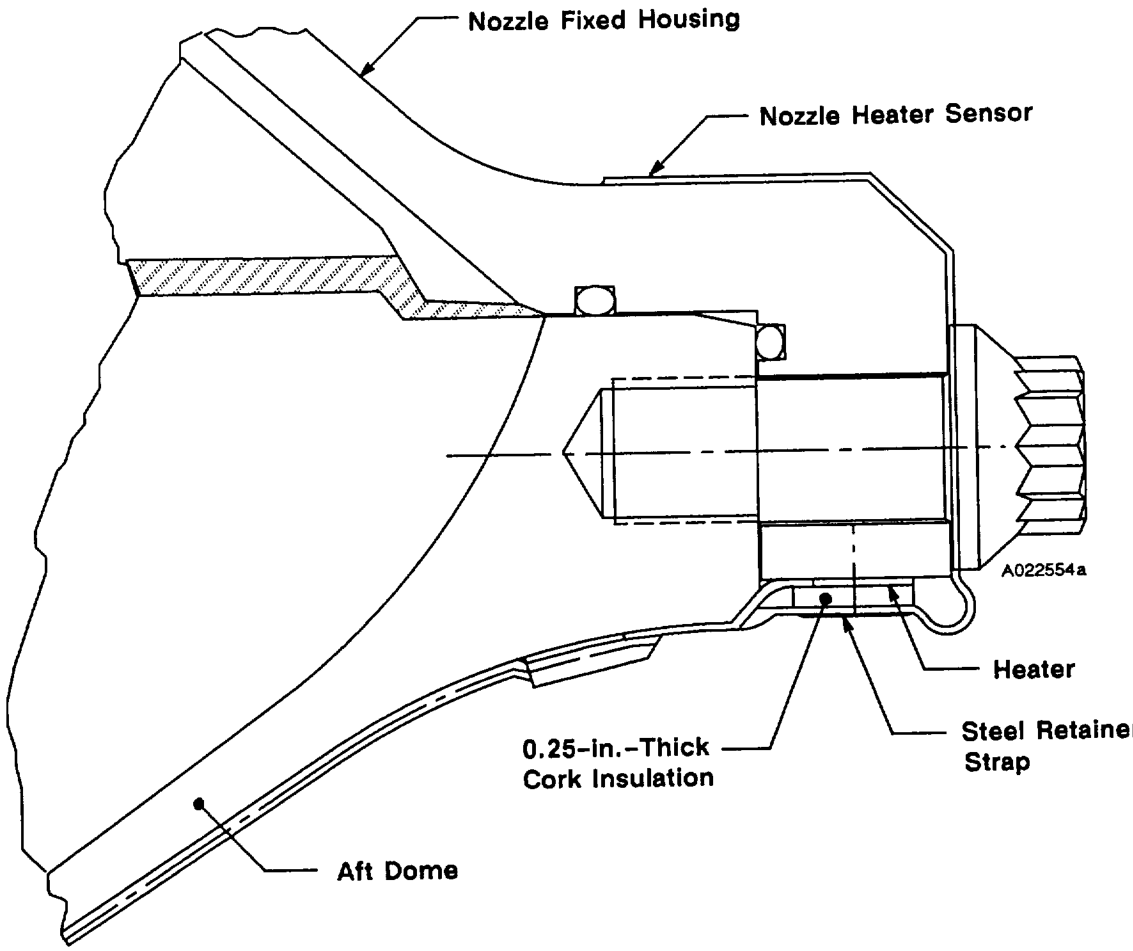

Figure 7.6.1-2. Case-to-Nozzle Joint Heater Configuration

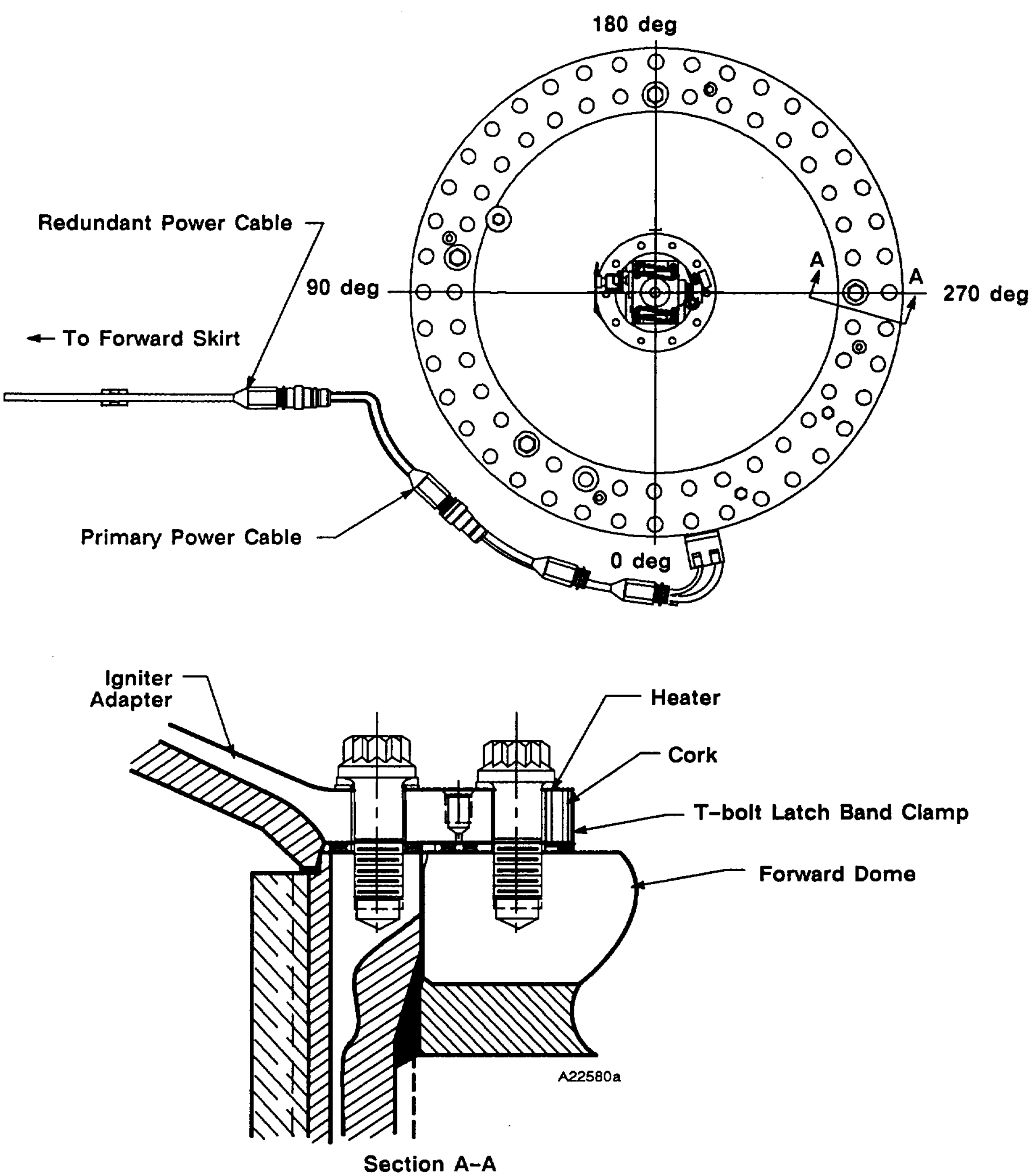

Figure 7.6.1-3. Igniter Joint Heater Configuration

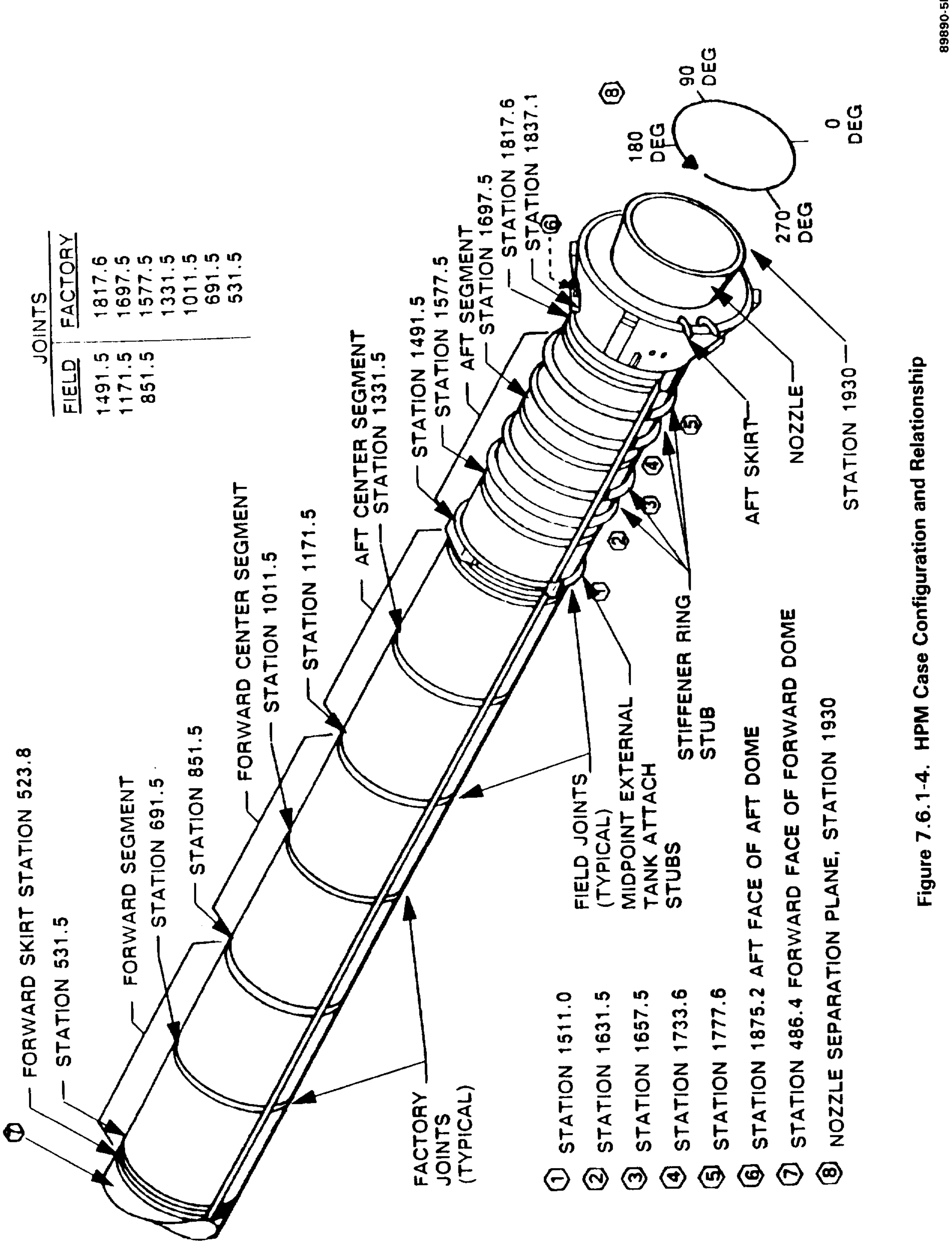

Figure 7.6.1-4. HPM Case Configuration and Relationship

electrical power, allowing that joint temperature to fall. The other two field joint heaters continued operation as planned. The four temperature sensors at each field joint were continuously monitored and the hottest of each four was manually selected for temperature control. Figure 7.6.4-1 is a plot of the temperature of the controlling RTD of the three field joints. The drop in temperature at 0600 and 1000 hours was due to heater power shutoff. The forward field joint drop in temperature at 1100 hours was an anomaly which resulted from loss of power to the heater. The plot in Figure 7.6.4-1 shows that the hottest (controlling) of the four sensors on the forward field joint was registering well above 100°F. Just prior to motor ignition the coldest of the four sensors fell to 82°F, five degrees below the stated minimum for TEM field joints.

After consultation with seal design engineering specialists, management determined that the risk to the TEM test was minimal and acceptable. The test continued, and was successful. After the test firing, an investigative team determined that the flight components (heater and cables) had not caused the anomaly. The most probable cause was the Tayco temperature controller. Evaluation of the controller is continuing.

7.6.4.2 Nozzle Heater Control System. The nozzle heater temperature control system operated as predicted and maintained the temperature well above the 75°F minimum launch commit temperature. Figure 7.6.4-2 is a plot of the temperature at the controlling RTD.

7.6.4.3 Igniter Heater Control System. The igniter temperature control system maintained the igniter temperature within the specified temperature range. When the building was removed the morning of the test firing, the igniter temperature began to drop. A plastic shroud was placed over the igniter to prevent the wind from blowing directly on the igniter; the heater was then able to maintain the proper temperature range. Figure 7.6.4-3 is a plot of the igniter temperature.

7.6.4.4 Post-Test Inspection

FJPS. Post-test inspection was conducted with the FJPS still on the motor, no evidence of damage was observed. Tables 7.6.4-1 through 7.6.4-3 are the evaluation checkoff worksheets used for the field joints and nozzle heaters prior to removal.

Cork Insulation. The cork insulation was in place and showed no signs of overheating or charring.

Kevlar Strap Condition. The straps were fully intact over the cork insulation.

Field Joint Heater. The heaters on TEM-3 were refurbished heaters. After the test firing, the heaters were operated for approximately 24 additional hours as part of the heater anomaly investigation. After removal from the motor, areas of discoloration were found on the heaters for the full circumference of the joints. Table 7.6.4-4 is the evaluation checkoff worksheet used for the field joint heaters.

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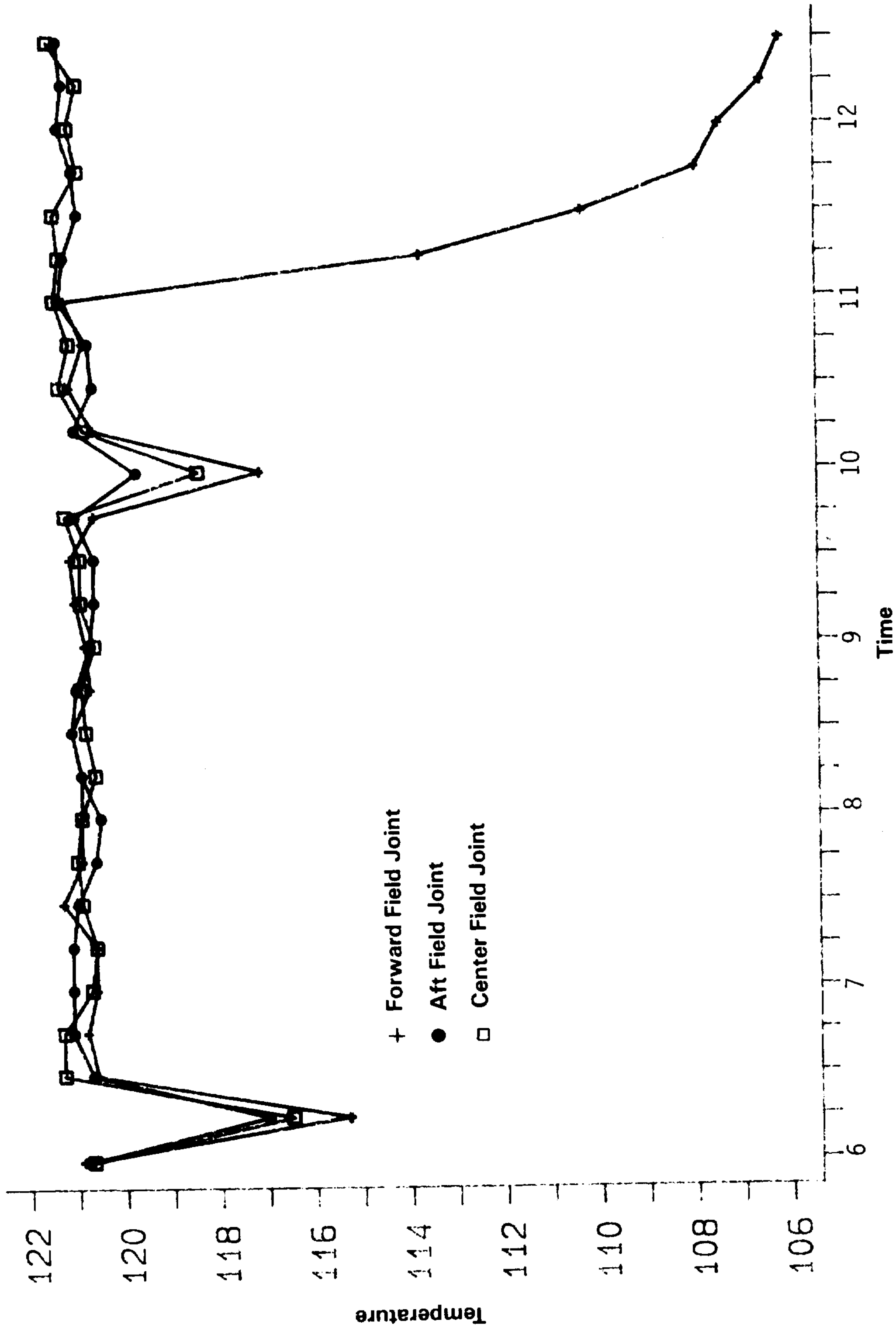

Figure 7.6.4-1. TEM-3 Field Joint Temperature

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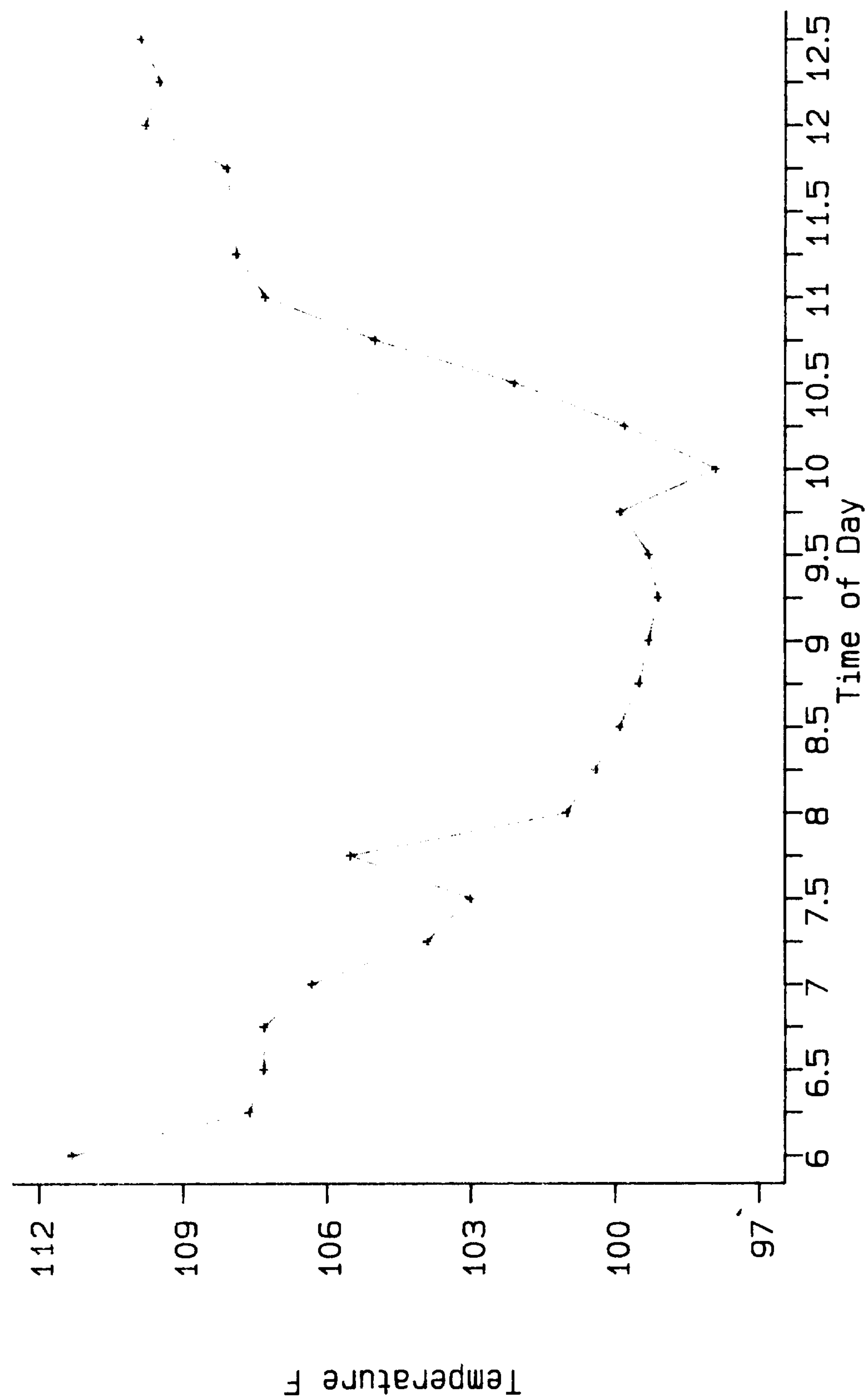

Figure 7.6.4-2. Case-to-Nozzle Joint Temperature

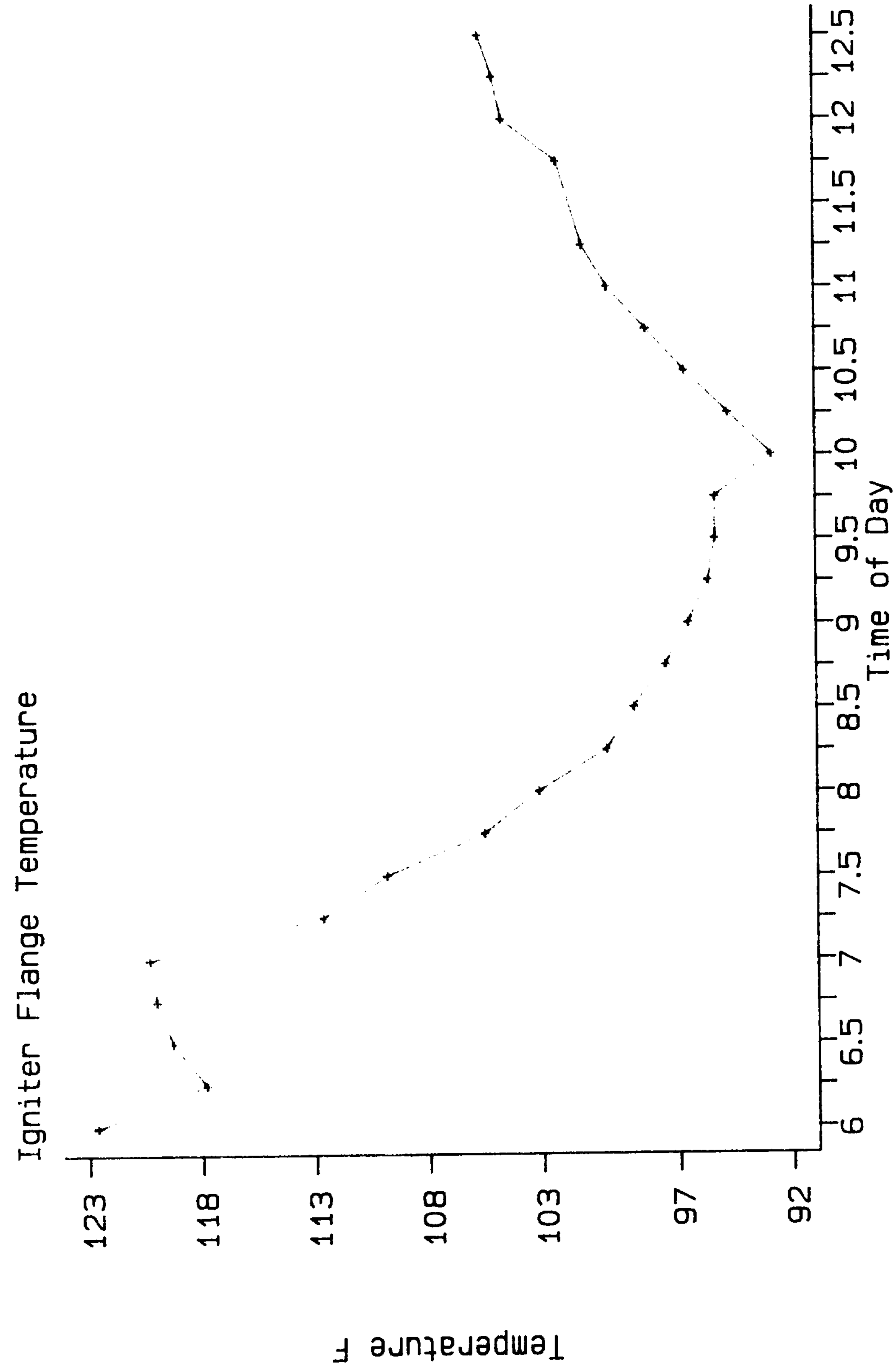

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Figure 7.6.4-3. Igniter-to-Case Joint Temperature

Table 7.6.4-1. Joint Heater Condition—Evaluation Checkoff Worksheet (after disassembly)

Inspector(s): E. HALE/D. HANSON

Motor No.: TEM-3 Date: 5/24/89

Joint: [X] Forward [X] Center [X] Aft [ ] Nozzle-to-Case

I. Heater Element
- A. Delamination? ____ yes __X__ no
- B. Adhesive to Case Separation? ____ yes __X__ no
- C. Discoloration? ____ yes __X__ no

II. Heater Sensor Assembly
- A. Evidence of Separation? ____ yes __X__ no
- B. Delaminations? ____ yes __X__ no

If any of the above conditions exist, note:

Affected Part (I, II or III)	Condition	Axial Location (In.)	Degree Location (Deg.)	Axial Length (In.)	Circumferential Width (In.)	Degree Arc

Notes / Comments

Table 7.6.4-2. Joint Heater Condition—Evaluation Checkoff Worksheet

Inspector(s): E. HALE/D. HANSON

Motor No.: TEM-3 Date: 5/24/89

Joint: ☐ Forward ☐ Center ☐ Aft ☒ Nozzle-to-Case

I. Heater Element

A. Delamination?	___ yes	X no
B. Adhesive to Case Separation?	___ yes	X no
C. Discoloration?	___ yes	X no

II. Heater Sensor Assembly

A. Evidence of Separation?	___ yes	X no
B. Delaminations?	___ yes	X no

If any of the above conditions exist, note:

Affected Part (I, II or III)	Condition	Axial Location (In.)	Degree Location (Deg.)	Axial Length (In.)	Circumferential Width (In.)	Degree Arc

Notes / Comments

Table 7.6.4-3. Igniter Heater Installation Condition — Evaluation Checkoff Worksheet (before removal)

Inspector(s): E. HALE/D. HANSON

Motor No.: TEM-3 | Time: 1400 | Date: 5/24/89

Joint: Igniter (IGN) | Case End: Igniter Adapter (FWD) | Component: JPS

I.	Igniter Heater		
	A. Securely held in place (LOOSE)?	X yes	___ no
	B. Proper position (DISCP)?	X yes	___ no
II.	Cork Insulation		
	A. Securely held in place (LOOSE)?	X yes	___ no
	B. Proper position (DISCP)?	X yes	___ no
III.	T-Bolt Latch Band Clamp		
	A. Securely held in place (LOOSE)?	X yes	___ no
	B. Proper position (DISCP)?	X yes	___ no
IV.	Igniter Heater Power Cables		
	A. Securely held in place (LOOSE)?	X yes	___ no
	B. Proper position (DISCP)?	X yes	___ no

If any of the above conditions exist, note:

Affected Part (I, II, III or IV)	Condition (Observation Code)	Starting Degree Location (Deg.)	Ending Degree Location (Deg.)	Circumferential Width (In.)	Axial Length (In.)

Notes / Comments

Table 7.6.4-4. Joint Heater Condition—Evaluation Checkoff Worksheet (after removal)

Inspector(s): T. SPENCER/D. BATES

Motor No.: TEM-3 Date: 6/6/89

Joint: [X] Forward [X] Center [X] Aft [ ] Nozzle-to-Case

		yes	no
I.	Heater Element		
	A. Delamination?		X
	B. Adhesive to Case Separation?		X
	C. Discoloration?	X	
II.	Heater Sensor Assembly		
	A. Evidence of Separation?		X
	B. Delaminations?		X

If any of the above conditions exist, note:

Affected Part (I, II or III)	Condition	Axial Location (In.)	Degree Location (Deg.)	Axial Length (In.)	Circumferential Width (In.)	Degree Arc
INTERMITTANT	DISCOLORATION FULL	CIRCUMFERENCE	OF JOINTS			

Notes / Comments
PHOTOS TAKEN FULL CIRCUMFERENCE OF JOINT FOR FORWARD, CENTER, AFT AND NOZZLE TO CASE WITH DEGREE LOCATIONS MARKED.

JPS Sensors. The sensor showed no anomalies such as cracking and delamination.

Heater Cable. The heater cables were found in excellent condition following the test. No voids or missing material, debonds, or charred material were observed.

Nozzle Heater. The nozzle showed evidence of overheating from 86° to 90°F where the heater had been installed over instrumentation wires. A procedure will be added to future test plans to eliminate this problem. Table 7.6.4-5 is the worksheet used for the nozzle heater after removal from the motor.

Factory Joint Weather Seal. Post-test inspection was conducted before removal, no evidence of damage was observed.

Igniter Heater. The post-test inspection of the igniter heater showed no anomalies. Tables 7.6.4-6 and 7.6.4-7 are the worksheets used for igniter heater after removal from the motor.

7.7 BALLISTICS/MASS PROPERTIES

7.7.1 Introduction

The SRM propellant, TP-H1148, was a composite-type solid propellant, formulated of PBAN, epoxy curing agent, AP oxidizer and Al powder fuel. A small amount of burning rate catalyst (iron oxide) was added to achieve the desired propellant burn rate.

The propellant grain design consists of a forward segment with an 11-point star that transitions into a tapered CP configuration, two center segment double-tapered CP configurations, and an aft segment triple-taper CP configuration with a cutout for the partially-submerged nozzle.

7.7.2 Objectives

The primary test objectives from Section 2 regarding ballistics/mass properties are:

B Obtain additional data on the effect of three-year open storage of loaded SRM case segments upon motor ignition and performance.

D Obtain additional data on the low-frequency chamber pressure oscillations in the motor forward end.

7.7.3 Conclusions/Recommendations

The TEM-3 ballistic performance was within expected limits. The TEM-3 ballistic performance compared well with previous TEM performance and HPM historical data. The three-year storage of loaded case segments did not appear to affect motor performance.

Table 7.6.4-5. Joint Heater Condition—Evaluation Checkoff Worksheet (after removal)

Inspector(s): T. SPENCER/D. BATES

Motor No.: TEM-3 | Date: 6/6/89

Joint: ☐ Forward ☐ Center ☐ Aft ☒ Nozzle-to-Case

	yes	no
I. Heater Element		
A. Delamination?		X
B. Adhesive to Case Separation?		X
C. Discoloration?	X	
II. Heater Sensor Assembly		
A. Evidence of Separation?		X
B. Delaminations?		X

If any of the above conditions exist, note:

Affected Part (I, II or III)	Condition	Axial Location (In.)	Degree Location (Deg.)	Axial Length (In.)	Circumferential Width (In.)	Degree Arc
I	DISCOLORATION	1875.2	86-90°	FULL WIDTH OF HEATER		

Notes / Comments

PHOTOS TAKEN FULL CIRCUMFERENCE OF JOINT FOR FORWARD, CENTER, AFT, AND NOZZLE TO CASE WITH DEGREE LOCATIONS MARKED.

Table 7.6.4-6. Igniter Heater Installation Condition—Evaluation Checkoff Worksheet (after removal)

Inspector(s): T. SPENCER/K. RICHARDS

Motor No.: TEM-3 Time: 1300 Date: 6/5/89

Joint: Igniter (IGN) Case End: Igniter Adapter (FWD) Component: JPS

I. Igniter Heater
   A. Securely held in place (LOOSE)? _X_ yes ___ no
   B. Proper position (DISCP)? _X_ yes ___ no

II. Cork Insulation
   A. Securely held in place (LOOSE)? _X_ yes ___ no
   B. Proper position (DISCP)? _X_ yes ___ no

III. T-Bolt Latch Band Clamp
   A. Securely held in place (LOOSE)? _X_ yes ___ no
   B. Proper position (DISCP)? _X_ yes ___ no

IV. Igniter Heater Power Cables
   A. Securely held in place (LOOSE)? _X_ yes ___ no
   B. Proper position (DISCP)? _X_ yes ___ no

If any of the above conditions exist, note:

Affected Part (I, II, III or IV)	Condition (Observation Code)	Starting Degree Location (Deg.)	Ending Degree Location (Deg.)	Circumferential Width (In.)	Axial Length (In.)

Notes / Comments

NO DAMAGE EXISTS.

Table 7.6.4-7. Igniter Heater Component—Evaluation Checkoff Worksheet (after removal)

Inspector(s): T. SPENCER

Motor No.: TEM-3 | Side: X Left X Right | Date: 6/5/89

Joint: Igniter (IGN) | Case End: Igniter Adapter (FWD) | Component: JPS

		yes	no
I.	T-Bolt Latch Band Clamp Assembly Intact (BAND)?	X	
II.	Igniter Heater		
	A. Delaminations (DLHTR)?		X
	B. Discolorations (DSCLR)?		X
	C. Charred (HTAFF)?		X
	D. Warped (HTAFF)?		X
III.	Heater Power Cables		
	A. Intact (LOOSE)?	X	
	B. Charred (HTAFF)?		X

If any of the above conditions exist, note:

Affected Part (I, II or III)	Condition (Observation Code)	Axial Location (Station) (In.)	Starting Degree Location (Deg.)	Ending Degree Location (Deg.)	Circumferential Width (In.)	Axial Length (In.)

Notes / Comments

NO DAMAGE.

The TEM-3 motor exhibited chamber pressure oscillations similar to previously tested space shuttle HPMs. The 1-L mode oscillations were typical for an HPM, with amplitudes significantly lower than those experienced in RSRM static tests.

7.7.4 Results/Discussion

A comparison of TEM-3 performance with predicted values and with the nominal HPM performance revealed few differences. The predicted burn rate for TEM-3 was 0.368 in./sec at 625 psia and 60°F; the target burn rate was 0.368 in./sec, and the delivered burn rate was 0.3672 in./sec. The predicted performance compared well with the measured.

Table 7.7.4-1 is a summary of the measured ballistic and nozzle performance data. Figure 7.7.4-1 is a comparison of measured and predicted pressure-time histories. Thrust was not measured for this static test, only reconstructed thrust based on nominal thrust to pressure ratios is available. The pressure curve differs slightly from the predicted curve during tailoff, but is still very close to predicted and within HPM variation. Figures 7.7.4-2 and 7.7.4-3 contain plots of the analytical reconstruction of the TEM-3 performance. The analytical model calculated the motor burn rate and surface burn rate error (SBRE) factor. The calculated burn rate of 0.3672 in./sec at 625 psia and 60°F was approximately 0.2 percent below the predicted value of 0.368 in./sec. The calculated SBRE table compared closely with the nominal HPM table as expected, since the propellant grain geometry was the same.

The motor average subscale burn rates, full-scale motor burn rates (determined from post-test curve matching) and resulting scale factors for SRM-15 to SRM-24, used to predict the TEM-3 burn rate are listed in Table 7.7.4-2. The full-scale motor burn rates were determined from post-test curve matching in which the analytical model was forced to match the measured motor performance. The mean scale factor was 1.0175, with a sigma 0.00440 and a coefficient of variation of 0.432 percent.

A plot of the measured data comparing the ignition transients of TEM-3 and TEM-2 is shown in Figure 7.7.4-4. The TEM-3 transient was very similar to that of TEM-2. The TEM-3 maximum pressure rise rate was 88.5 psi/10-ms. The historical 3-point average pressure rise rate is 90.49 psi/10-ms, with a variation of 7.07 psi/10-ms. TEM-3 was consistent with the nominal rise rates for the HPM population. A summary table showing the historical pressure rise rates, thrust rise rates, and ignition intervals is shown in Table 7.7.4-3. A summary of the TEM-3 ignition events is shown in Table 7.7.4-4.

The TEM-3 igniter grain configuration was identical to the HPM flight and static test igniter design. The igniter was cast from propellant batch D760031 using TP-H1178 propellant. The delivered maximum mass flow rate was 351.5 lbm/sec at 70°F for the TEM-3 igniter. The TEM-3

Table 7.7.4-1. Summary of Measured Ballistic and Nozzle Performance Data

MORTON THIOKOL SPACE SHUTTLE TEST TEM-03, 23 MAY 1989

A. Ambient Conditions		
Date and Time at Fire Pulse	1300 Hr	02-24-89
Ambient Temperature	75	Deg F
Measured Mean Bulk Temperature	70	Deg F
Measured Ambient Pressure	12.26	PSIA
B. Weight Data		
Total Loaded Propellant Weight	1,109,386	Lbf
Total expended Weight	1,114,236	Lbf
Unexpended Propellant Residue (slag)	1500	Lbf
Expended Inert Weight		
1. Forward Segment	718.0	lbf
2. Forward Center Segment	598.0	lbf
3. Aft Center Segment	962.0	lbf
4. Aft Segment (including nozzle less aft exit cone)	4072.0	lbf
5. Total expended Inerts	6350.0	lbf
Total Expended Propellant Weight	1,107,886	lbf
C. Nozzle Data		
Initial Throat Area	2278.2	Sq In
Final Throat Area	2457.3	Sq In
Web Time Average Throat Area	2371.3	Sq In
Action Time Average Throat Area	2379.4	Sq In
Total Time Average Throat Area	2379.7	Sq In
Initial Exit Area	17,588	Sq In
Final Exit Area	17,704	Sq In
Total Time Average Exit Area	17,646	Sq In
Web Time Average Throat Radial Erosion Rate	0.00912	In/Sec
Action Time Average Throat Radial Erosion Rate	0.00851	In/Sec
Total Time Average Throat Radial Erosion Rate	0.00846	In/Sec
Initial Expansion Ratio	7.7200	
Web Time Average Expansion Ratio	7.4415	
Action Time Average Expansion Ratio	7.4160	
Action Time Average Nozzle Efficiency	0.97975	
Total Time Average Nozzle Efficiency	0.97988	

Table 7.7.4-1. Summary of Measured Ballistic and Nozzle Performance Data (Cont)

MORTON THIOKOL SPACE SHUTTLE TEST TEM-03, 23 MAY 1989

D. Time and Ballistic Data

Time at First Indication of Head-end Pressure	0.029	Sec
Ignition Delay Time	-0.025	Sec
Time at 90% Max. Igniter Pressure	0.054	Sec
Ignition Interval Time	0.228	Sec
Ignition Rise Time	0.200	Sec
Time When Head-end Chamber Pressure Achieves 563.5 PSIA during ignition	0.228	Sec
Time at Last Indication of Head-end Pressure	122.8	Sec
Time at Web Bisector	110.3	Sec
Web Time	110.1	Sec
Action Time	121.9	Sec
Total Time	122.7	Sec
Tail-off Thrust Decay Time	0.634	Sec
Maximum Pressure Rise Rate	88.5	psi/10-msec
Maximum Thrust Rise Rate		Lbf/10-msec
Maximum Igniter Pressure	1964	PSIA
Maximum Measured Head-end Pressure	929.3	PSIA
Time at Maximum Head-end Pressure	0.628	Sec
Maximum Thrust	3.128,000	Lbf
Time at Maximum Thrust	20.5	Sec
Maximum Thrust Corrected to Vacuum	3,343,000	Lbf
Maximum Thrust Corrected to Sea Level	3,085,000	Lbf
Maximum Nozzle Stagnation Pressure	845.4	PSIA
Web Time Average Head-end Chamber Pressure	671.8	PSIA
Action Time Average Head-end Chamber Pressure	622.6	PSIA
Web Time Average Nozzle Stagnation Pressure	653.4	PSIA
Action Time Average Nozzle Stagnation Pressure	605.9	PSIA
Initial Thrust	2,917,000	Lbf
Initial Thrust Corrected to Vacuum	3,132,000	Lbf
Initial Thrust Corrected to Sea Level	2,874,000	Lbf
Web Time Average Thrust	2,412,000	Lbf
Web Time Average Thrust Corrected to Vacuum	2,628,000	Lbf
Action Time Average Thrust	2,226,000	Lbf
Action Time Average Thrust Corrected to Vacuum	2,437,000	Lbf
Characteristic Exhaust Velocity	5043.8	Ft/Sec

Table 7.7.4-1. Summary of Measured Ballistic and Nozzle Performance Data (Cont)

MORTON THIOKOL SPACE SHUTTLE TEST TEM-03, 23 MAY 1989

E. Impulse Data		
Measured Total Impulse	271.46	Mlbf-sec
Total Impulse Corrected to Vacuum	297.25	Mlbf-sec
Measured Impulse at 20 Seconds	60.41	Mlbf-sec
20 Second Impulse Corrected to Vacuum	64.72	Mlbf-sec
Measured Impulse at 60 Seconds	161.11	Mlbf-sec
60 Second Impulse Corrected to Vacuum	174.06	Mlbf-sec
Web Time Impulse	265.48	Mlbf-sec
Web Time Impulse Corrected to Vacuum	289.28	Mlbf-sec
Action Time Impulse	271.34	Mlbf-sec
Action Time Impulse Corrected to Vacuum	297.04	Mlbf-sec
Specific Impulse	243.63	Sec
Specific Impulse Corrected to Vacuum	266.77	Sec
Web Time Specific Impulse	245.07	Sec
Web Time Specific Impulse Corrected to Vacuum	267.05	Sec
Action Time Specific Impulse	243.68	Sec
Action Time Specific Impulse Corrected to Vacuum	266.76	Sec
Propellant Specific Impulse	245.03	Sec
Propellant Specific Impulse Corrected to Vacuum	268.30	Sec
F. Pressure Integral Data		
Total Time Pressure Integral	75944	PSIA-Sec
Web Time Pressure Integral	73947	PSIA-Sec
Action Time Pressure Integral	75903	PSIA-Sec

Table 7.7.4-1. Summary of Measured Ballistic and Nozzle Performance Data (Cont)

MORTON THIOKOL SPACE SHUTTLE TEST TEM-03, 23 MAY 1989

CORRECTED TO 40 DEGREES F

D. Time and Ballistic Data

Time at First Indication of Head-end Pressure	0.030	Sec
Time When Head-end Chamber Pressure Achieves 563.5 PSIA during ignition	0.242	Sec
Time at Last Indication of Head-end Pressure	126.8	Sec
Time at Web Bisector	114.2	Sec
Web Time	113.9	Sec
Action Time	126.0	Sec
Maximum Measured Head-end Pressure	897.0	PSIA
Time at Maximum Head-end Pressure	0.649	Sec
Maximum Thrust Corrected to Vacuum	3,230,000	Lbf
Maximum Nozzle Stagnation Pressure	816.0	PSIA
Web Time Average Head-end Chamber Pressure	648.2	PSIA
Action Time Average Head-end Chamber Pressure	601.2	PSIA
Web Time Average Nozzle Stagnation Pressure	630.4	PSIA
Action Time Average Nozzle Stagnation Pressure	585.0	PSIA
Web Time Average Thrust Corrected to Vacuum	2,536,000	Lbf
Action Time Average Thrust Corrected to Vacuum	2,353,000	Lbf

E. Impulse Data

Total Impulse Corrected to Vacuum	296.68	Mlbf-sec
20 Second Impulse Corrected to Vacuum	62.38	Mlbf-sec
60 Second Impulse Corrected to Vacuum	168.83	Mlbf-sec
Web Time Impulse Corrected to Vacuum	288.89	Mlbf-sec
Action Time Impulse Corrected to Vacuum	296.48	Mlbf-sec
Specific Impulse Corrected to Vacuum	266.26	Sec
Web Time Specific Impulse Corrected to Vacuum	266.55	Sec
Action Time Specific Impulse Corrected to Vacuum	266.26	Sec
Propellant Specific Impulse Corrected to Vacuum	267.79	Sec

Table 7.7.4-1. Summary of Measured Ballistic and Nozzle Performance Data (Cont)

CORRECTED TO 60 DEGREES F

D. Time and Ballistic Data

Time at First Indication of Head-end Pressure	0.029	Sec
Time When Head-end Chamber Pressure Achieves 563.5 PSIA during ignition	0.233	Sec
Time at Last Indication of Head-end Pressure	124.1	Sec
Time at Web Bisector	111.6	Sec
Web Time	111.4	Sec
Action Time	123.2	Sec
Maximum Measured Head-end Pressure	918.4	PSIA
Time at Maximum Head-end Pressure	0.635	Sec
Maximum Thrust Corrected to Vacuum	3,304,000	Lbf
Maximum Nozzle Stagnation Pressure	835.5	PSIA
Web Time Average Head-end Chamber Pressure	663.8	PSIA
Action Time Average Head-end Chamber Pressure	615.4	PSIA
Web Time Average Nozzle Stagnation Pressure	645.6	PSIA
Action Time Average Nozzle Stagnation Pressure	598.8	PSIA
Web Time Average Thrust Corrected to Vacuum	2,597,000	Lbf
Action Time Average Thrust Corrected to Vacuum	2,409,000	Lbf

E. Impulse Data

Total Impulse Corrected to Vacuum	297.04	Mlbf-sec
20 Second Impulse Corrected to Vacuum	63.92	Mlbf-sec
60 Second Impulse Corrected to Vacuum	172.28	Mlbf-sec
Web Time Impulse Corrected to Vacuum	289.18	Mlbf-sec
Action Time Impulse Corrected to Vacuum	296.86	Mlbf-sec
Specific Impulse Corrected to Vacuum	266.59	Sec
Web Time Specific Impulse Corrected to Vacuum	266.88	Sec
Action Time Specific Impulse Corrected to Vacuum	266.59	Sec
Propellant Specific Impulse Corrected to Vacuum	268.12	Sec

Table 7.7.4-1. Summary of Measured Ballistic and Nozzle Performance Data (Cont)

CORRECTED TO 90 DEGREES F

D. Time and Ballistic Data

Time at First Indication of Head-end Pressure	0.028	Sec
Time When Head-end Chamber Pressure Achieves 563.5 PSIA during ignition	0.220	Sec
Time at Last Indication of Head-end Pressure	120.1	Sec
Time at Web Bisector	107.9	Sec
Web Time	107.6	Sec
Action Time	119.2	Sec
Maximum Measured Head-end Pressure	951.4	PSIA
Time at Maximum Head-end Pressure	0.614	Sec
Maximum Thrust Corrected to Vacuum	3,423,000	Lbf
Maximum Nozzle Stagnation Pressure	865.6	PSIA
Web Time Average Head-end Chamber Pressure	687.9	PSIA
Action Time Average Head-end Chamber Pressure	637.3	PSIA
Web Time Average Nozzle Stagnation Pressure	669.0	PSIA
Action Time Average Nozzle Stagnation Pressure	620.1	PSIA
Web Time Average Thrust Corrected to Vacuum	2,691,000	Lbf
Action Time Average Thrust Corrected to Vacuum	2,494,000	Lbf

E. Impulse Data

Total Impulse Corrected to Vacuum	297.59	Mlbf-sec
20 Second Impulse Corrected to Vacuum	66.30	Mlbf-sec
60 Second Impulse Corrected to Vacuum	177.64	Mlbf-sec
Web Time Impulse Corrected to Vacuum	289.66	Mlbf-sec
Action Time Impulse Corrected to Vacuum	297.41	Mlbf-sec
Specific Impulse Corrected to Vacuum	267.08	Sec
Web Time Specific Impulse Corrected to Vacuum	267.37	Sec
Action Time Specific Impulse Corrected to Vacuum	267.08	Sec
Propellant Specific Impulse Corrected to Vacuum	268.61	Sec

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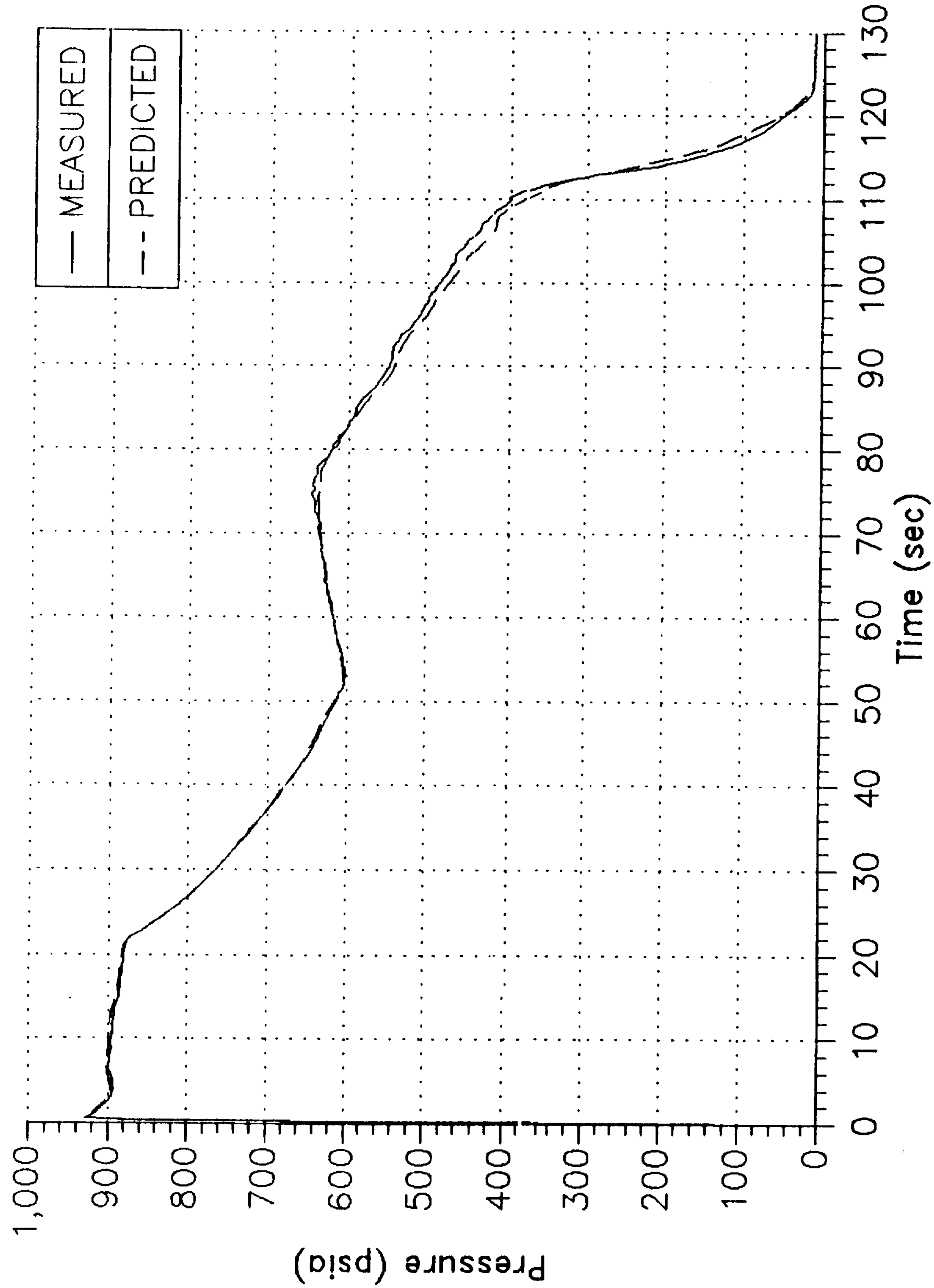

Figure 7.7.4-1. TEM-3 Predicted and Measured Pressure at 70°F

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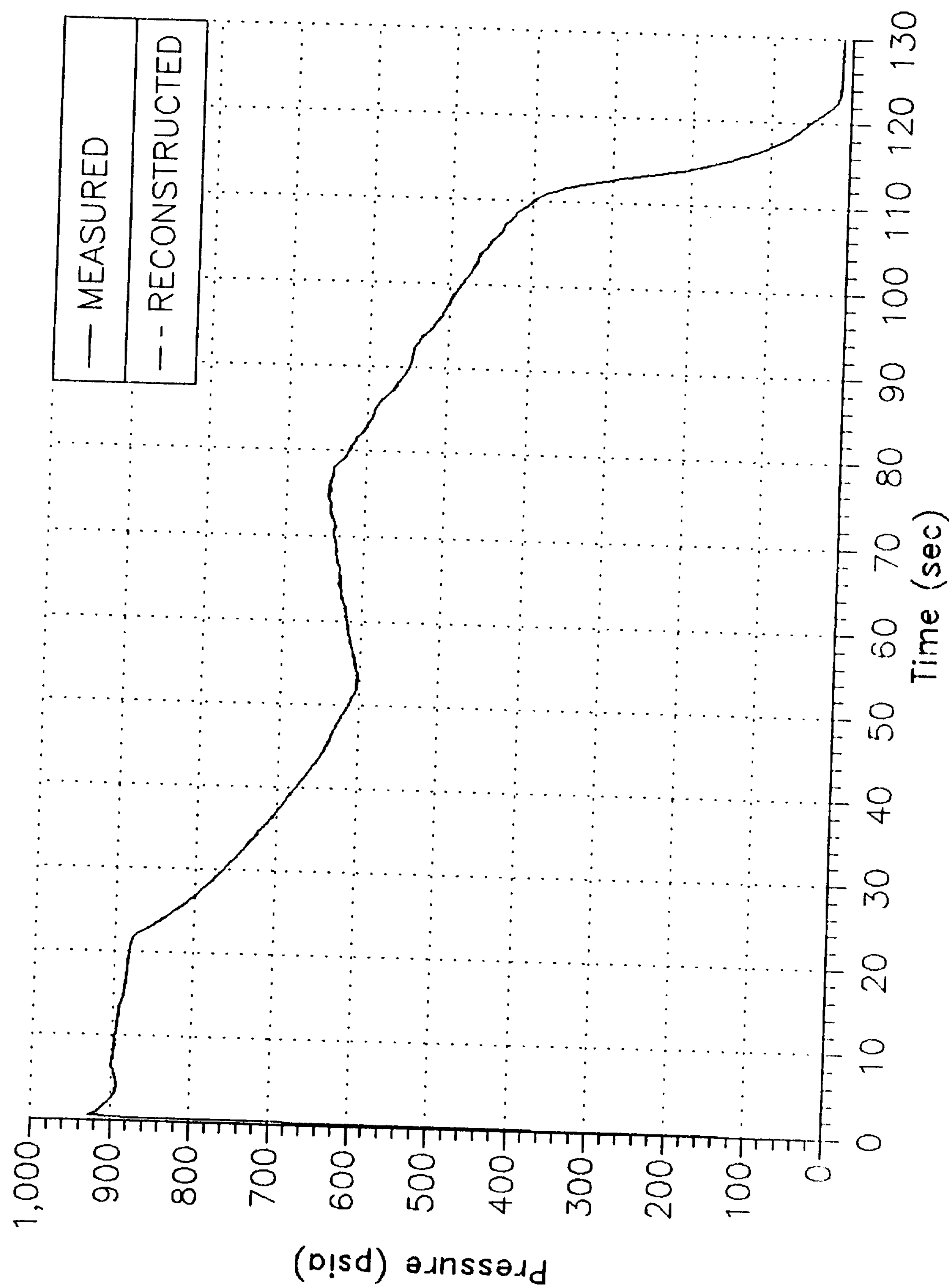

Figure 7.7.4-2. TEM-3 Reconstructed and Measured Pressure at 70°F

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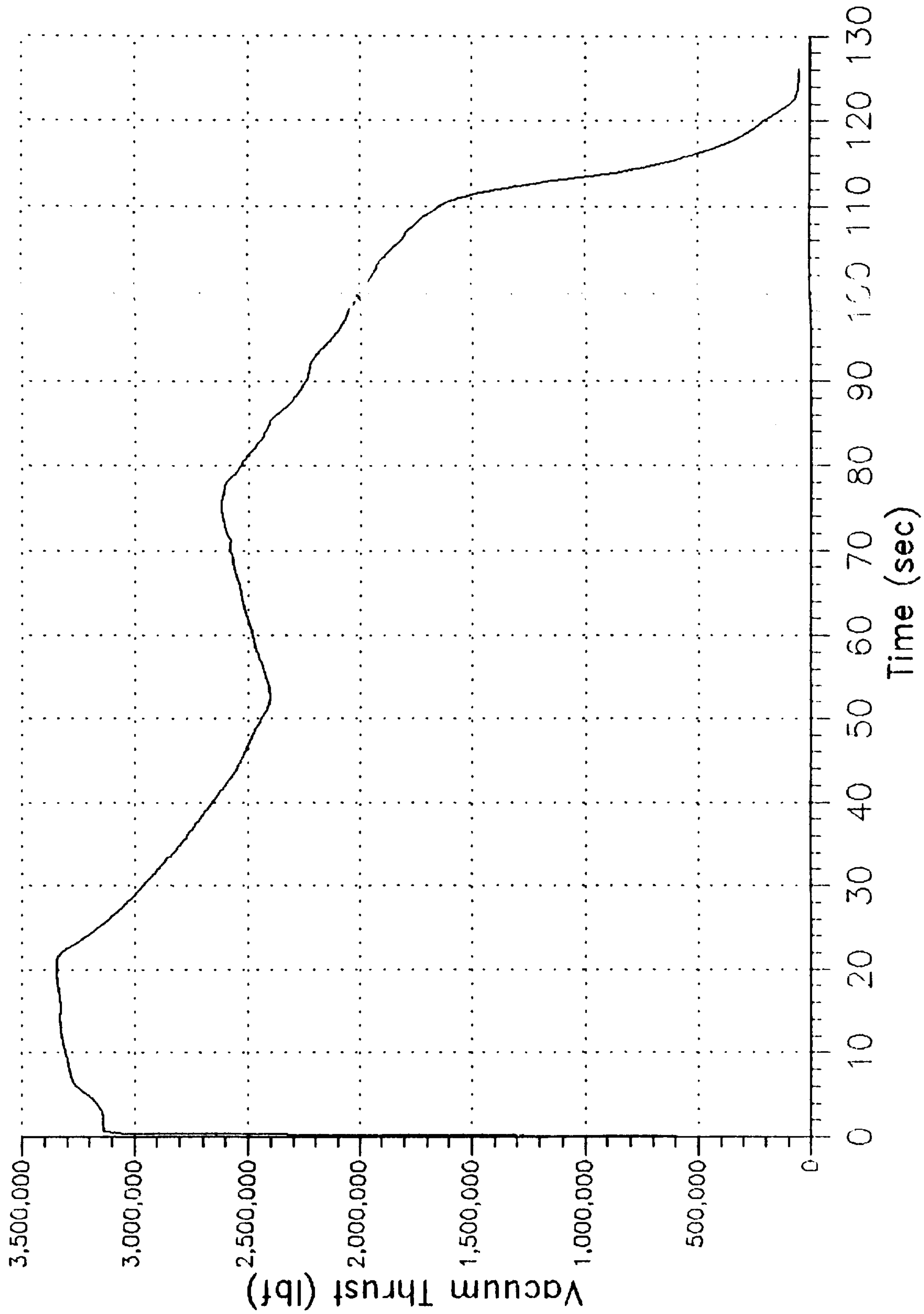

Figure 7.7.4-3. TEM-3 Reconstructed Vacuum Thrust at 70°F

Table 7.7.4-2. Burnrate Data Comparison Subscale to Full-Scale

	BURN RATE				SCALE FACTOR
MOTOR	SRM TARGET	5" CP STD.	SRM PRED.	SRM DEL.	5" CP STD.
SRM-15A	0.368	0.366	0.370	0.3701	1.0112
SRM-15B	0.368	0.366	0.370	0.3709	1.0134
SRM-16A	0.368	0.365	0.369	0.3684	1.0093
SRM-16B	0.368	0.365	0.369	0.3688	1.1040
SRM-17A	0.368	0.363	0.367	0.3680	1.0138
SRM-17B	0.368	0.362	0.366	0.3694	1.0204
SRM-18A	0.368	0.362	0.367	0.3693	1.0202
SRM-18B	0.368	0.363	0.368	0.3690	1.0165
SRM-19A	0.368	0.364	0.369	0.3703	1.0173
SRM-19B	0.368	0.364	0.369	0.3704	1.0176
SRM-20A	0.368	0.368	0.373	0.3742	1.0168
SRM-20B	0.368	0.366	0.371	0.3744	1.0230
SRM-21A	0.368	0.367	0.370	0.3737	1.0183
SRM-21B	0.368	0.365	0.368	0.3744	1.0258
SRM-22A	0.368	0.362	0.365	0.3675	1.0152
SRM-22B	0.368	0.362	0.365	0.3697	1.0213
SRM-23A	0.368	0.364	0.367	0.3713	1.0201
SRM-23B	0.368	0.364	0.367	0.3721	1.0223
SRM-24A	0.368	0.360	0.365	0.3678	1.0217
SRM-24B	0.368	0.361	0.366	0.3674	1.0177
AVERAGE SCALE FACTOR = 1.0175, SIGMA = 0.00440, %CV = 0.432					
ETM-1	0.368	0.365	0.372	0.3681	1.0085
DM-8	0.368	0.360	0.366	0.3677	1.0214
DM-9	0.368	0.362	0.368	0.3691	1.0196
QM-6	0.368	0.360	0.366	0.3665	1.0181
QM-7	0.368	0.358	0.364	0.3657	1.0215
PVM-1	0.368	0.360	0.366	0.3677	1.0214
TEM-01	0.368	0.362	0.368	0.3659	1.0108
TEM-02	0.368	0.362	0.368	0.3664	1.0130
TEM-03	0.368	0.362	0.368	0.3672	1.0156

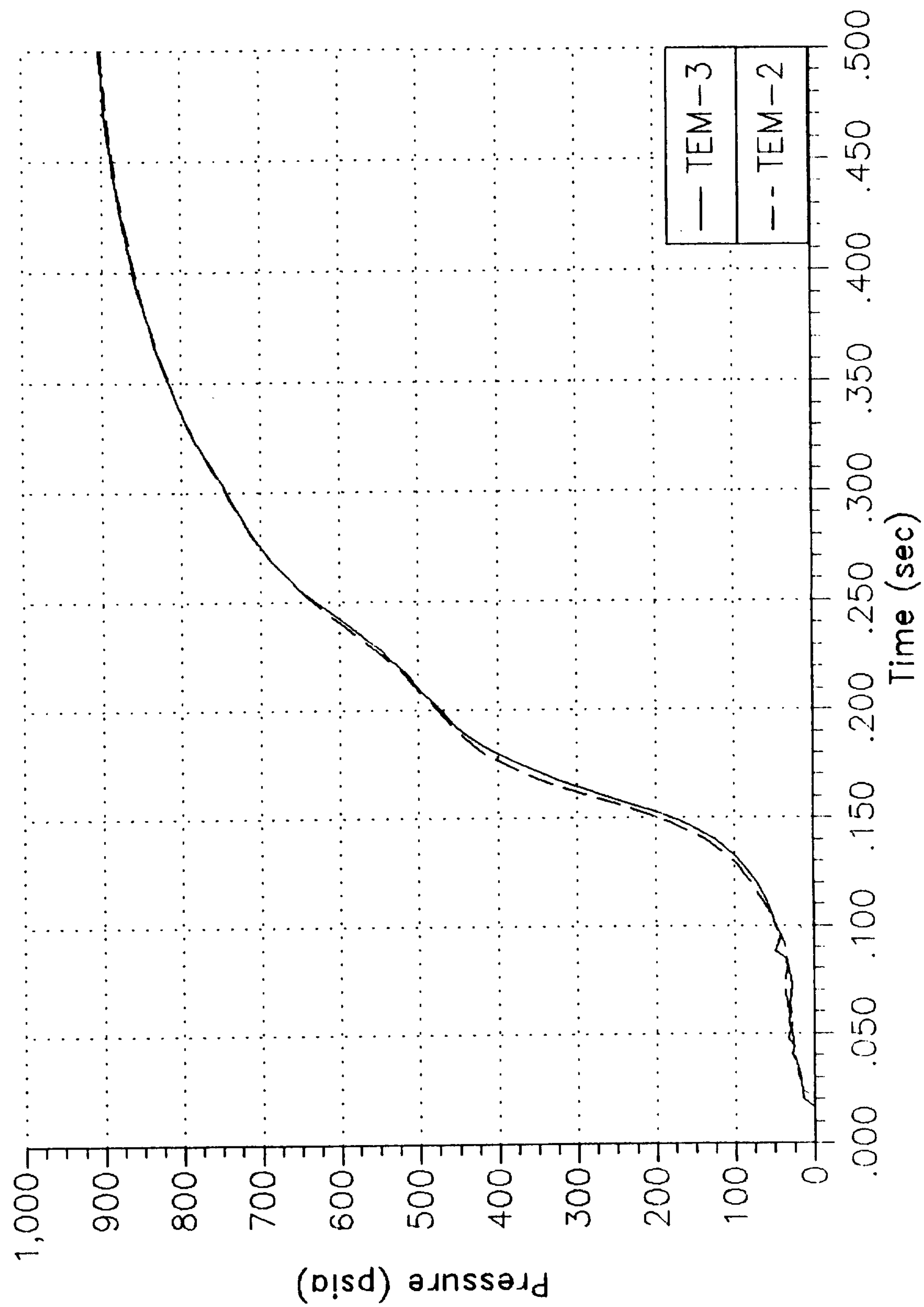

Figure 7.7.4-4. Measured Head-End Pressure Transients

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Table 7.7.4-3. Historical Three-Point Average Thrust and Pressure Rise Rate Data

MOTOR	OCCURRENCE TIME	PRESSURE RISE RATE	OCCURRENCE TIME	THRUST RISE RATE	IGNITION INTERVAL
STATIC TEST					
DM-2	0.1480	85.30	0.1480	245,380	0.2330
QM-1	0.1560	86.38	0.1560	246,128	0.2362
QM-2	0.1640	93.58	0.1720	234,950	0.2391
QM-3	0.1560	94.45	0.1520	245,615	0.2287
QM-4	0.1505	91.96	0.2225	234,438	0.2192
ETM-1A	0.1520	86.72	0.1560	230,023	0.2279
DM-8	0.1680	77.00	0.1760	257,272	0.2424
DM-9	0.1640	81.00	0.1720	275,525	0.2436
QM-6	0.1480	87.40	0.1520	211,476	0.2321
QM-7	0.1480	99.60	N/A	N/A	0.2230
PVM-1	0.1520	92.80	0.1520	294,664	0.2338
TEM-1	0.1520	85.13	0.1520	238,583	0.2255
QM-8	0.1720	72.30	N/A	N/A	0.2517
FLIGHT MOTORS					
SRM-1A	0.1530	87.58			0.2373
SRM-1B	0.1500	91.57			0.2358
SRM-2A	0.1530	90.74			0.2348
SRM-2B	0.1660	90.27			0.2345
SRM-3A	0.1500	91.05			0.2308
SRM-3B	0.1500	89.68			0.2271
SRM-5A	0.1530	95.10			0.2361
SRM-5B	0.1660	84.43			0.2380
SRM-6A	0.1530	92.72			0.2342
SRM-6B	0.1470	88.22			0.2329
SRM-7A	0.1500	99.90			0.2282
SRM-7B	0.1500	99.32			0.2276
SRM-8A	0.1530	106.29			0.2224
SRM-8B	0.1500	91.06			0.2196
SRM-9A	0.1530	92.31			0.2303
SRM-10A	0.1530	92.89			0.2373
SRM-10B	0.1500	84.56			0.2342
SRM-13B	0.1410	98.85			0.2115
RSRM-1A	0.1501	99.0			0.2296
RSRM-1B	0.1596	80.5			0.2310
RSRM-2A	0.1564	87.3			0.2390
RSRM-2B	0.1501	100.2			0.2342
NUMBER		35		11	35
AVERAGE		90.49		246,732	0.2321
STANDARD DEVIATION		7.07		22,627	0.0076
% COEFFICIENT OF VARIATION		7.82		9.17	3.27
TEM-02	0.1520	94.40	0.1520	288,722	0.2280
TEM-03	0.1520	88.51	N/A	N/A	0.2272

Table 7.7.4-4. Measured SRM Ignition Performance Data at 70°F

Parameter	TEM-3	Specification Requirement
Maximum Igniter Mass Flow Rate (lbm/sec)	351.5	NA
Ignition Transient (sec) (0 to 563.5 psia)	0.227	0.170 - 0.340
Maximum Pressure Rise Rate (psi/10-MSFC)	88.5	109
Pressure Level at Start of Maximum Rise Rate (psia)	220	NA
Time Span of Maximum Pressure Rise (ms)	1,520 - 1,620	NA
Equilibrium Pressure 0.6 sec (ignition end) (psia)	929	NA
Time to First Ignition (sec) (begin pressure rise)	0.029	NA

igniter performance characteristics were within the expected ranges. TEM-3 igniter performance corrected to 80°F is compared to the igniter limits at 80°F and is shown in Figure 7.7.4-5. TEM-3 is well within the limits at 80°F.

A comparison of the igniter pressure versus motor head-end and nozzle stagnation pressure for the first 1.4 sec of motor operation is shown in Figure 7.7.4-6. A plot of head-end and nozzle stagnation pressure for the full duration of the static test is shown in Figure 7.7.4-7. These curves are characteristic of the ratio of the head-end:nozzle stagnation pressures from previous SRM static test motors.

The TEM-3 static test motor was instrumented with a dynamic (A-C coupled) pressure gage to provide oscillatory head-end to nozzle chamber pressure data. This gage was designated as P000016, and was provided with a dedicated port for accurate measurement of oscillating pressure.

Data acquired from gage P000016 are displayed in a waterfall plot format in Figure 7.7.4-8. The 1-L and 2-L acoustic modes can be observed at about 15 and 30 Hz, respectively. This waterfall plot is fairly typical of HPM designs. Figure 7.7.4-9 describes the running, instantaneous, peak-to-peak oscillation amplitudes of the 1-L acoustic mode for the TEM-3 motor during the last half of operation. This type of analysis is more representative of instantaneous oscillations than are the time averaged oscillations presented in a waterfall plot. Figure 7.7.4-9 shows maximum peak-to-peak oscillations of 1.15 psi.

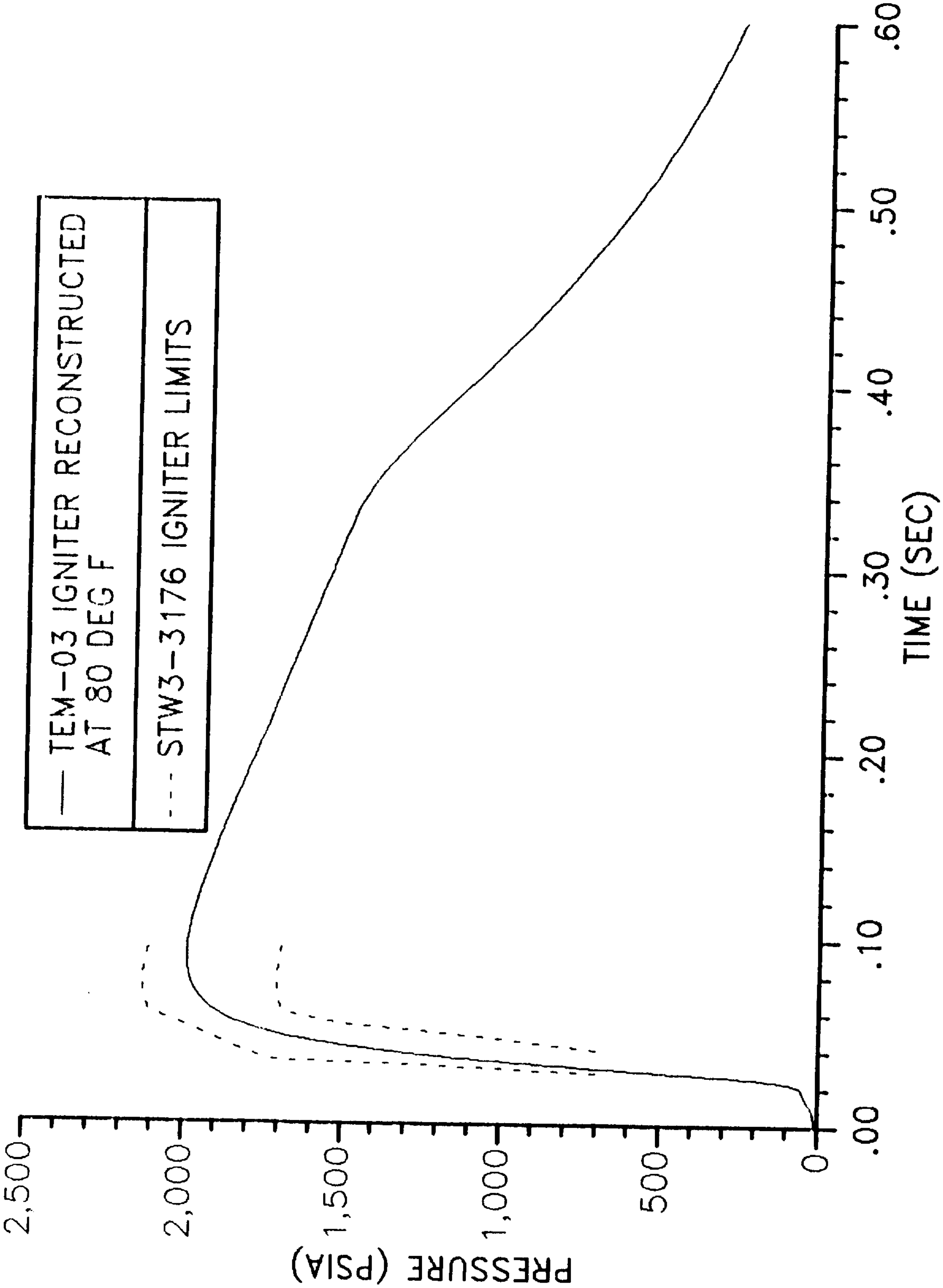
Figure 7.7.4-10 is waterfall plot of P000016 data acquired from the last HPM static test motor, TEM-2. This figure is provided for comparison purposes, and a number of observations regarding the two motors can be made:

--Both motors have similar acoustic signatures.

--TEM-3 experienced slightly stronger 2-L mode oscillations than TEM-2.

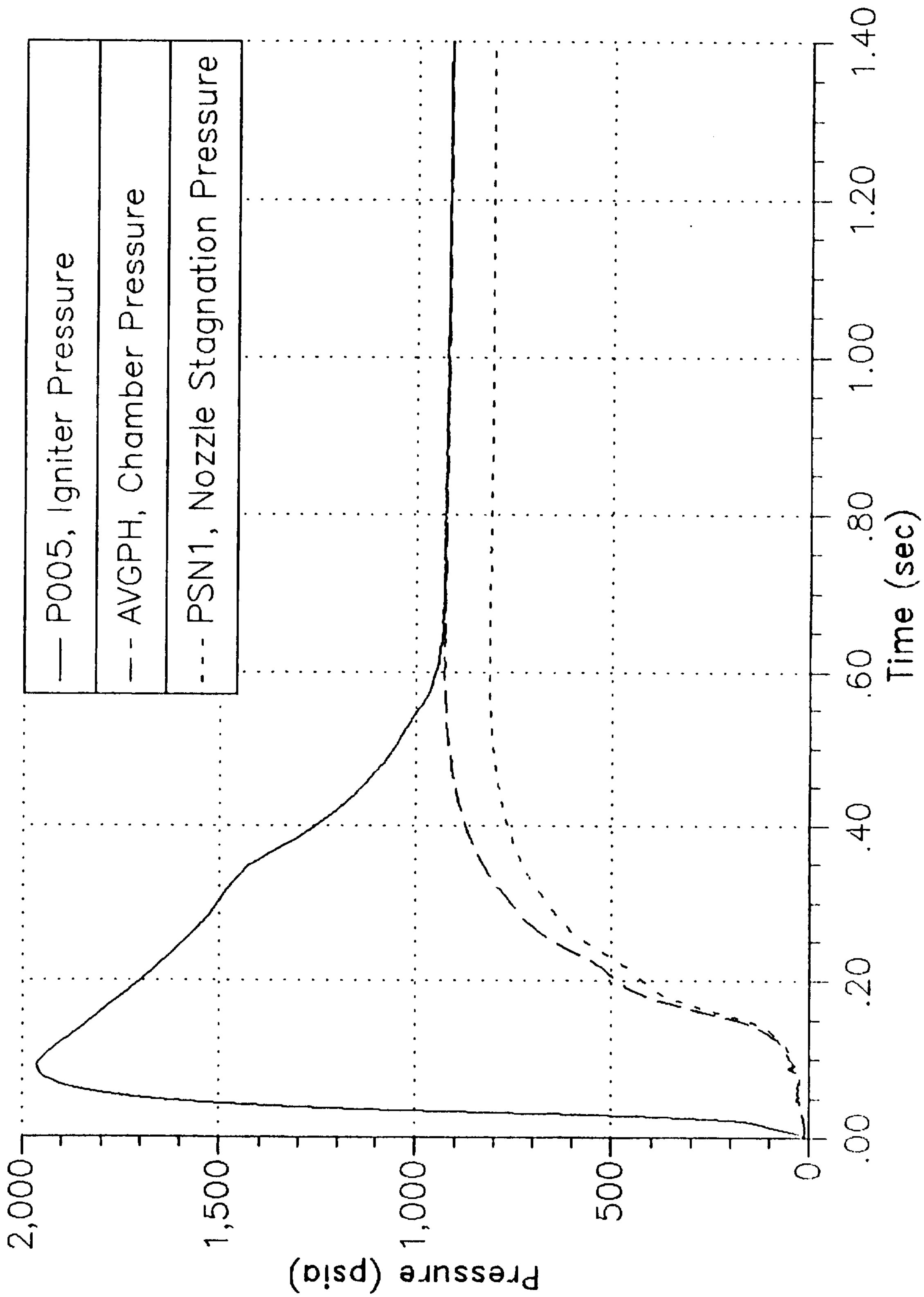
--Both motors have acoustic behavior typical of HPM designs. The 1-L mode amplitude is low compared to RSRM static test motors.

When using waterfall plots to compare static test motor oscillation amplitudes, it is important to remember that this format uses an averaging method of analysis. This presents no difficulty for steady state signals but has an attenuating effect on transient signals. Since most of the data obtained from a solid rocket motor are transient, any oscillation magnitudes referred to as maxima are not true but averaged values over a given time slice. Nonetheless, these numbers are very useful for comparison. Table 7.7.4-5 shows such a comparison for recent static test motors and the flight motors. DM-6 and DM-7 were filament wound case (FWC) motors.



89890-5E

Figure 7.7.4-5. Comparison of Igniter Performance to Igniter Limits



89890-5F

Figure 7.7.4-6. TEM-3 Igniter Pressure Versus Head-End and Nozzle Stagnation Pressure

89890-5C

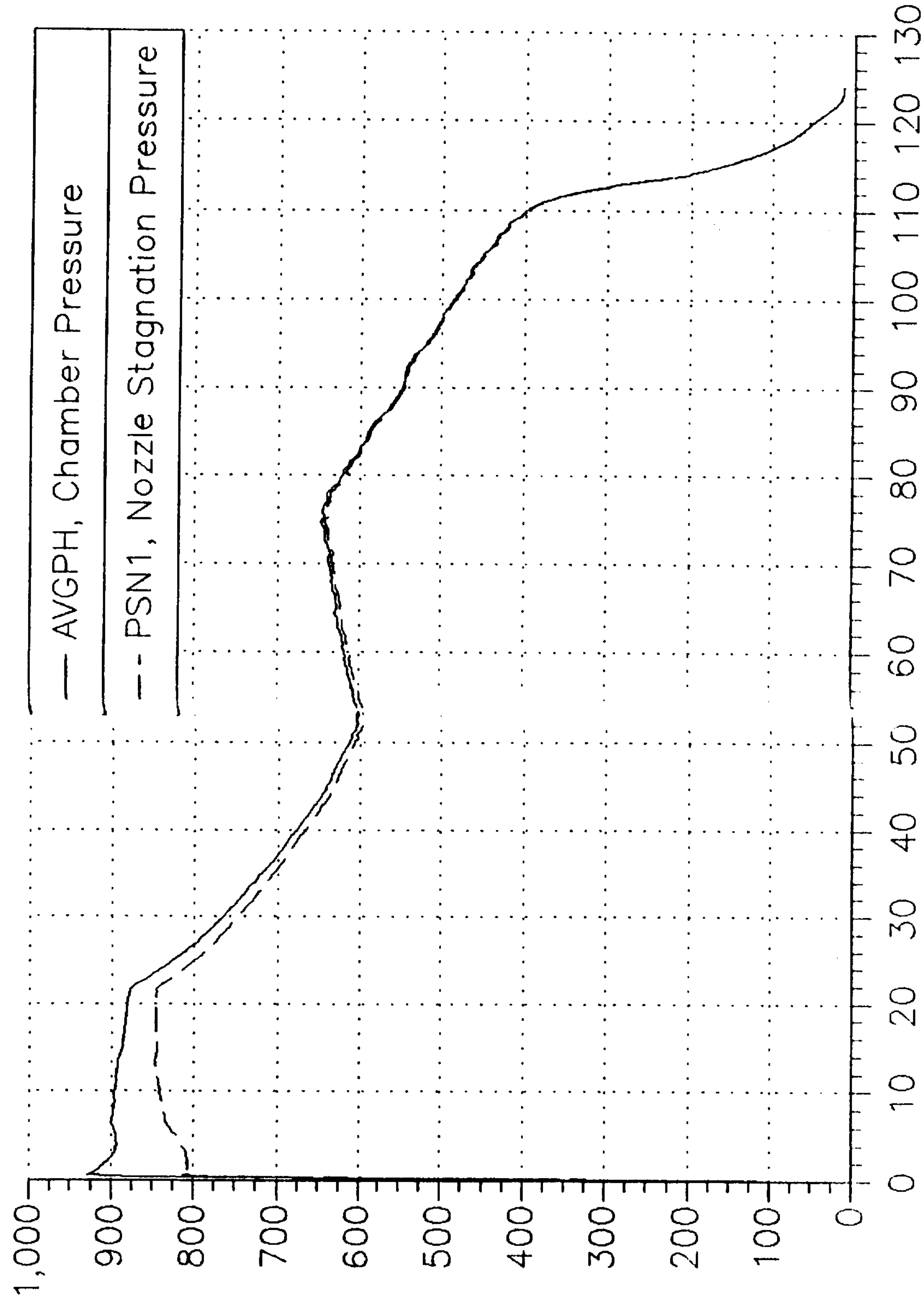


Figure 7.7.4-7. TEM-3 Measured Head-End and Nozzle Stagnation Pressure Time Histories

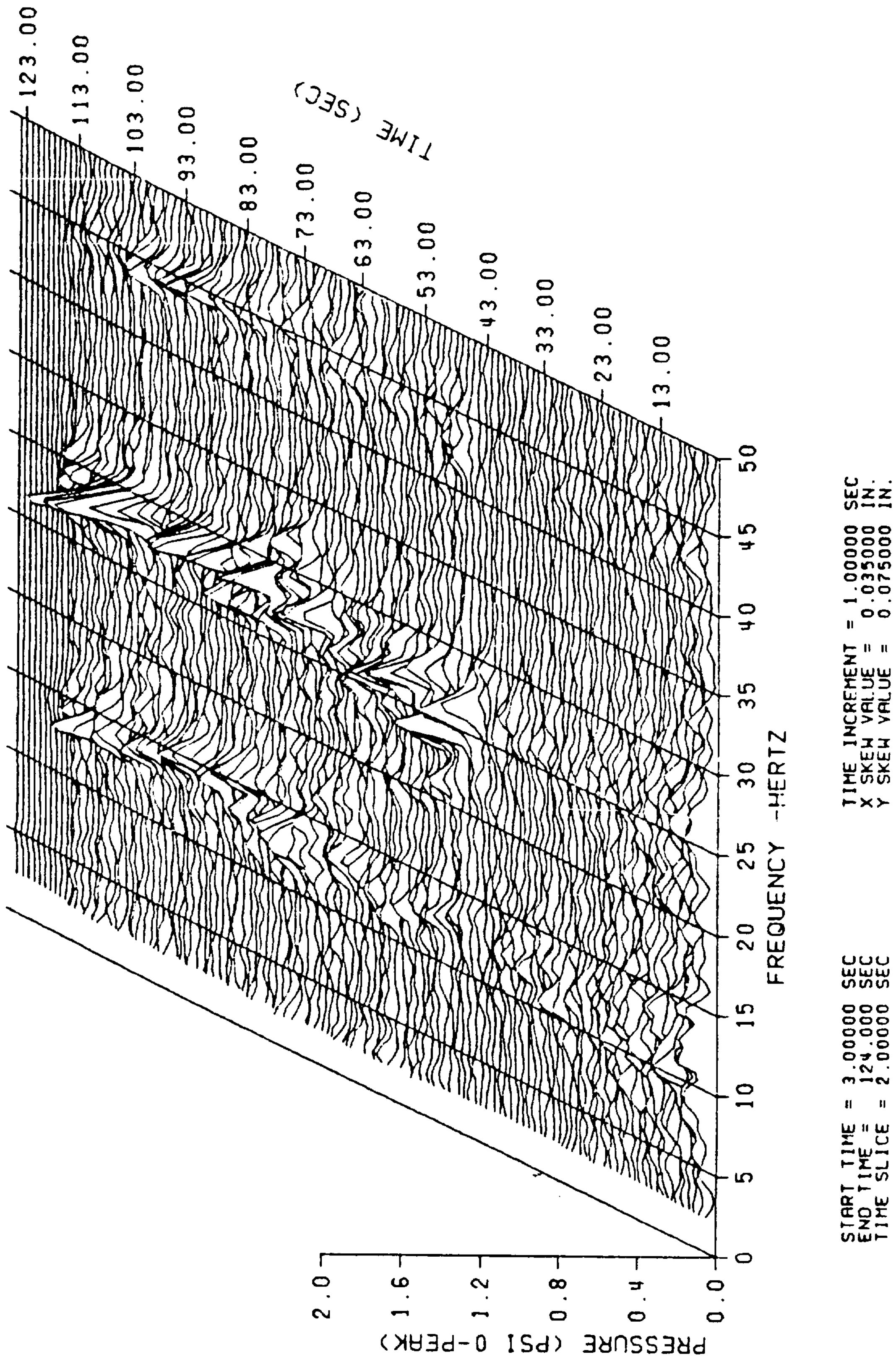


Figure 7.7.4-8. Shuttle TEM-3 P016 FM

89890-5Q

89890-50

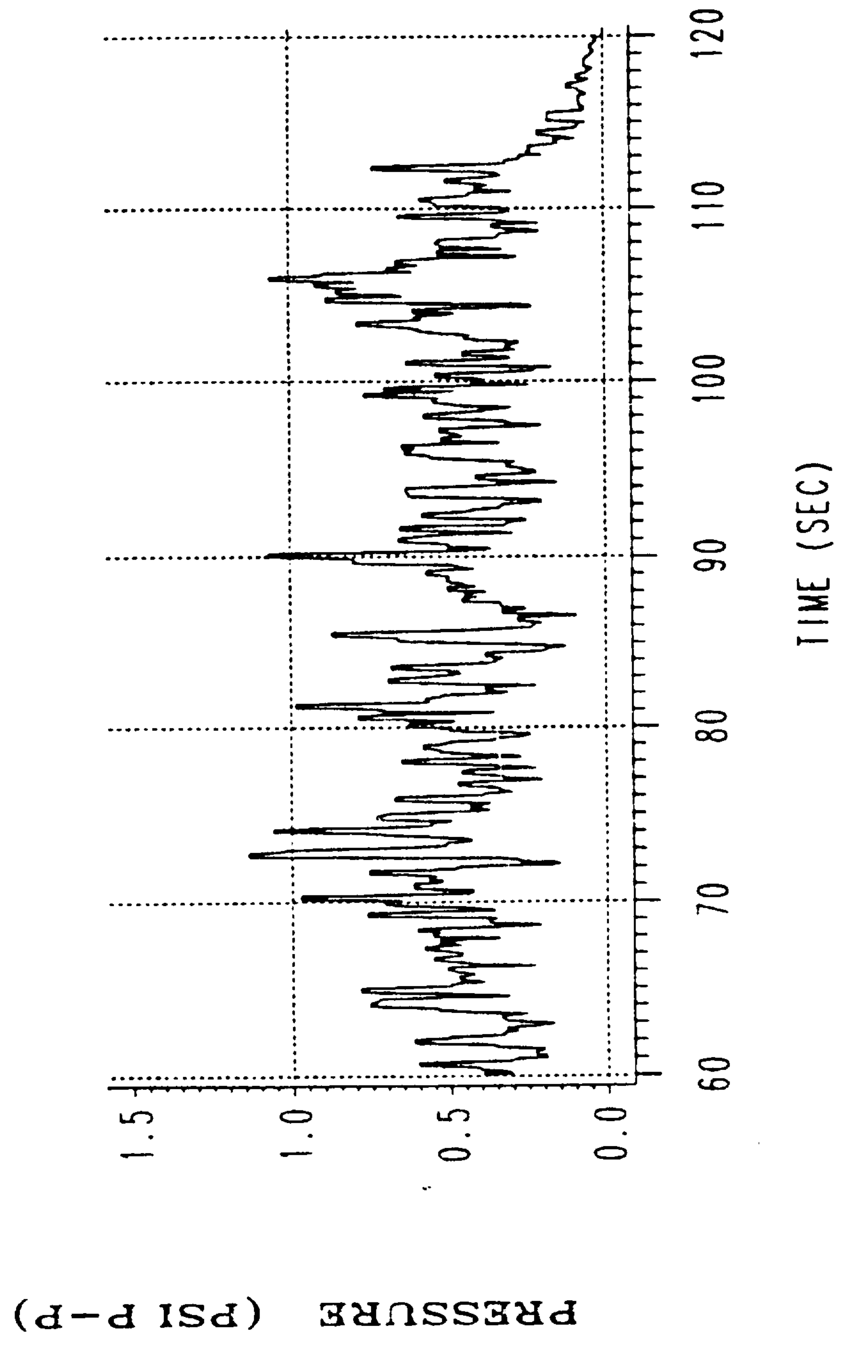


Figure 7.7.4-9. Maximum Oscillation Amplitudes 1-L Acoustic Mode 2000 SPS

89890-5P

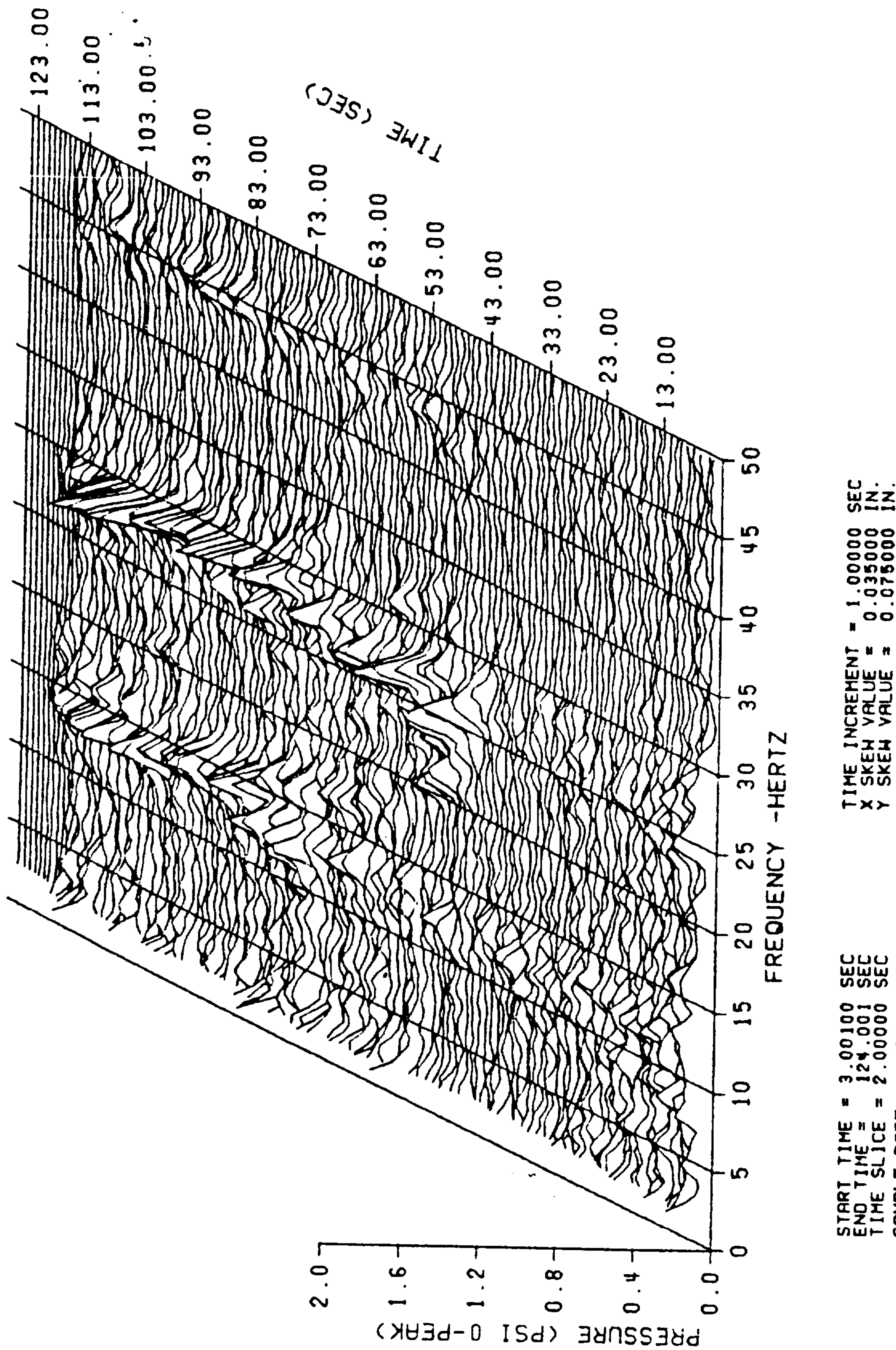
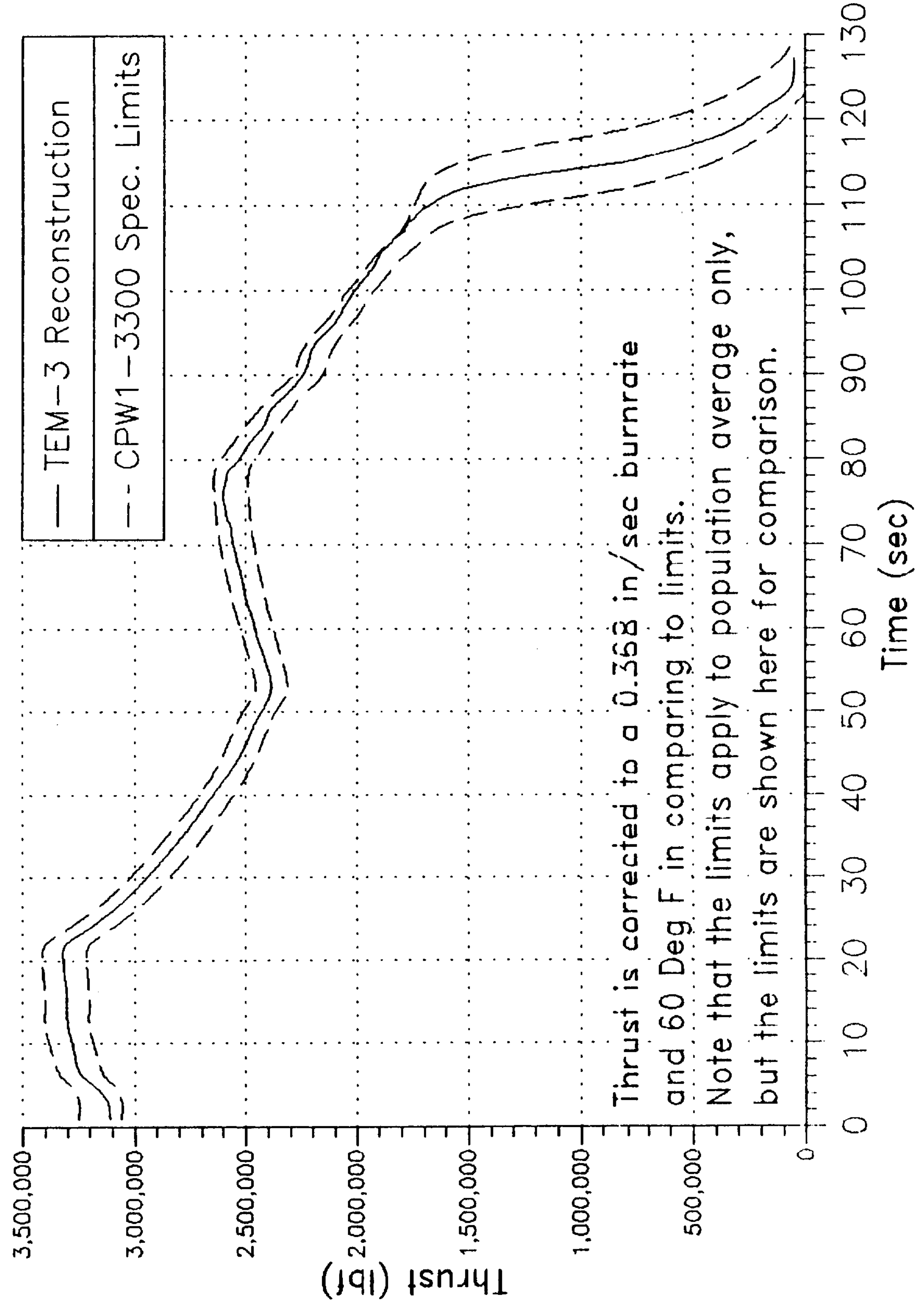


Figure 7.7.4-10. Shuttle TEM-2 P016

Table 7.7.4-5. Maximum Pressure Oscillation Amplitude Comparison

MOTOR	SOURCE OF MEASUREMENT	MODE	TIME OF MEASUREMENT	FREQUENCY (HZ)	MAX PRESSURE (PSI 0-TO-PEAK)
TEM-03	Waterfall	1-L	106	15.0	0.36
		2-L	102	30.0	0.61
TEM-02	Waterfall	1-L	78	16.0	0.40
		2-L	100	29.5	0.59
QM-8	Waterfall	1-L	104	14.5	1.11
		2-L	55	27.5	0.45
TEM-01	Waterfall	1-L	79	15.5	0.53
		2-L	95	29.5	1.07
STS-27 (left)	Waterfall	1-L	82	15.5	0.37
	AC OPT	2-L	82	29.5	0.60
STS-27 (right)	Waterfall	1-L	82	15.5	0.57
	AC OPT	2-L	83	29.5	0.72
STS-26 (left)	Waterfall	1-L	79	16.0	0.70
	AC OPT	2-L	95	29.5	0.87
STS-26 (right)	Waterfall	1-L	83	15.0	0.54
	AC OPT	2-L	94	30.0	0.47
PVM-1	Waterfall	1-L	99	14.5	1.76
		2-L	79	29.5	1.05
QM-7	Waterfall	1-L	93	14.5	1.40
	P000001	2-L	79	29.5	0.95
QM-6	Waterfall	1-L	107	14.5	1.50
		2-L	83	29.5	0.65
DM-9	Waterfall	1-L	107	14.5	1.15
		2-L	96	30.0	0.88
DM-8	Waterfall	1-L	78	16.0	0.83
		2-L	97	29.5	0.85
ETM-1A	Waterfall	1-L	83	15.5	0.47
		2-L	100	29.5	0.55
DM-7	Waterfall	1-L	77	15.5	1.29
		2-L	93, 96	29.5	0.86
DM-6	Waterfall	1-L	76	15.5	0.51
		2-L	86	29	0.78
QM-4	Waterfall	1-L	93	14	0.41
		2-L	83	29	0.35

A comparison of TEM-3 reconstructed thrust data, corrected to 60°F and a burn rate of 0.368 in./sec at 625 psia and 60°F with the CEI Specification CPW1-3300, 15 Jan 1986, thrust time limits at 0.368 in./sec, is shown in Figure 7.7.4-11. The TEM-3 performance is within average population limits, except at 106 sec. Note that the limits are for the average of the historical SRM population, not an individual motor. The historical motor population is well within the limits. None of the individual motor performance tolerances and limit parameters were exceeded. The TEM-3 ignition performance satisfied the ignition interval and the maximum pressure rise rate requirements. Both the ignition interval and maximum pressure rise rate were well within the specification limits as shown in Table 7.7.4-4.



89890-5D

Figure 7.7.4-11. TEM-3 Reconstructed Thrust Compared to CEI Specification Limits

Appendix A

TEM-3 DRAWING TREES

DRAWING TREES

TEM–3

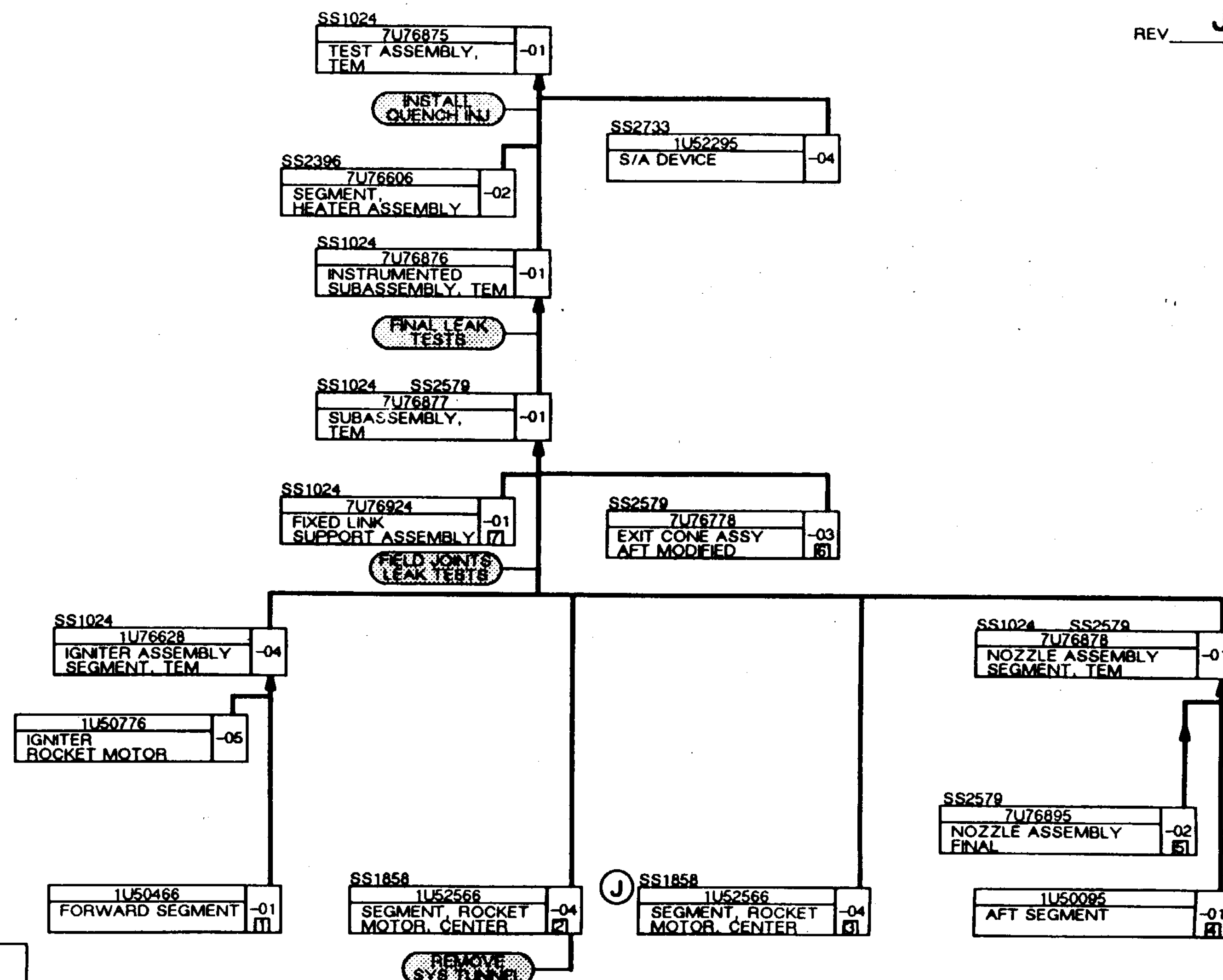
REV I **DATE 03–31–89**

PREPARED BY: Hilda Beutler 4-3-89
H. BEUTLER
CCB PROJECT ENGINEER

APPROVED BY: J F Rittenhouse
J. F. RITTENHOUSE
PROJECT ENGINEER

AUTOMATED BY: Lynn Koberna
L. KOBERNA
SYSTEM INTEGRATION

REV J



J

1. USE S/N 0000041 (31B)
2. C/F, USE S/N 0000001 (29A)
3. MAKE FROM 1U52566-01 (908) S/N 0000001
4. USE S/N 0000002 (30B)
5. MAKE FROM 1U52728-01(909), S/N 0000001(26B)
6. MAKE FROM 1U50524-01, S/N 0000007
7. MAKE FROM 1U52034

Appendix B

INSTRUMENTATION LIST

TABLE A --TEM-3 INSTRUMENTATION LIST
(SEE LAST PAGE FOR NOTES AND DEFINITIONS)

PL7U76876 SHEET 4

INST NO.	ANG LOC	STATION	MEAS DIR	EXPECTED RANGE	REQ ACC	FM (Hz)	DIG (SPS)	REMARKS	PPIORITY, NOTES
D000205	25.0	1898.30	RADIAL	+/- 10IN	+/-1%		250	NOZZLE CENTERLINE	R
D000206	151.0	1898.30	RADIAL	+/- 10IN	+/-1%		250	NOZZLE CENTERLINE	R
D000207	151.0	1898.30	RADIAL	+/- 10IN	+/-1%		250	NOZZLE CENTERLINE	R
D000208	209.0	1898.30	RADIAL	+/- 10IN	+/-1%		250	NOZZLE CENTERLINE	R
D000209	209.0	1898.30	RADIAL	+/- 10IN	+/-1%		250	NOZZLE CENTERLINE	R
D000210	299.0	1898.30	RADIAL	+/- 10IN	+/-1%		250	NOZZLE CENTERLINE	R
D000211	299.0	1898.30	RADIAL	+/- 10IN	+/-1%		250	NOZZLE CENTERLINE	R
D000212	25.0	1898.30	RADIAL	+/- 10IN	+/-1%		250	NOZZLE CENTERLINE	R
D000213	151.0	1898.30	RADIAL	+/- 10IN	+/-1%		250	NOZZLE CENTERLINE	R
D000214	209.0	1898.30	RADIAL	+/- 10IN	+/-1%		250	NOZZLE CENTERLINE	R
D000215	299.0	1898.30	RADIAL	+/- 10IN	+/-1%		250	NOZZLE CENTERLINE	R
D000216	25.0	1898.30	RADIAL	+/- 10IN	+/-1%		250	NOZZLE CENTERLINE	R
D000230	0.0	1867.41	AXIAL	+/- 2IN	+/-1%		250	NOZZLE CENTERLINE	R
D000231	90.0	1867.41	AXIAL	+/- 2IN	+/-1%		250	NOZZLE CENTERLINE	R
D000232	180.0	1867.41	AXIAL	+/- 2IN	+/-1%		250	NOZZLE CENTERLINE	R
D000233	270.0	1867.41	AXIAL	+/- 2IN	+/-1%		250	NOZZLE CENTERLINE	R
F001000	45.0		AXIAL	0-10,000 LBS	+/-5%		250	FIXED LINK (FULL BRIDGE)	R,5
F001001	135.0		AXIAL	0-10,000 LBS	+/-5%		250	FIXED LINK (FULL BRIDGE)	R,5
P000001	40.0	487.00		0-1,000 PSI	+/-2%	2K	2K	CHAMBER PRESSURE	M,1,5
P000002	270.0	487.00		0-1,000 PSI	+/-1%		2K	CHAMBER PRESSURE	R,1,5
P000003	180.0	487.00		0-1,000 PSI	+/-1%		2K	CHAMBER PRESSURE	M,1,5
P000005	115.0	487.00		0-3,000 PSI	+/-2%	2K	2K	IGNITER PRESSURE	R,1,5
P000016	100.0	487.00		+/-10 PSI	+/-2%	100	1K	CHAMBER OSCILLATION	R,5
P000020				0-500 PSIG	+/-5%		250	WATER DELUGE PRESSURE	R,2,7
T000638	0.0	1511.00		0-2,400 DEG F	+/-5%			SLAG TEMP,AFT SEGMENT	M,7,10
T000830	0.0	772.00		0-2,400 DEG F	+/-5%			SLAG TEMP,FORWARD SEGMENT	M,7,10
T000831	0.0	1091.00		0-2,400 DEG F	+/-5%			SLAG TEMP,CENTER/FWD SEG	M,7,10
T000832	0.0	1411.00		0-2,400 DEG F	+/-5%			SLAG TEMP,CENTER/AFT SEG	M,7,10
T000833	17.3	1511.00		0-2,400 DEG F	+/-5%			SLAG TEMP,AFT SEGMENT	M,7,10
T000834	28.3	1511.00		0-2,400 DEG F	+/-5%			SLAG TEMP,AFT SEGMENT	M,7,10
T000835	334.9	1511.00		0-2,400 DEG F	+/-5%			SLAG TEMP,AFT SEGMENT	M,7,10

TABLE A --TEM-3 INSTRUMENTATION LIST
(SEE LAST PAGE FOR NOTES AND DEFINITIONS)

INST NO.	ANG LOC	STATION	MEAS DIR	EXPECTED RANGE	REQ ACC	FM (Hz)	DIG (SPS)	REMARKS	PRIORITY, NOTES
T000836	349.8	1511.00		0-2,400 DEG F	+/-5%			SLAG TEMP,AFT SEGMENT	M,7,10
T000837	0.0	1529.00		0-2,400 DEG F	+/-5%			SLAG TEMP,AFT SEGMENT	M,7,10
T000838	0.0	1547.00		0-2,400 DEG F	+/-5%			SLAG TEMP,AFT SEGMENT	M,7,10
T000839	0.0	1598.00		0-2,400 DEG F	+/-5%			SLAG TEMP,AFT SEGMENT	M,7,10
T000840	0.0	1652.00		0-2,400 DEG F	+/-5%			SLAG TEMP,AFT SEGMENT	M,7,10
T000841	0.0	1727.00		0-2,400 DEG F	+/-5%			SLAG TEMP,AFT SEGMENT	M,7,10
T000842	344.0	1563.00		0-2,400 DEG F	+/-5%			SLAG TEMP,AFT SEGMENT	M,7,10
T000843	13.3	1566.00		0-2,400 DEG F	+/-5%			SLAG TEMP,AFT SEGMENT	M,7,10
T000844	354.9	1538.00		0-2,400 DEG F	+/-5%			SLAG TEMP,AFT SEGMENT	M,7,10
T000845	27.0	1535.00		0-2,400 DEG F	+/-5%			SLAG TEMP,AFT SEGMENT	M,7,10
T000846	339.2	1533.00		0-2,400 DEG F	+/-5%			SLAG TEMP,AFT SEGMENT	M,7,10
T000875	94.5	487.00		0-400 DEG F	+/-5%		32	IGNITER HEATER TEMP	M,6,7
T000878	274.5	487.00		0-400 DEG F	+/-5%		32	IGNITER HEATER TEMP	M,6,7
T001001	15.0	848.00		0-200 DEG F	+/-5%		32	HEATER TEMP	M,5,6,7
T001002	135.0	848.00		0-200 DEG F	+/-5%		32	HEATER TEMP	M,5,6,7
T001003	195.0	848.00		0-200 DEG F	+/-5%		32	HEATER TEMP	M,5,6,7
T001004	285.0	848.00		0-200 DEG F	+/-5%		32	HEATER TEMP	M,5,6,7
T001005	15.0	1168.00		0-200 DEG F	+/-5%		32	HEATER TEMP	M,5,6,7
T001006	135.0	1168.00		0-200 DEG F	+/-5%		32	HEATER TEMP	M,5,6,7
T001007	195.0	1168.00		0-200 DEG F	+/-5%		32	HEATER TEMP	M,5,6,7
T001008	285.0	1168.00		0-200 DEG F	+/-5%		32	HEATER TEMP	M,5,6,7
T001009	15.0	1488.00		0-200 DEG F	+/-5%		32	HEATER TEMP	M,5,6,7
T001010	135.0	1488.00		0-200 DEG F	+/-5%		32	HEATER TEMP	M,5,6,7
T001011	195.0	1488.00		0-200 DEG F	+/-5%		32	HEATER TEMP	M,5,6,7
T001012	285.0	1488.00		0-200 DEG F	+/-5%		32	HEATER TEMP	M,5,6,7
T001300	270.0	1875.00		0-400 DEG F	+/-5%		32	NOZZLE-CASE JOINT HEATER TEMP	M,5,6,7
T001301	275.0	1875.00		0-400 DEG F	+/-5%		32	NOZZLE-CASE JOINT HEATER TEMP	M,5,6,7
X000001				+/-0.1 SEC			32	PRIMARY IGNITION (T-0)	M,4
X000004				+/-0.1 SEC			32	QUENCH SYSTEM FWD	R,4
X000005				+/-0.1 SEC			32	QUENCH SYSTEM AFT	R,4
X000026				+/-0.1 SEC				(T-0) FM1	M,4

TABLE A—TEM-3 INSTRUMENTATION LIST

PRIORITY:
M MANDATORY. APPROVAL BY VP SPACE PROGRAMS, VP SPACE ENGINEERING, AND NASA SRM PROJECT MANAGER REQUIRED FOR ELIMINATION.
R REQUIRED. APPROVAL BY PROGRAM MANAGER AND PROJECT ENGINEER REQUIRED FOR ELIMINATION OF MEASUREMENT.

INSTRUMENT CODE:

A---ACCELERATION	E---VOLTAGE	K---TVC INTERLOCK	G---STRAIN	T---TEMPERATURE
I---CURRENT	D---DISPLACEMENT	F---FORCE	P---PRESSURE	S---STRAIN
X---EVENT				

NOTES:
1 THE NOTED INSTRUMENTS WILL BE RECORDED REDUNDANTLY ON FM WITH AN ACCURACY OF +/- 10%.

2 THE NOTED INSTRUMENT IS PART OF THE THRUST STAND.

3 THE NOTED INSTRUMENT SHALL BE RECORDED REDUNDANTLY ON FM WITH AN ACCURACY OF +/- 5%.

4 THE NOTED MEASUREMENT IS PART OF THE TEST BAY FACILITY.

5 THE NOTED INSTRUMENTS ARE REFERENCED ON THE FIELD OF THE DRAWING, BUT WERE INSTALLED ON A PREVIOUS DRAWING.

6 THE NOTED INSTRUMENT SHALL BE MONITORED DURING HEATER OPERATION AS WELL AS DURING MOTOR FIRING.

7 THE NOTED INSTRUMENT SHALL BE MONITORED ON ENGINEERING UNITS DISPLAY (EUD).

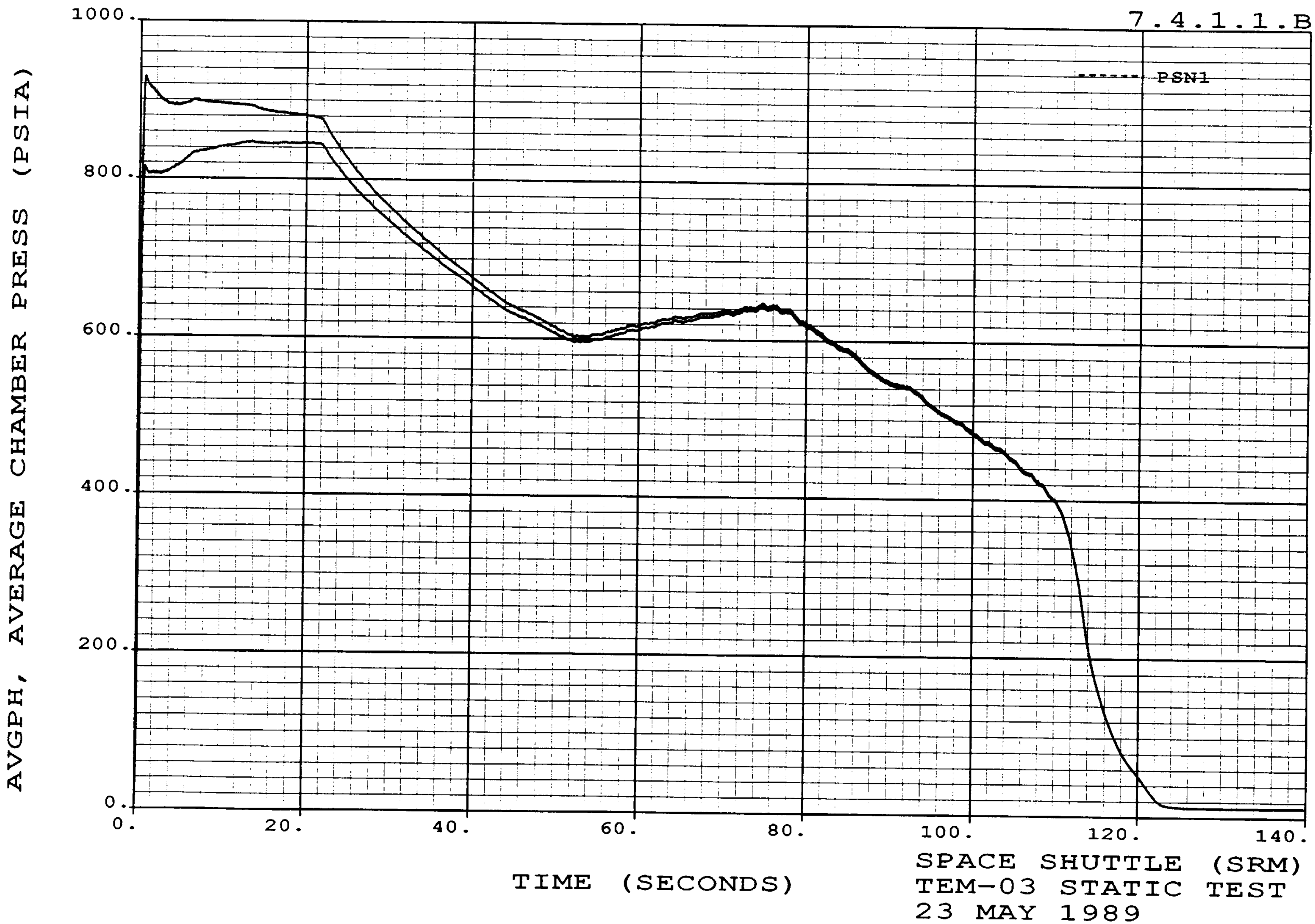
8. DELETED

9. DELETED

10. THE NOTED INSTRUMENT SHALL BE MONITORED WITH TEST AREA SOLARTRON SYSTEM AND RECORDED FROM T-15 MIN TO AT LEAST T+ 6 MIN

Appendix C

DATA PLOTS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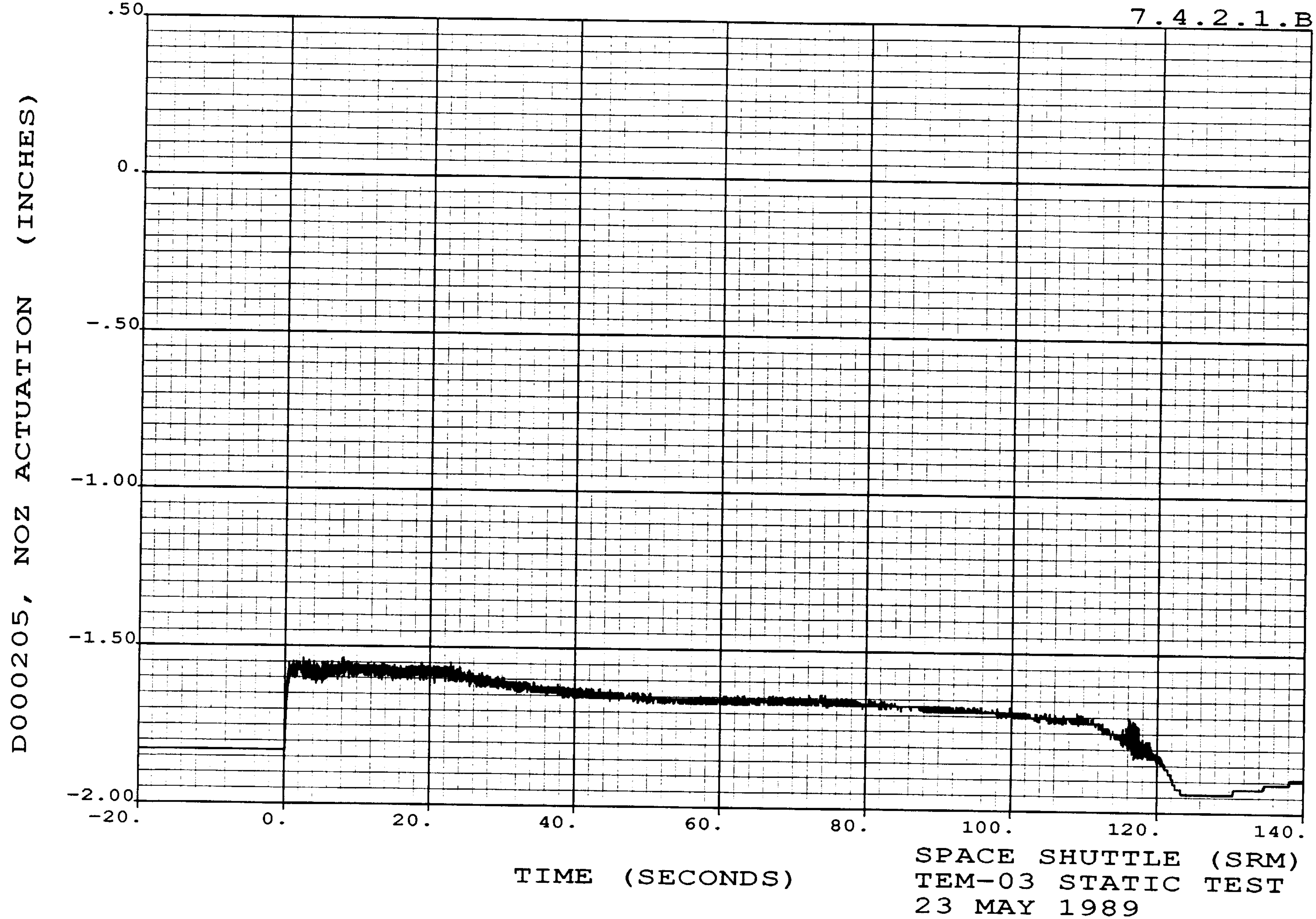
600.
400.
200.
0.
0.
20.
40.
60.
80.
100.
120.
140.
TIME (SECONDS)
SPACE SHUTTLE (SRM)
TEM-03 STATIC TEST
23 MAY 1989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60.
80.
100.
120.
140.
D000205, NOZ ACTUATION (INCHES)
TIME (SECONDS)
SPACE SHUTTLE (SRM)
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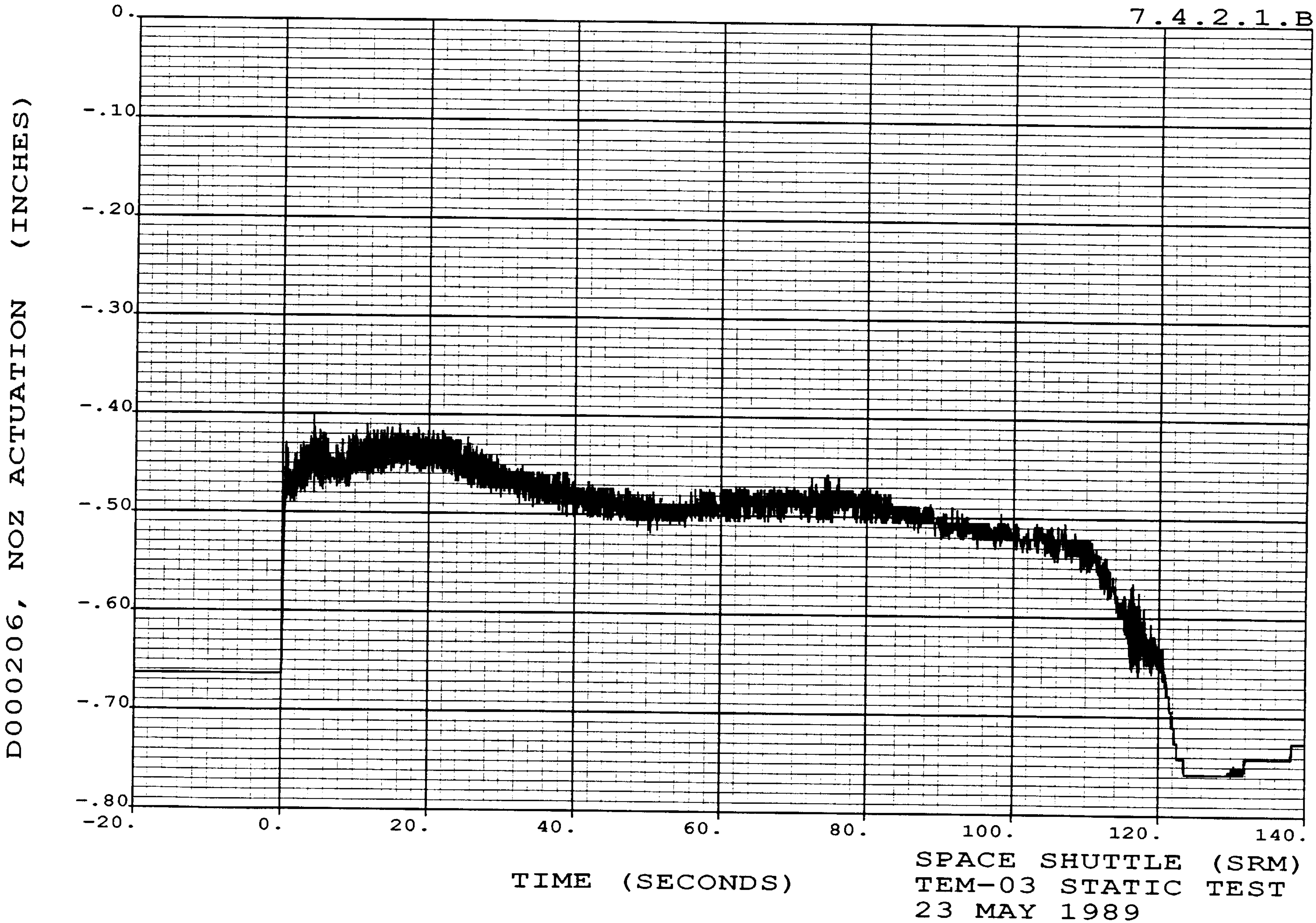
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-.60
-.70
-.80
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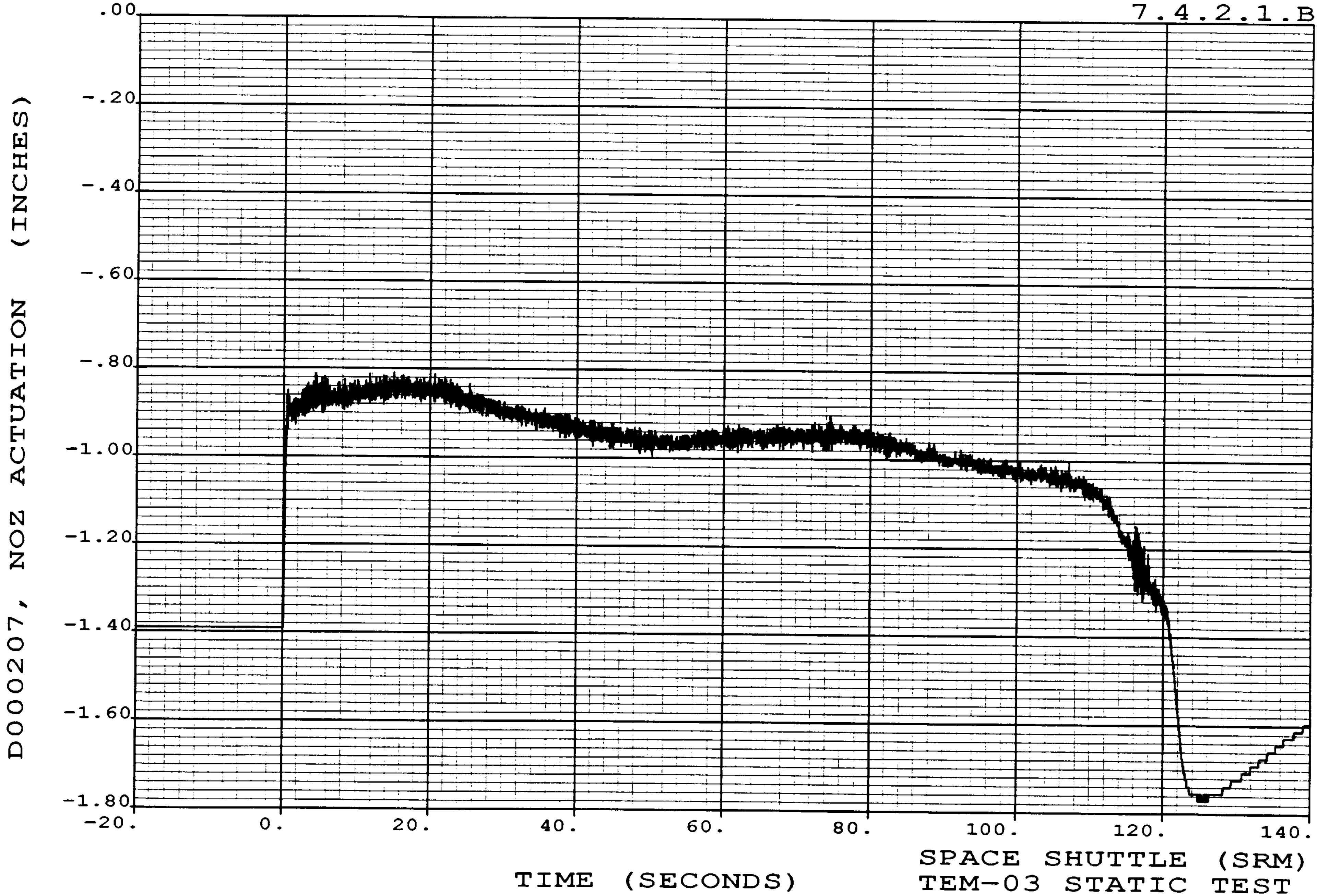
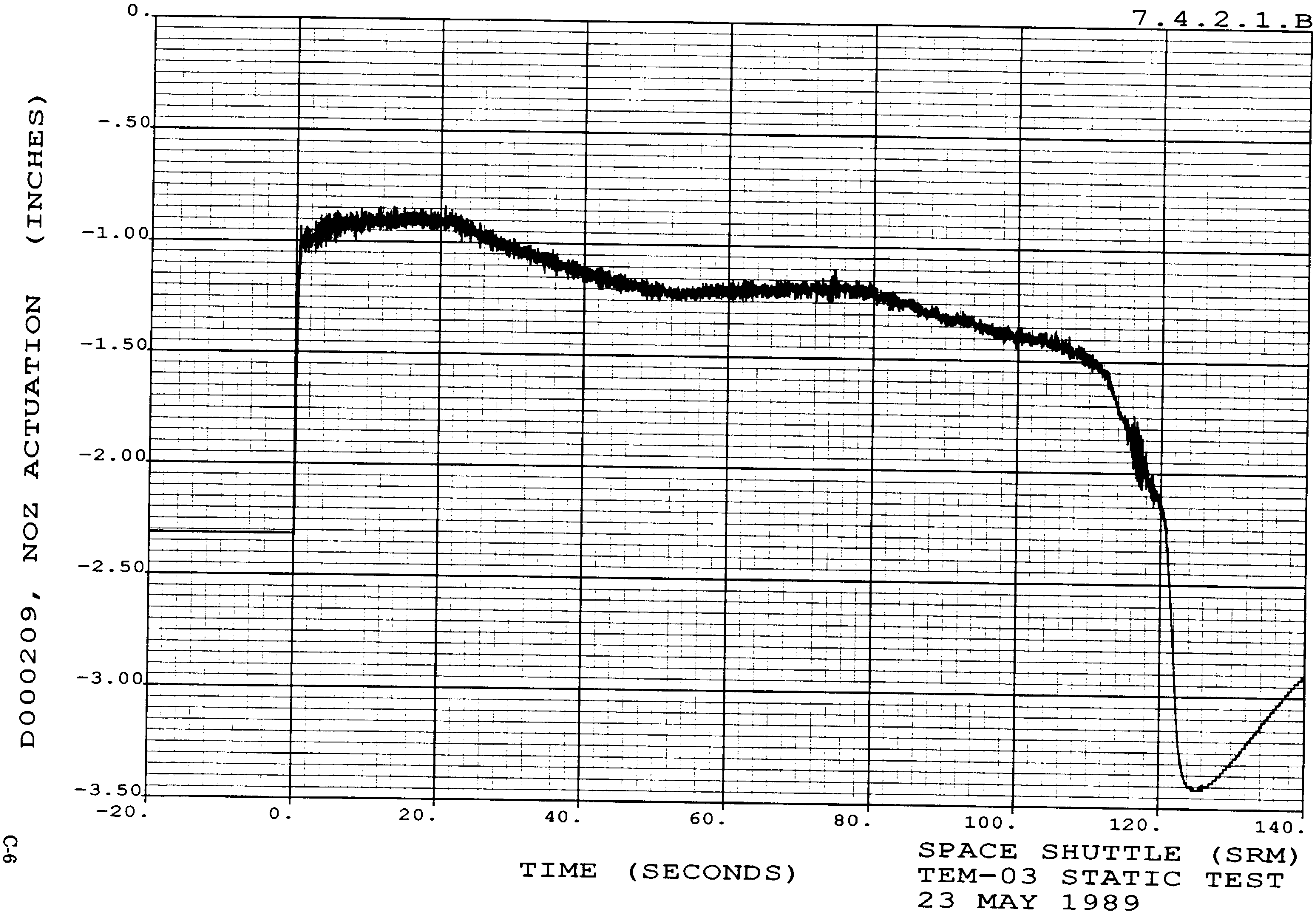
0.
20.
40.
60.
80.
100.
120.
140.
D000206, NOZ ACTUATION (INCHES)
TIME (SECONDS)
SPACE SHUTTLE (SRM)
TEM-03 STATIC TEST
23 MAY 1989

7.4.2.1.B



SPACE SHUTTLE (SRM)
TEM-03 STATIC TEST
23 MAY 1989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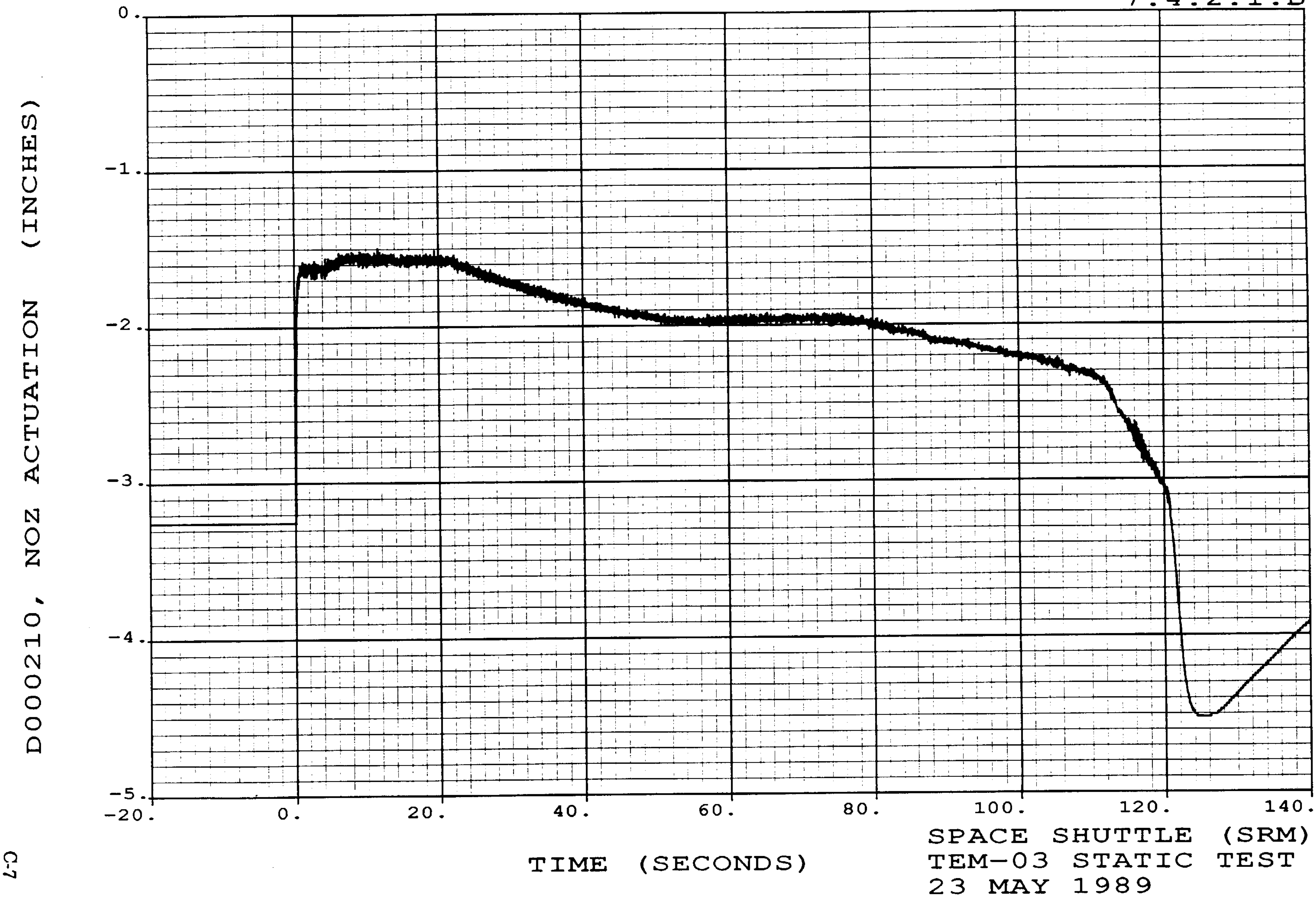
-3.00
-3.50
-20.
0.
20.
40.
60.
80.
100.
120.
140.
TIME (SECONDS)
SPACE SHUTTLE (SRM)
TEM-03 STATIC TEST
23 MAY 1989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-4.
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0.
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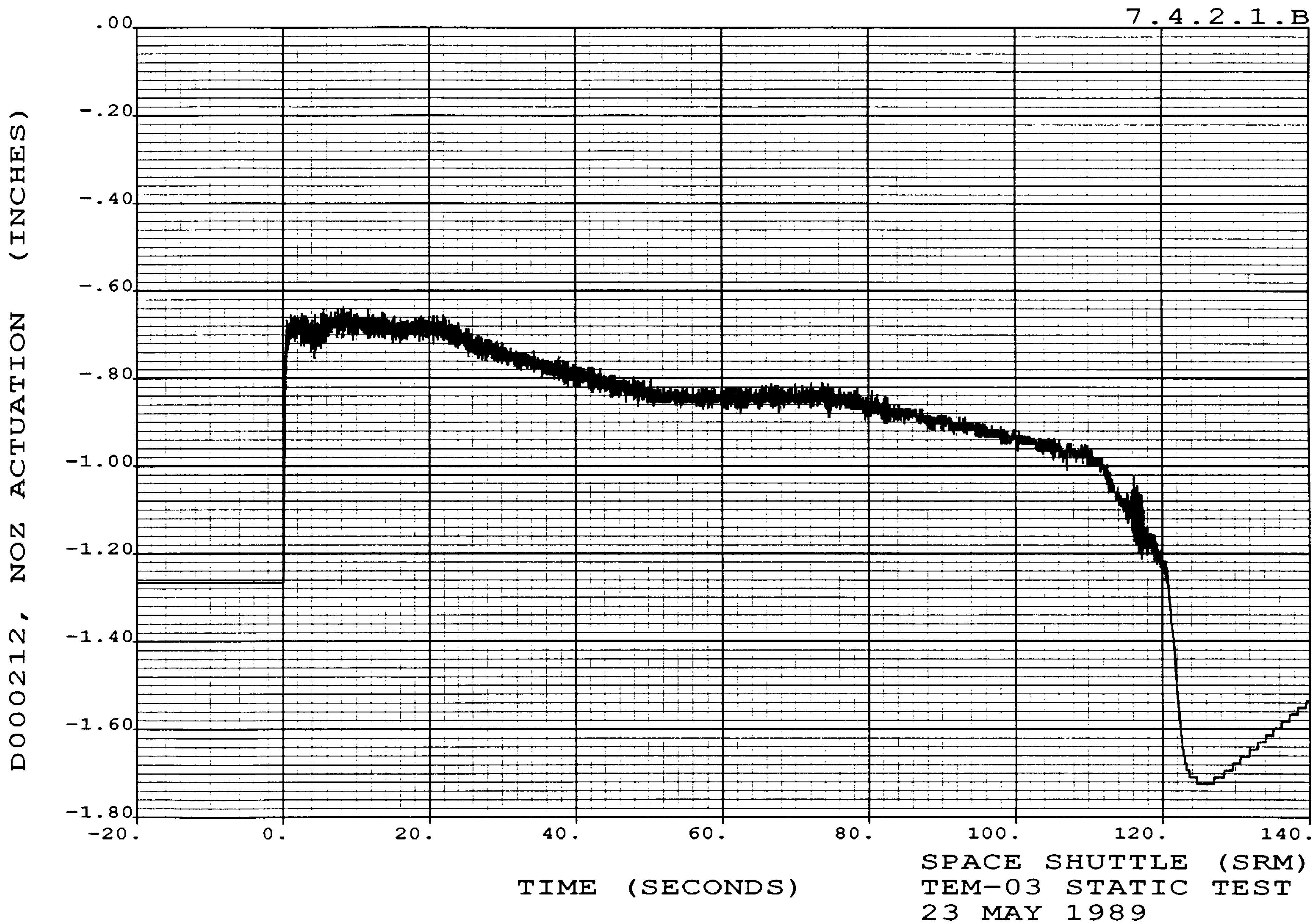
40.
60.
80.
100.
120.
140.
TIME (SECONDS)
SPACE SHUTTLE (SRM)
TEM-03 STATIC TEST
23 MAY 1989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-.80
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D000212, NOZ ACTUATION (INCHES)
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0.
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40.
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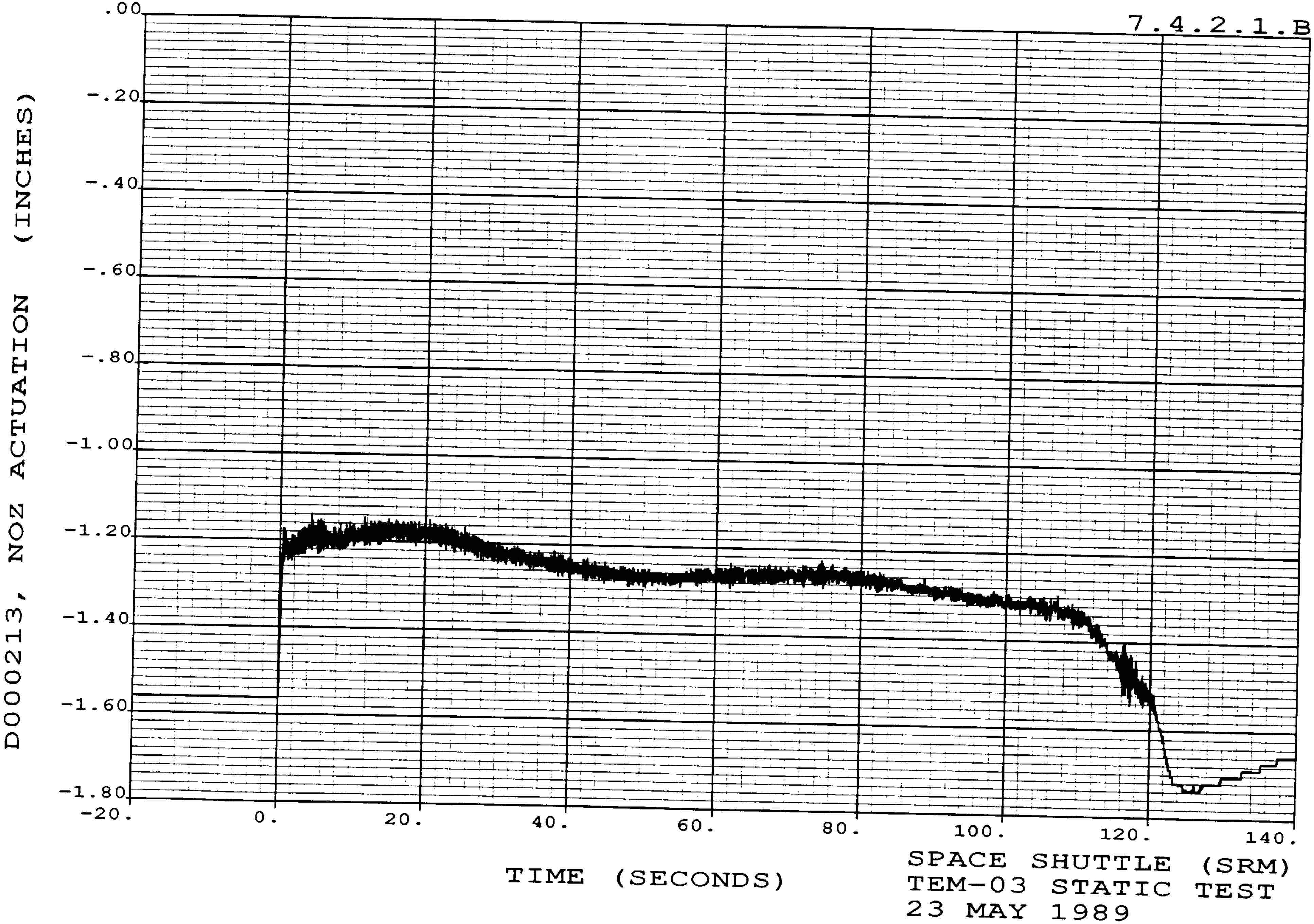
80.
100.
120.
140.
TIME (SECONDS)
SPACE SHUTTLE (SRM)
TEM-03 STATIC TEST
23 MAY 1989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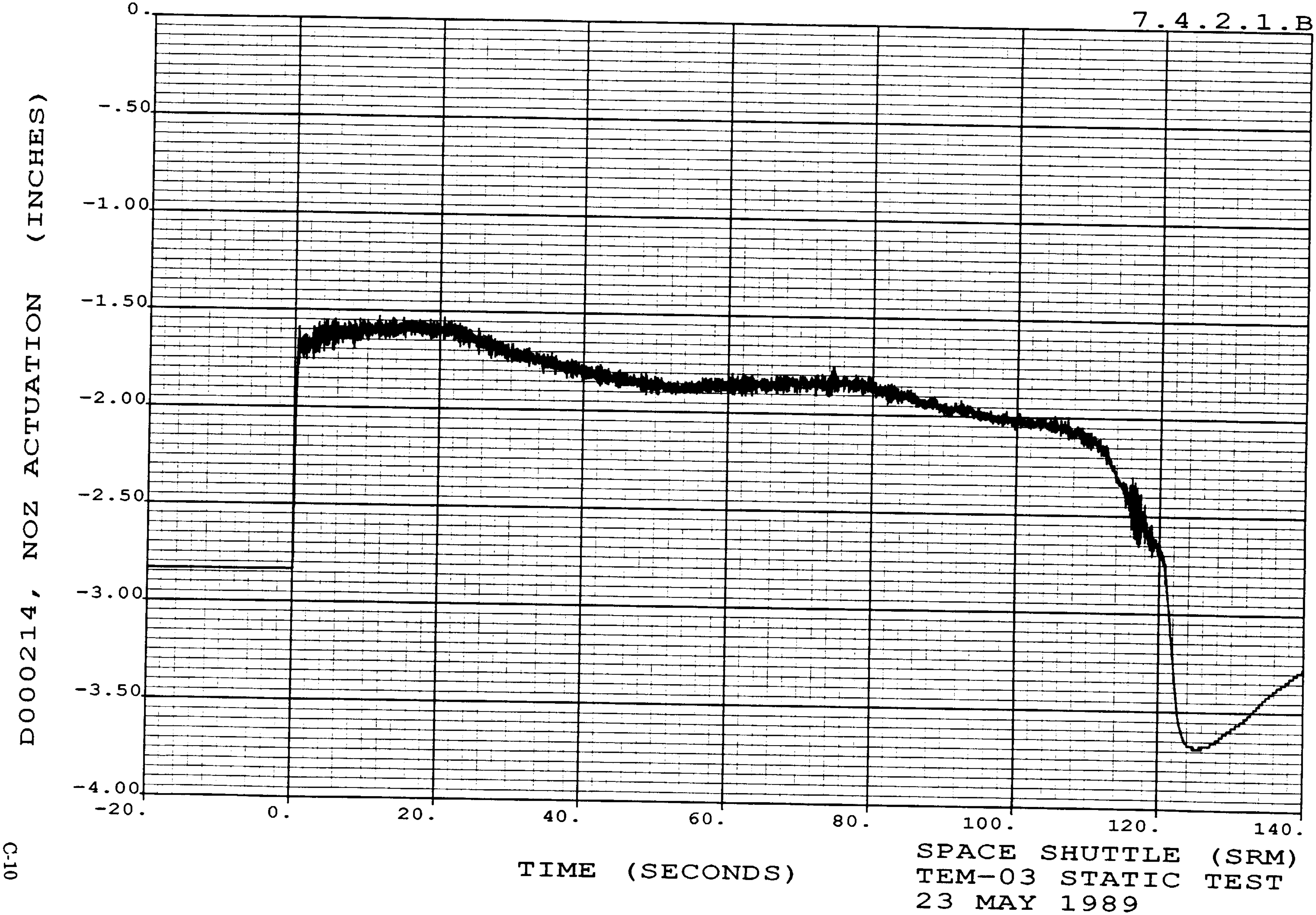
-20.
0.
20.
40.
60.
80.
100.
120.
140.
TIME (SECONDS)
SPACE SHUTTLE (SRM)
TEM-03 STATIC TEST
23 MAY 1989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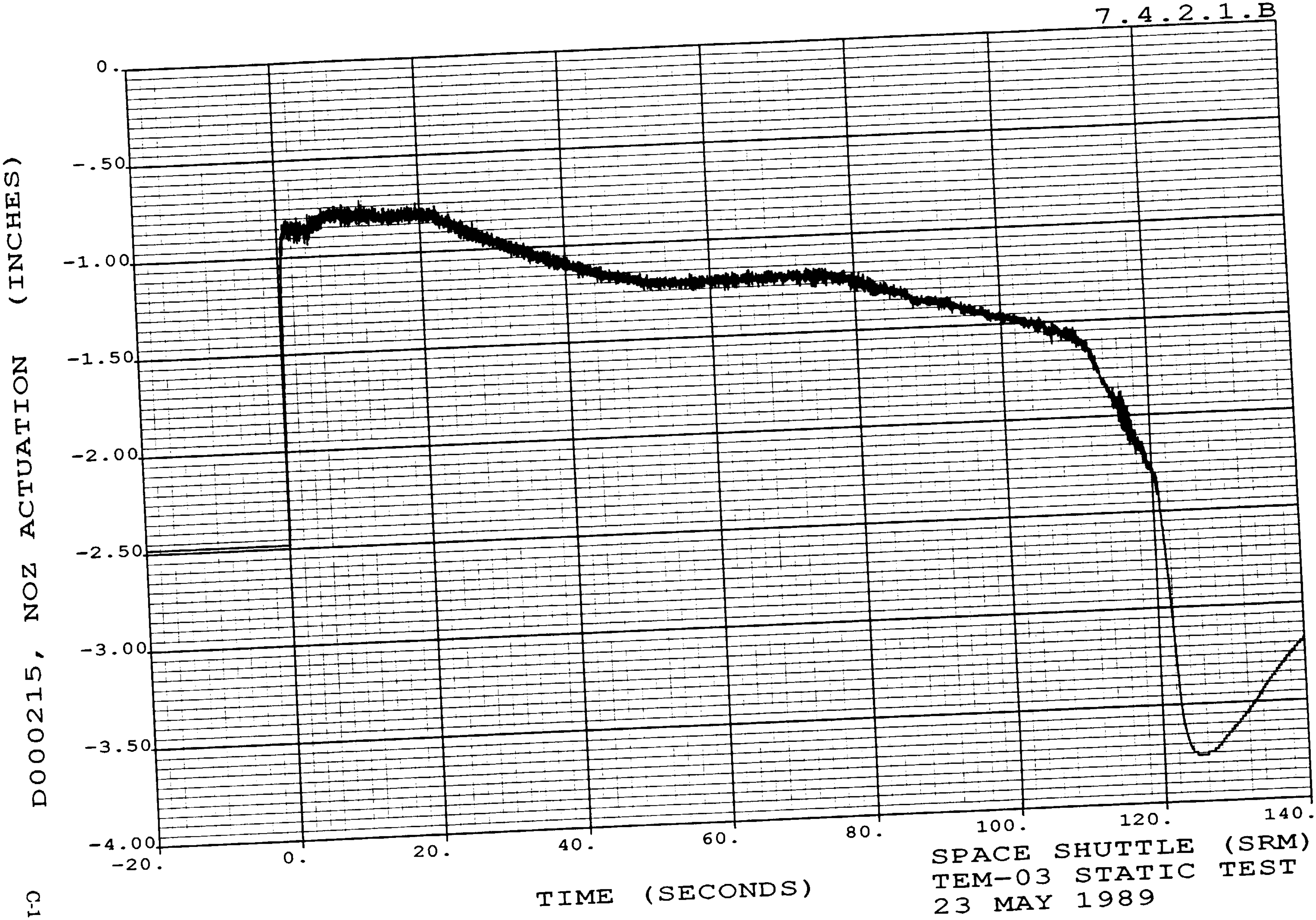
-4.00
-20.
0.
20.
40.
60.
80.
100.
120.
140.
TIME (SECONDS)
SPACE SHUTTLE (SRM)
TEM-03 STATIC TEST
23 MAY 1989

7.4.2.1.B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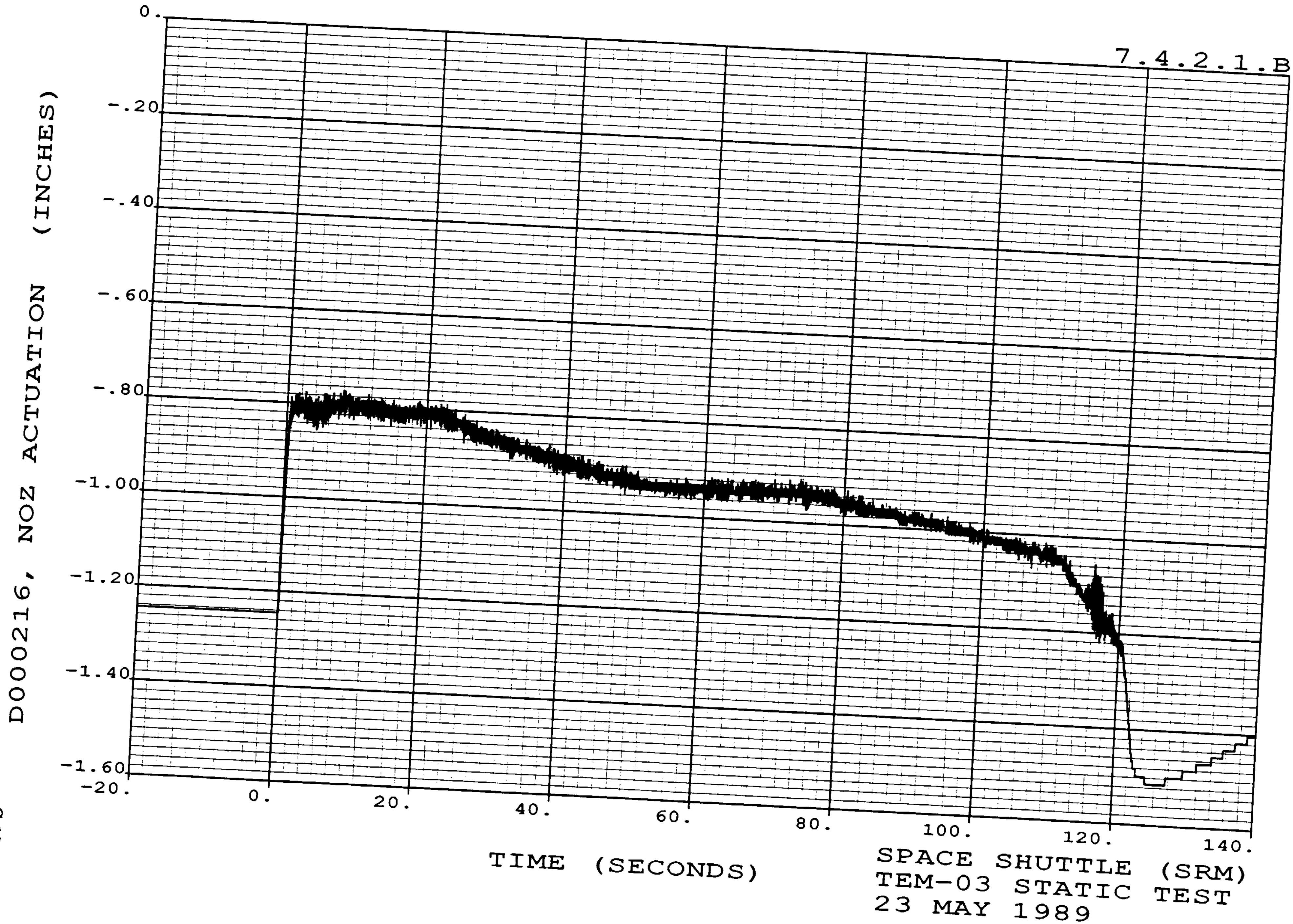
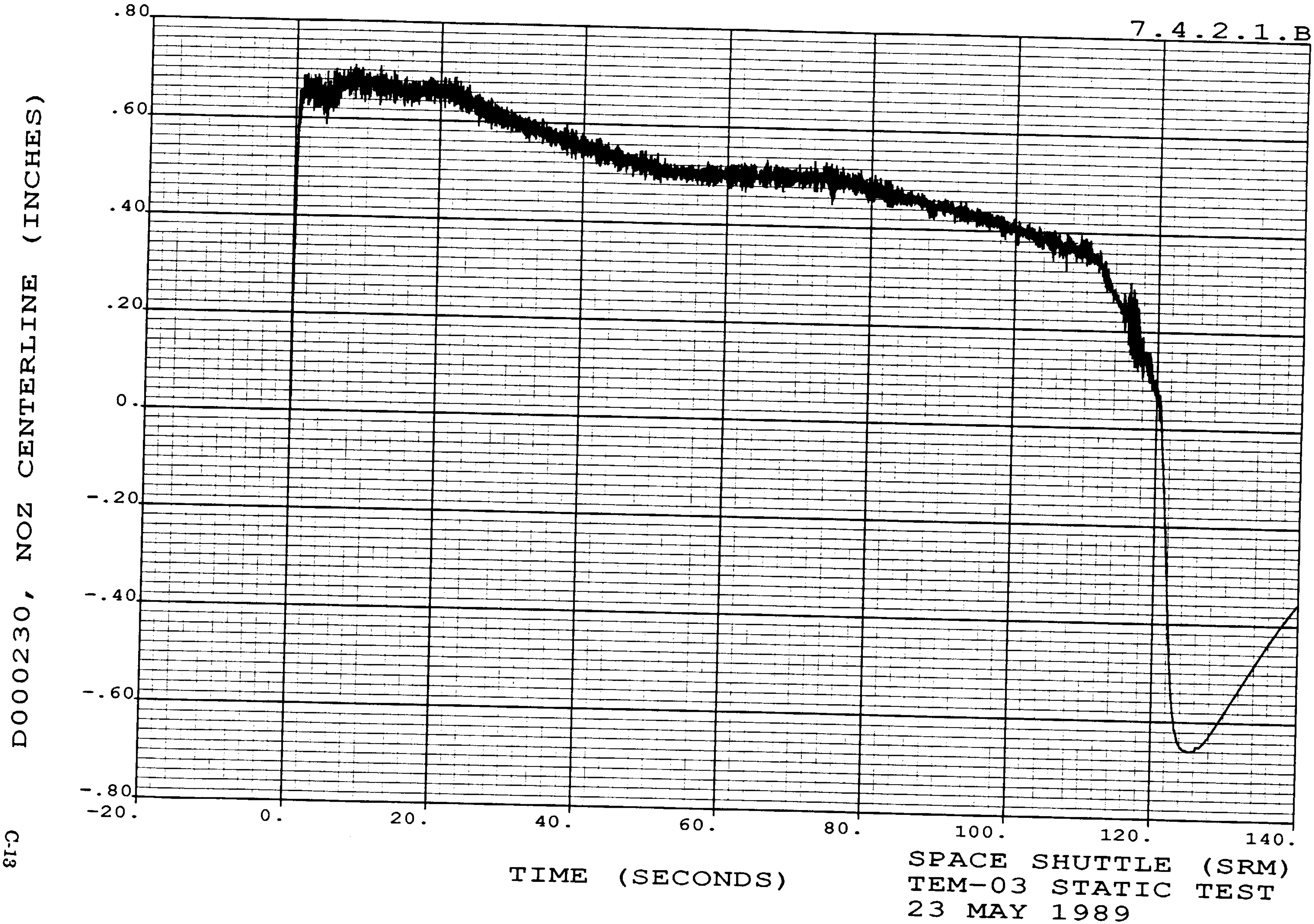
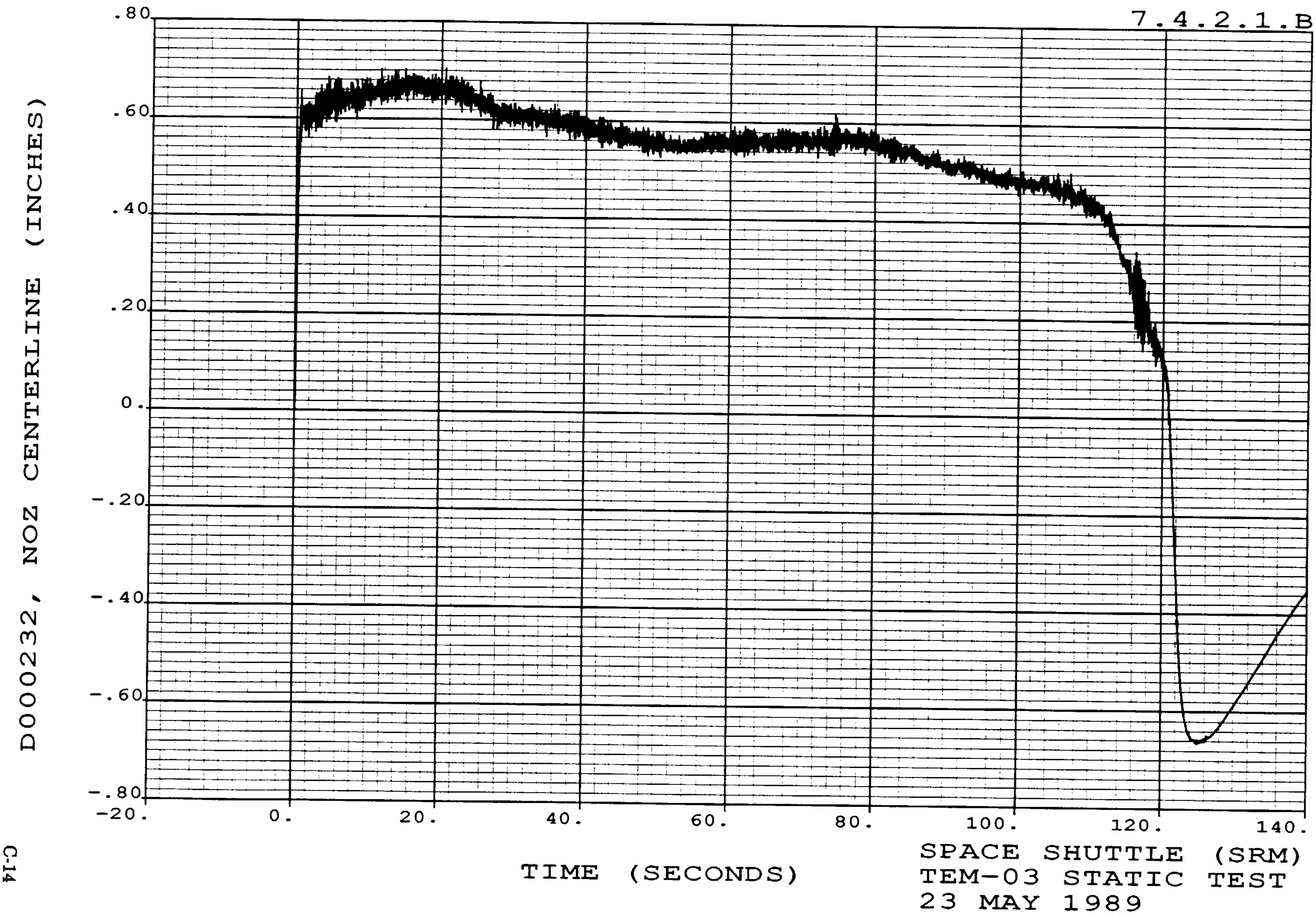
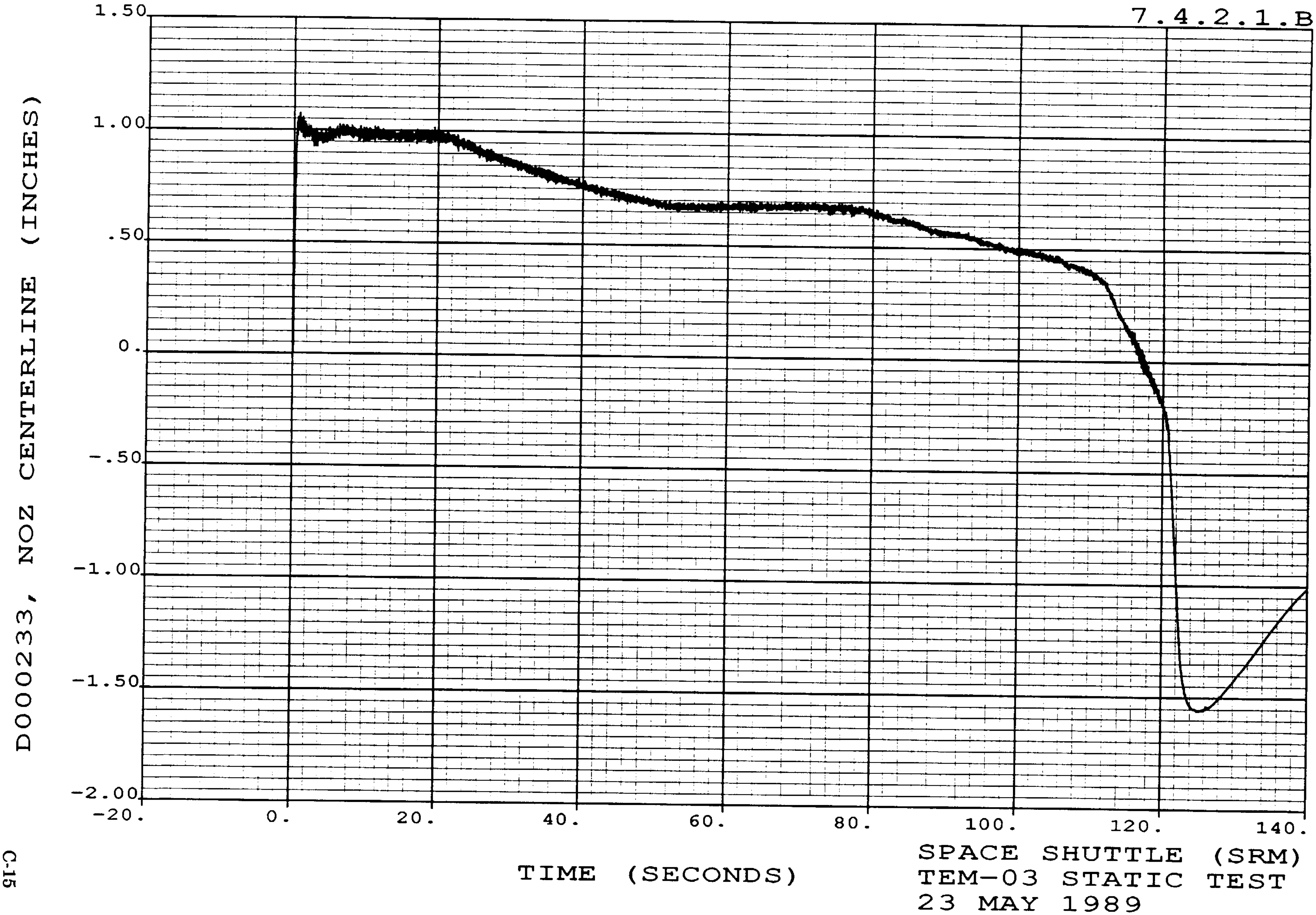
-3.00
-3.50
-4.00
-20.
0.
20.
40.
60.
80.
100.
120.
140.
TIME (SECONDS)
SPACE SHUTTLE (SRM)
TEM-03 STATIC TEST
23 MAY 1989

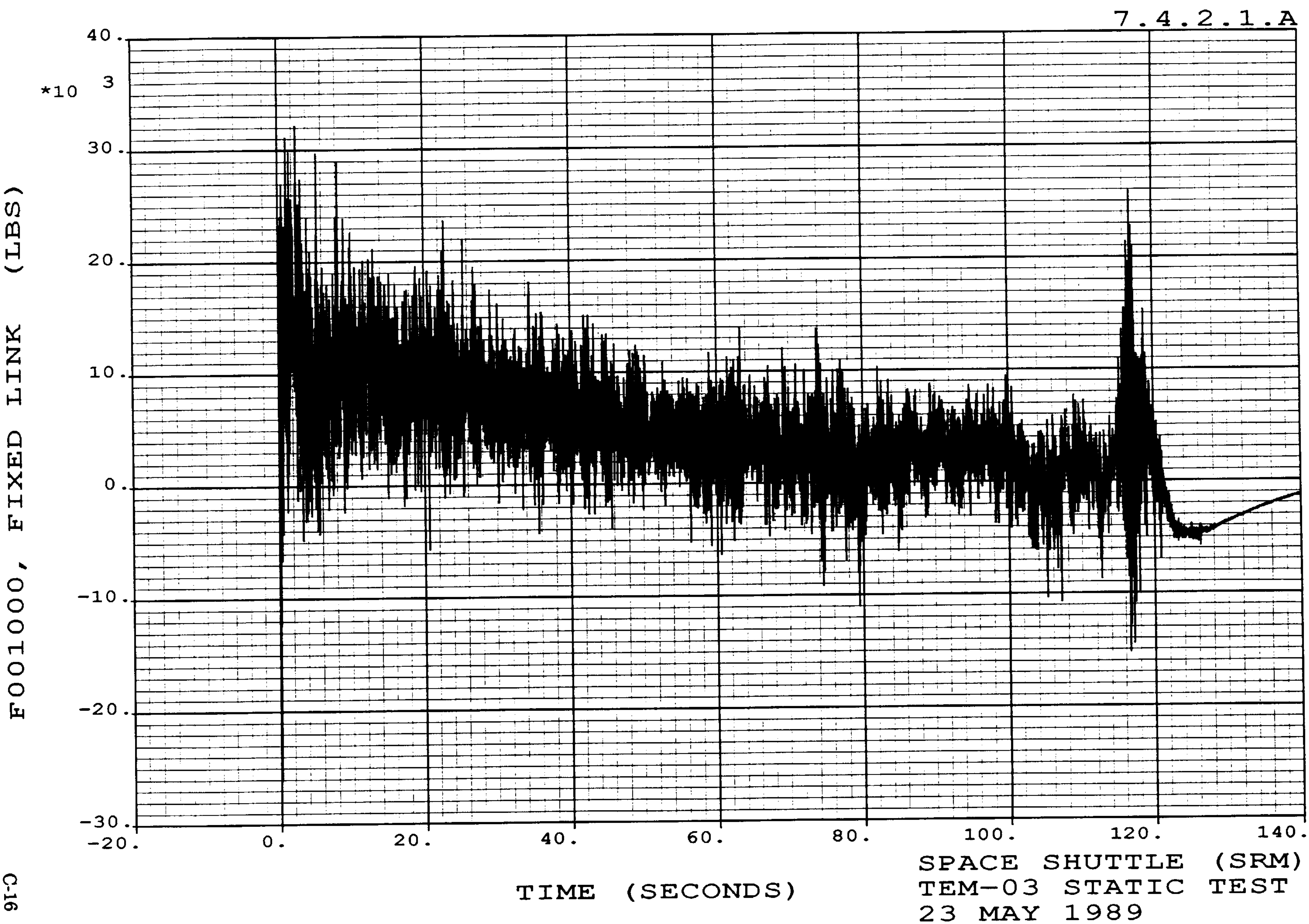

7.4.2.1.B
D000216, NOZ ACTUATION (INCHES)
0.
-.20
-.40
-.60
-.80
-1.00
-1.20
-1.40
-1.60
-20.
0.
20.
40.
60.
80.
100.
120.
140.
TIME (SECONDS)
SPACE SHUTTLE (SRM)
TEM-03 STATIC TEST
23 MAY 1989

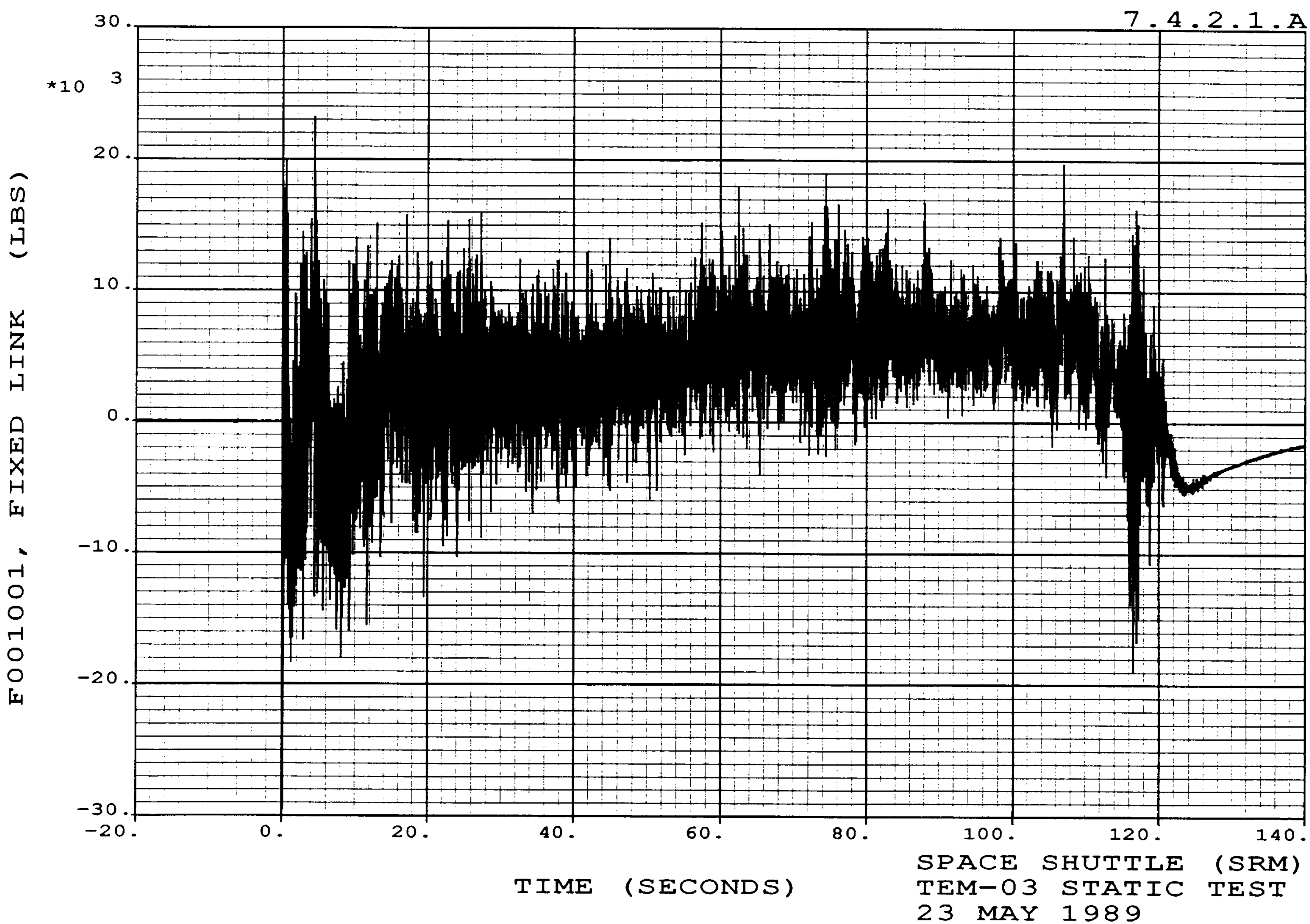


7.4.2.1.B
.80
.60
.40
.20
0.
-.20
-.40
-.60
-.80
-20.
0.
20.
40.
60.
80.
100.
120.
140.
D000230, NOZ CENTERLINE (INCHES)
TIME (SECONDS)
SPACE SHUTTLE (SRM)
TEM-03 STATIC TEST
23 MAY 1989


7.4.2.1.B
.80
.60
.40
.20
0.
-.20
-.40
-.60
-.80
D000232, NOZ CENTERLINE (INCHES)
-20.
0.
20.
40.
60.
80.
100.
120.
140.
TIME (SECONDS)
SPACE SHUTTLE (SRM)
TEM-03 STATIC TEST
23 MAY 1989

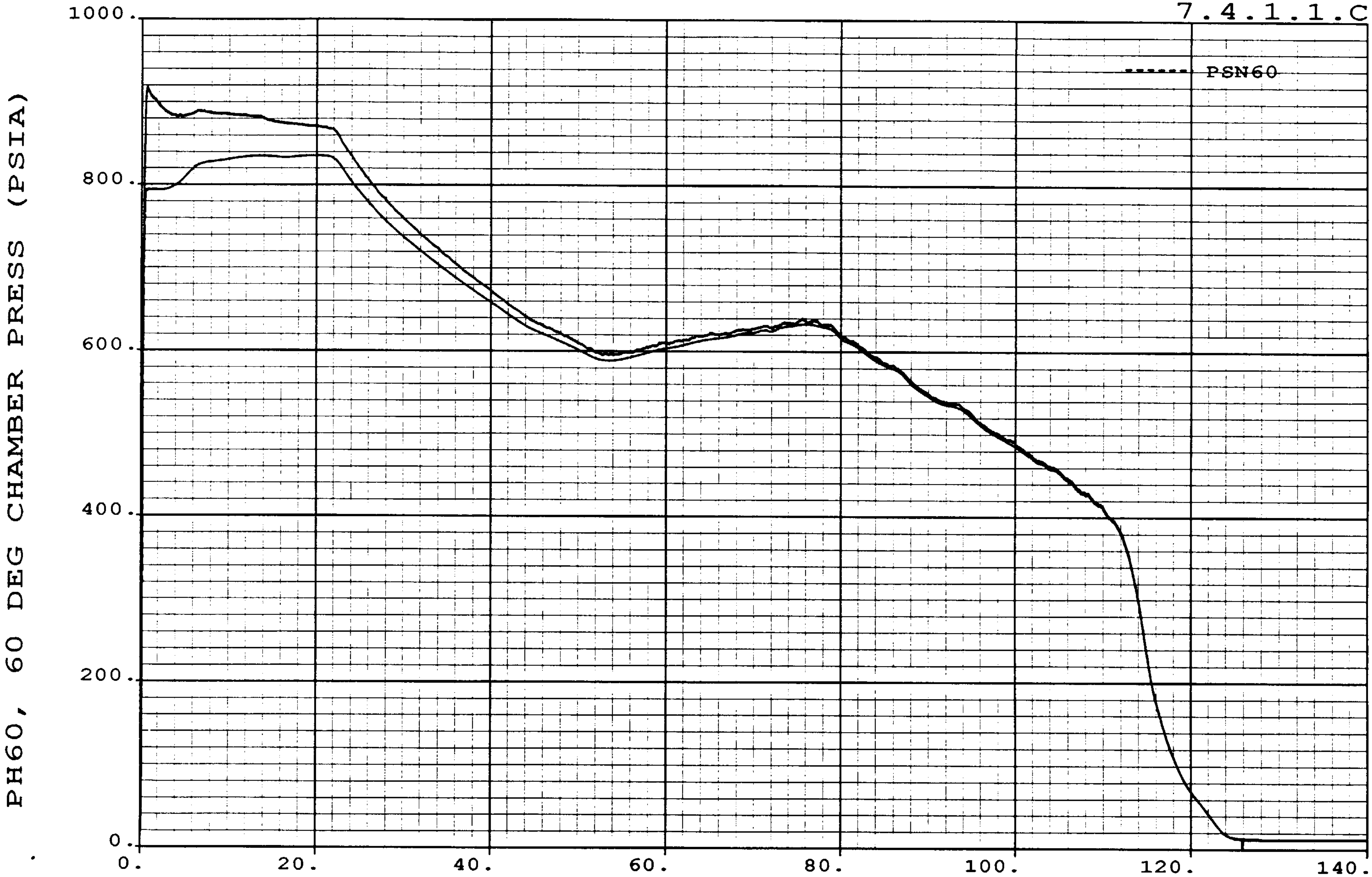

7.4.2.1.B
1.50
1.00
.50
0.
-.50
-1.00
-1.50
-2.00
-20.
0.
20.
40.
60.
80.
100.
120.
140.
D000233, NOZ CENTERLINE (INCHES)
TIME (SECONDS)
SPACE SHUTTLE (SRM)
TEM-03 STATIC TEST
23 MAY 1989


7.4.2.1.A
*10 3
F001000, FIXED LINK (LBS)
40.
30.
20.
10.
0.
-10.
-20.
-30.
-20.
0.
20.
40.
60.
80.
100.
120.
140.
TIME (SECONDS)
SPACE SHUTTLE (SRM)
TEM-03 STATIC TEST
23 MAY 1989

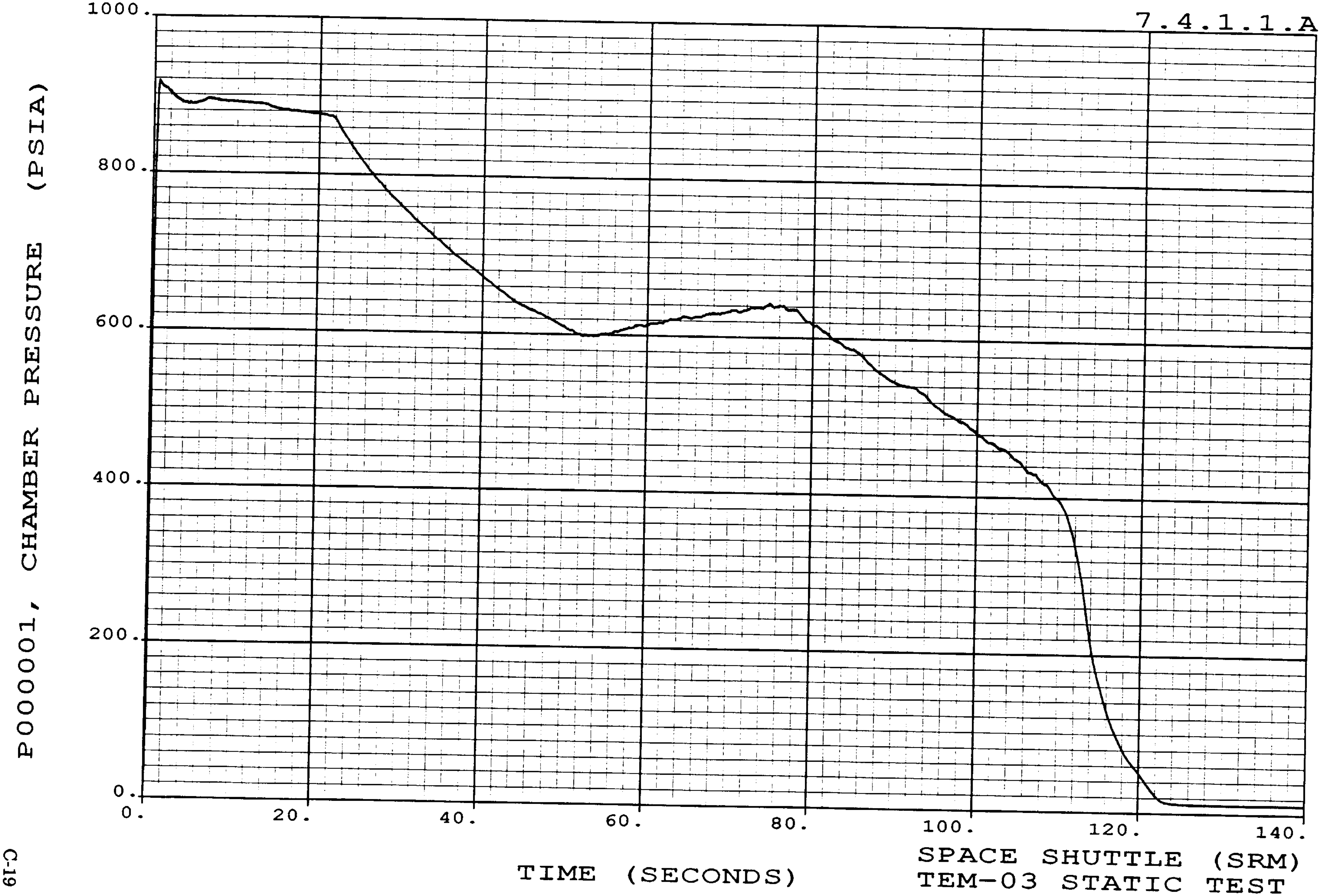


7.4.2.1.A
*10 3
30.
20.
10.
0.
-10.
-20.
-30.
F001001, FIXED LINK (LBS)
-20.
0.
20.
40.
60.
80.
100.
120.
140.
TIME (SECONDS)
SPACE SHUTTLE (SRM)
TEM-03 STATIC TEST
23 MAY 1989

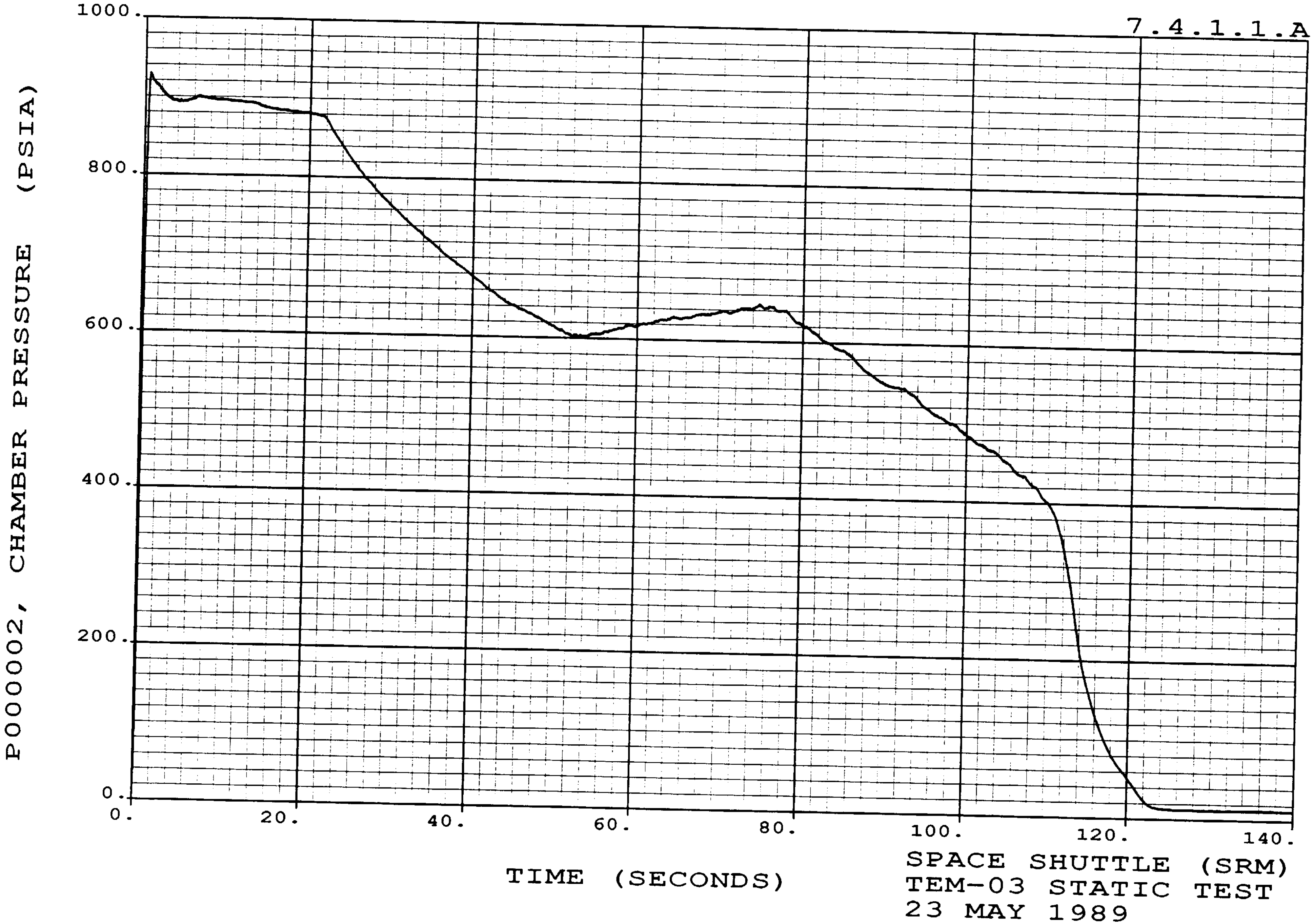
7.4.1.1.C

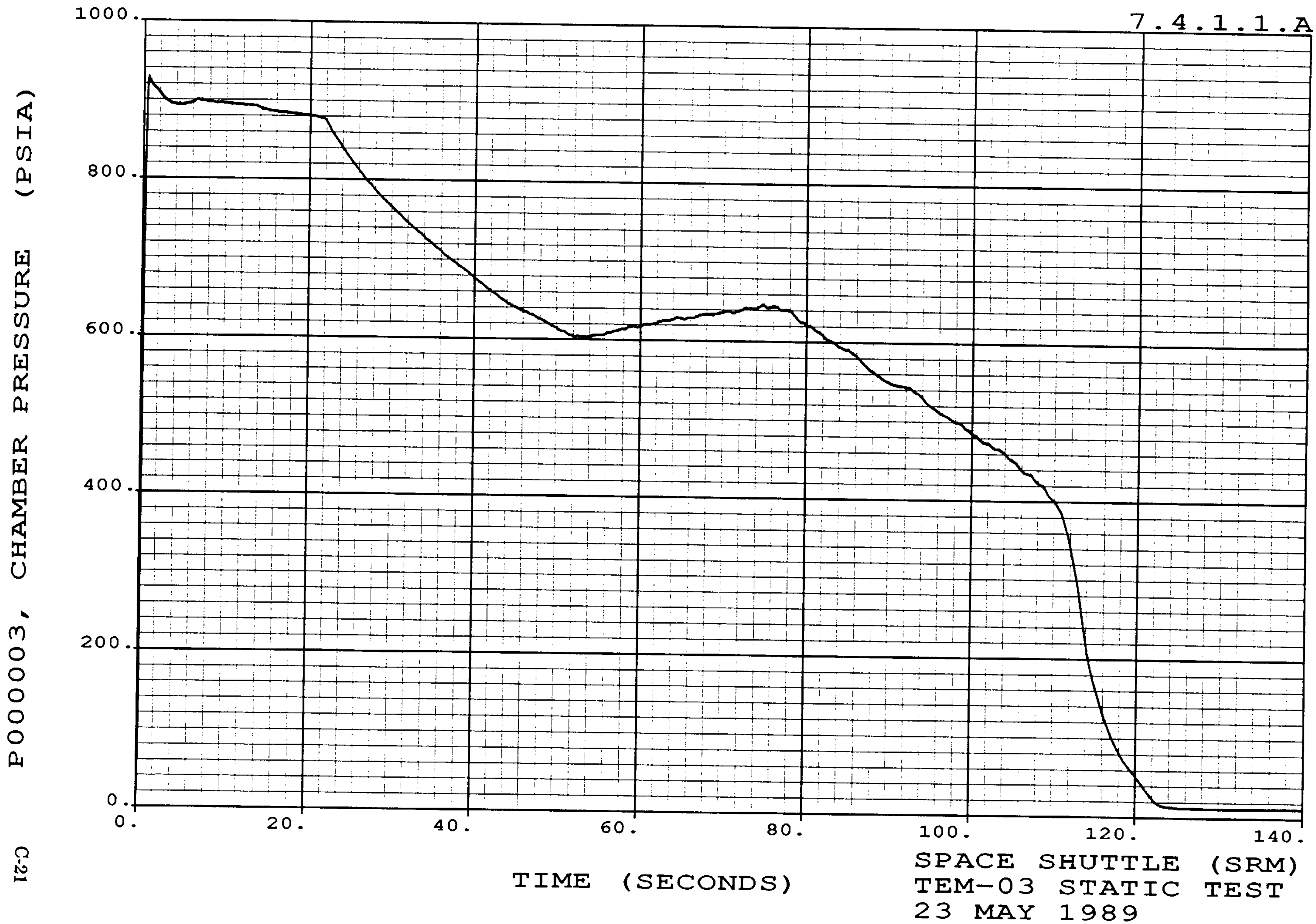


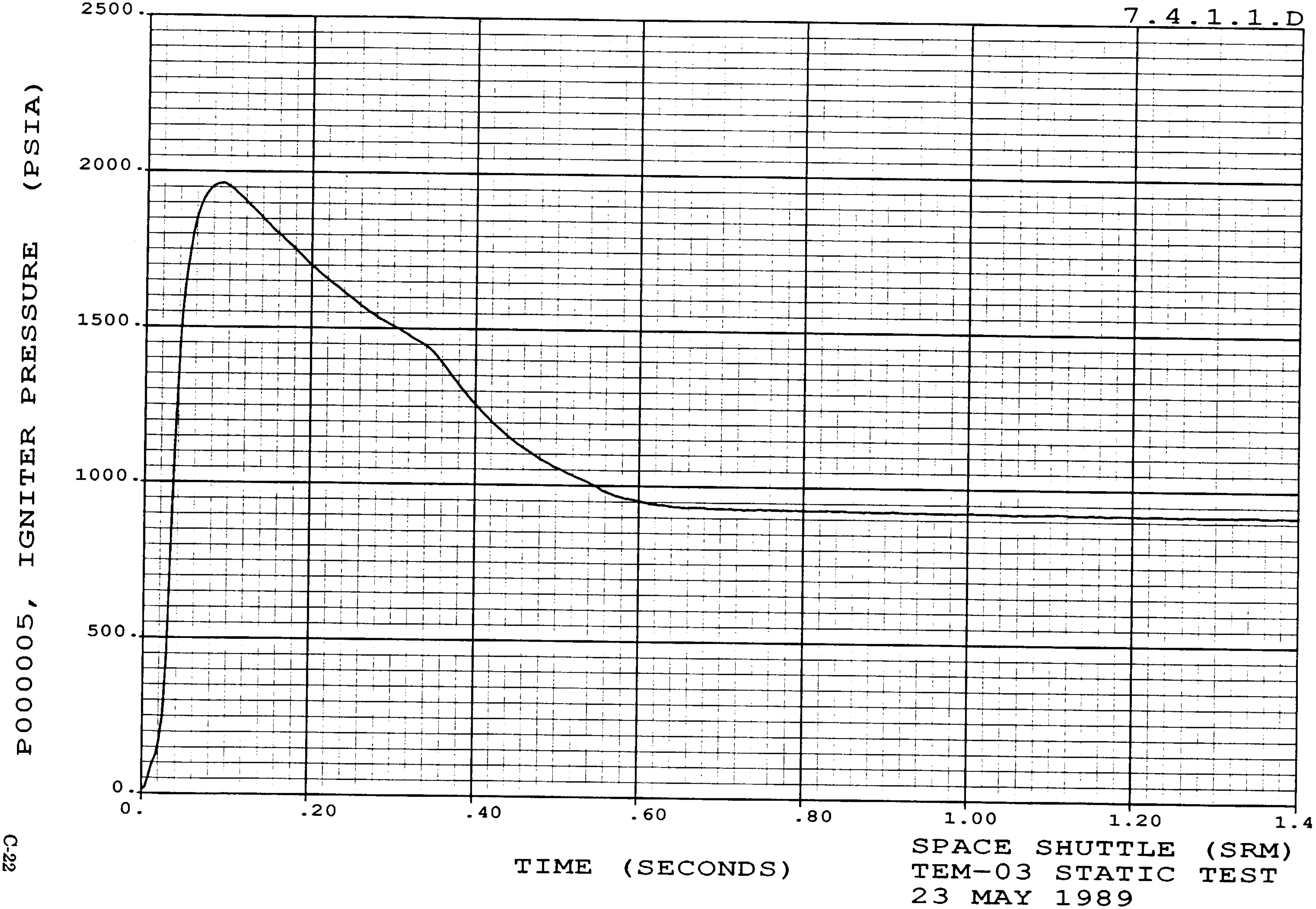
SPACE SHUTTLE (SRM)
TEM-03 STATIC TEST
23 MAY 1989

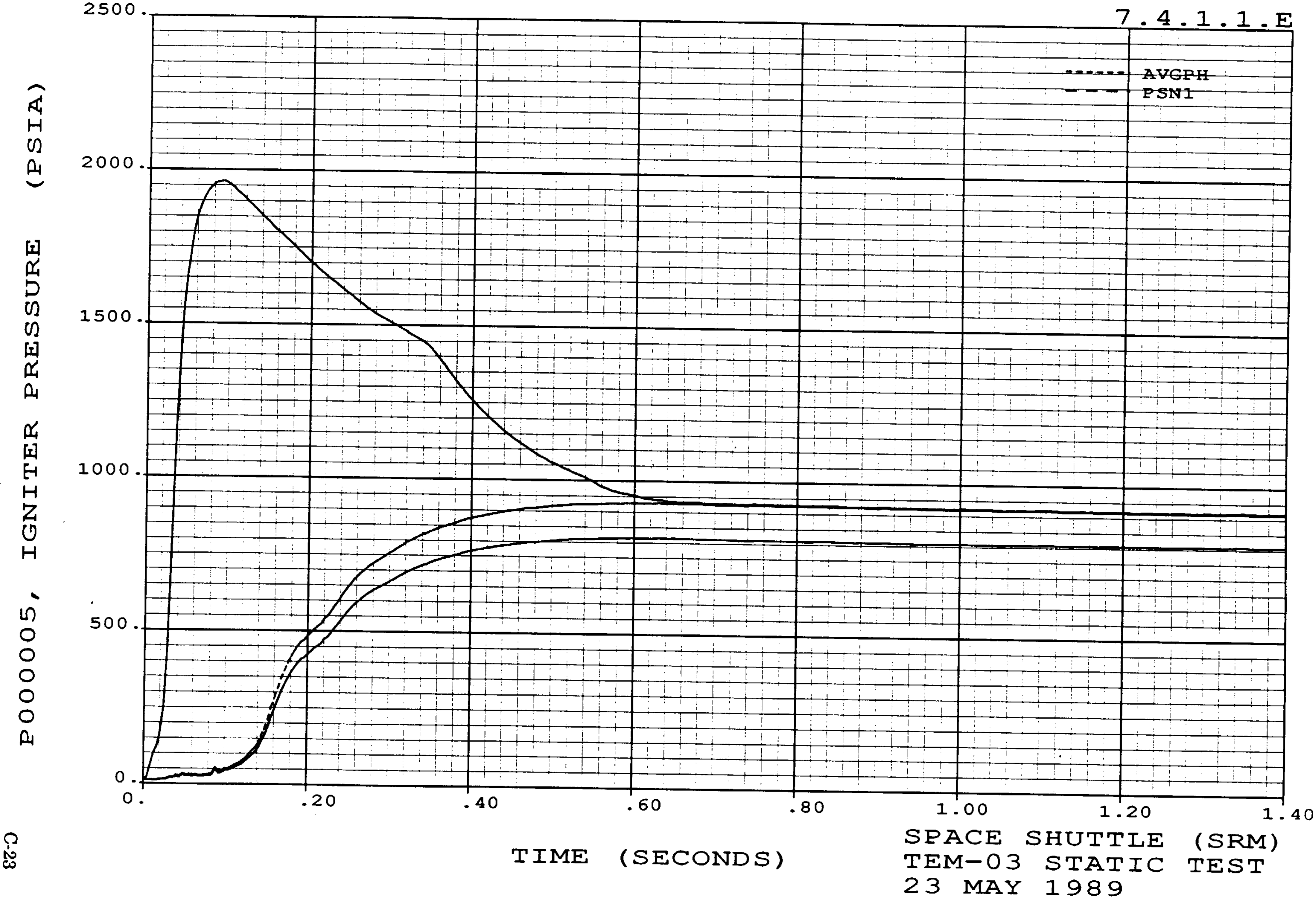


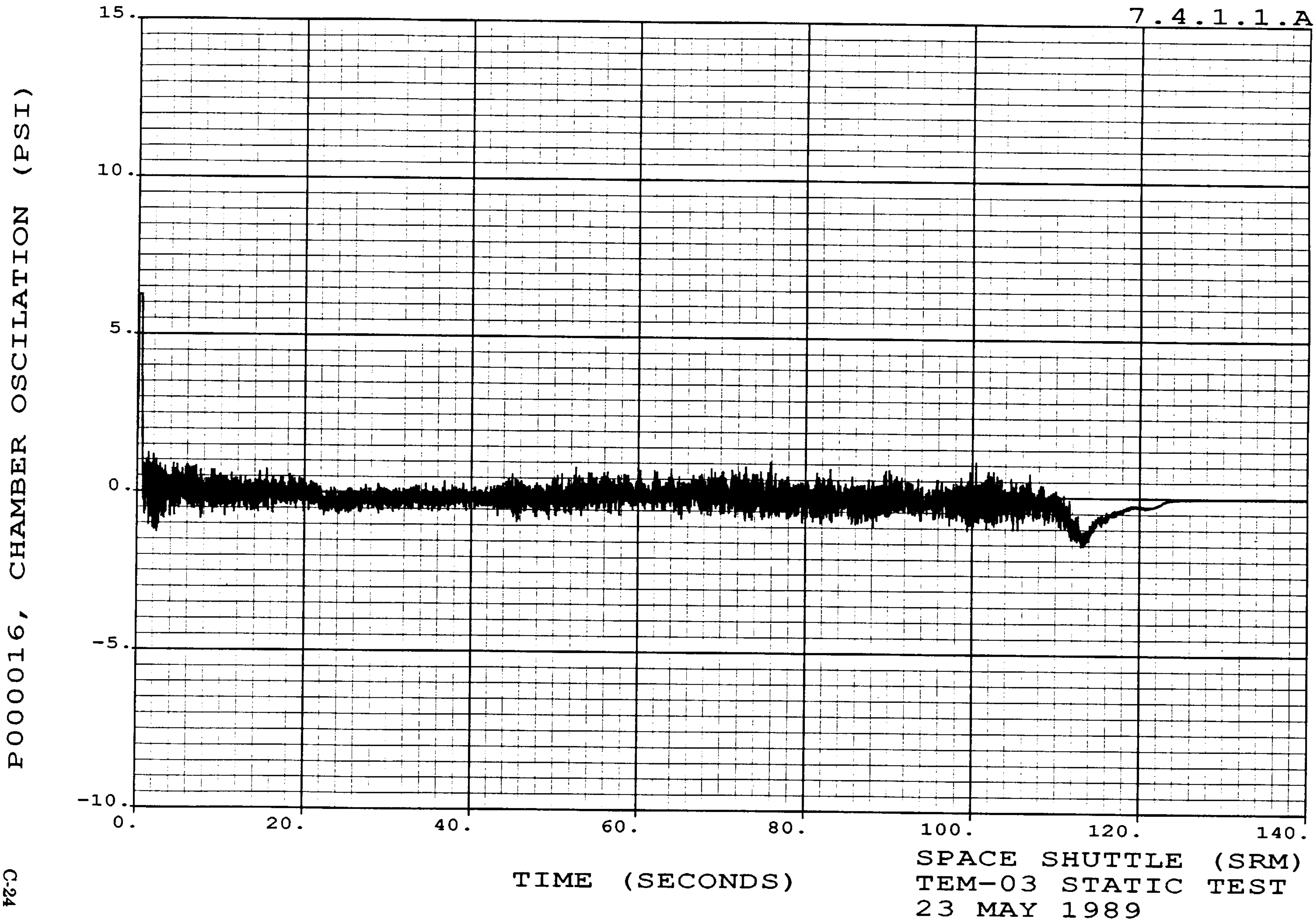
SPACE SHUTTLE (SRM)
TEM-03 STATIC TEST
23 MAY 1989


7.4.1.1.A
1000.
800.
600.
400.
200.
0.
0.
20.
40.
60.
80.
100.
120.
140.
P000002, CHAMBER PRESSURE (PSIA)
TIME (SECONDS)
SPACE SHUTTLE (SRM)
TEM-03 STATIC TEST
23 MAY 1989

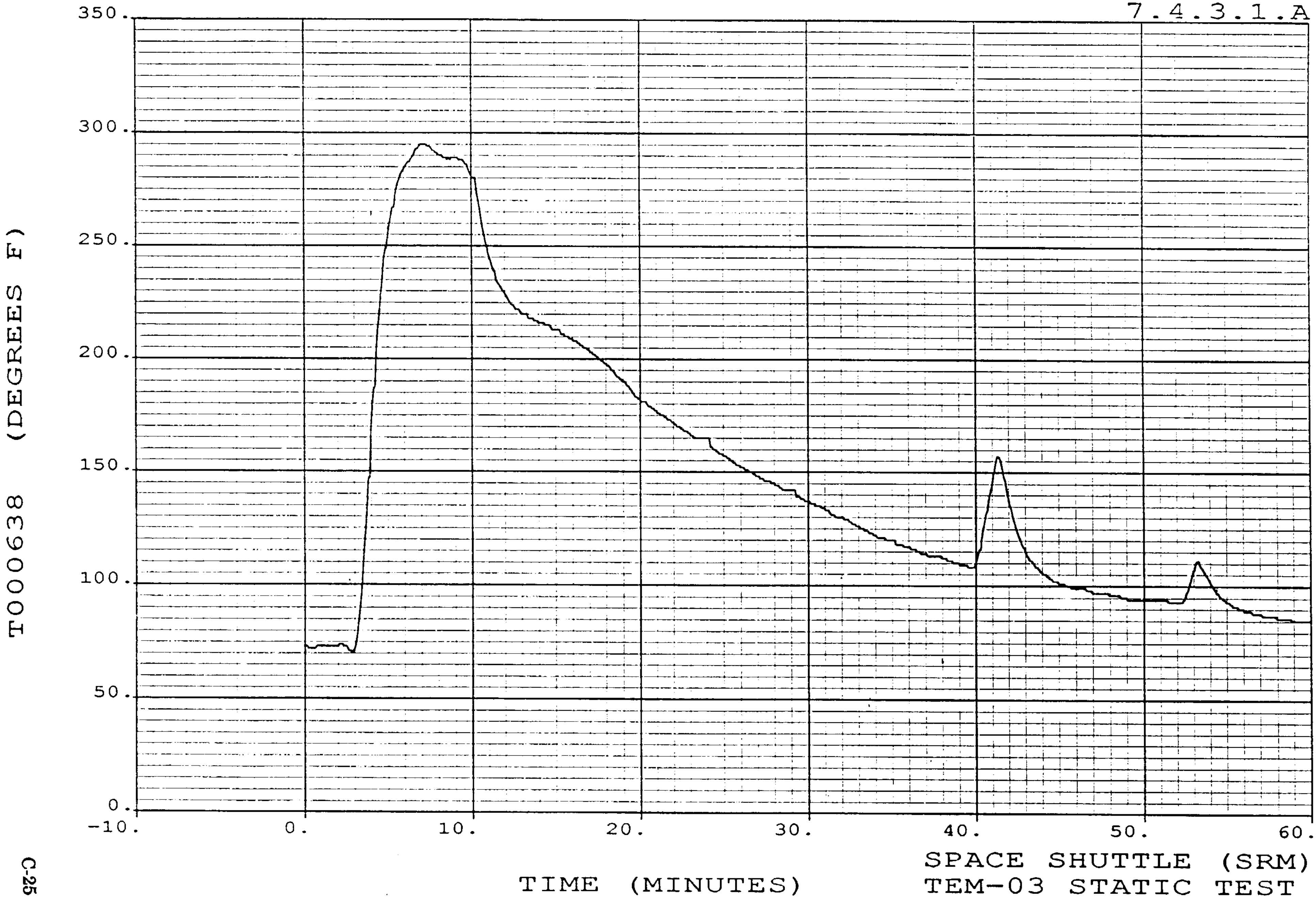

7.4.1.1.A
P000003, CHAMBER PRESSURE (PSIA)
1000.
800.
600.
400.
200.
0.
0.
20.
40.
60.
80.
100.
120.
140.
TIME (SECONDS)
SPACE SHUTTLE (SRM)
TEM-03 STATIC TEST
23 MAY 1989


7.4.1.1.D
P000005, IGNITER PRESSURE (PSIA)
2500.
2000.
1500.
1000.
500.
0.
0.
.20
.40
.60
.80
1.00
1.20
1.40
TIME (SECONDS)
SPACE SHUTTLE (SRM)
TEM-03 STATIC TEST
23 MAY 1989

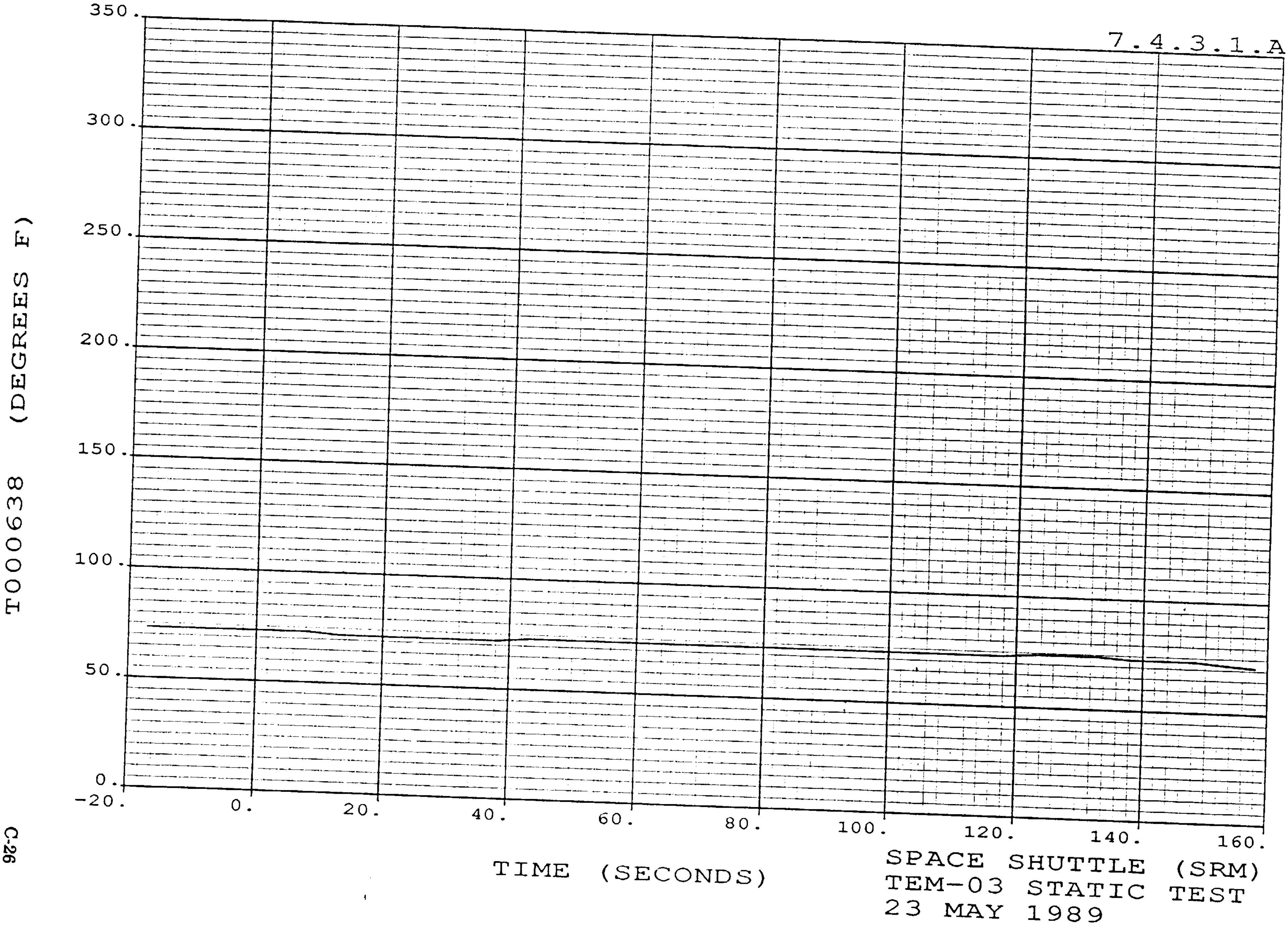

7.4.1.1.E
AVGPH
PSN1
P000005, IGNITER PRESSURE (PSIA)
2500.
2000.
1500.
1000.
500.
0.
0.
.20
.40
.60
.80
1.00
1.20
1.40
TIME (SECONDS)
SPACE SHUTTLE (SRM)
TEM-03 STATIC TEST
23 MAY 1989

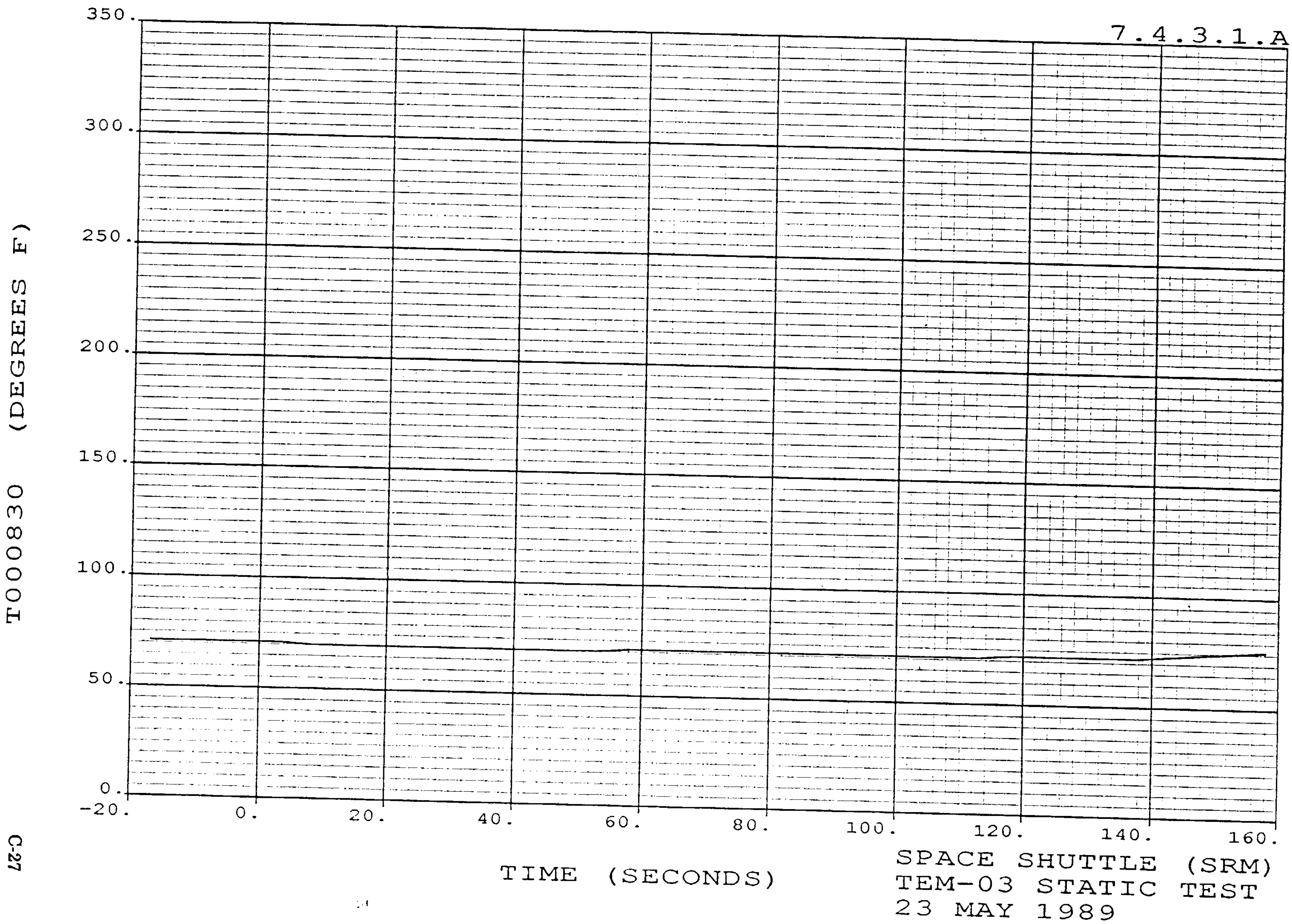


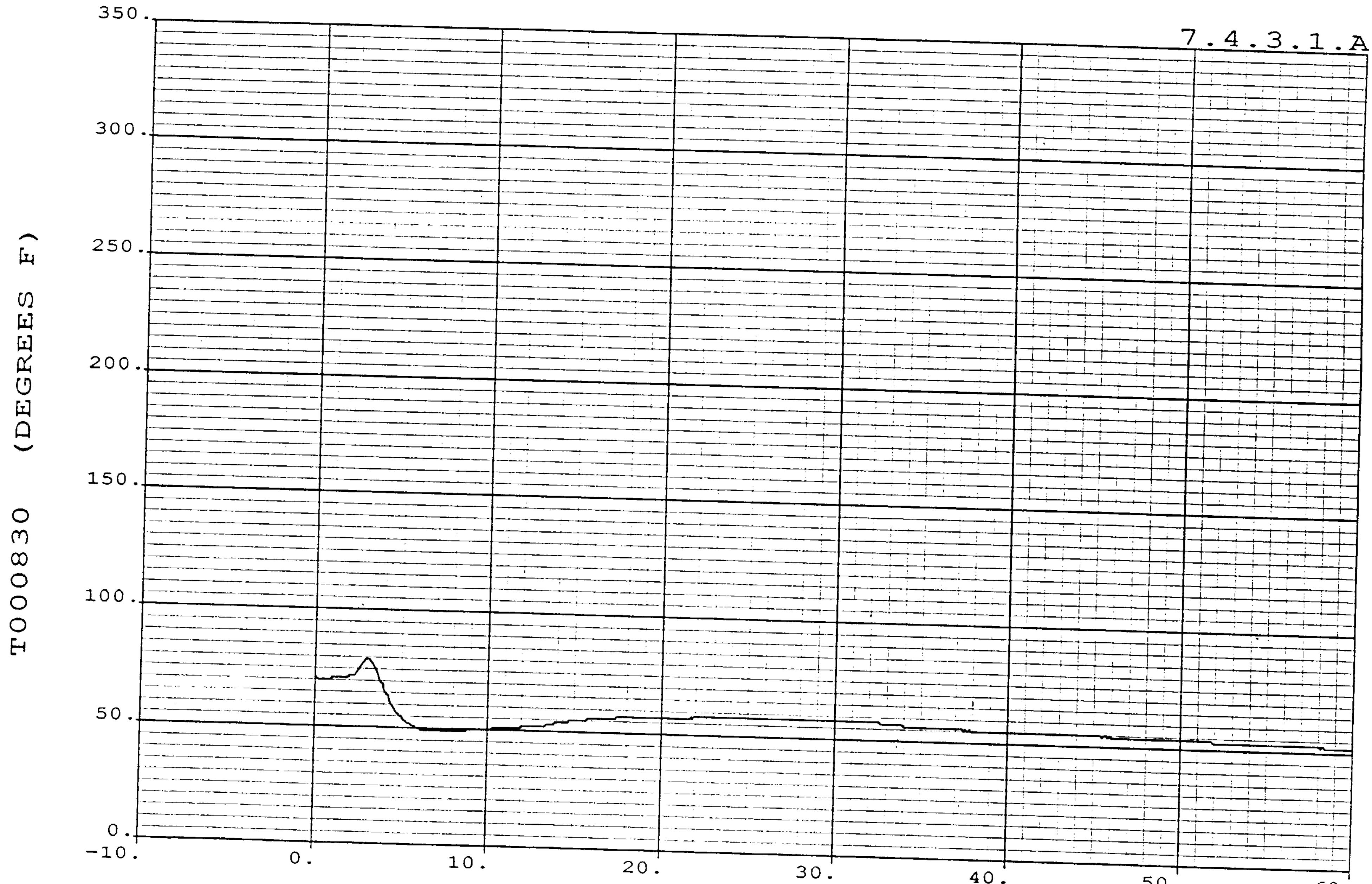
7.4.1.1.A
15.
10.
5.
0.
-5.
-10.
P000016, CHAMBER OSCILATION (PSI)
0.
20.
40.
60.
80.
100.
120.
140.
TIME (SECONDS)
SPACE SHUTTLE (SRM)
TEM-03 STATIC TEST
23 MAY 1989



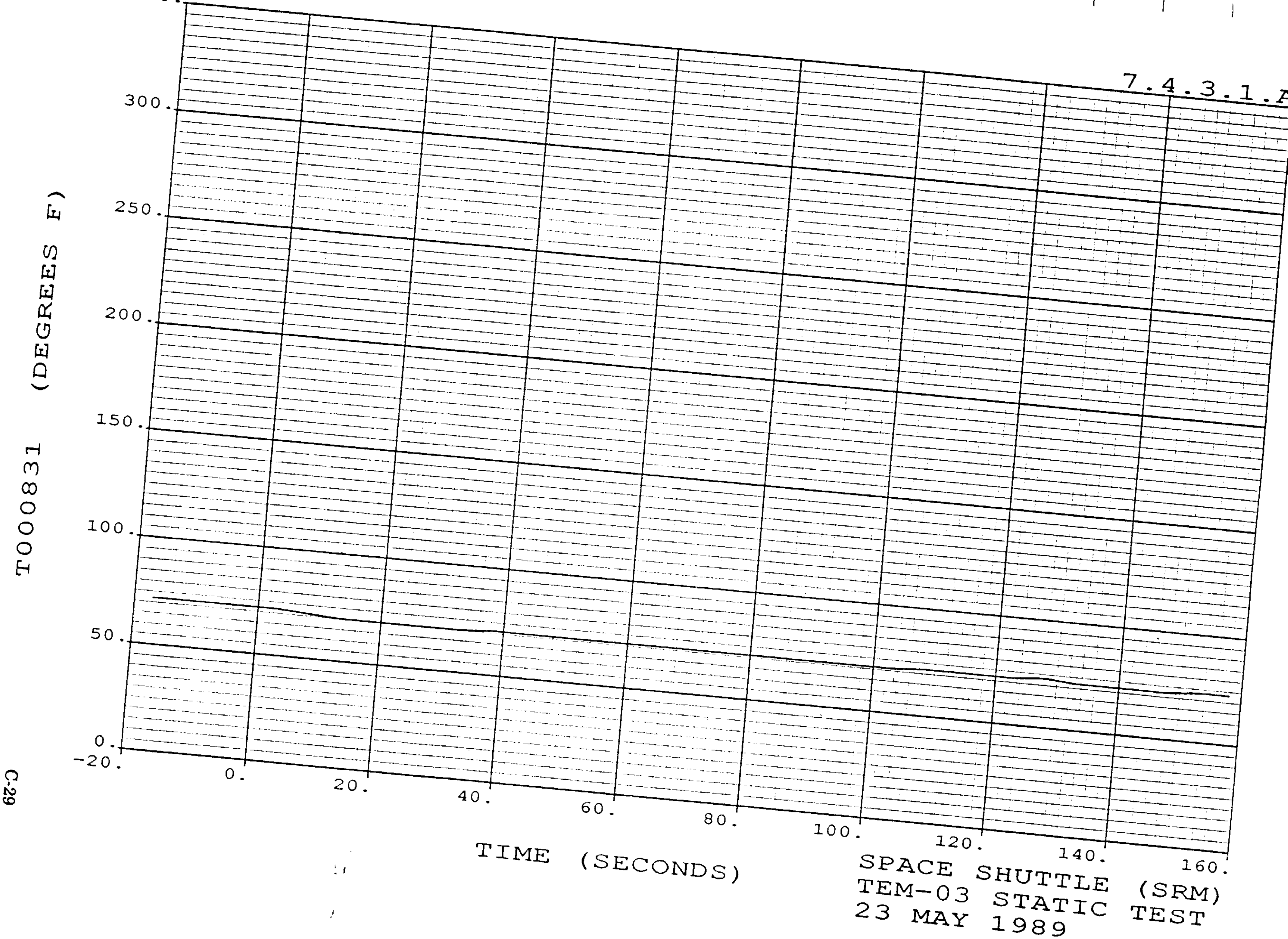
SPACE SHUTTLE (SRM)
TEM-03 STATIC TEST
23 MAY 1989

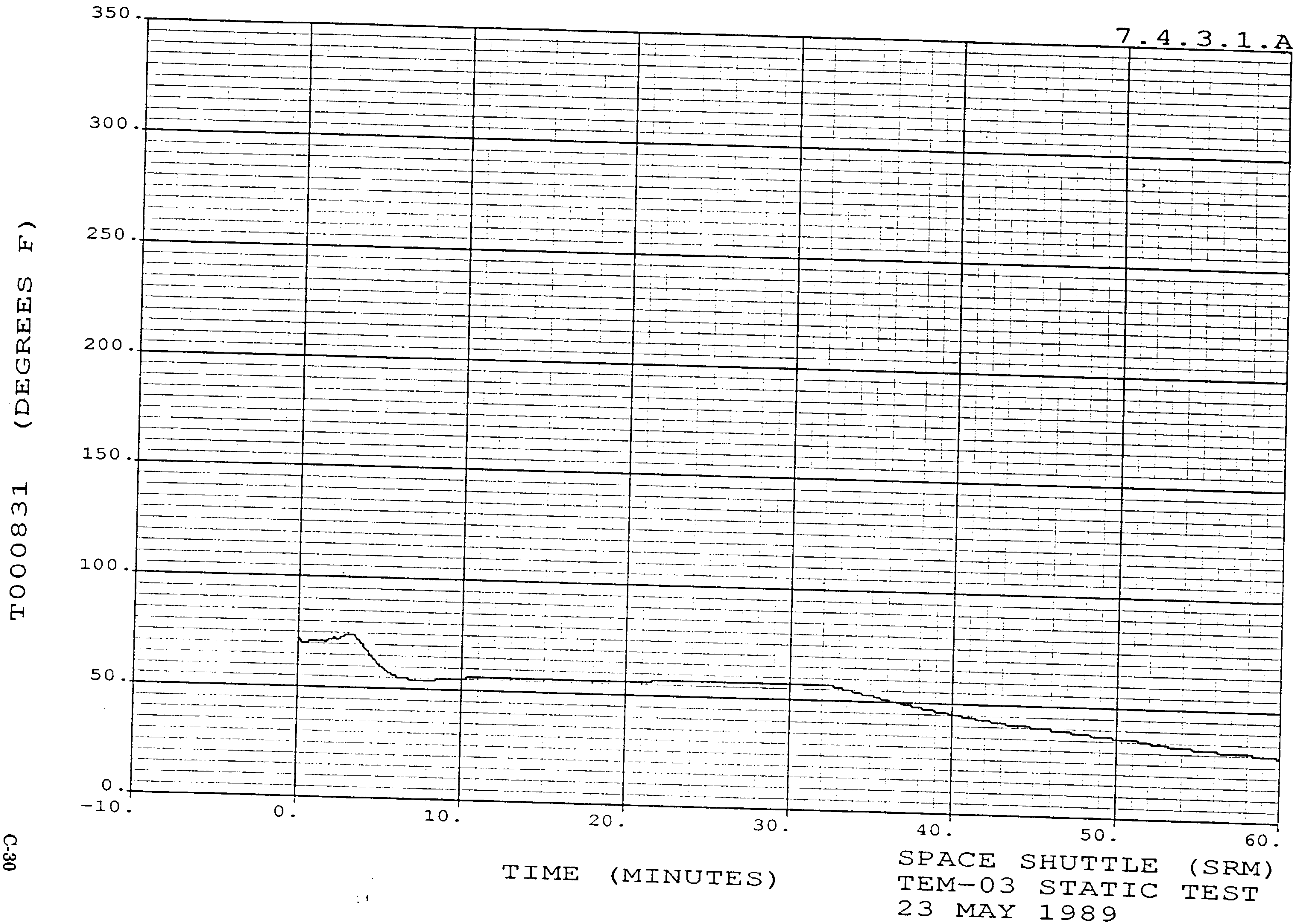

7.4.3.1.A
350.
300.
250.
200.
150.
100.
50.
0.
-20.
0.
20.
40.
60.
80.
100.
120.
140.
160.
T000638 (DEGREES F)
TIME (SECONDS)
SPACE SHUTTLE (SRM)
TEM-03 STATIC TEST
23 MAY 1989


7.4.3.1.A
T000830 (DEGREES F)
350.
300.
250.
200.
150.
100.
50.
0.
-20.
0.
20.
40.
60.
80.
100.
120.
140.
160.
TIME (SECONDS)
SPACE SHUTTLE (SRM)
TEM-03 STATIC TEST
23 MAY 1989

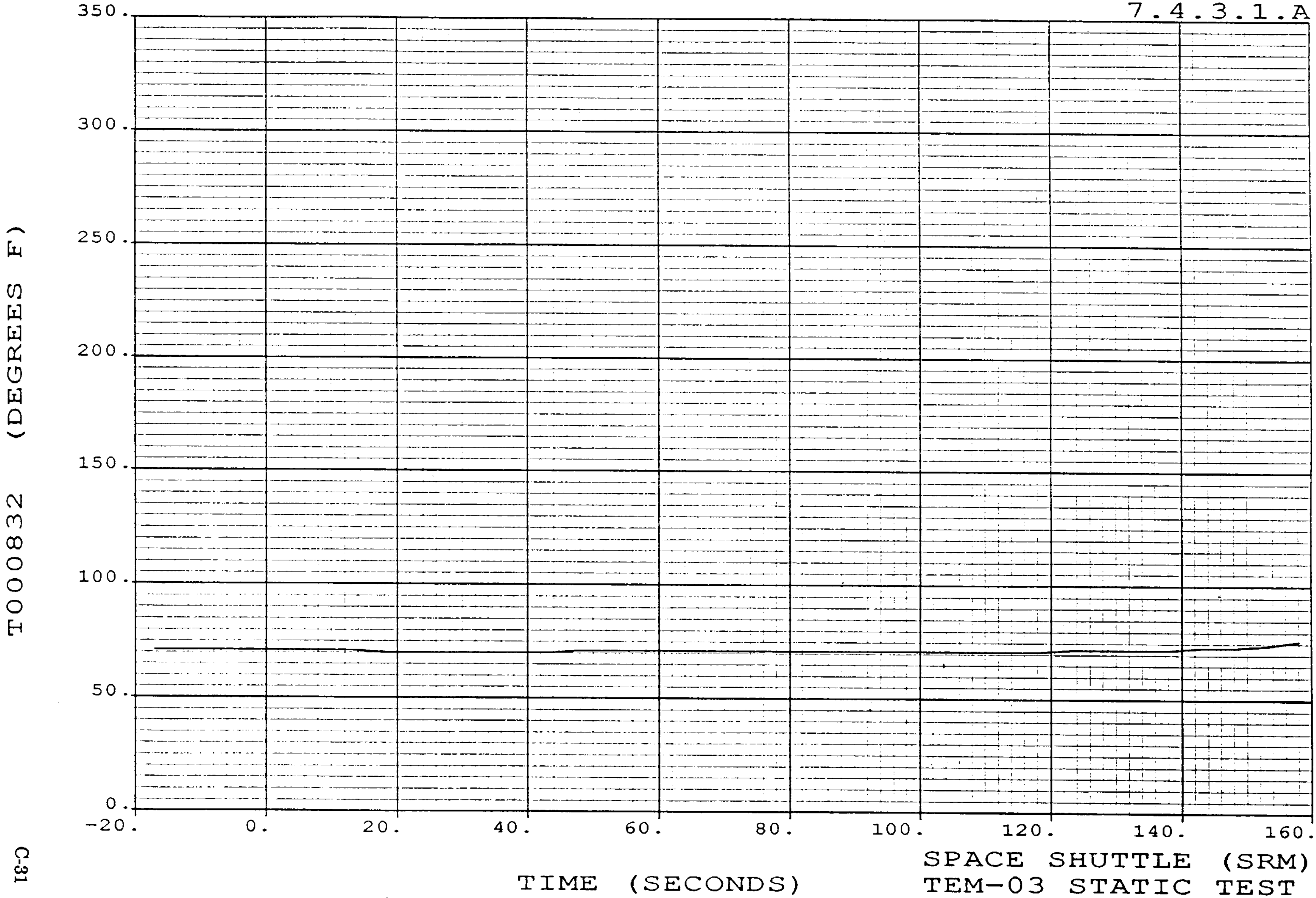


SPACE SHUTTLE (SRM)
TEM-03 STATIC TEST
23 MAY 1989

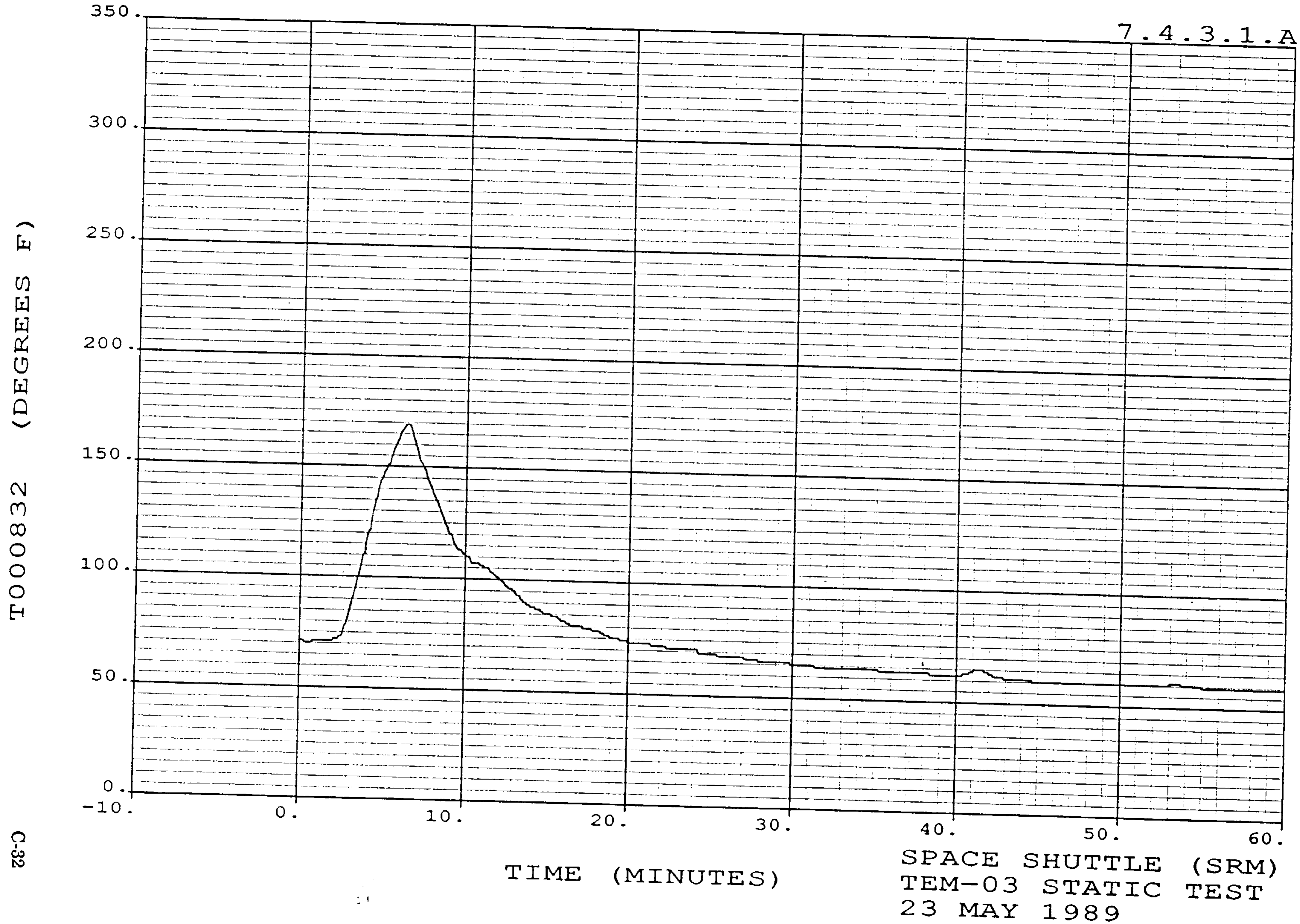

7.4.3.1.A
T000831 (DEGREES F)
300.
250.
200.
150.
100.
50.
0.
-20.
0.
20.
40.
60.
80.
100.
120.
140.
160.
TIME (SECONDS)
SPACE SHUTTLE (SRM)
TEM-03 STATIC TEST
23 MAY 1989

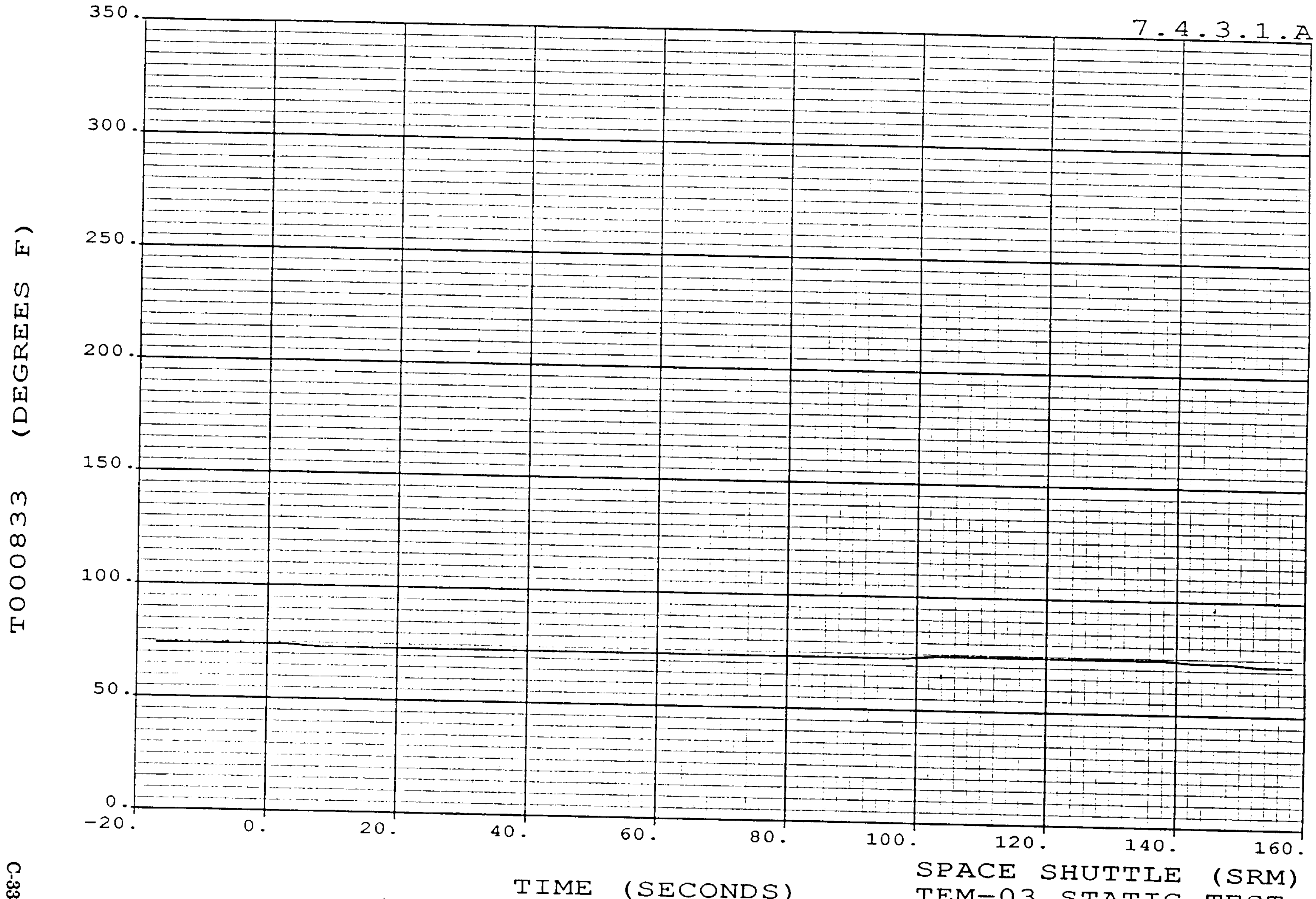

7.4.3.1.A
350.
300.
250.
200.
150.
100.
50.
0.
-10.
T000831 (DEGREES F)
0.
10.
20.
30.
40.
50.
60.
TIME (MINUTES)
SPACE SHUTTLE (SRM)
TEM-03 STATIC TEST
23 MAY 1989

7.4.3.1.A

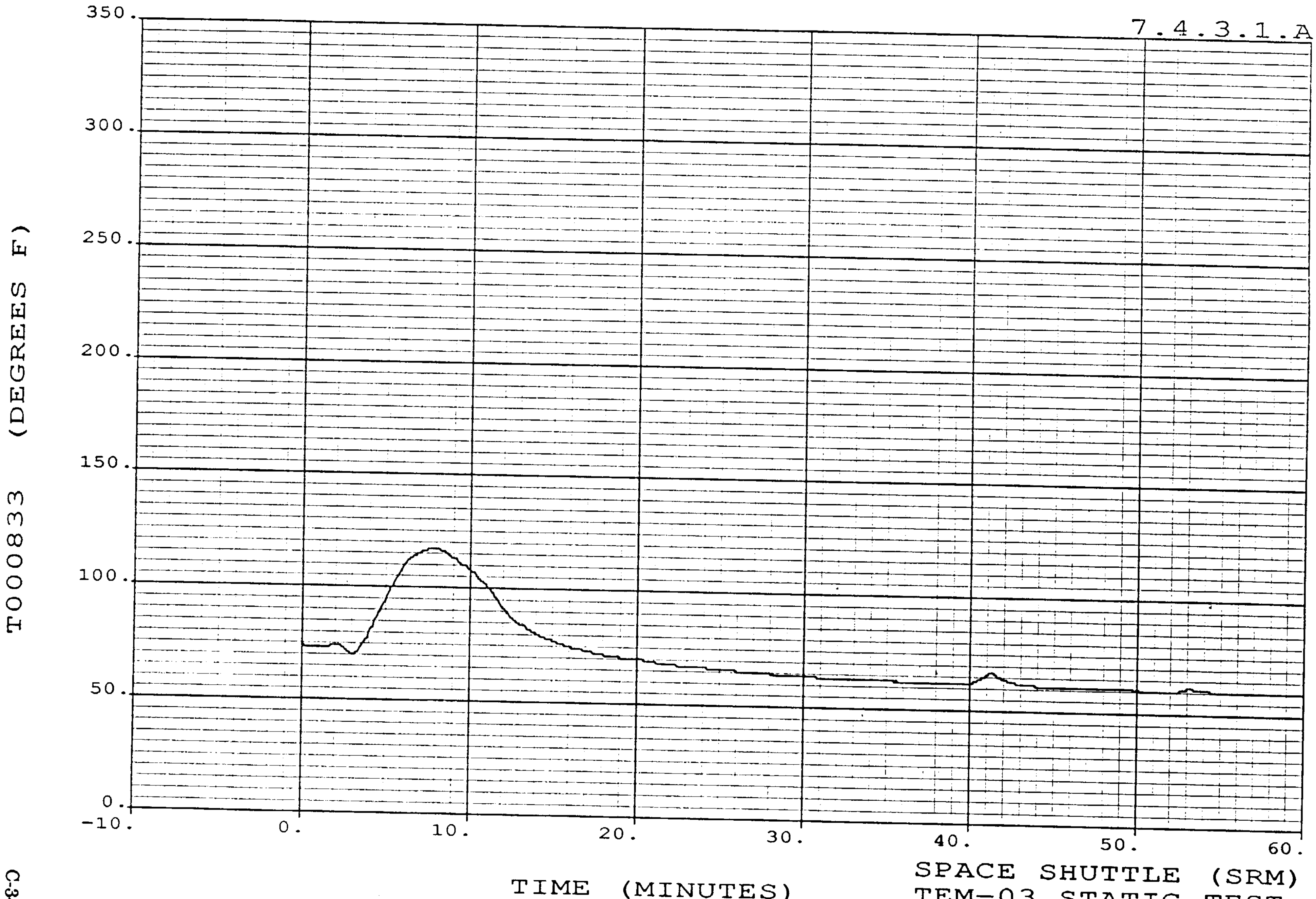


SPACE SHUTTLE (SRM)
TEM-03 STATIC TEST
23 MAY 1989


7.4.3.1.A
350.
300.
250.
200.
150.
100.
50.
0.
-10.
0.
10.
20.
30.
40.
50.
60.
T000832 (DEGREES F)
TIME (MINUTES)
SPACE SHUTTLE (SRM)
TEM-03 STATIC TEST
23 MAY 1989

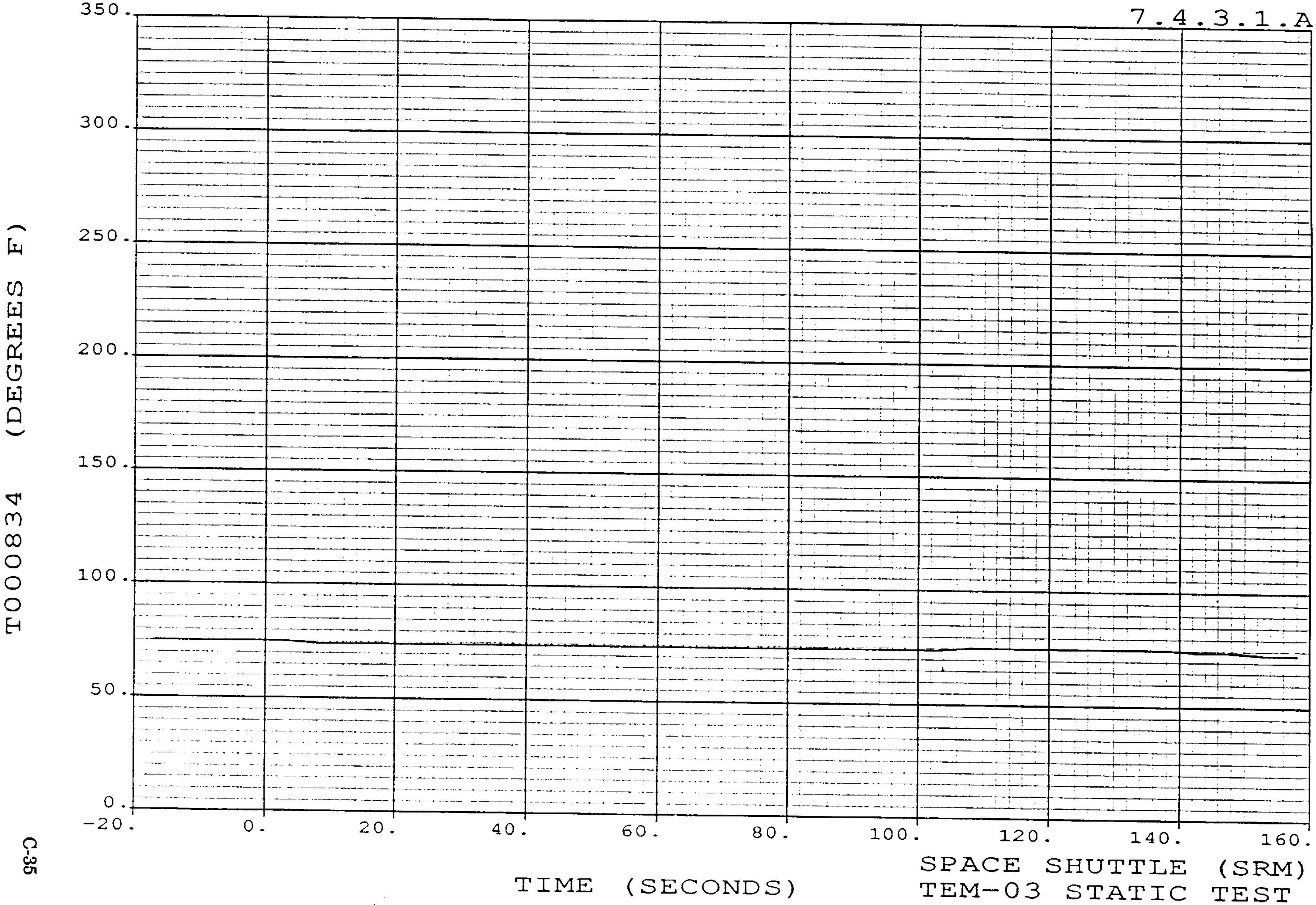


SPACE SHUTTLE (SRM)
TEM-03 STATIC TEST
23 MAY 1989

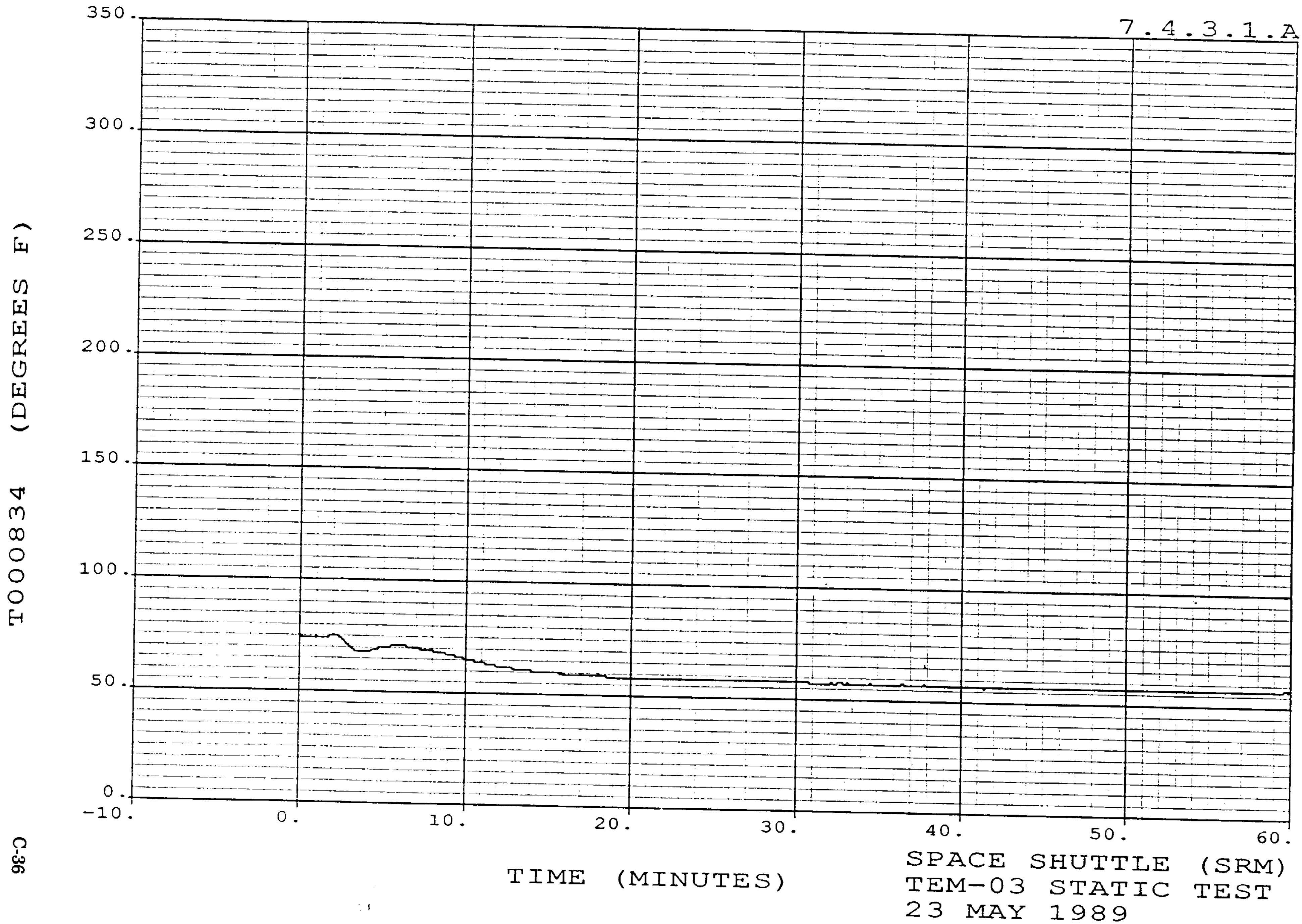


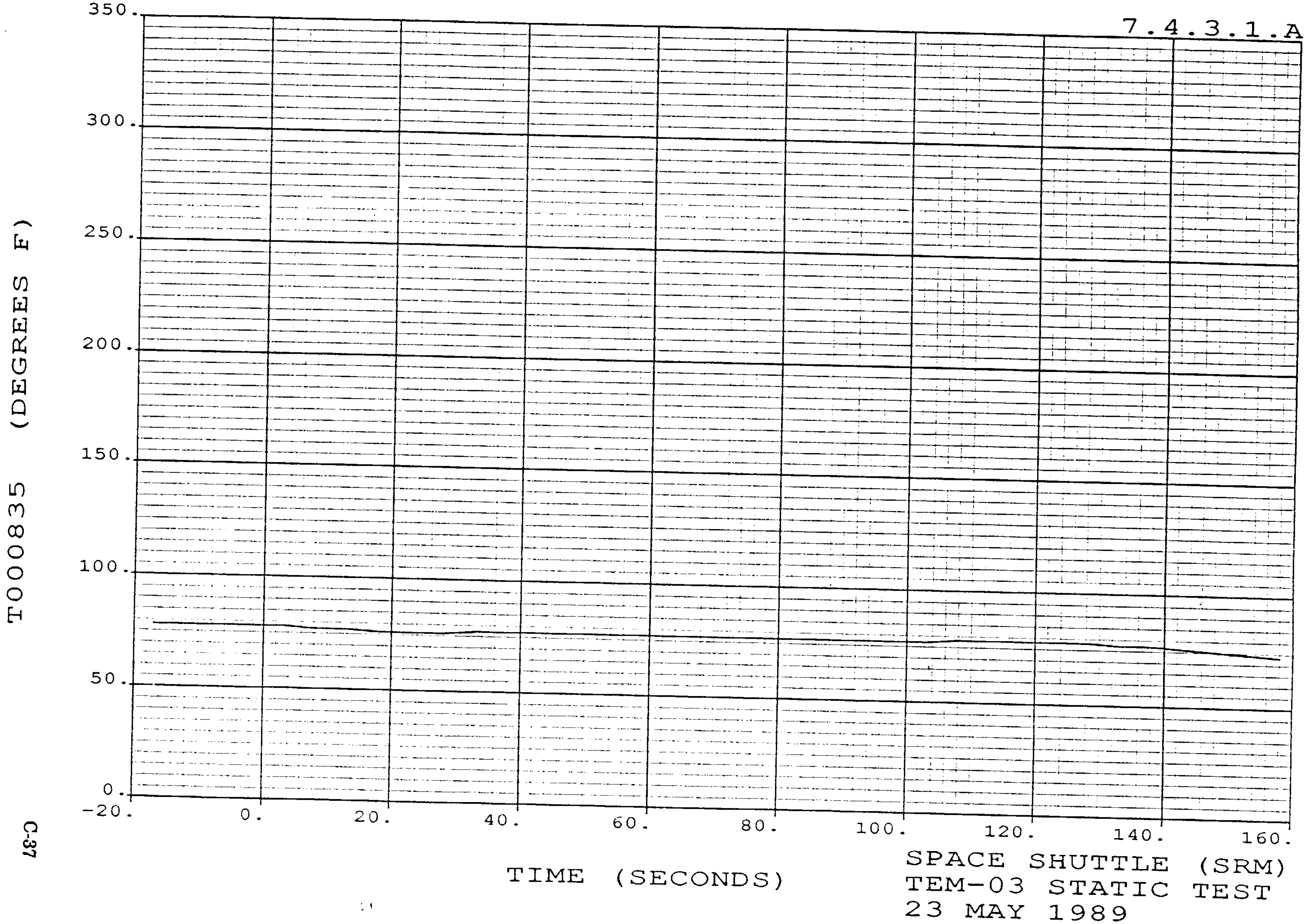
SPACE SHUTTLE (SRM)
TEM-03 STATIC TEST
23 MAY 1989

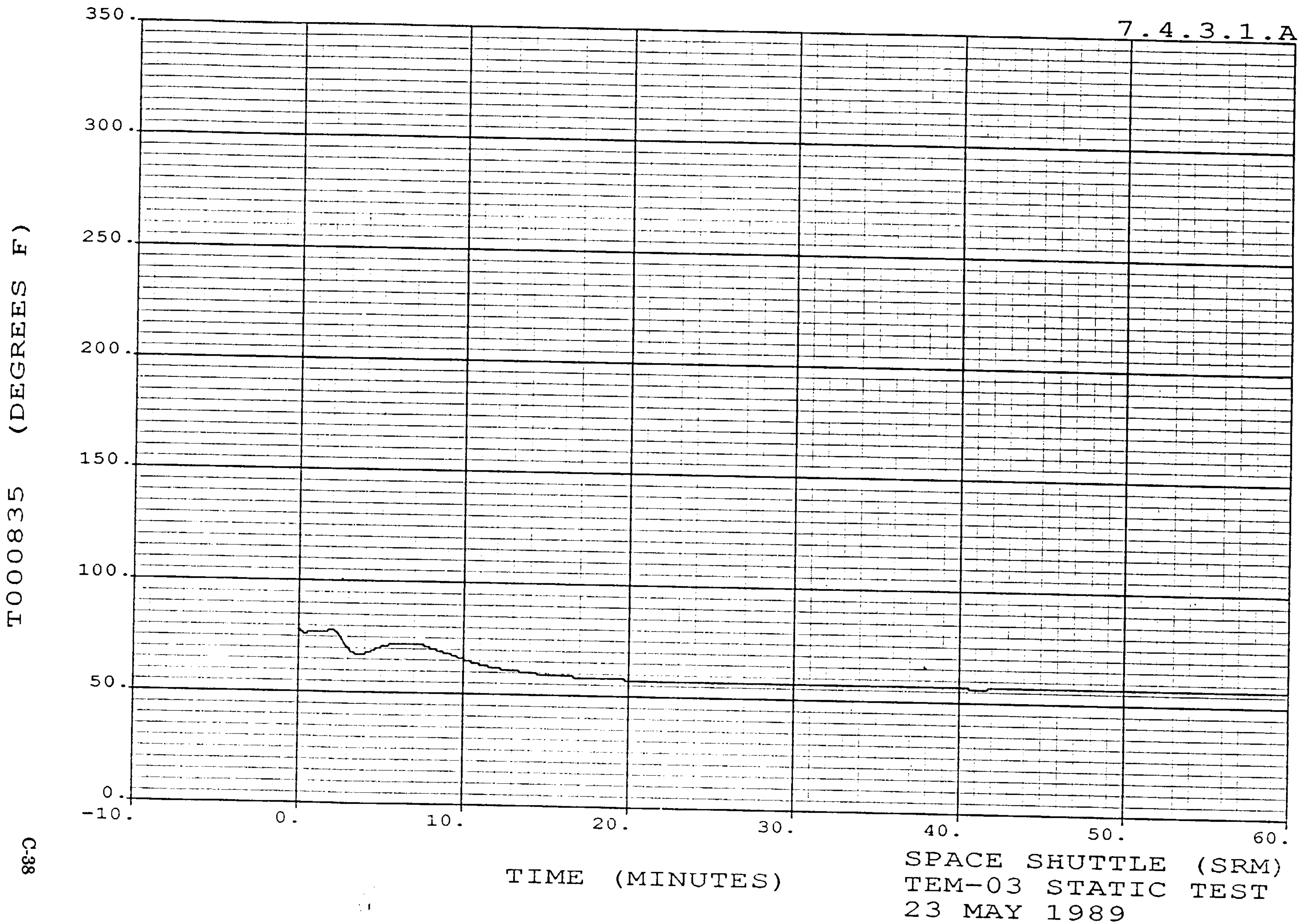
7.4.3.1.A

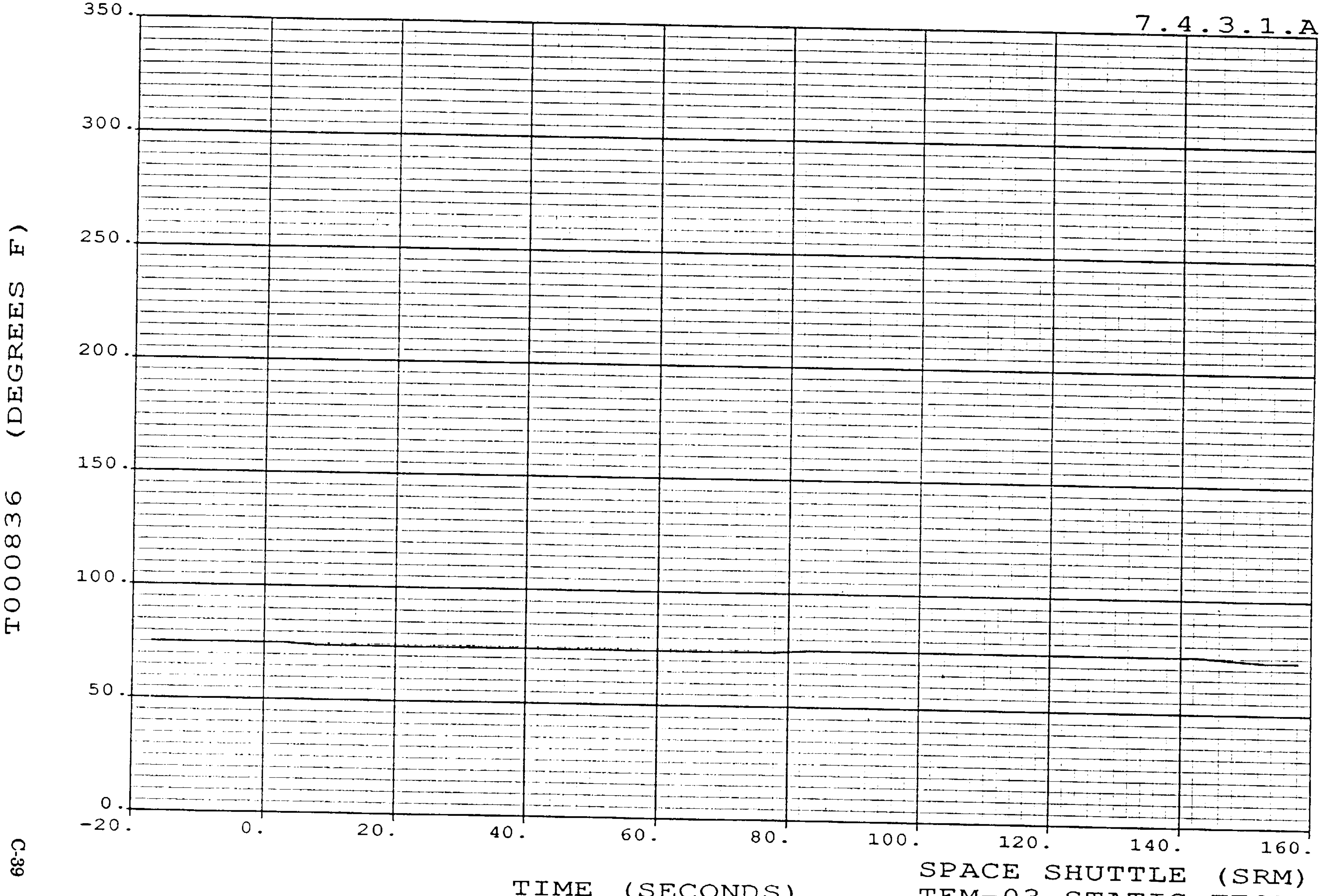


SPACE SHUTTLE (SRM)
TEM-03 STATIC TEST
23 MAY 1989

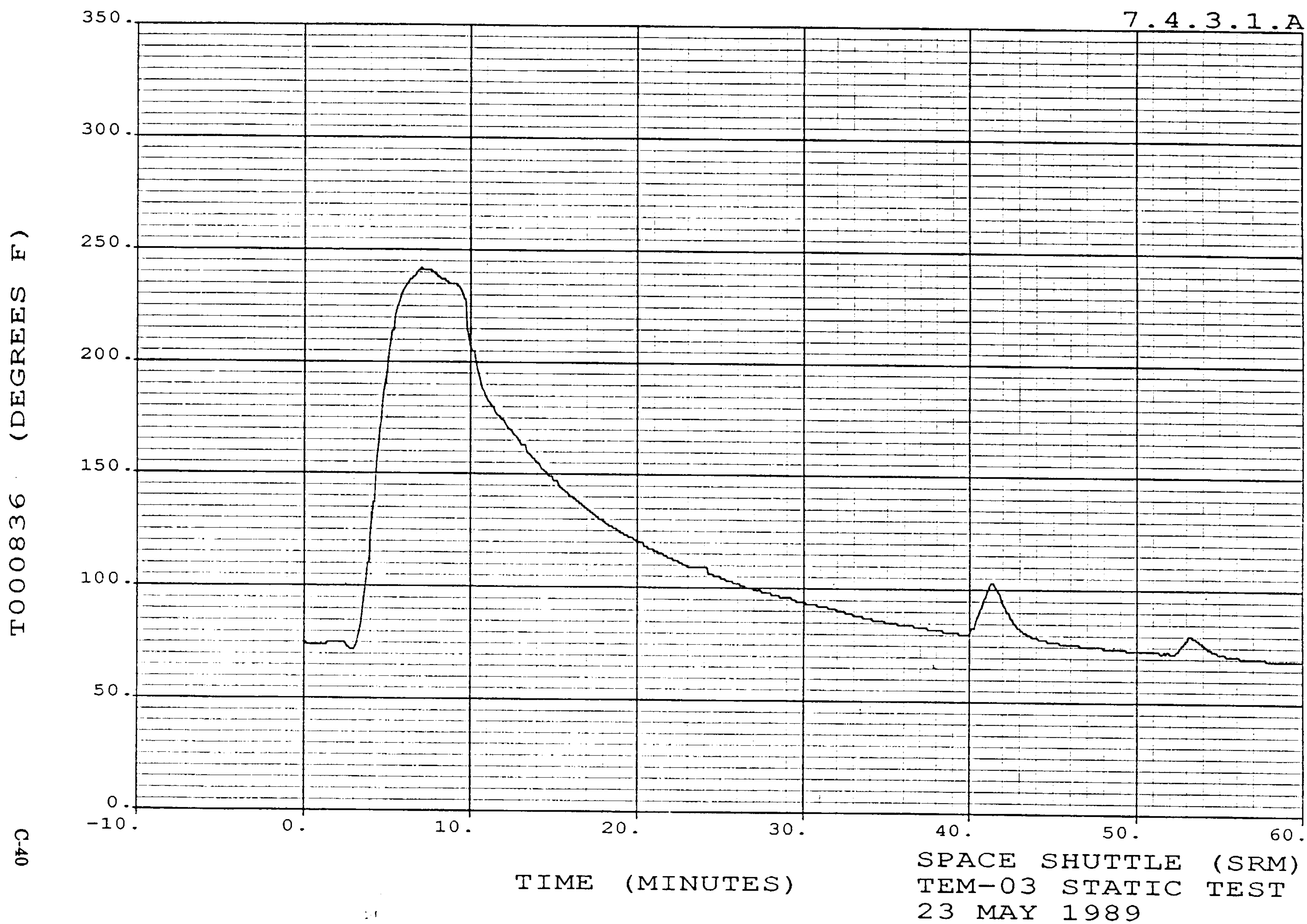

7.4.3.1.A
350.
300.
250.
200.
150.
100.
50.
0.
T000834 (DEGREES F)
-10.
0.
10.
20.
30.
40.
50.
60.
TIME (MINUTES)
SPACE SHUTTLE (SRM)
TEM-03 STATIC TEST
23 MAY 1989

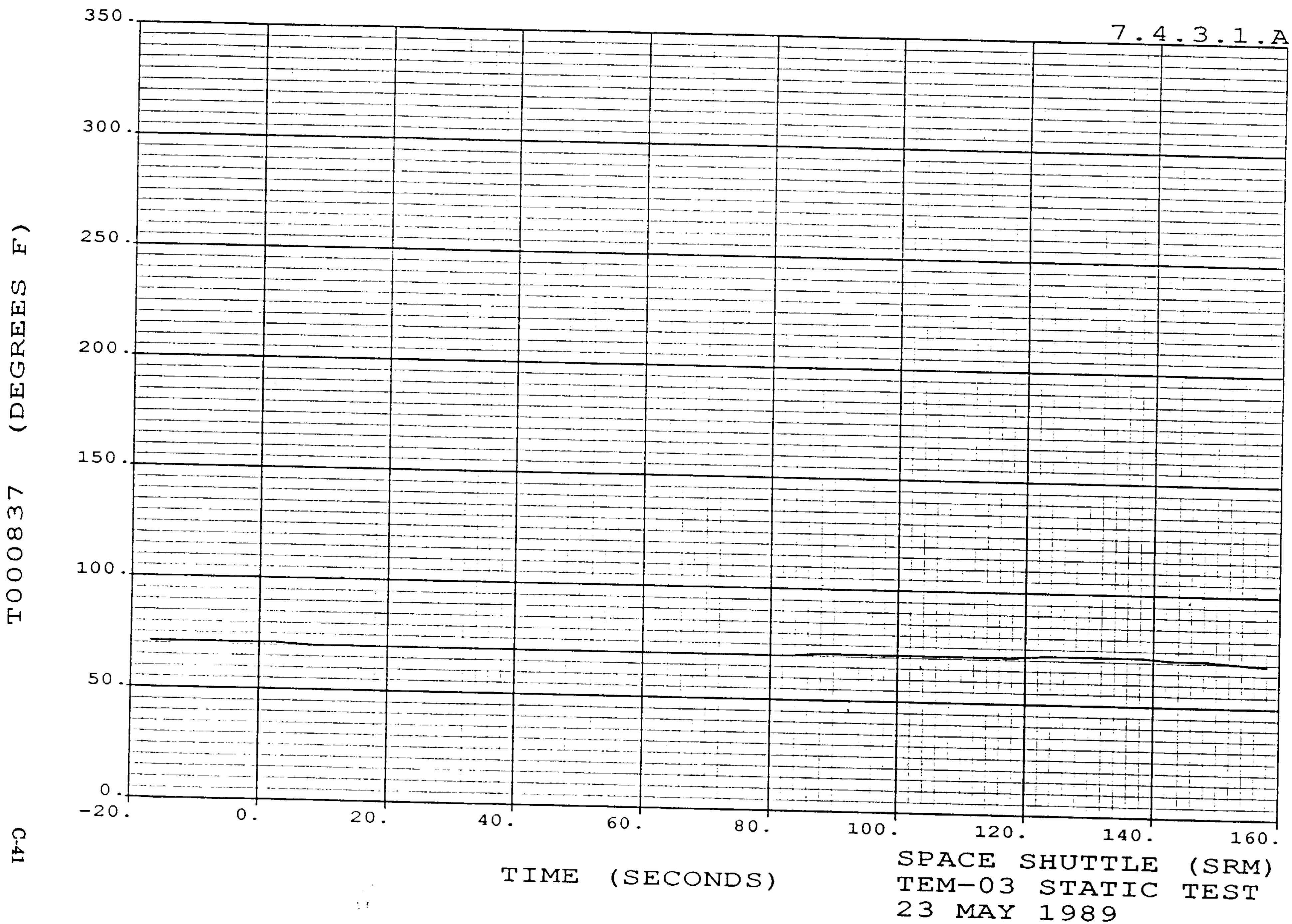

7.4.3.1.A
T000835 (DEGREES F)
350.
300.
250.
200.
150.
100.
50.
0.
-20.
0.
20.
40.
60.
80.
100.
120.
140.
160.
TIME (SECONDS)
SPACE SHUTTLE (SRM)
TEM-03 STATIC TEST
23 MAY 1989

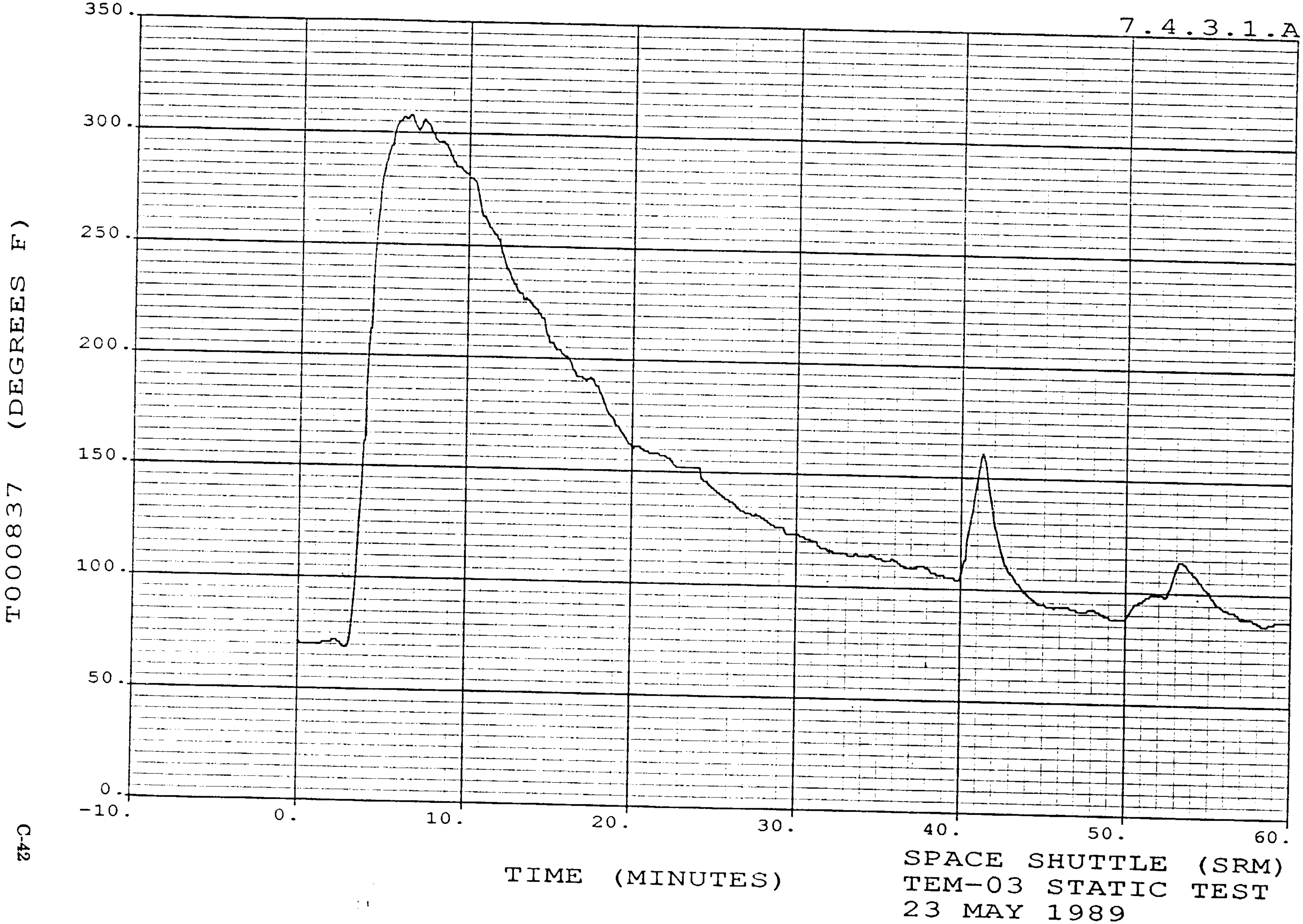

7.4.3.1.A
T000835 (DEGREES F)
350.
300.
250.
200.
150.
100.
50.
0.
-10.
0.
10.
20.
30.
40.
50.
60.
TIME (MINUTES)
SPACE SHUTTLE (SRM)
TEM-03 STATIC TEST
23 MAY 1989

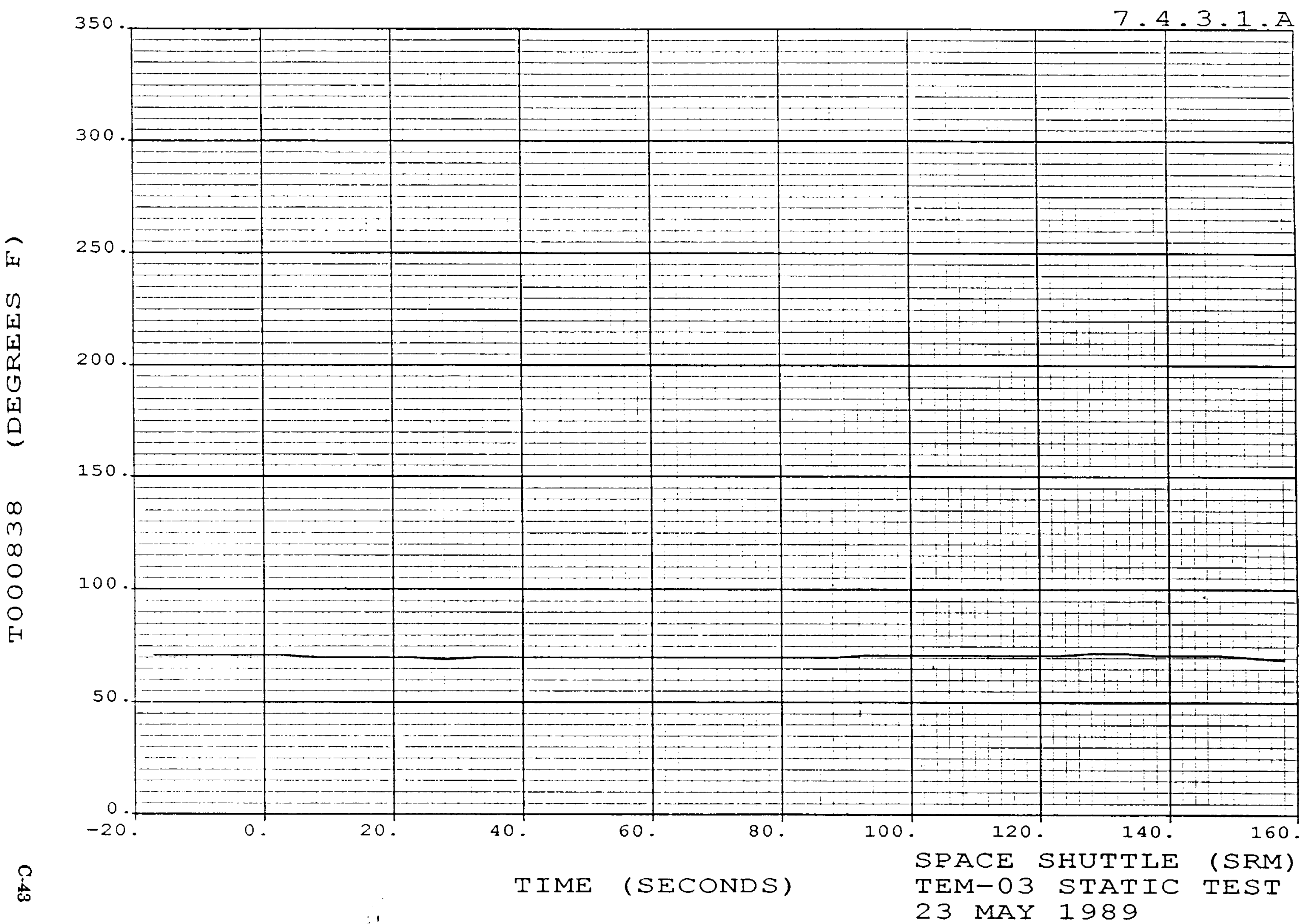


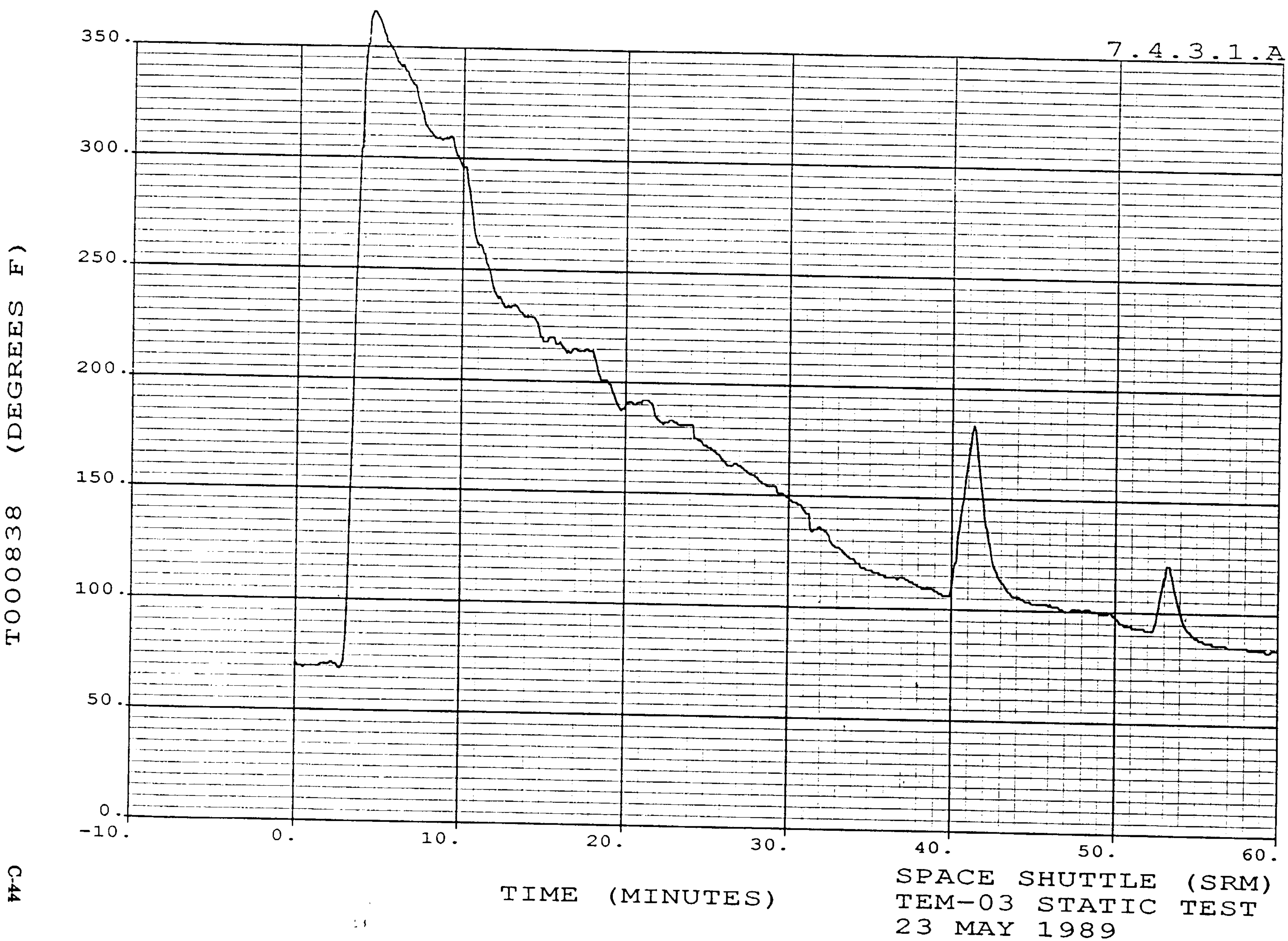
SPACE SHUTTLE (SRM)
TEM-03 STATIC TEST
23 MAY 1989


7.4.3.1.A
350.
300.
250.
200.
150.
100.
50.
0.
-10.
0.
10.
20.
30.
40.
50.
60.
T000836 (DEGREES F)
TIME (MINUTES)
SPACE SHUTTLE (SRM)
TEM-03 STATIC TEST
23 MAY 1989

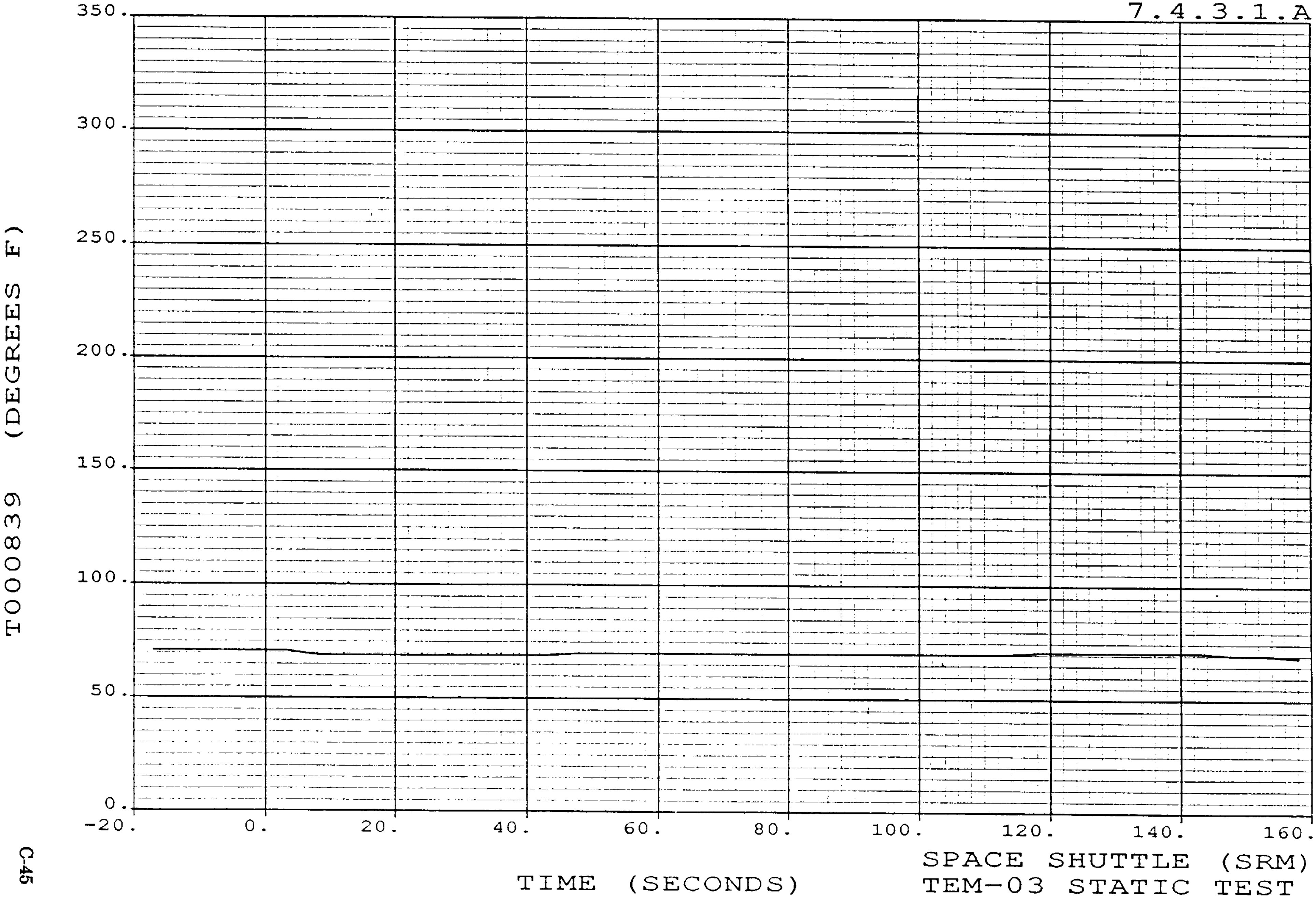

7.4.3.1.A
T000837 (DEGREES F)
350.
300.
250.
200.
150.
100.
50.
0.
-20.
0.
20.
40.
60.
80.
100.
120.
140.
160.
TIME (SECONDS)
SPACE SHUTTLE (SRM)
TEM-03 STATIC TEST
23 MAY 1989


7.4.3.1.A
350.
300.
250.
200.
150.
100.
50.
0.
-10.
0.
10.
20.
30.
40.
50.
60.
T000837 (DEGREES F)
TIME (MINUTES)
SPACE SHUTTLE (SRM)
TEM-03 STATIC TEST
23 MAY 1989

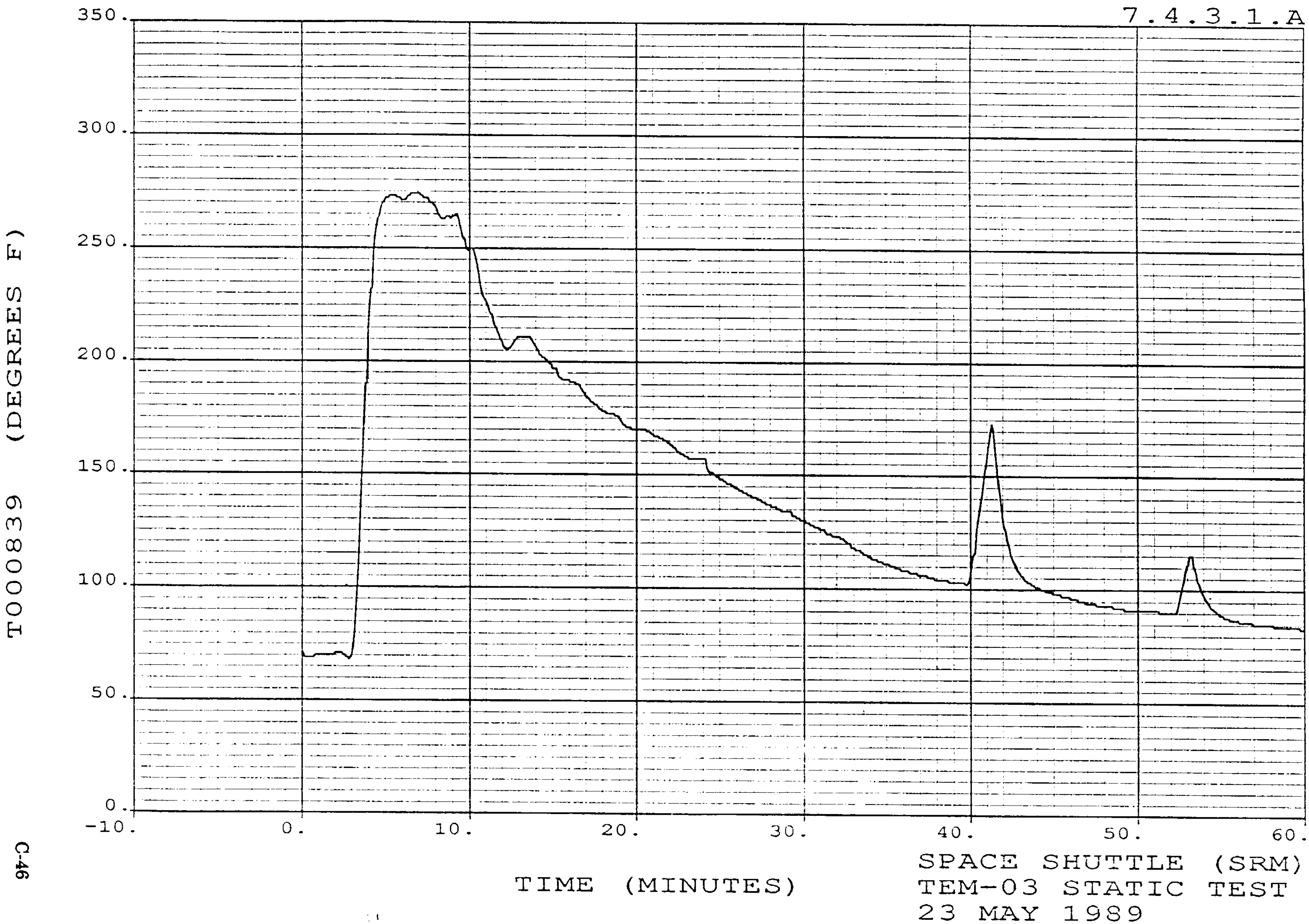

7.4.3.1.A
T000838 (DEGREES F)
350.
300.
250.
200.
150.
100.
50.
0.
-20.
0.
20.
40.
60.
80.
100.
120.
140.
160.
TIME (SECONDS)
SPACE SHUTTLE (SRM)
TEM-03 STATIC TEST
23 MAY 1989


7.4.3.1.A
350.
300.
250.
200.
150.
100.
50.
0.
-10.
0.
10.
20.
30.
40.
50.
60.
T000838 (DEGREES F)
TIME (MINUTES)
SPACE SHUTTLE (SRM)
TEM-03 STATIC TEST
23 MAY 1989

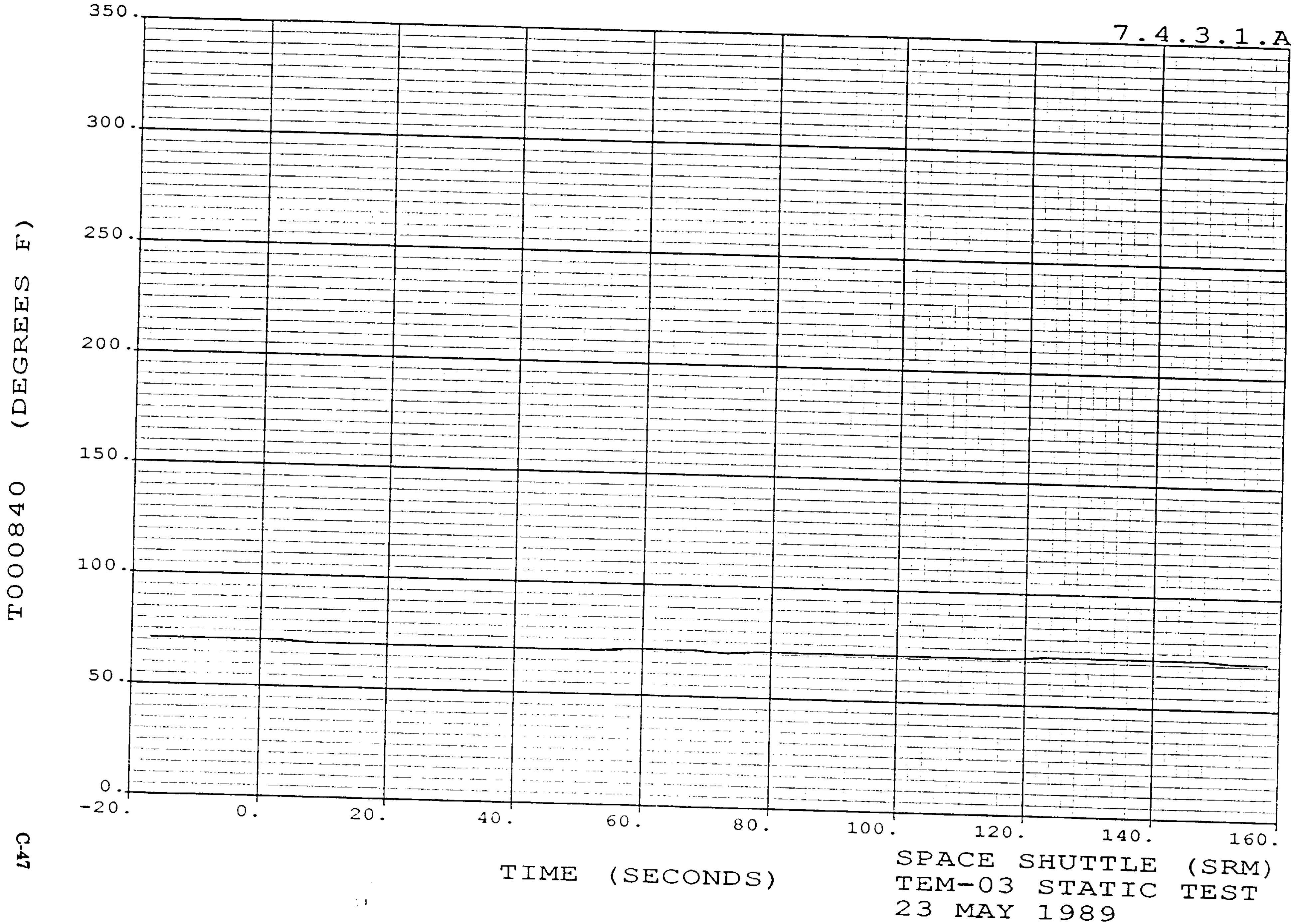
7.4.3.1.A

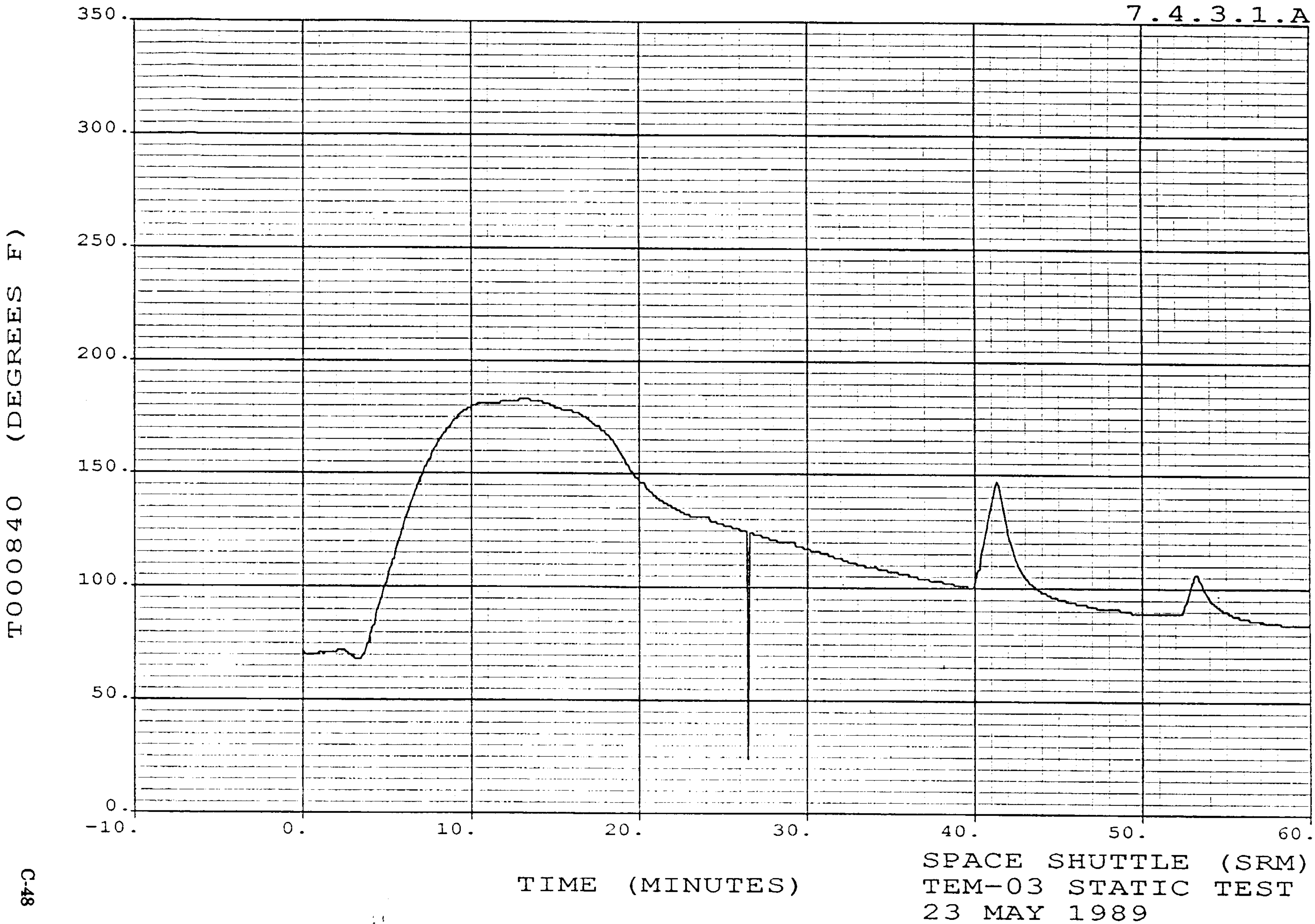


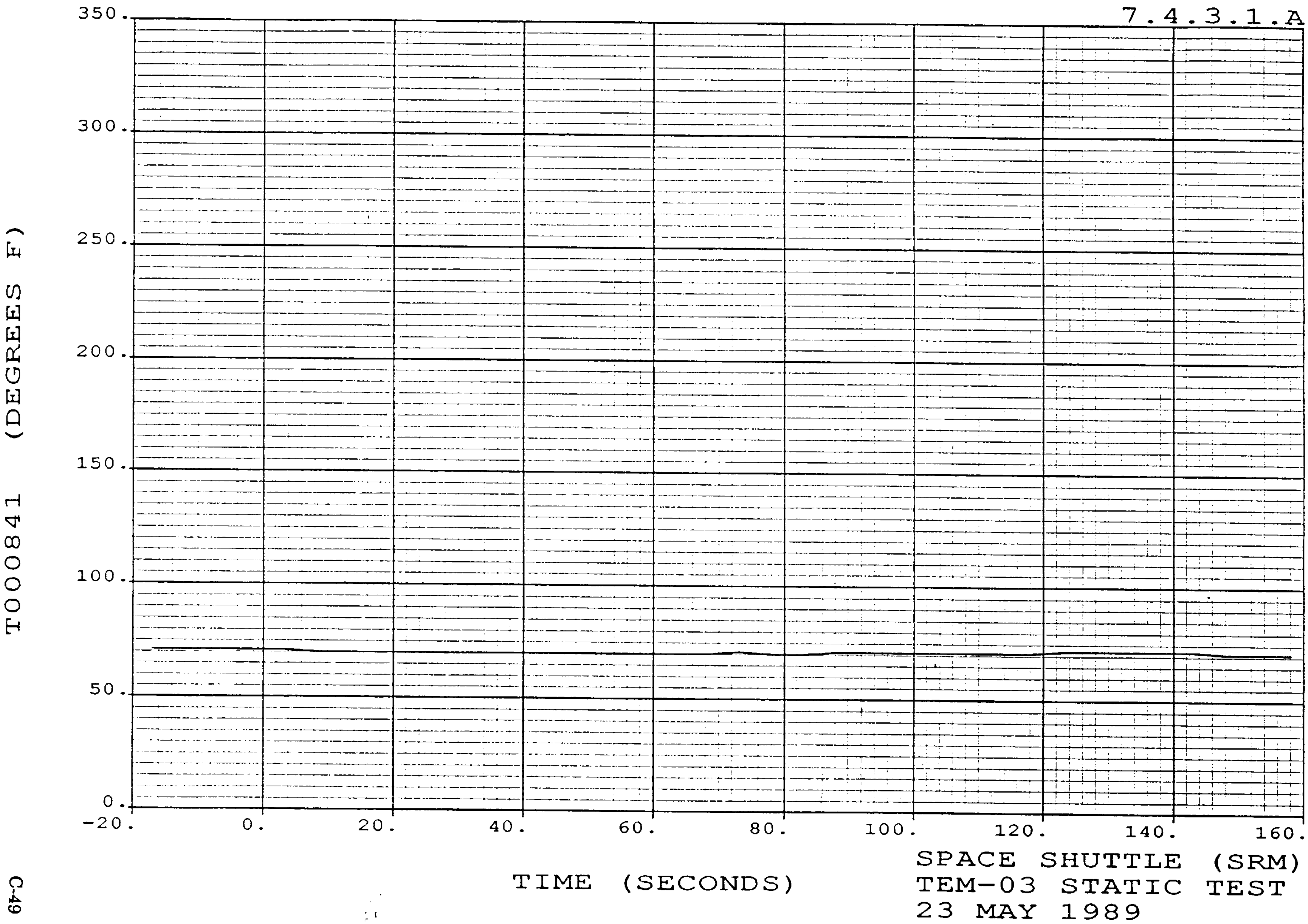
SPACE SHUTTLE (SRM)
TEM-03 STATIC TEST
23 MAY 1989

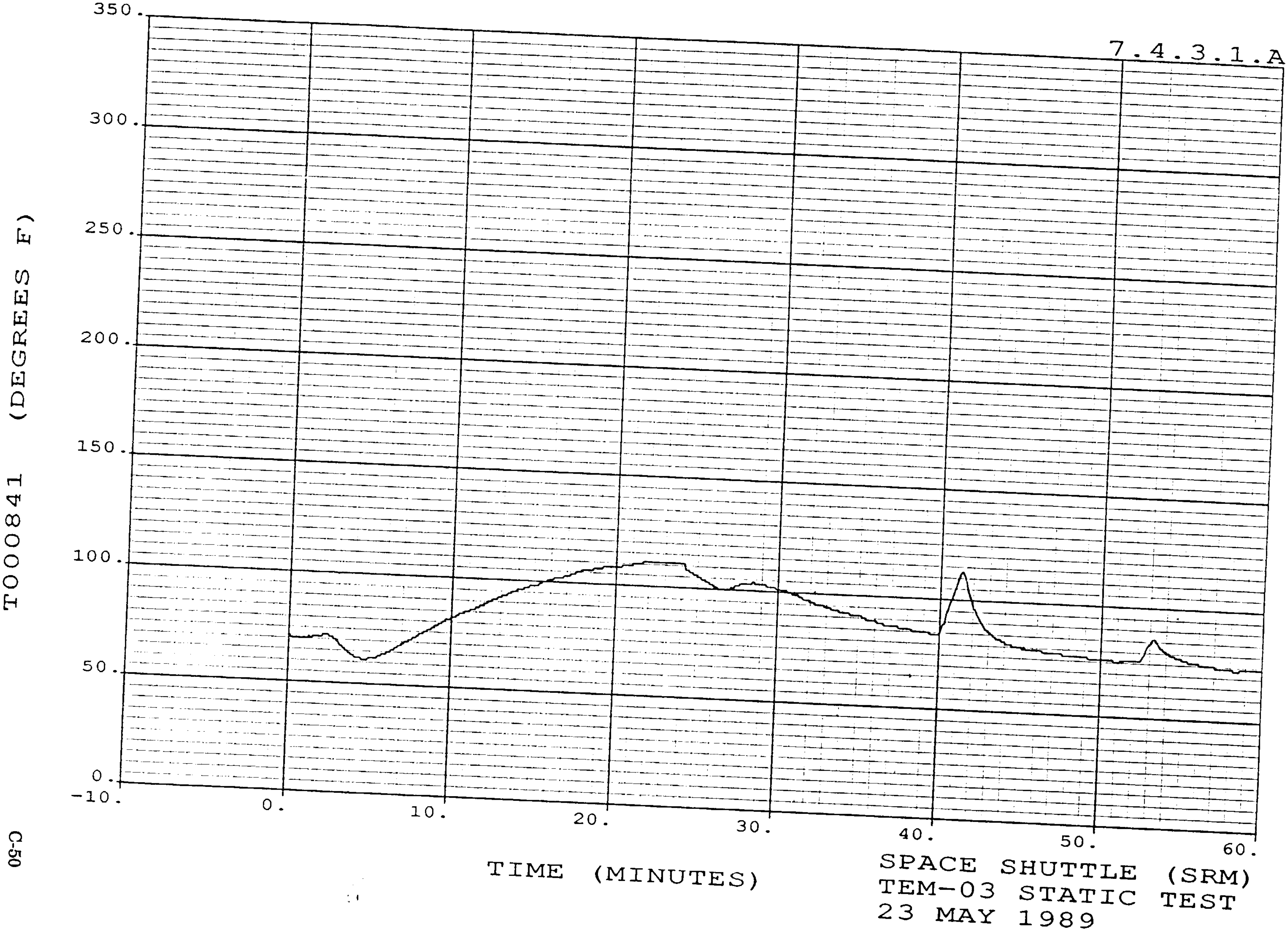


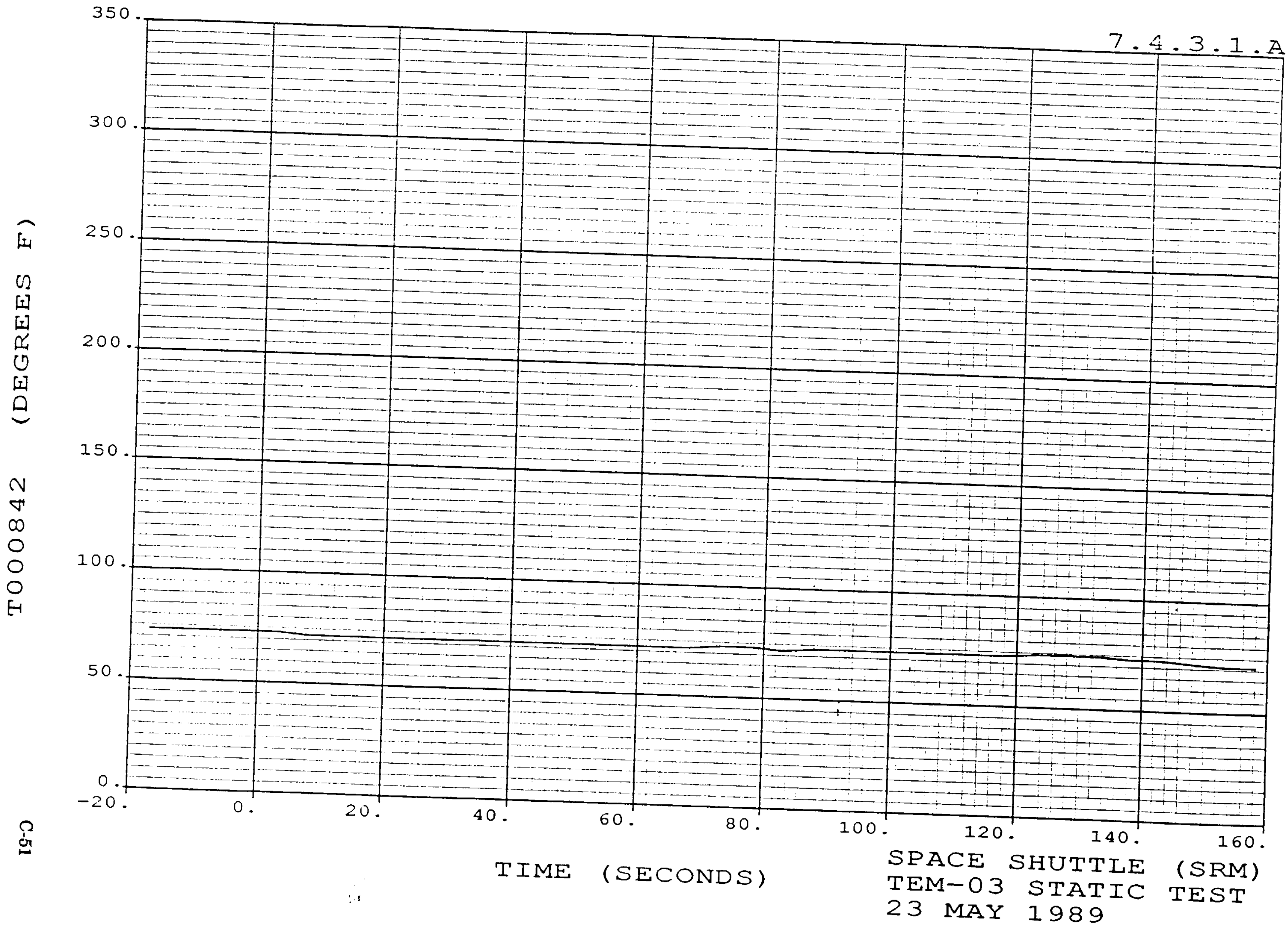
7.4.3.1.A
T000839 (DEGREES F)
350.
300.
250.
200.
150.
100.
50.
0.
-10.
0.
10.
20.
30.
40.
50.
60.
TIME (MINUTES)
SPACE SHUTTLE (SRM)
TEM-03 STATIC TEST
23 MAY 1989

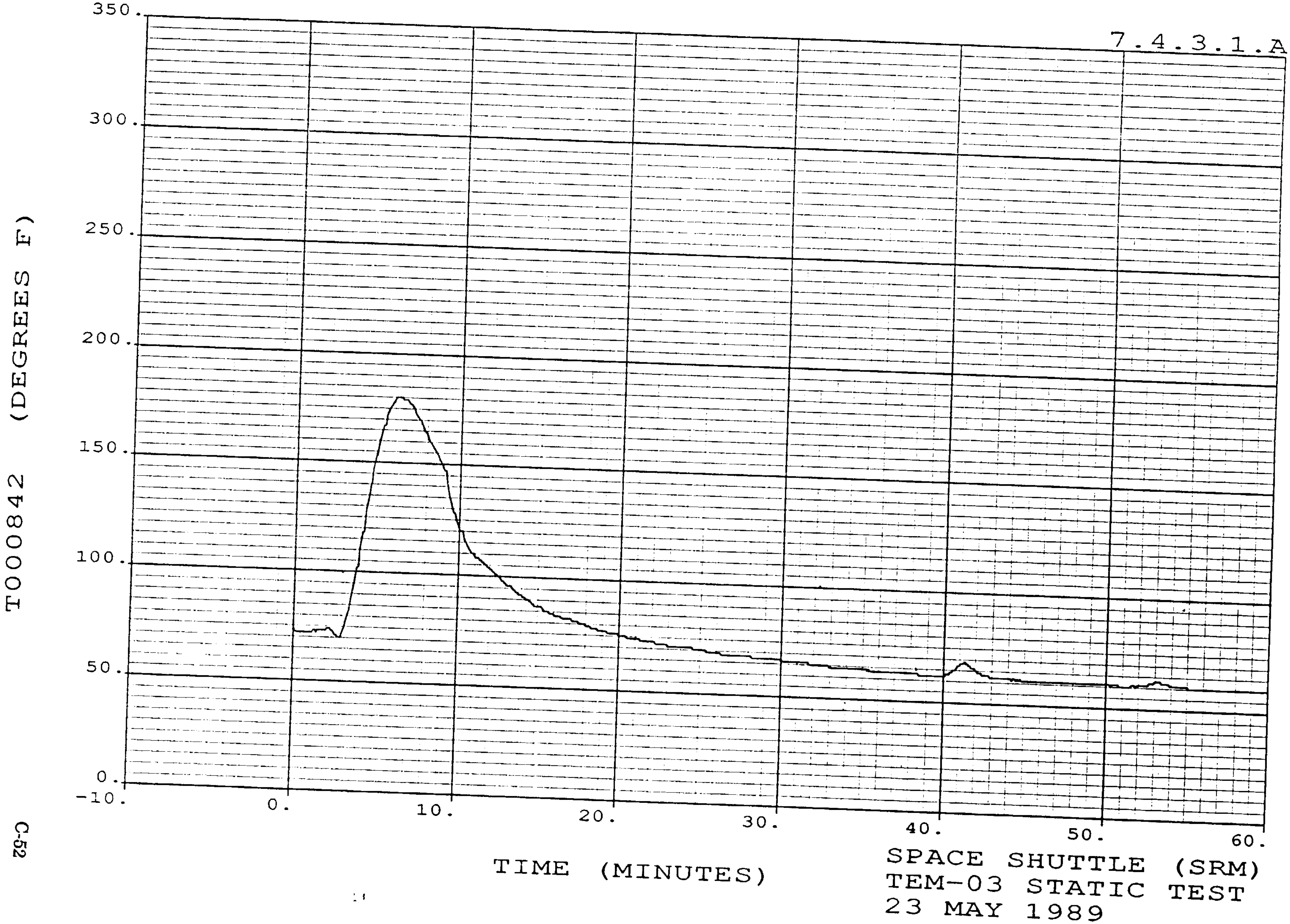

7.4.3.1.A
350.
300.
250.
200.
150.
100.
50.
0.
-20.
0.
20.
40.
60.
80.
100.
120.
140.
160.
T000840 (DEGREES F)
TIME (SECONDS)
SPACE SHUTTLE (SRM)
TEM-03 STATIC TEST
23 MAY 1989

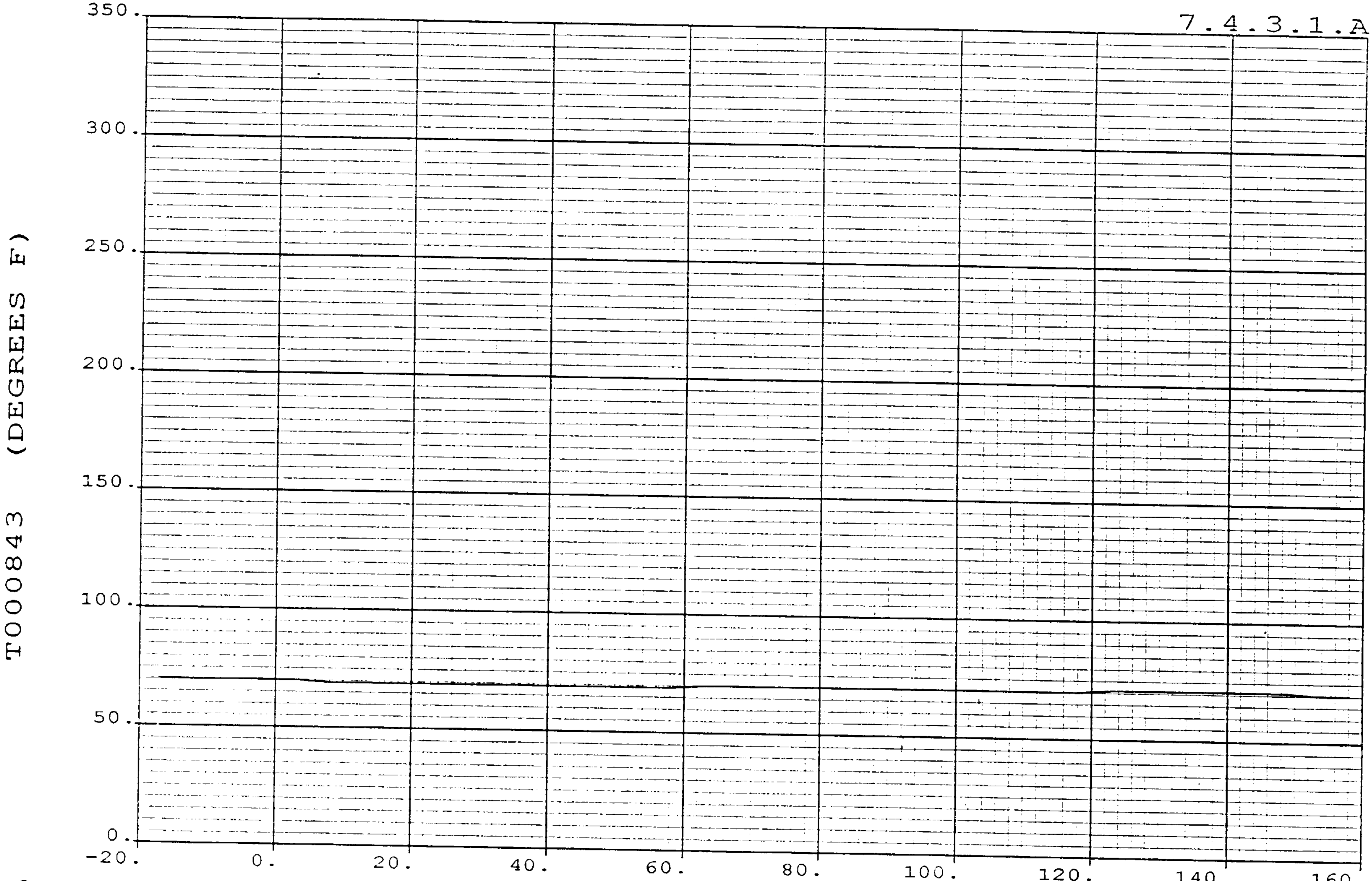

7.4.3.1.A
350.
300.
250.
200.
150.
100.
50.
0.
-10.
0.
10.
20.
30.
40.
50.
60.
T000840 (DEGREES F)
TIME (MINUTES)
SPACE SHUTTLE (SRM)
TEM-03 STATIC TEST
23 MAY 1989


7.4.3.1.A
350.
300.
250.
200.
150.
100.
50.
0.
T000841 (DEGREES F)
-20.
0.
20.
40.
60.
80.
100.
120.
140.
160.
TIME (SECONDS)
SPACE SHUTTLE (SRM)
TEM-03 STATIC TEST
23 MAY 1989

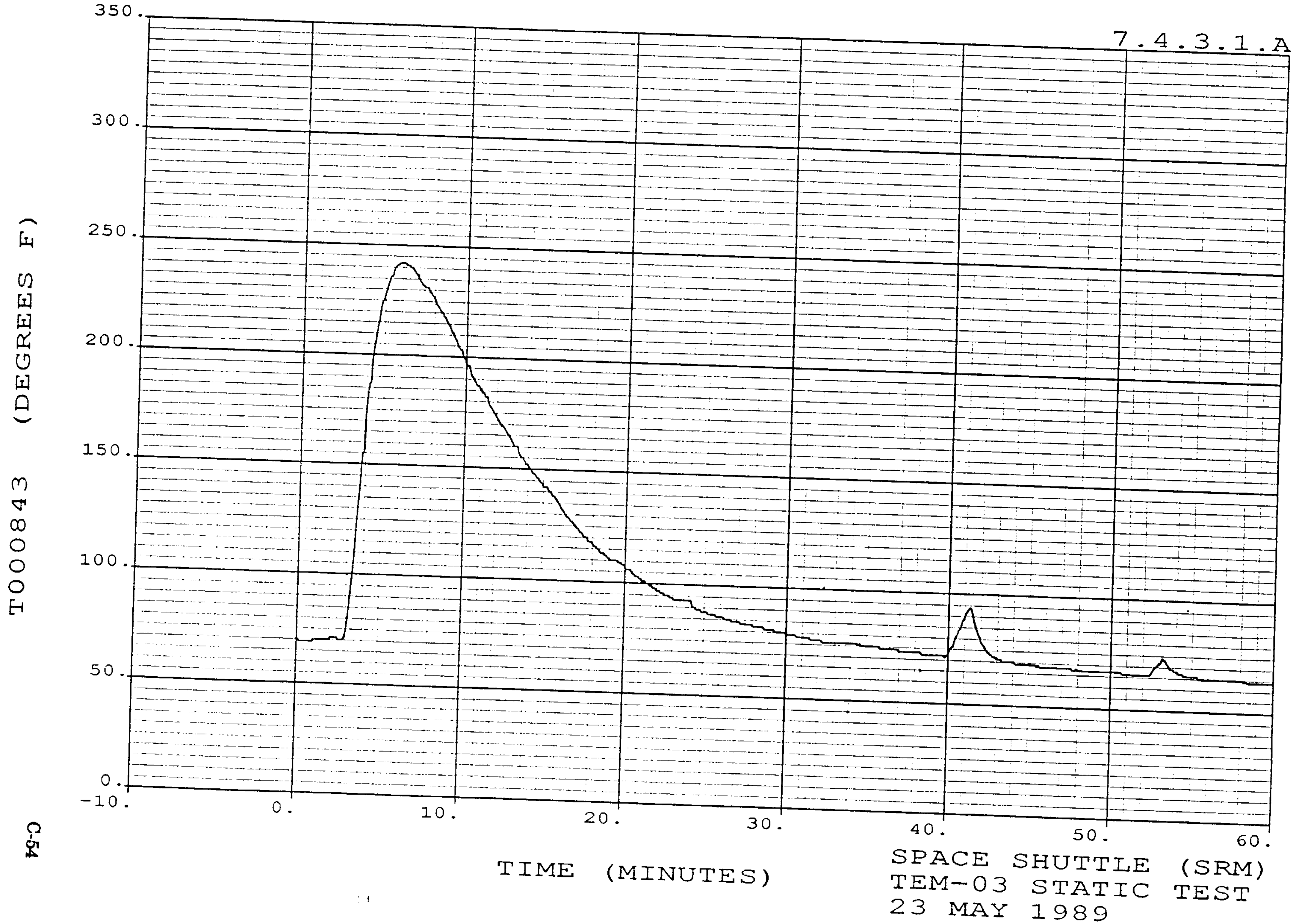

7.4.3.1.A
T000841 (DEGREES F)
350.
300.
250.
200.
150.
100.
50.
0.
-10.
0.
10.
20.
30.
40.
50.
60.
TIME (MINUTES)
SPACE SHUTTLE (SRM)
TEM-03 STATIC TEST
23 MAY 1989


7.4.3.1.A
350.
300.
250.
200.
150.
100.
50.
0.
-20.
0.
20.
40.
60.
80.
100.
120.
140.
160.
T000842 (DEGREES F)
TIME (SECONDS)
SPACE SHUTTLE (SRM)
TEM-03 STATIC TEST
23 MAY 1989


7.4.3.1.A
T000842 (DEGREES F)
350.
300.
250.
200.
150.
100.
50.
0.
-10.
0.
10.
20.
30.
40.
50.
60.
TIME (MINUTES)
SPACE SHUTTLE (SRM)
TEM-03 STATIC TEST
23 MAY 1989



SPACE SHUTTLE (SRM)
TEM-03 STATIC TEST
23 MAY 1989


7.4.3.1.A
T000843 (DEGREES F)
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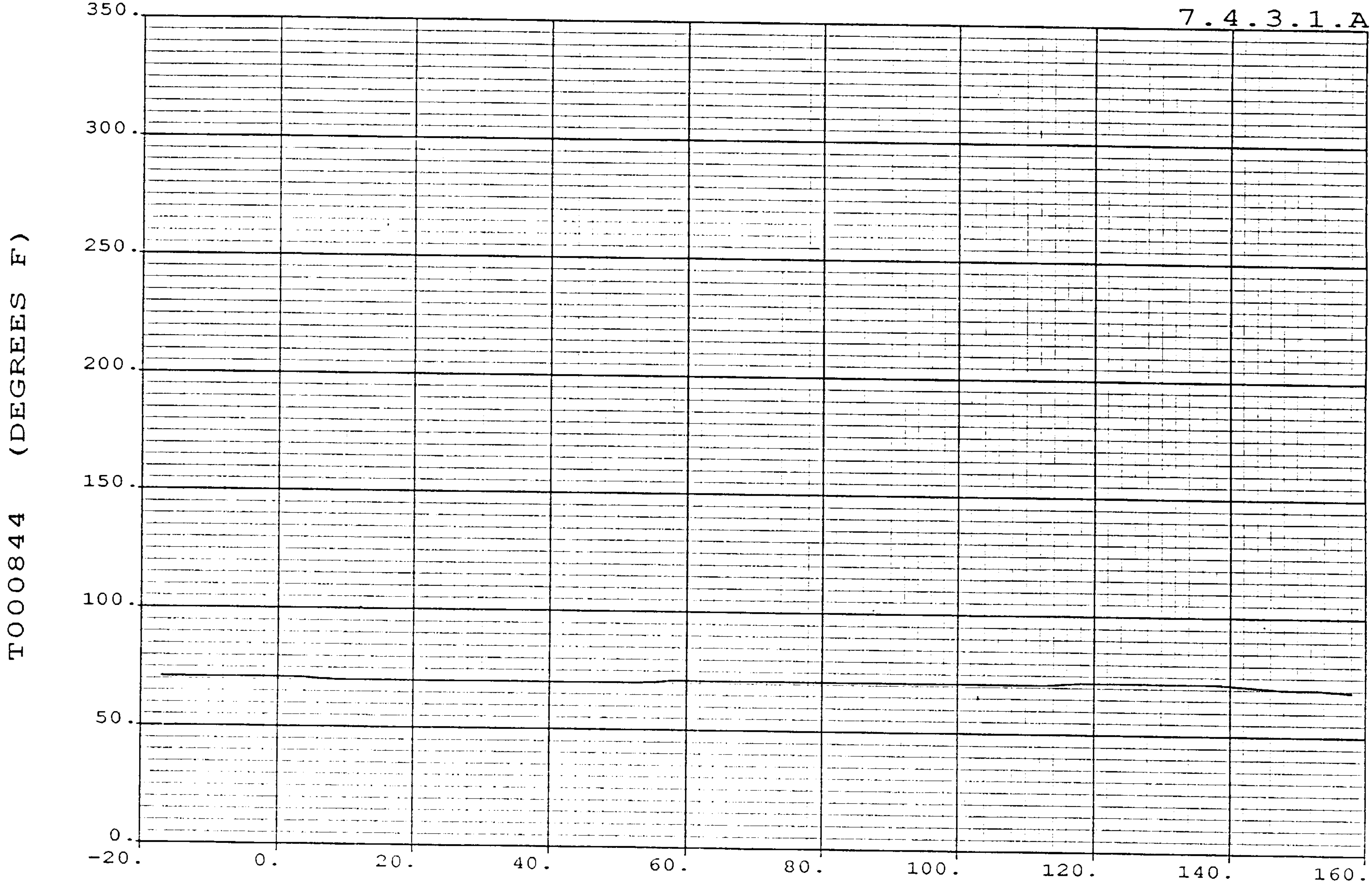
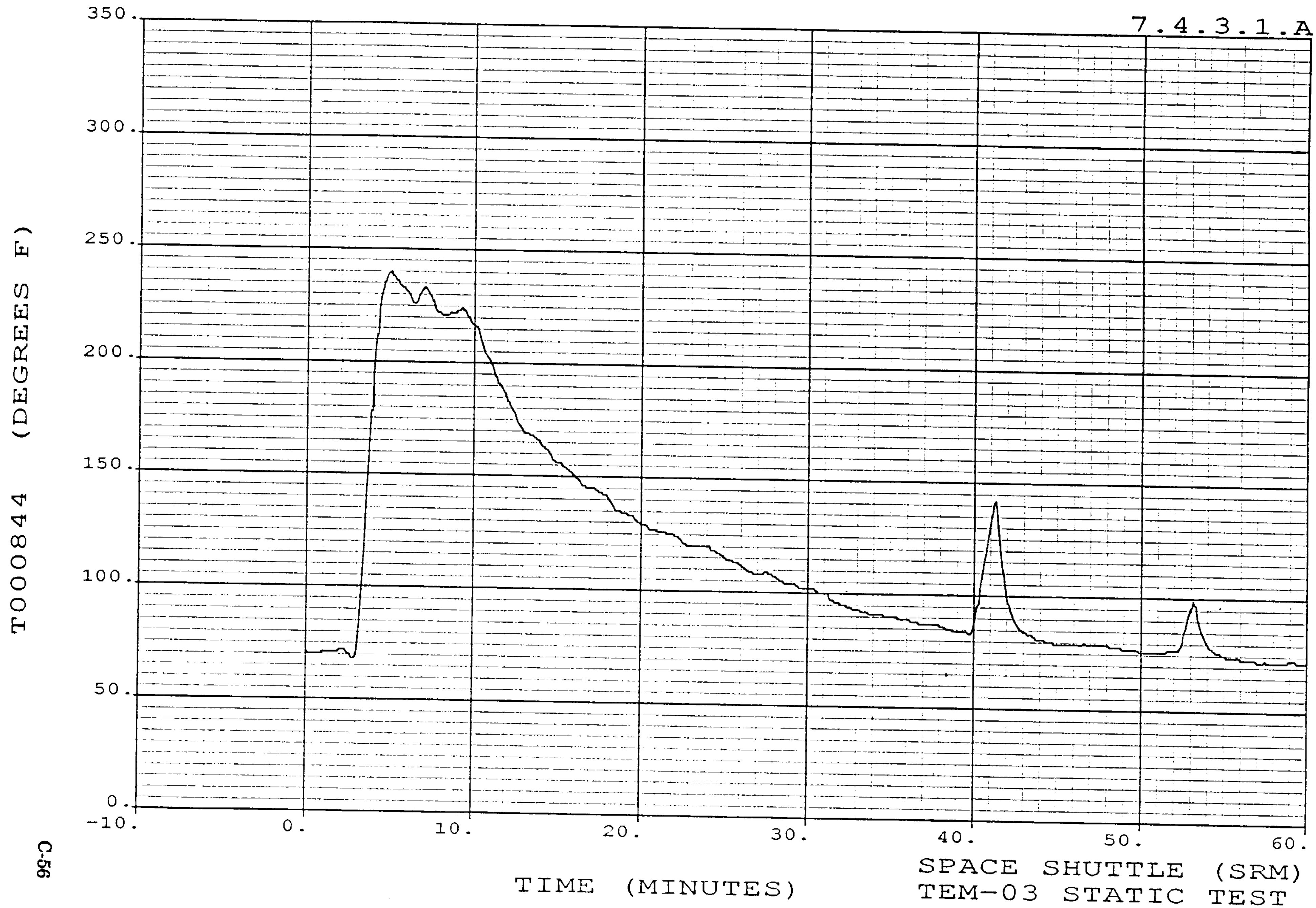
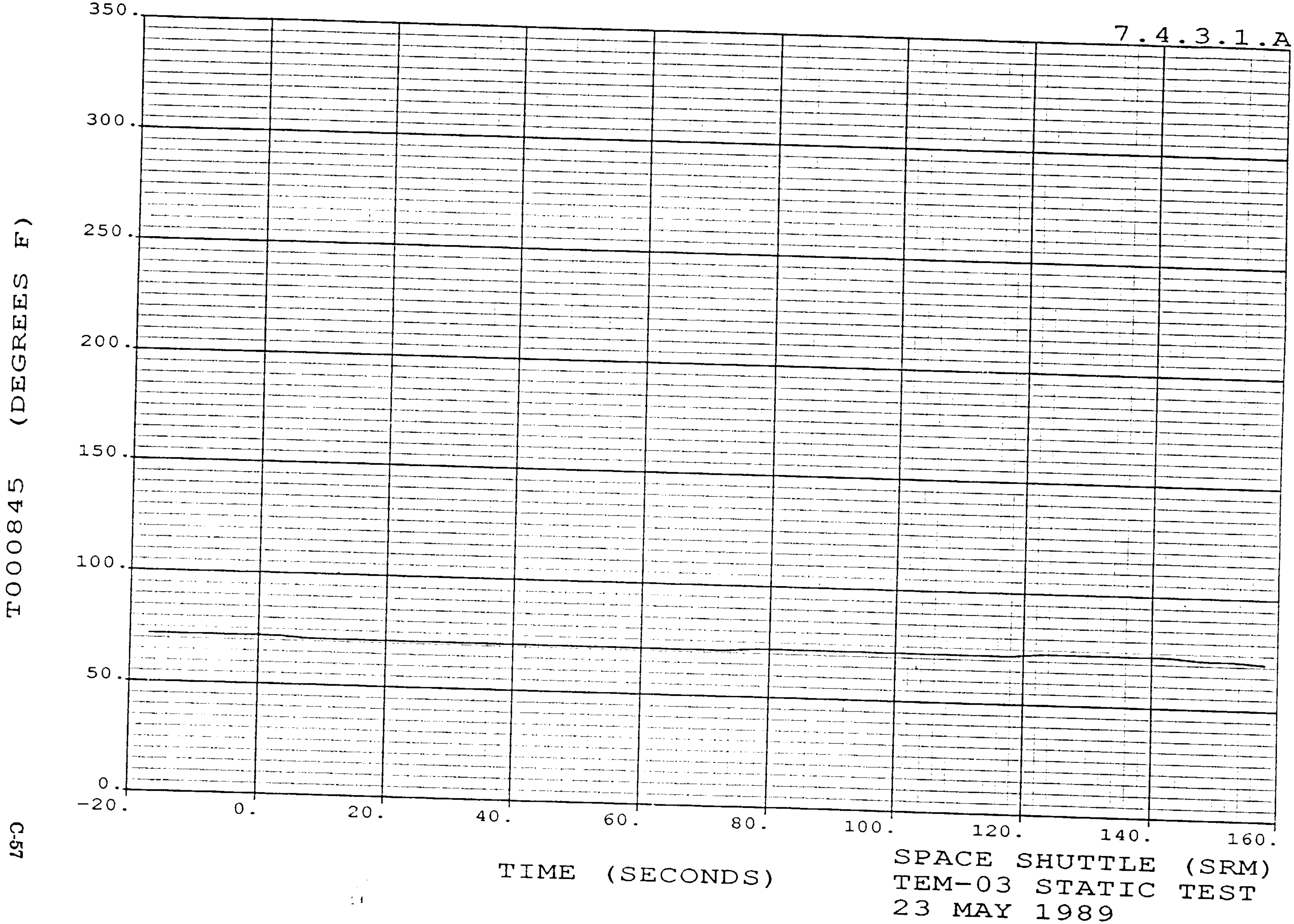
300.
250.
200.
150.
100.
50.
0.
-10.
0.
10.
20.
30.
40.
50.
60.
TIME (MINUTES)
SPACE SHUTTLE (SRM)
TEM-03 STATIC TEST
23 MAY 1989

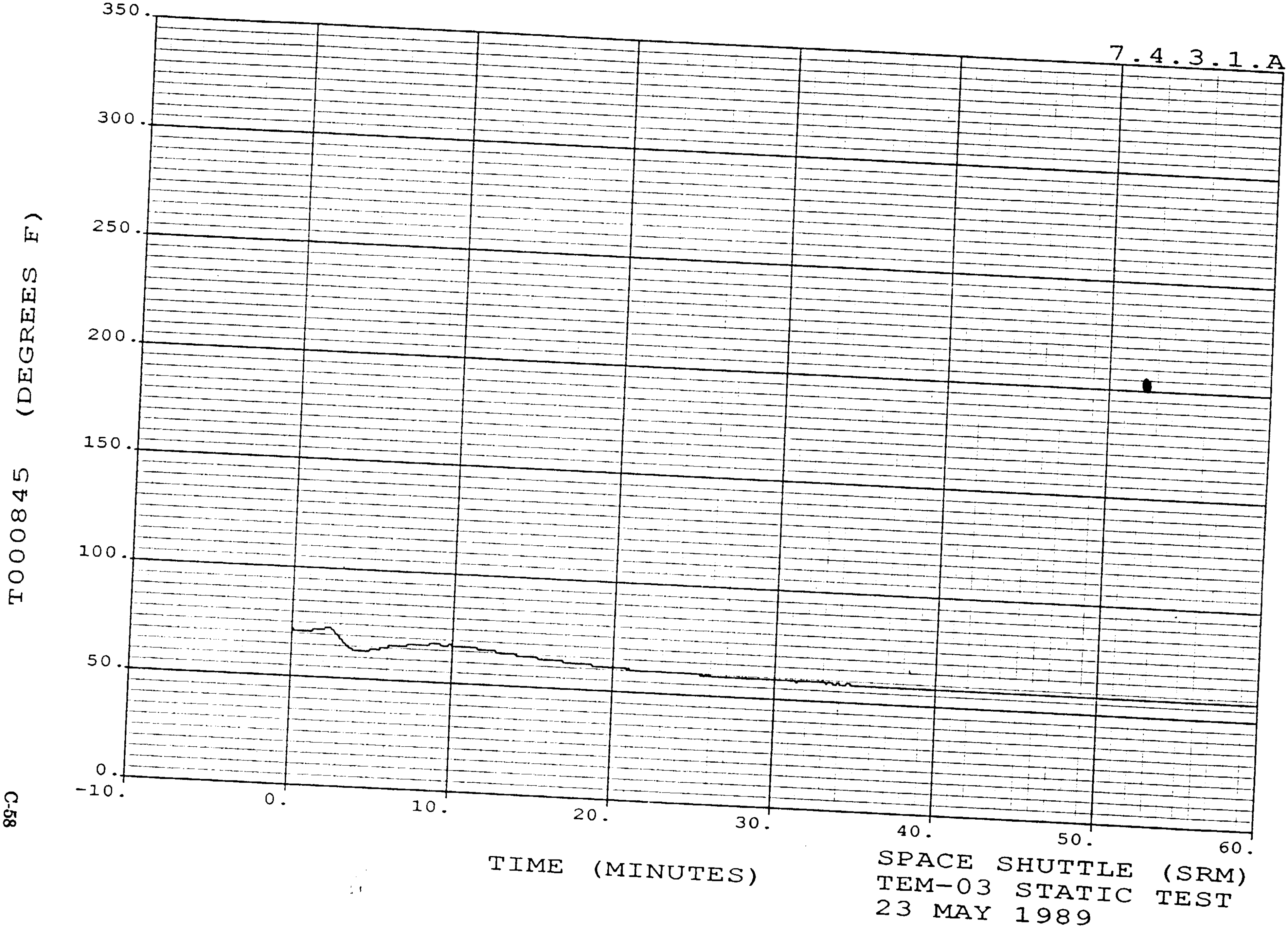


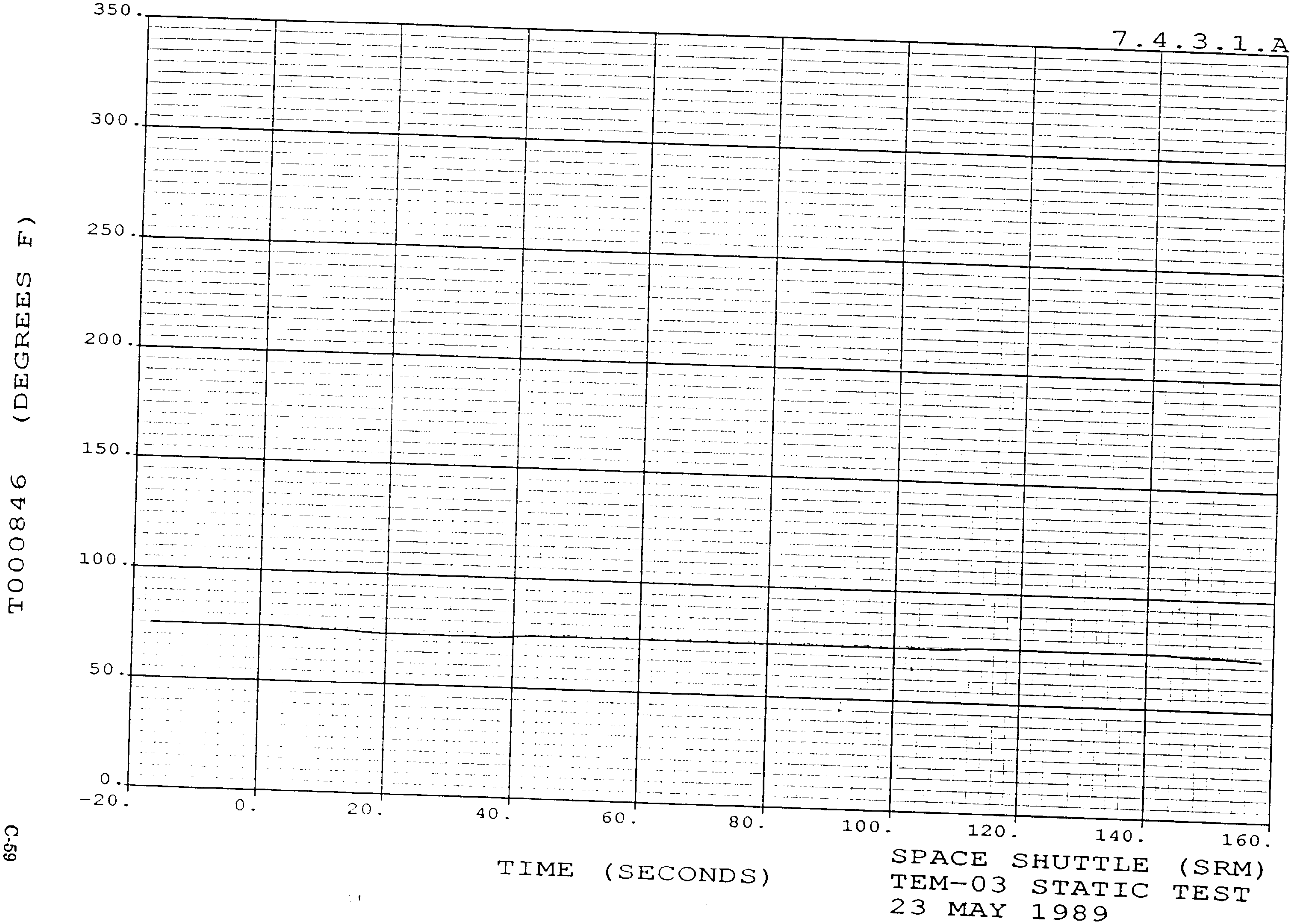
SPACE SHUTTLE (SRM)
TEM-03 STATIC TEST
23 MAY 1989

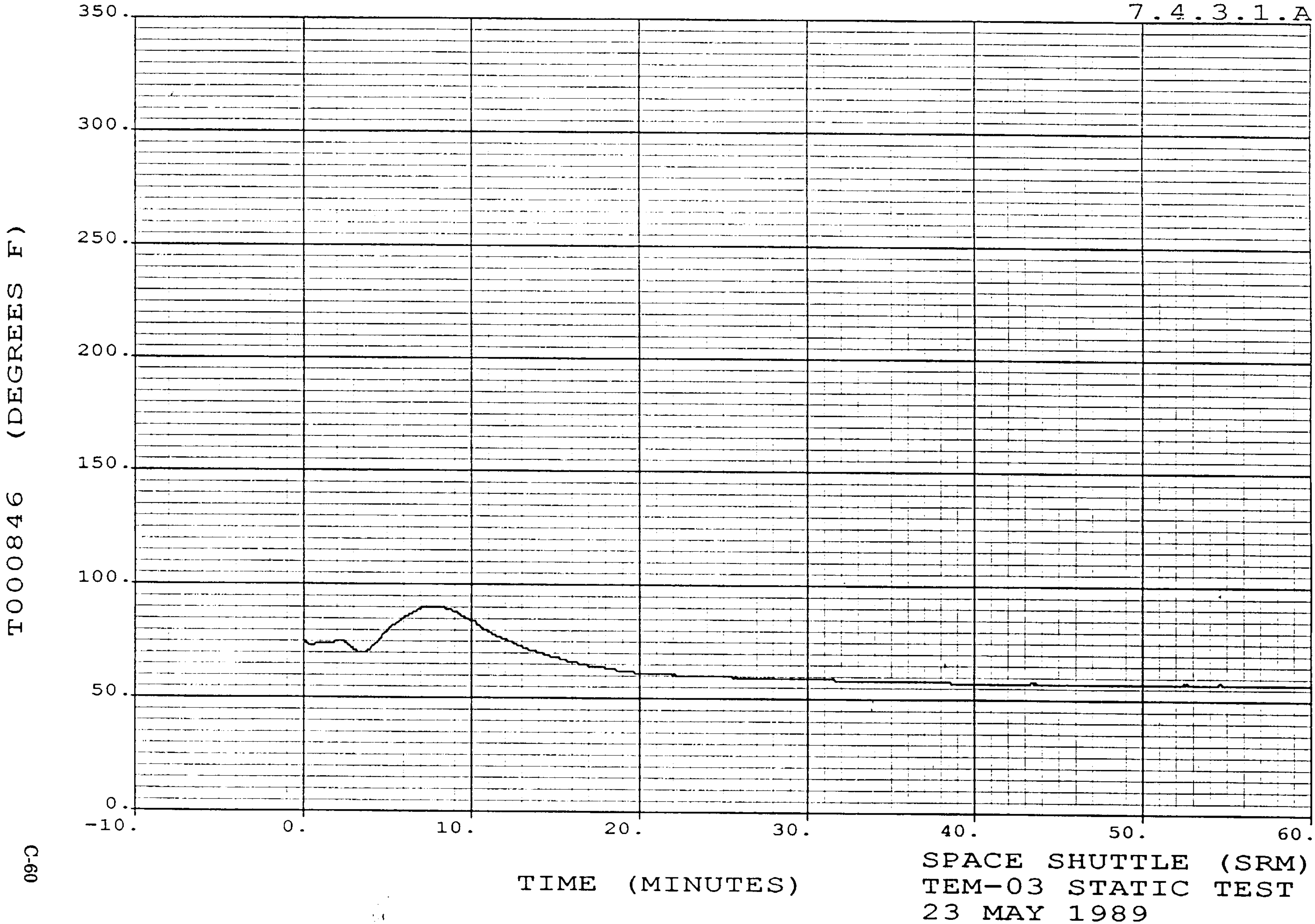


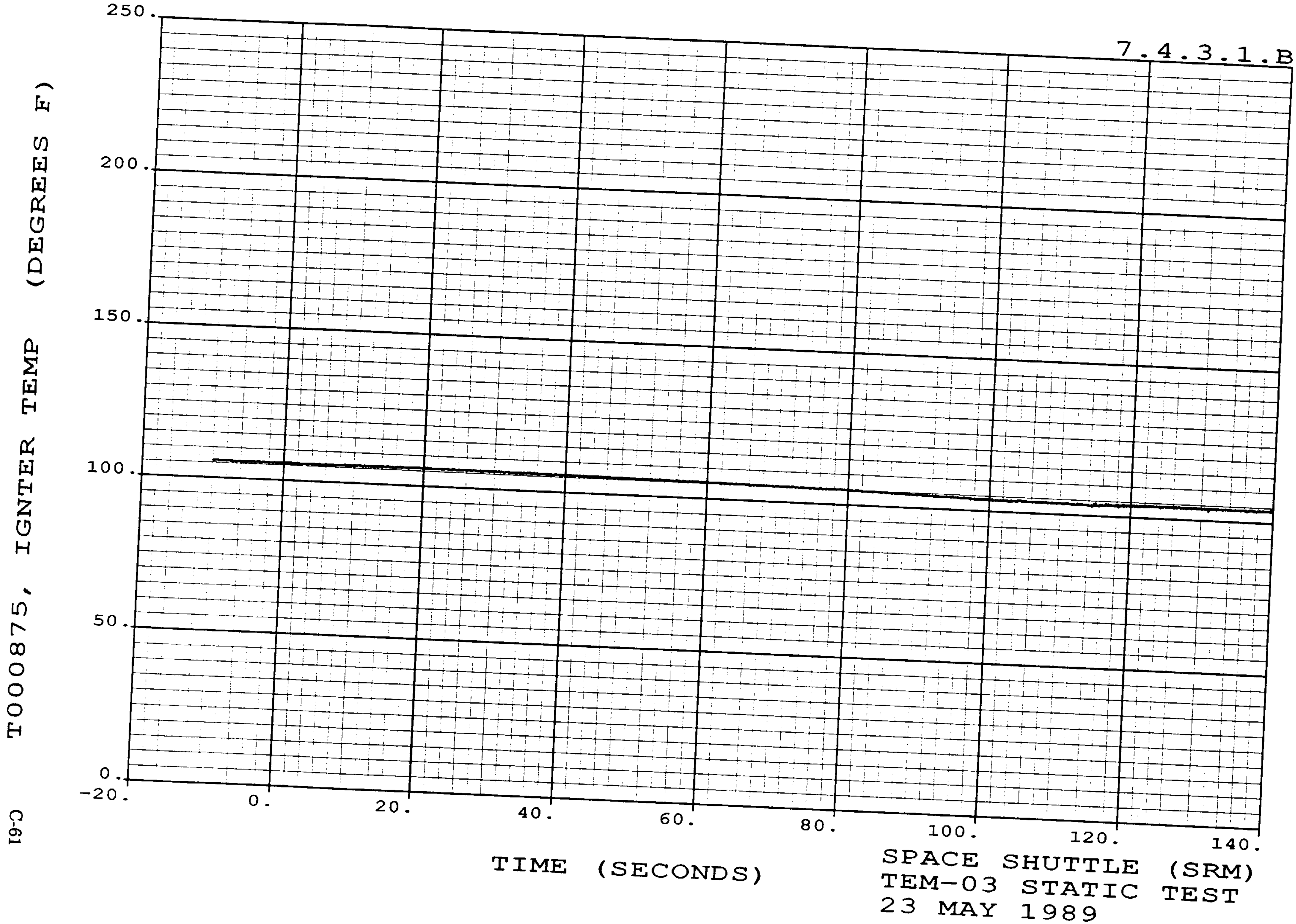
SPACE SHUTTLE (SRM)
TEM-03 STATIC TEST
23 MAY 1989


7.4.3.1.A
350.
300.
250.
200.
150.
100.
50.
0.
-20.
0.
20.
40.
60.
80.
100.
120.
140.
160.
T000845 (DEGREES F)
TIME (SECONDS)
SPACE SHUTTLE (SRM)
TEM-03 STATIC TEST
23 MAY 1989

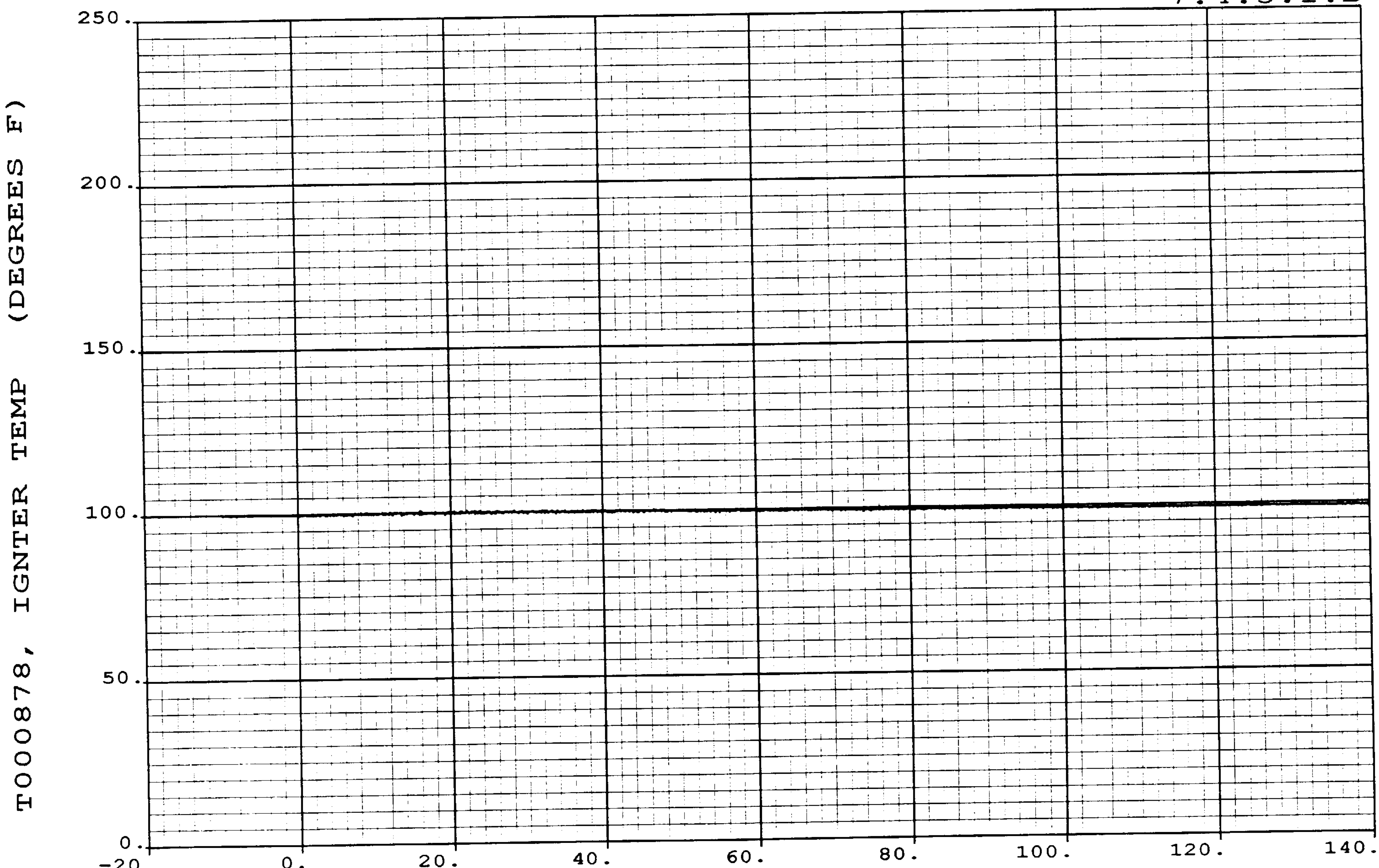

7.4.3.1.A
350.
300.
250.
200.
150.
100.
50.
0.
-10.
0.
10.
20.
30.
40.
50.
60.
T000845 (DEGREES F)
TIME (MINUTES)
SPACE SHUTTLE (SRM)
TEM-03 STATIC TEST
23 MAY 1989


7.4.3.1.A
350.
300.
250.
200.
150.
100.
50.
0.
-20.
0.
20.
40.
60.
80.
100.
120.
140.
160.
T000846 (DEGREES F)
TIME (SECONDS)
SPACE SHUTTLE (SRM)
TEM-03 STATIC TEST
23 MAY 1989

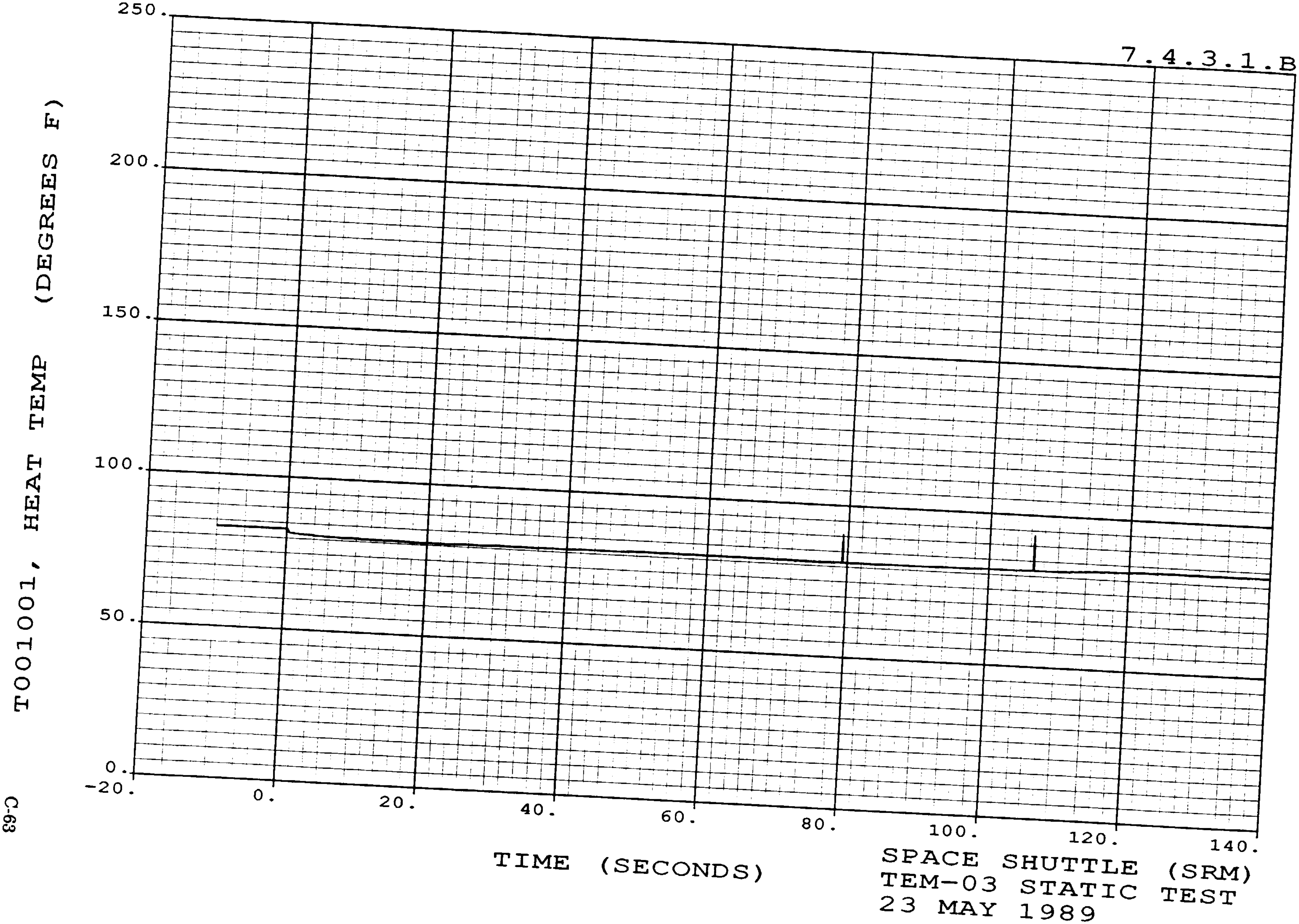

7.4.3.1.A
T000846 (DEGREES F)
350.
300.
250.
200.
150.
100.
50.
0.
-10.
0.
10.
20.
30.
40.
50.
60.
TIME (MINUTES)
SPACE SHUTTLE (SRM)
TEM-03 STATIC TEST
23 MAY 1989

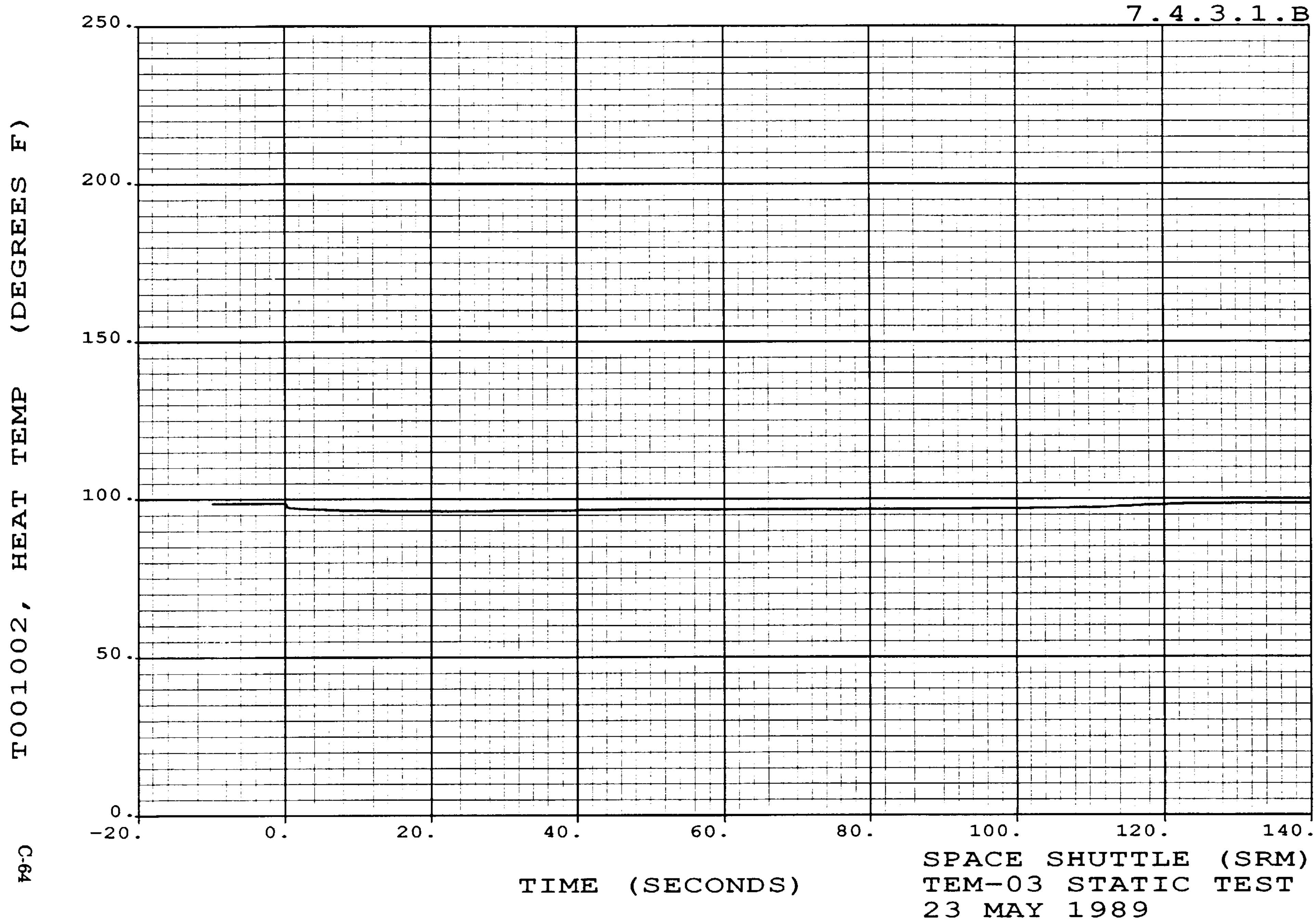

7.4.3.1.B
T000875, IGNTER TEMP (DEGREES F)
250.
200.
150.
100.
50.
0.
-20.
0.
20.
40.
60.
80.
100.
120.
140.
TIME (SECONDS)
SPACE SHUTTLE (SRM)
TEM-03 STATIC TEST
23 MAY 1989

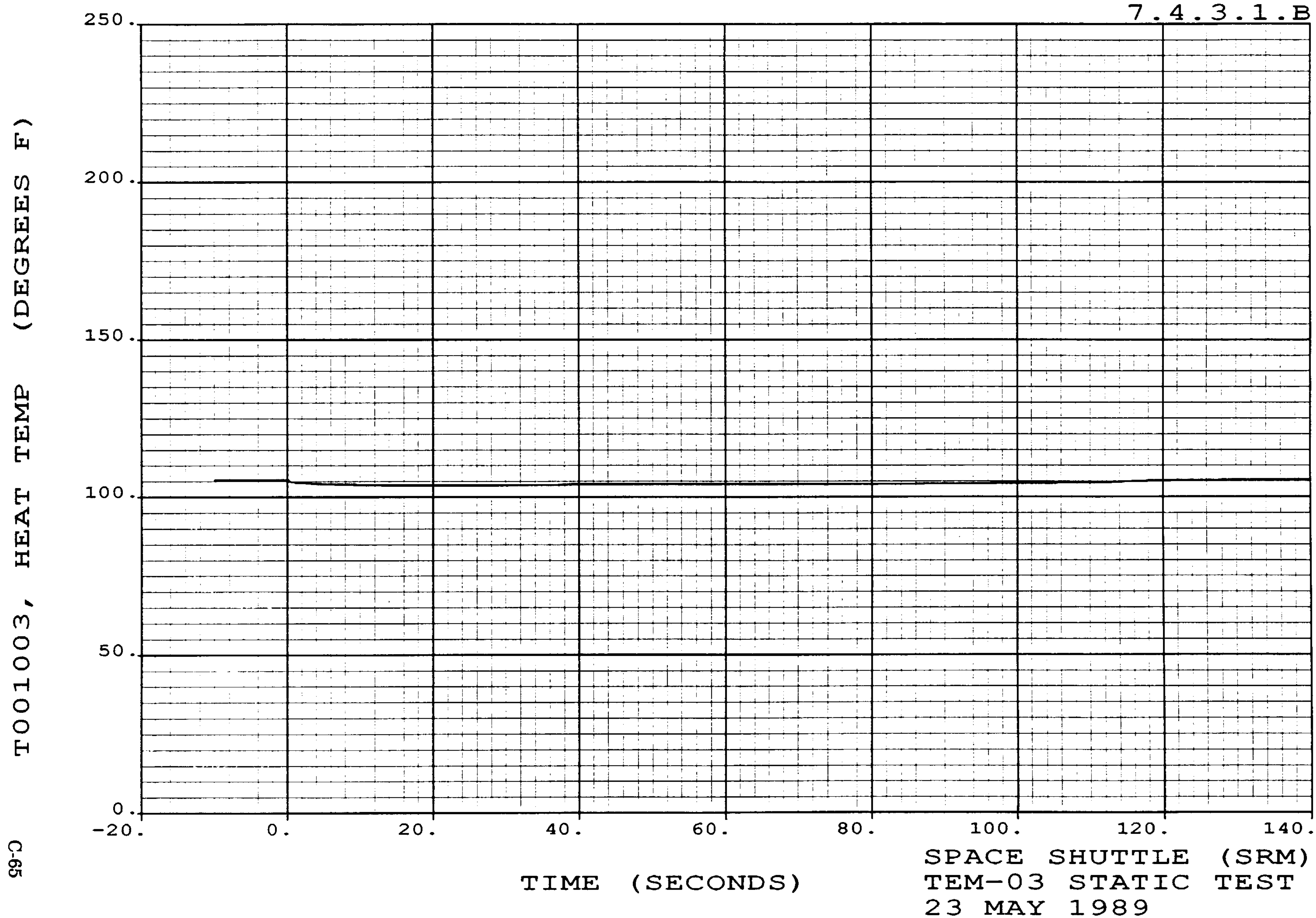
7.4.3.1.B

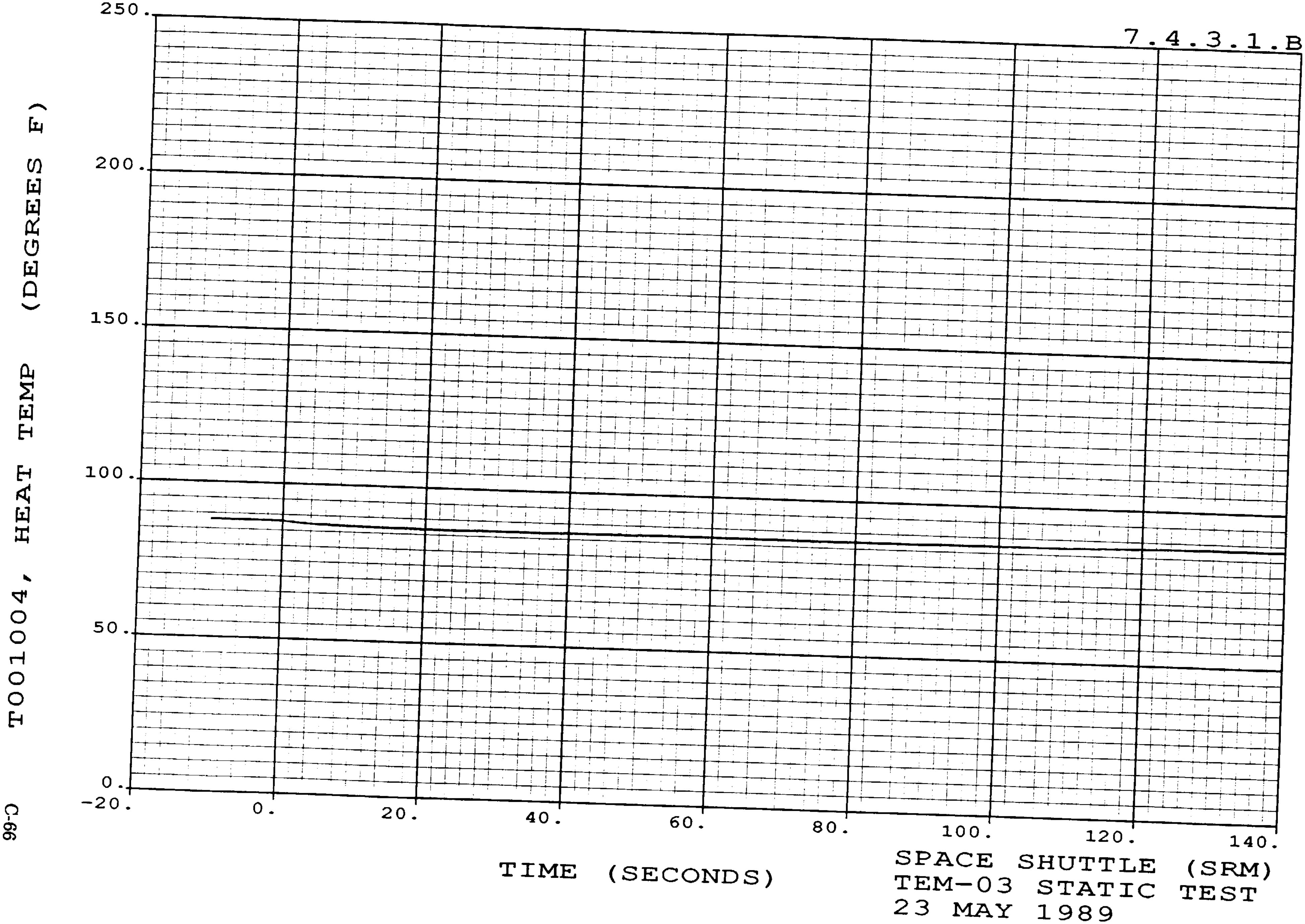


SPACE SHUTTLE (SRM)
TEM-03 STATIC TEST
23 MAY 1989

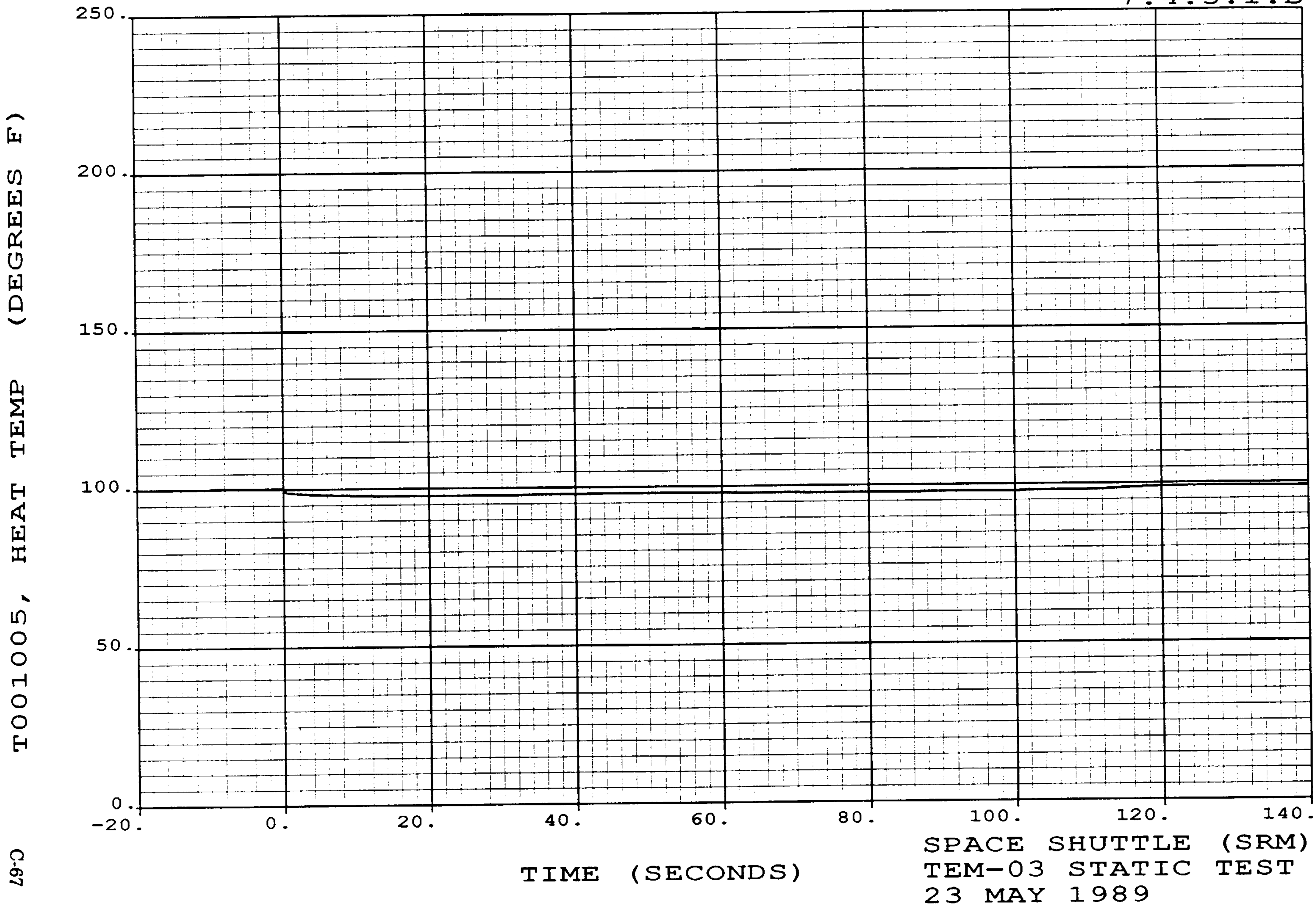

7.4.3.1.B
250.
200.
150.
100.
50.
0.
-20.
0.
20.
40.
60.
80.
100.
120.
140.
T001001, HEAT TEMP (DEGREES F)
TIME (SECONDS)
SPACE SHUTTLE (SRM)
TEM-03 STATIC TEST
23 MAY 1989


7.4.3.1.B
250.
200.
150.
100.
50.
0.
-20.
0.
20.
40.
60.
80.
100.
120.
140.
T001002, HEAT TEMP (DEGREES F)
TIME (SECONDS)
SPACE SHUTTLE (SRM)
TEM-03 STATIC TEST
23 MAY 1989

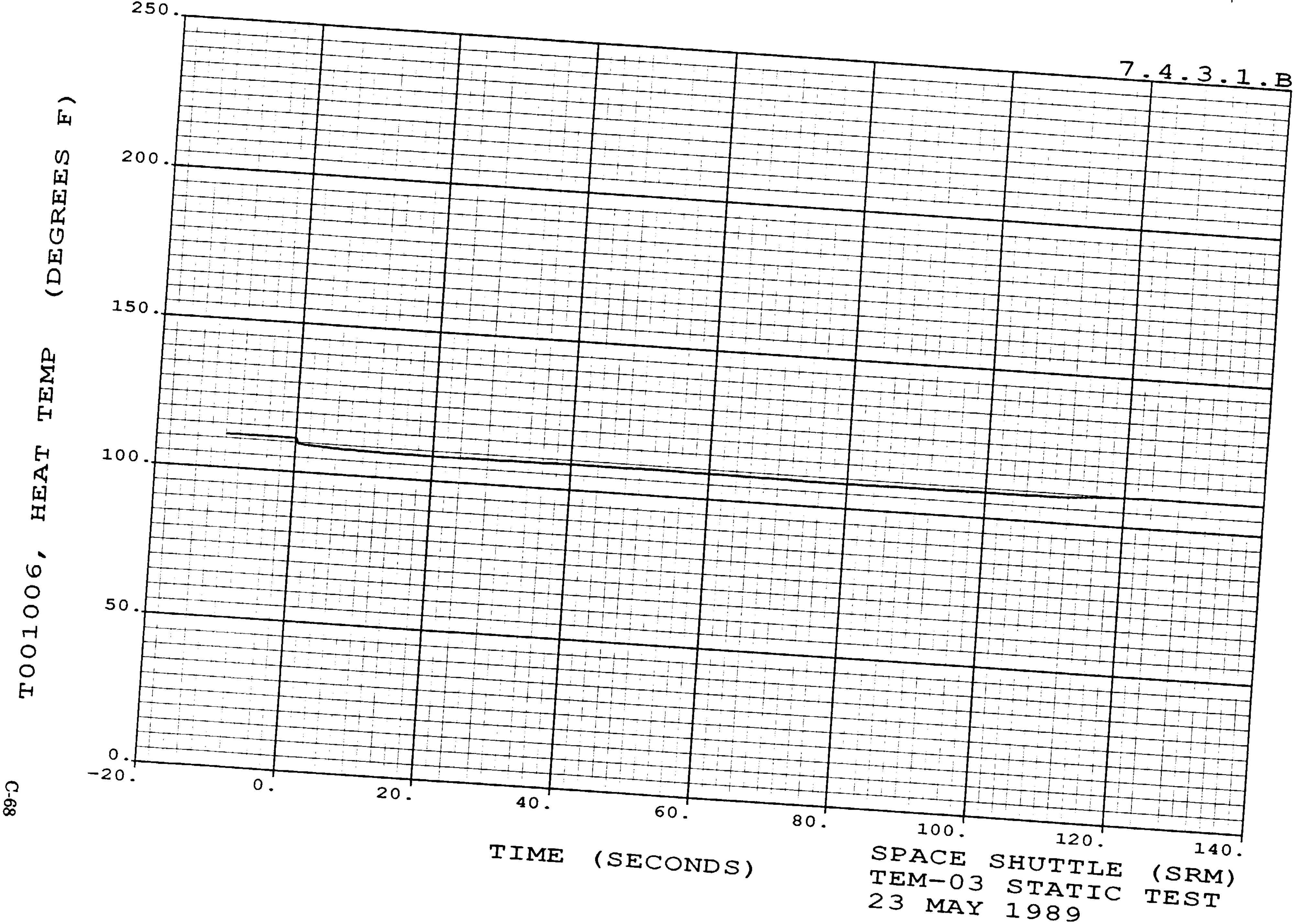

7.4.3.1.B
250.
200.
150.
100.
50.
0.
-20.
0.
20.
40.
60.
80.
100.
120.
140.
T001003, HEAT TEMP (DEGREES F)
TIME (SECONDS)
SPACE SHUTTLE (SRM)
TEM-03 STATIC TEST
23 MAY 1989


7.4.3.1.B
T001004, HEAT TEMP (DEGREES F)
250.
200.
150.
100.
50.
0.
-20.
0.
20.
40.
60.
80.
100.
120.
140.
TIME (SECONDS)
SPACE SHUTTLE (SRM)
TEM-03 STATIC TEST
23 MAY 1989

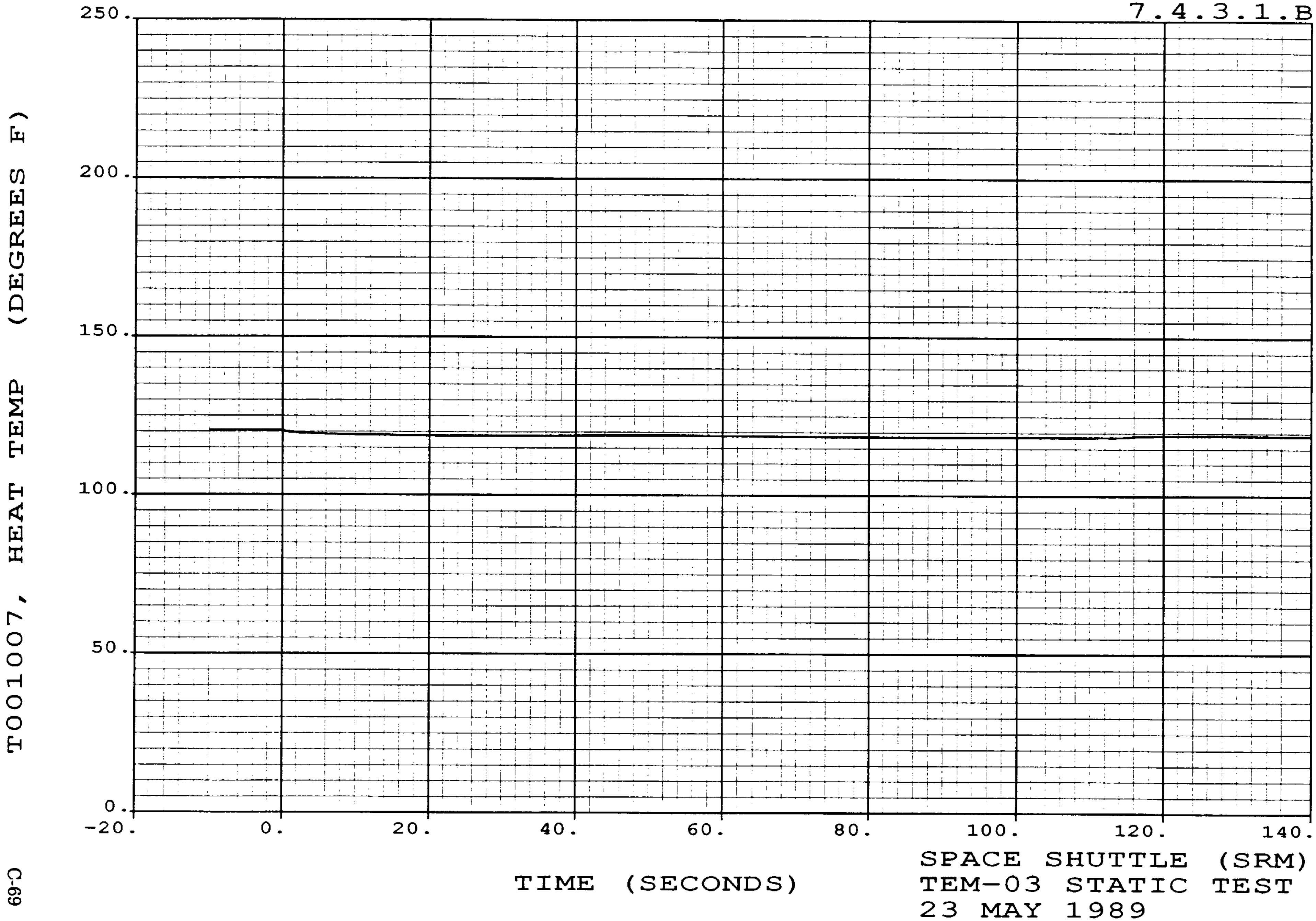
7.4.3.1.B

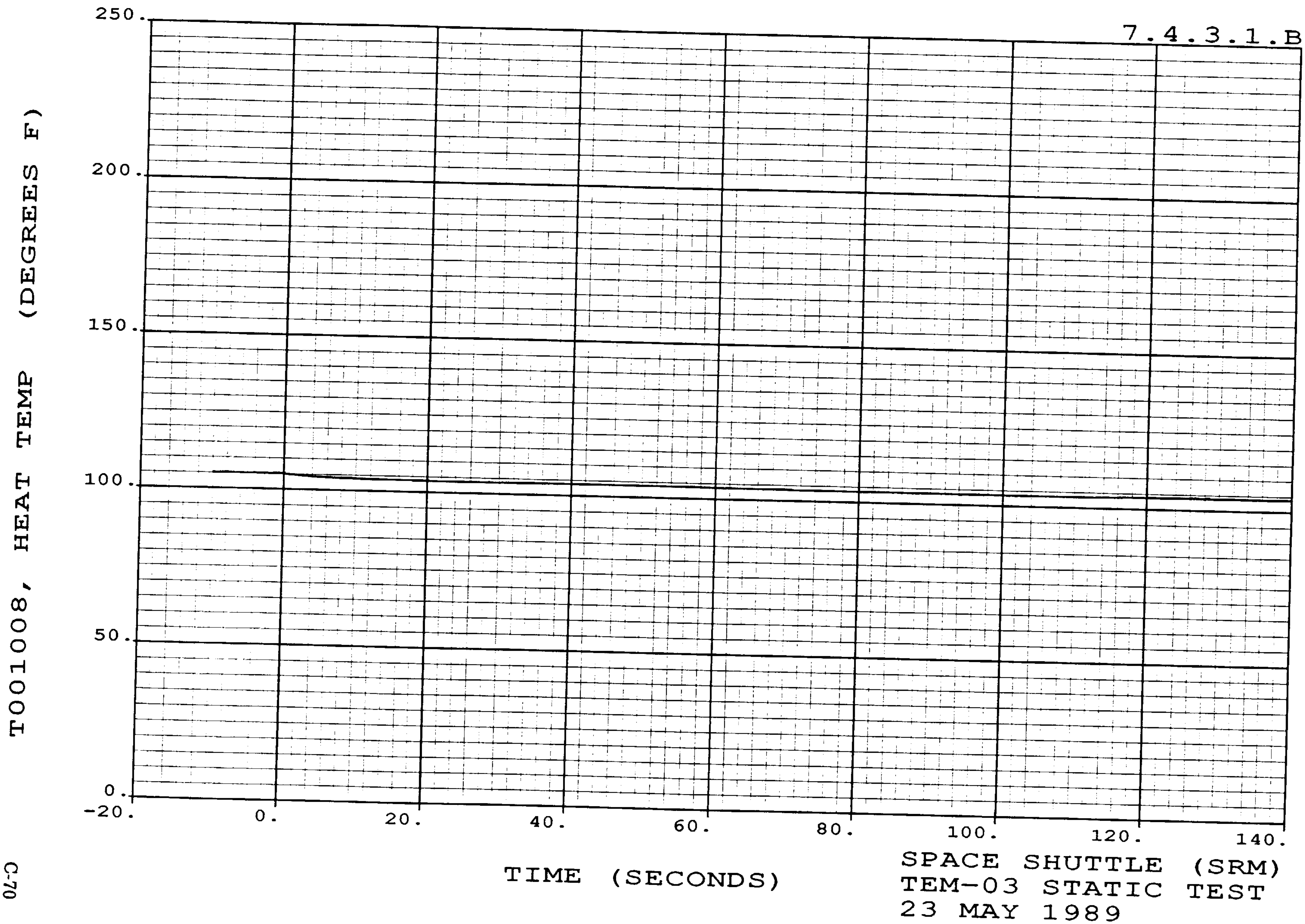


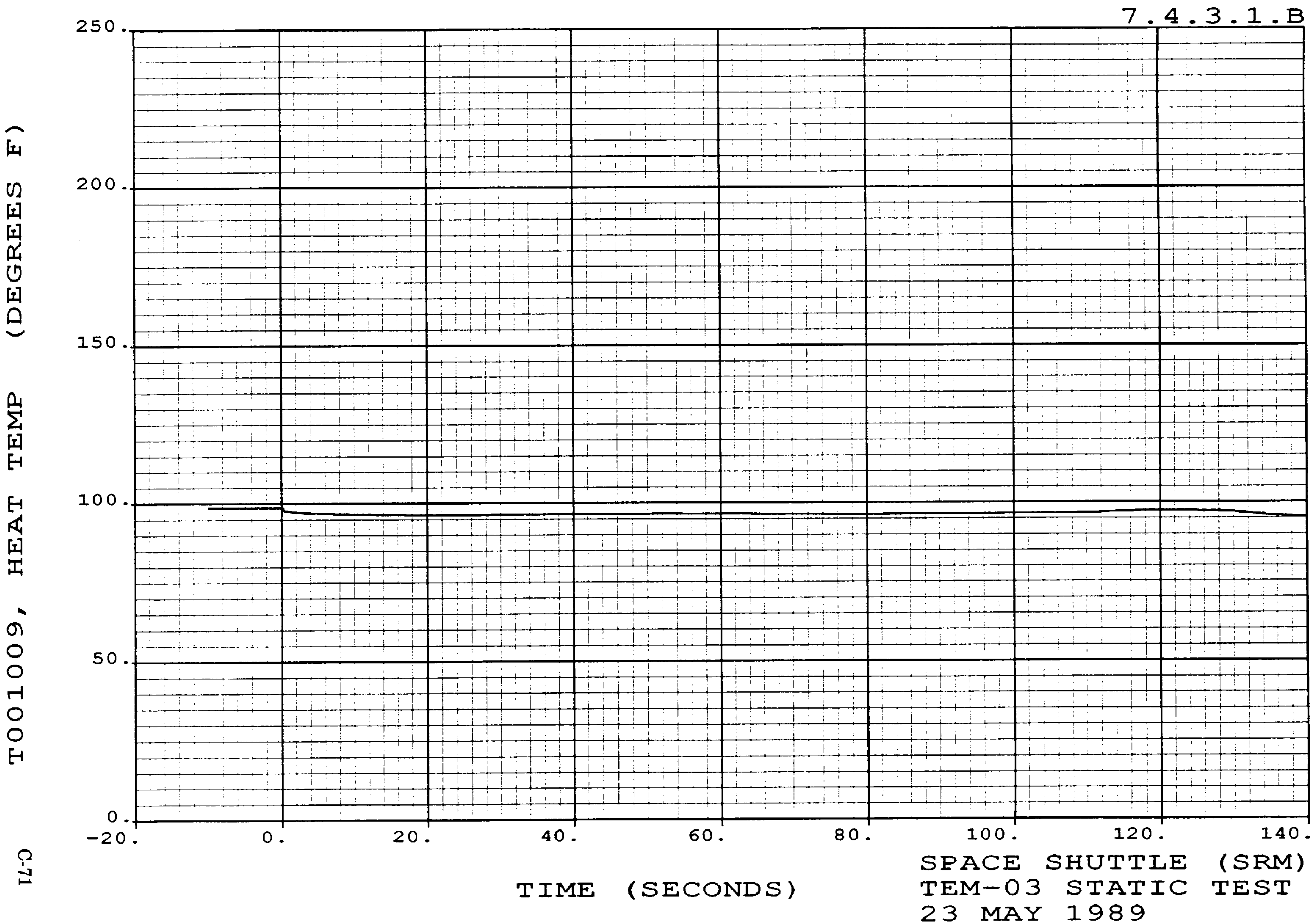
SPACE SHUTTLE (SRM)
TEM-03 STATIC TEST
23 MAY 1989

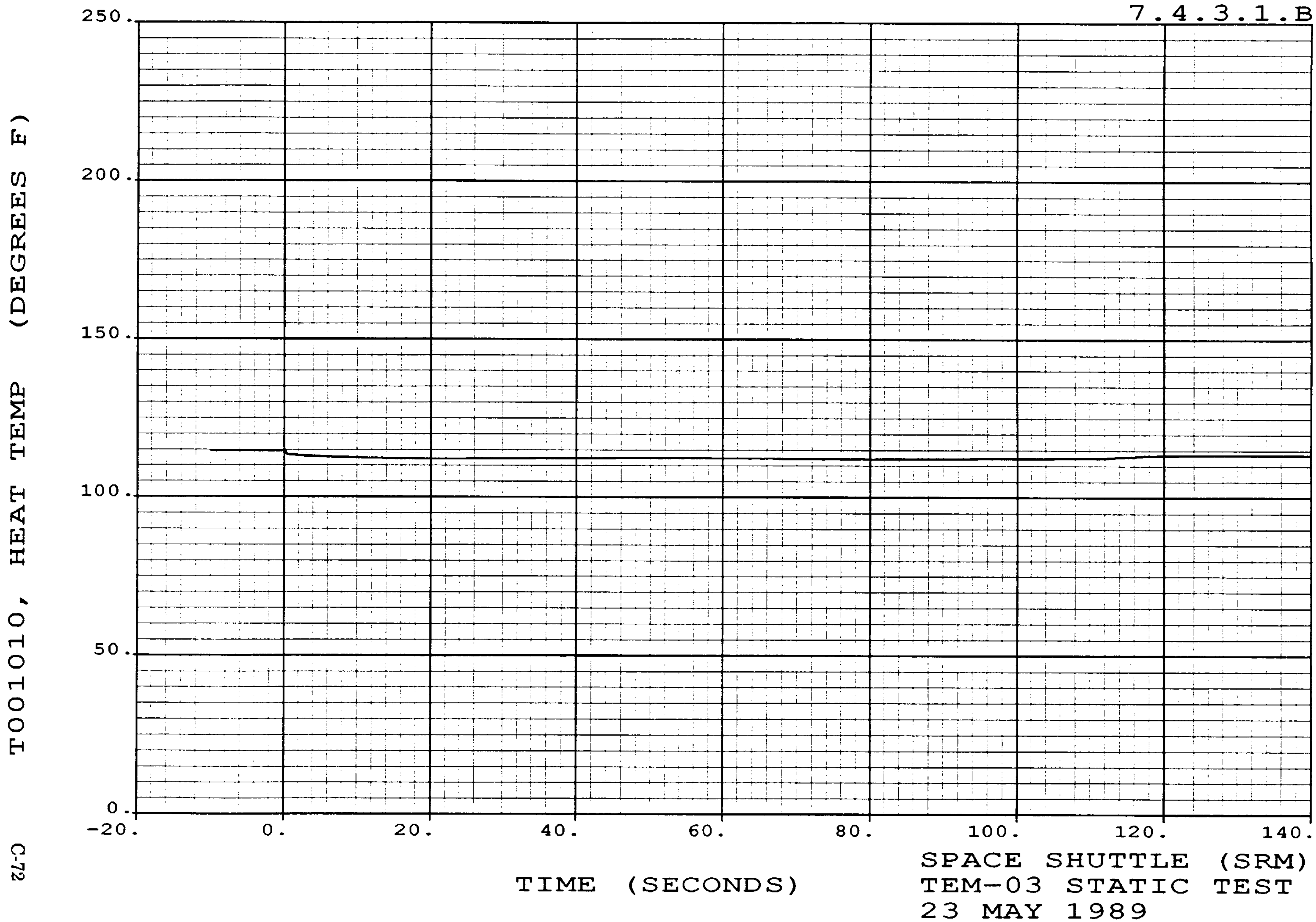

7.4.3.1.B
250.
200.
150.
100.
50.
0.
T001006, HEAT TEMP (DEGREES F)
-20.
0.
20.
40.
60.
80.
100.
120.
140.
TIME (SECONDS)
SPACE SHUTTLE (SRM)
TEM-03 STATIC TEST
23 MAY 1989

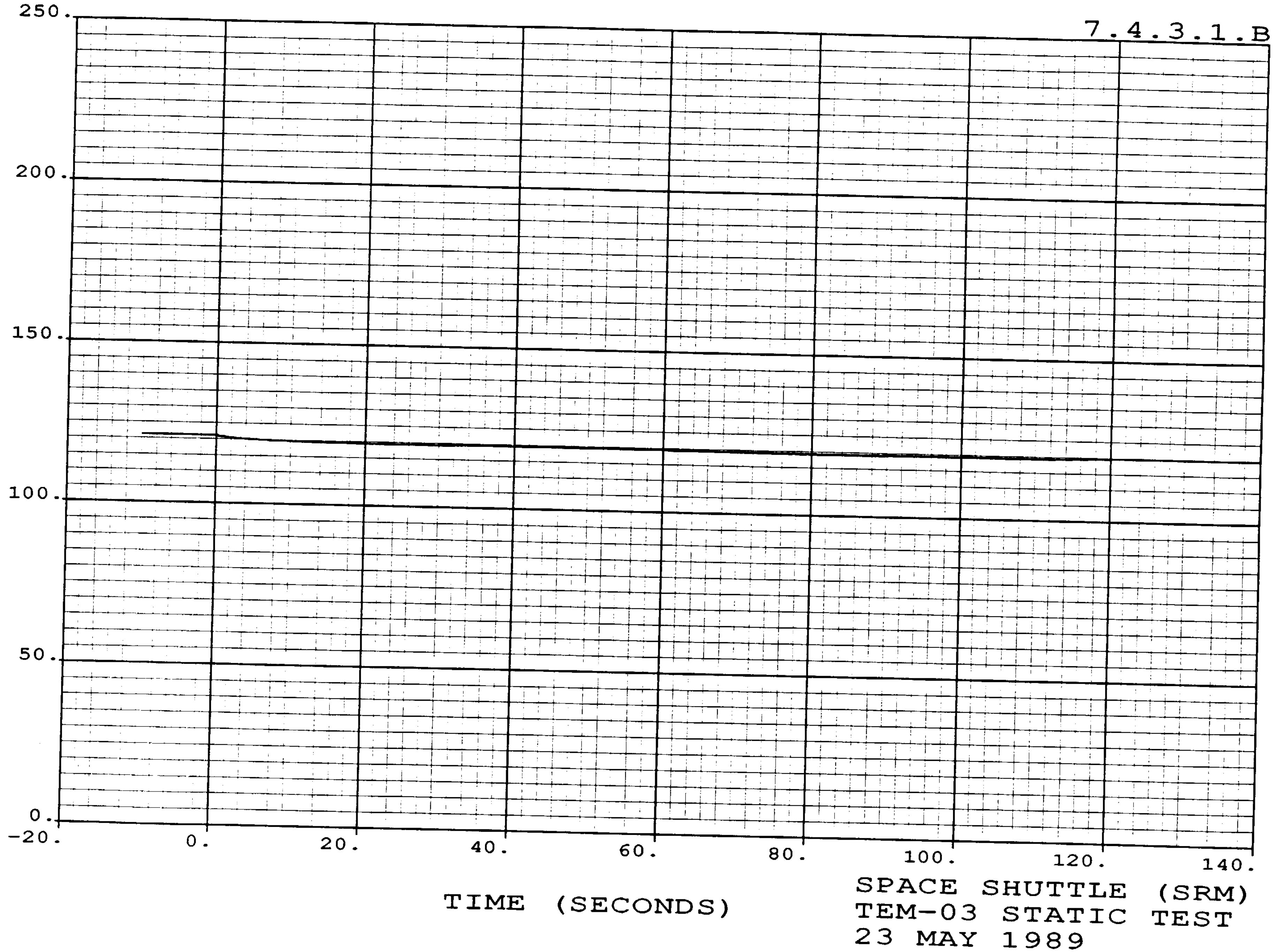
7.4.3.1.B


T001007, HEAT TEMP (DEGREES F)
250.
200.
150.
100.
50.
0.
-20.
0.
20.
40.
60.
80.
100.
120.
140.
TIME (SECONDS)
SPACE SHUTTLE (SRM)
TEM-03 STATIC TEST
23 MAY 1989


7.4.3.1.B
T001008, HEAT TEMP (DEGREES F)
250.
200.
150.
100.
50.
0.
-20.
0.
20.
40.
60.
80.
100.
120.
140.
TIME (SECONDS)
SPACE SHUTTLE (SRM)
TEM-03 STATIC TEST
23 MAY 1989

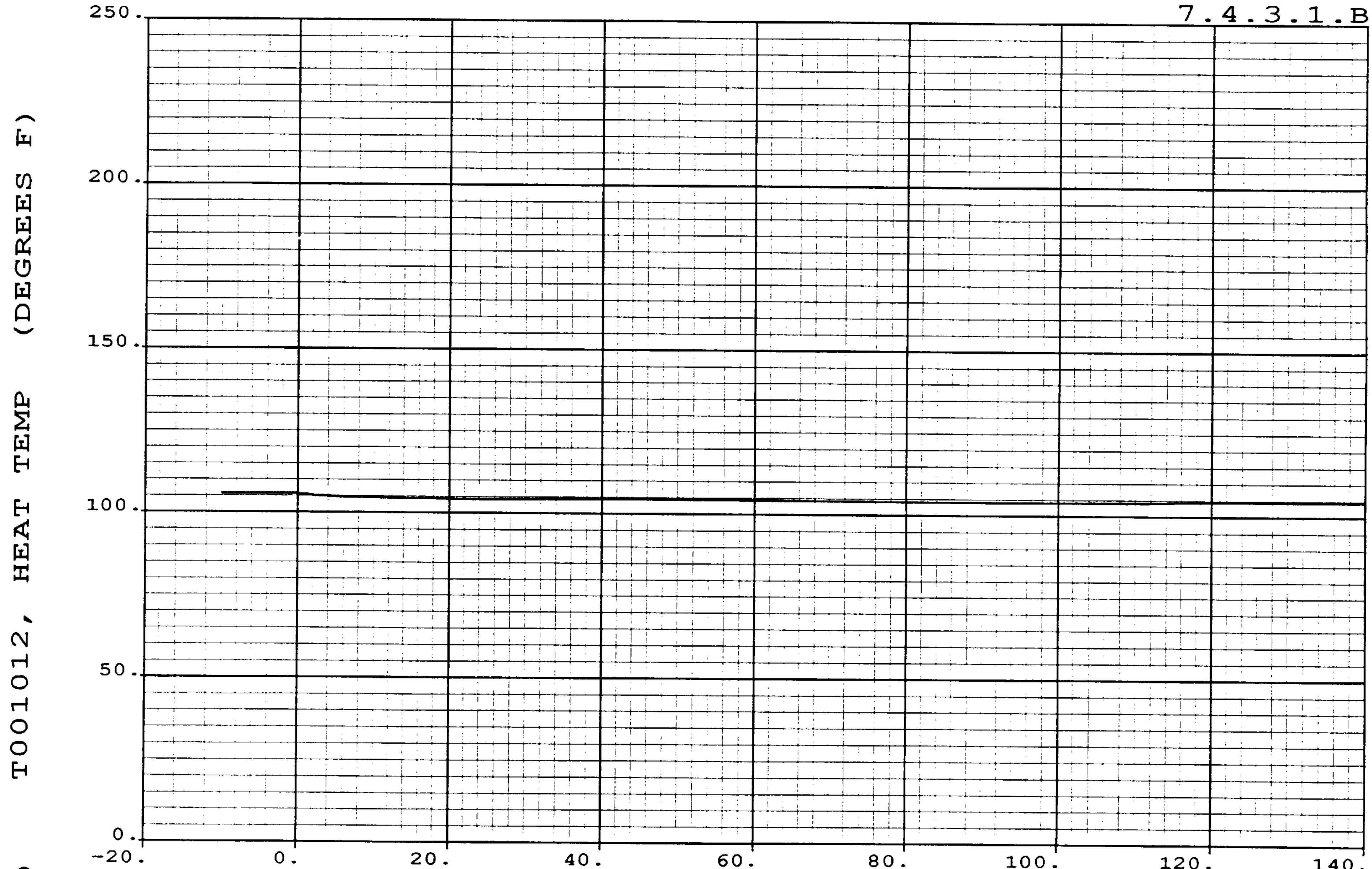

7.4.3.1.B
250.
200.
150.
100.
50.
0.
-20.
0.
20.
40.
60.
80.
100.
120.
140.
T001009, HEAT TEMP (DEGREES F)
TIME (SECONDS)
SPACE SHUTTLE (SRM)
TEM-03 STATIC TEST
23 MAY 1989


7.4.3.1.B
T001010, HEAT TEMP (DEGREES F)
250.
200.
150.
100.
50.
0.
-20.
0.
20.
40.
60.
80.
100.
120.
140.
TIME (SECONDS)
SPACE SHUTTLE (SRM)
TEM-03 STATIC TEST
23 MAY 1989

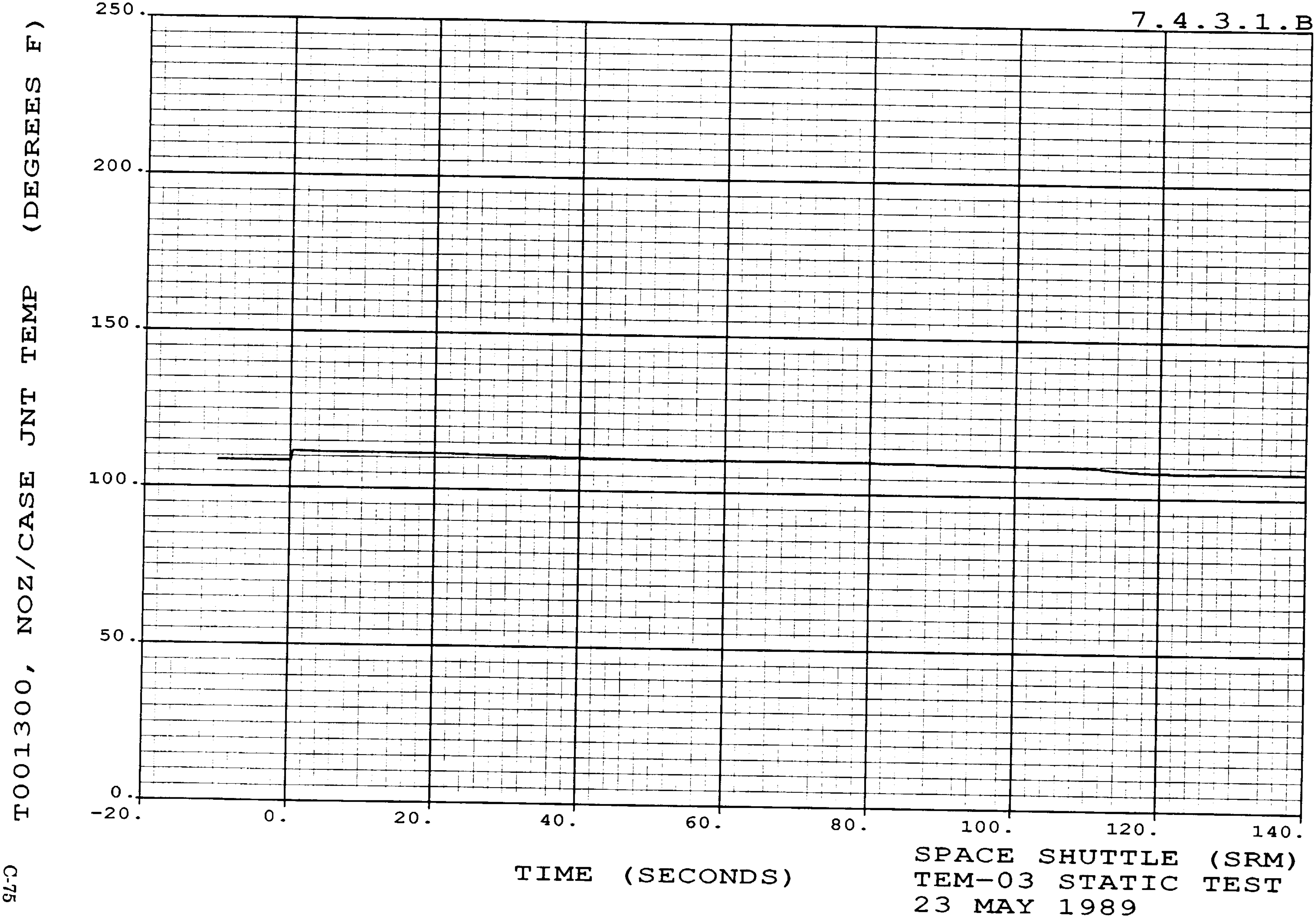

7.4.3.1.B
T001011, HEAT TEMP (DEGREES F)
250.
200.
150.
100.
50.
0.
-20.
0.
20.
40.
60.
80.
100.
120.
140.
TIME (SECONDS)
SPACE SHUTTLE (SRM)
TEM-03 STATIC TEST
23 MAY 1989

C-3

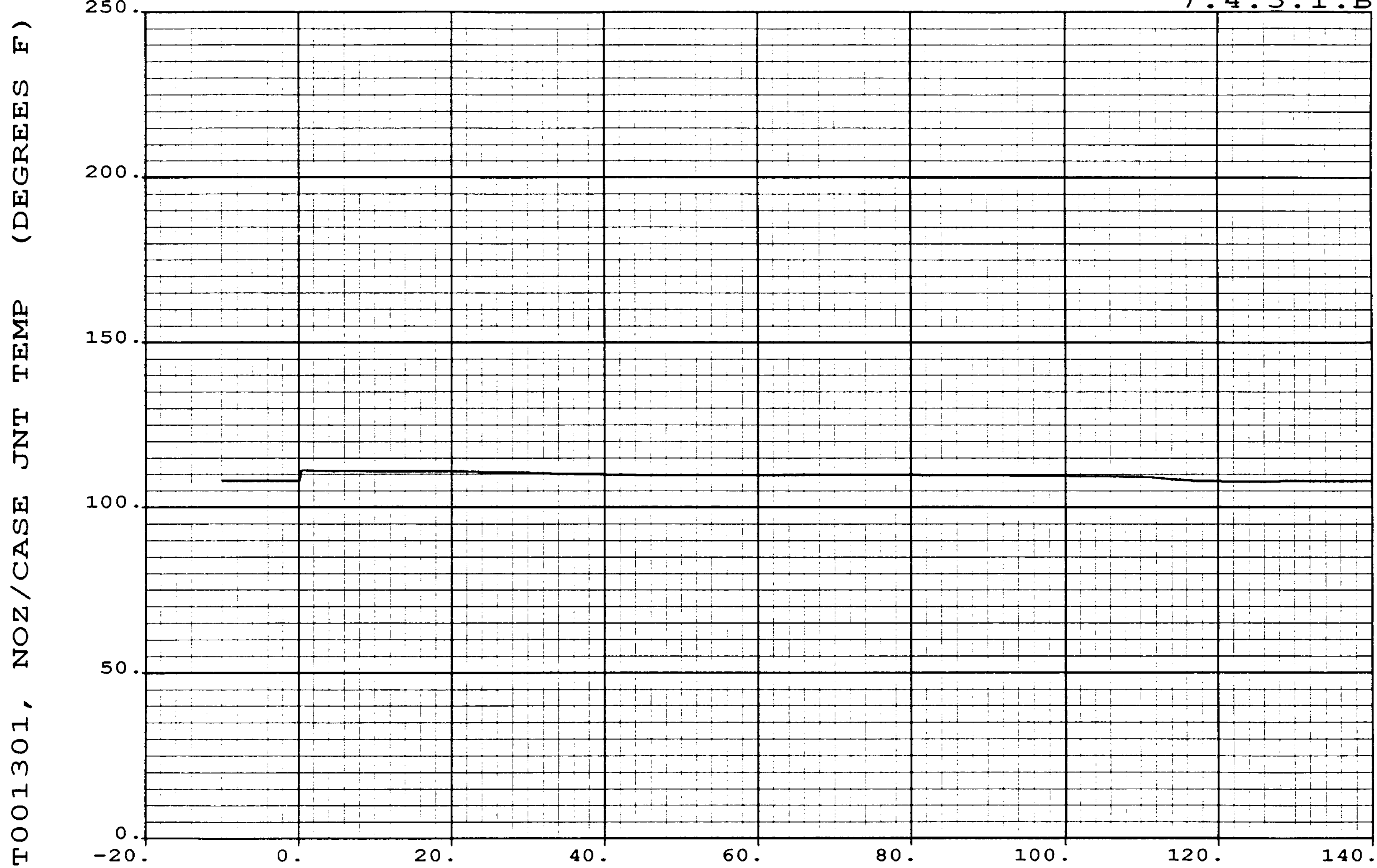
7.4.3.1.B



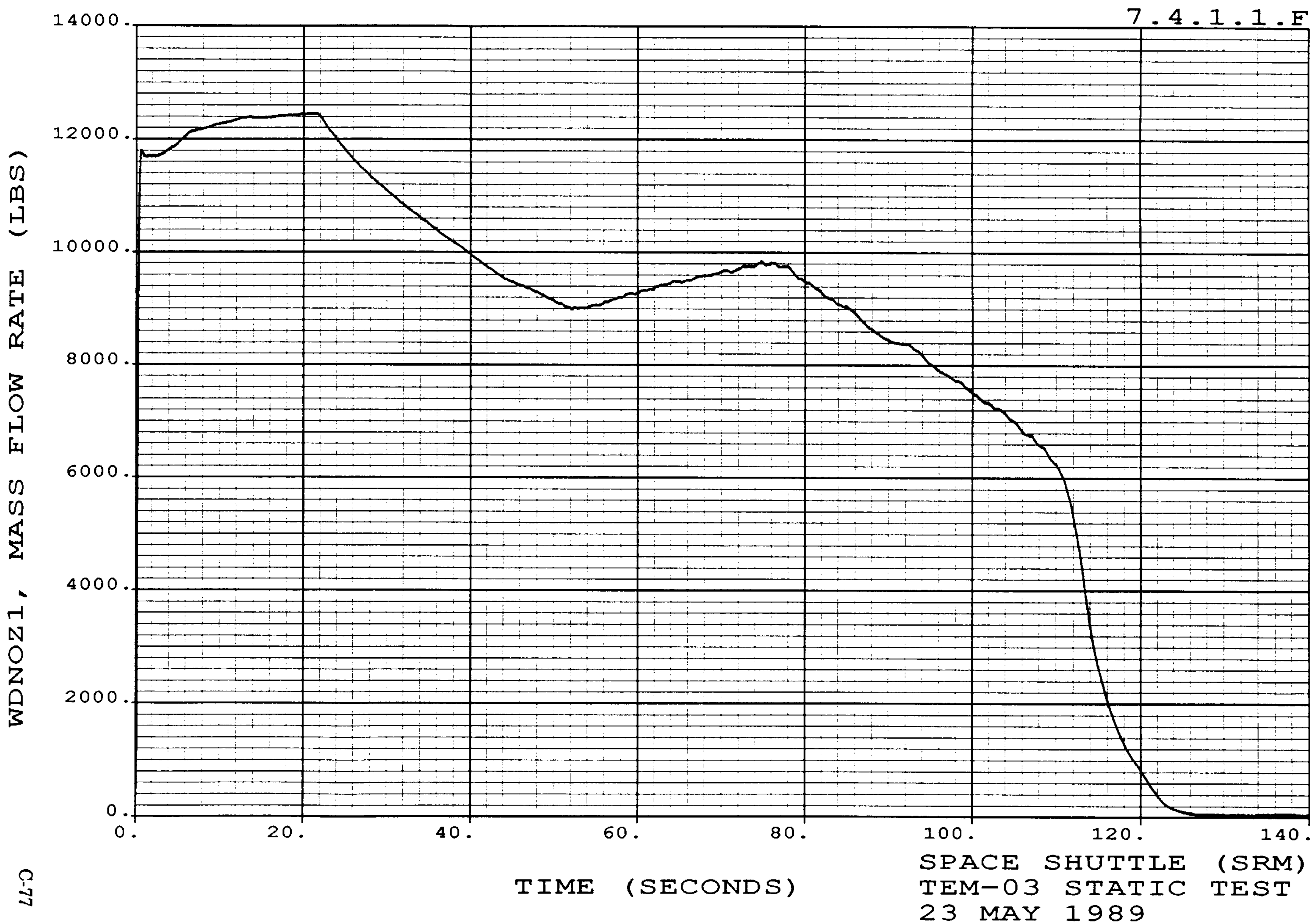
SPACE SHUTTLE (SRM)
TEM-03 STATIC TEST
23 MAY 1989


7.4.3.1.B
250.
200.
150.
100.
50.
0.
-20.
0.
20.
40.
60.
80.
100.
120.
140.
T001300, NOZ/CASE JNT TEMP (DEGREES F)
TIME (SECONDS)
SPACE SHUTTLE (SRM)
TEM-03 STATIC TEST
23 MAY 1989

7.4.3.1.B



SPACE SHUTTLE (SRM)
TEM-03 STATIC TEST
23 MAY 1989



7.4.1.1.F
WDNOZ1, MASS FLOW RATE (LBS)
14000.
12000.
10000.
8000.
6000.
4000.
2000.
0.
0.
20.
40.
60.
80.
100.
120.
140.
TIME (SECONDS)
SPACE SHUTTLE (SRM)
TEM-03 STATIC TEST
23 MAY 1989

Appendix D

FLASH REPORT

TEM-03 FLASH REPORT

TWR-17636

24 May 1989

CONTRACT NO.:	NAS8-30490
DR NO.	5-2
WBS NO.	HQ601-20-10
TEST DATE:	23 May 1989
TEST TITLE:	Technical Evaluation Motor No. 3 (TEM-03)
TEST LOCATION:	Morton Thiokol Inc., Space Operations Brigham City, Utah

I. TEM-03 TEST ARTICLE CONFIGURATION

A. Ignition System
- o HPM S&A using Krytox grease
- o SRM igniter modified for CO_2 quench port
- o Igniter joint strip heater installed
  - o Set point at 122°F, with a minimum of 87°F at sensors
- o All OPTs lockwired

B. Propellant/Liner
- o HPM configuration

C. Systems Tunnel
- o N/A

D. Case-to-case factory joints

- o HPM tang and clevis hardware design joint
- o Insulation overlaid and cured over interior of the joint (HPM configuration)
- o HPM-type short pins and HPM-type pin retainer consisting of a steel band which is installed on each joint
- o Standard SRM shim clips

E. Case-to-case field joints
- o RSRM-type long pins and RSRM-type hat band pin retainers
- o Custom-fit shims

TEST ARTICLE CONFIGURATION: (cont)

- o Seals are 7U75204-21-HPM
- o O-ring squeeze was calculated for each assembly (minimum 10% squeeze for each seal)
- o Standard HPM insulation configuration with putty joint filler (STW4-3266)
- o Field joint heater- Set point 121°F, with a minimum of 87°F at sensors
- o No joint protection system (JPS)

F. Case-to-nozzle joint
- o Standard HPM nozzle joint insulation configuration with putty joint filler (STW4-3266)
- o Fluorocarbon O-rings (primary, secondary)
  - o New RSRM O-ring used for primary
    - o HPM groove will accommodate larger diameter RSRM sizes
- o Joint heater-Set point at 114°F, with a minimum of 87°F at sensors
- o One hundred axial bolts installed using torque

G. Internal Nozzle Joints
- o RSRM O-rings to be used for forward-to-aft exit cone

H. ET Attach Ring
- o No ET Attach Ring

I. Stiffener Rings
- o None installed

J. Aft skirt ring
- o Aft skirt ring/actuator support ring assembly installed in place of the aft skirt. This ring provides mounting provisions for the fixed links which will be used in place of the TVC actuators
- o No nozzle vectoring

K. Instrumentation
- o Limited

L. Nozzle assembly
- o Pre-51-L design
- o No linear shaped charge (LSC)

II. TEM-03 TEST OBJECTIVE SUMMARY WITH PRE-TEST PREDICTIONS:

A. General Ballistics Performance

Individual motor performance values are listed below:

TEM-03 Predicted Ballistics Performance Summary (vacuum, 70°F)*

	Prediction**
Web time (sec)	110.5
Action time (sec)	122.7
MOP Headend (psia)	928.2
MOF (Mlb_f)****	3.36
Web time average headend pressure (psia)	668.2
Web time average thrust (Mlb_f)	2.62
Web time pressure integral (psi/sec)	73885
Web time total impulse(Mlb_f*sec)	290.0
Action time impulse (Mlb_f*-sec)	297.7
Action time average head-end pressure (psia)	618.5
Action time average thrust (Mlb_f)	2.43
Action time pressure integral (psia/sec)	75746
I_{sp} average delivered (lb_f-sec/lb_m)	268.3
Ignition Interval (sec), Time 563.5 psia	0.232
Maximum pressure rise rate (psi/10-ms)	90.5
Burn rate (in/sec)	0.371
Igniter max pressure	1929
Loaded propellant weight including igniter(lb)	1,109,386***

* TEM-03 prediction based on the following motor segments: Forward:SRM-31B; Forward Center: SRM-29A; Aft Center: SRM-27A; Aft: SRM-30B

** Based on burn rate of 0.368 at 60°F, 625 psia

*** Based on nominal propellant weights

**** Spec. limit adjusted from sea level thrust (14.7 psia) and 60°F

Qualification objectives of this test are as follows:

H. Certify the Nylock thread locking device of the 1U100269-03 leak check port plug (3.3.6.10).

I. Certify for use on RSRM the 1U52295-04 S&A Device which utilizes Krytox grease on the barrier-booster shaft o-rings (3.2.1.5.a).

- All joints will function within the HPM experience base
  - Pressure and/or gas jetting may reach the primary O-ring of nozzle joint
  - Low probability that gas paths may occur through the putty to the primary o-ring of field and nozzle joints
  - Secondary o-ring expected to maintain seal
    - low probability of metal hardware damage
  - Voids (trapped air) may occur in the putty of field and nozzle joints

III. INITIAL ENGINEERING ASSESSMENT

The TEM-03 static test was successfully conducted at T-97 on 23 May 1989. The motor performed well with no apparent anomalies. All comments presented here are based on preliminary data and external observations. The final test report (TWR-17639) will include a detailed assessment of the test data and physical inspection information gathered from the test and during disassembly.

Ballistics Preliminary ballistic performance data is shown in Table I.

Nozzle

Nozzle Assembly. Initial walkaround observations indicate no anomalous conditions. Nozzle erosion was typical. There was some smoke coloration which occurred just before quench activation (no paint blistering) on the north side of the nozzle because of blowing wind.

Nozzle TVC. The nozzle was held rigid using fixed links with no thrust vector control.

Case

Case Membrane. There was no evidence of slag damage to the case. There was one area near the stiffener stubs with brown paint discoloration, but this is not considered an anomaly. A much higher temperature is required to cause case damage than what is required to cause brown discolored paint.

IGNITER

Preliminary data verifies that the igniter performed within the specified requirements. See preliminary data included with this report.

FIXED LINK FORCE

The forces applied to the fixed links were measured. Nozzle axial deflection was measured using two different sets of extensometers, which initially seems to have measured in the same range. See preliminary data included with this report.

TEMPERATURE SPECIFICATIONS

Field joints. All field joint temperature sensors registered between 87°F and 121°F with the exception of the forward field joint which had a minimum of 83°F. It is not known at this time whether or not an anomaly occurred in the field joint heater sensors. A complete discussion of this will be included in the final test report.

Igniter joint temperature. The igniter joint temperature was approximately 106°F, well over the minimum of 87°F.

Case-to-nozzle joint. Case-to-nozzle joint temperature was approximately 109°F, well over the minimum of 87°F.

INSTRUMENTATION

Valuable data was collected. Instrumentation performed well. The pressure transducer (P000149) located between the barrier booster o-rings in the S&A was removed and the port plugged due to lack of confidence in transducer test performed prior to TEM-03.

STATIC TEST SUPPORT EQUIPMENT

The water deluge system, CO_2 quench and other test support equipment performed as expected during all required test operations.

INTERIM DATA DUE: 22 June 1989

FINAL REPORT DUE: 20 July 1989 (TWR-17639)

NEXT TEST: TEM-04 - Approximate Test Date: 02 August 1989

D M. Garecht

D. M. Garecht
Test Planning and Reporting

Neal Black

I. N. Black, Supervisor
Test Planning and Reporting

S G Harris

S. Harris
Program Manager

Norm Millsap for

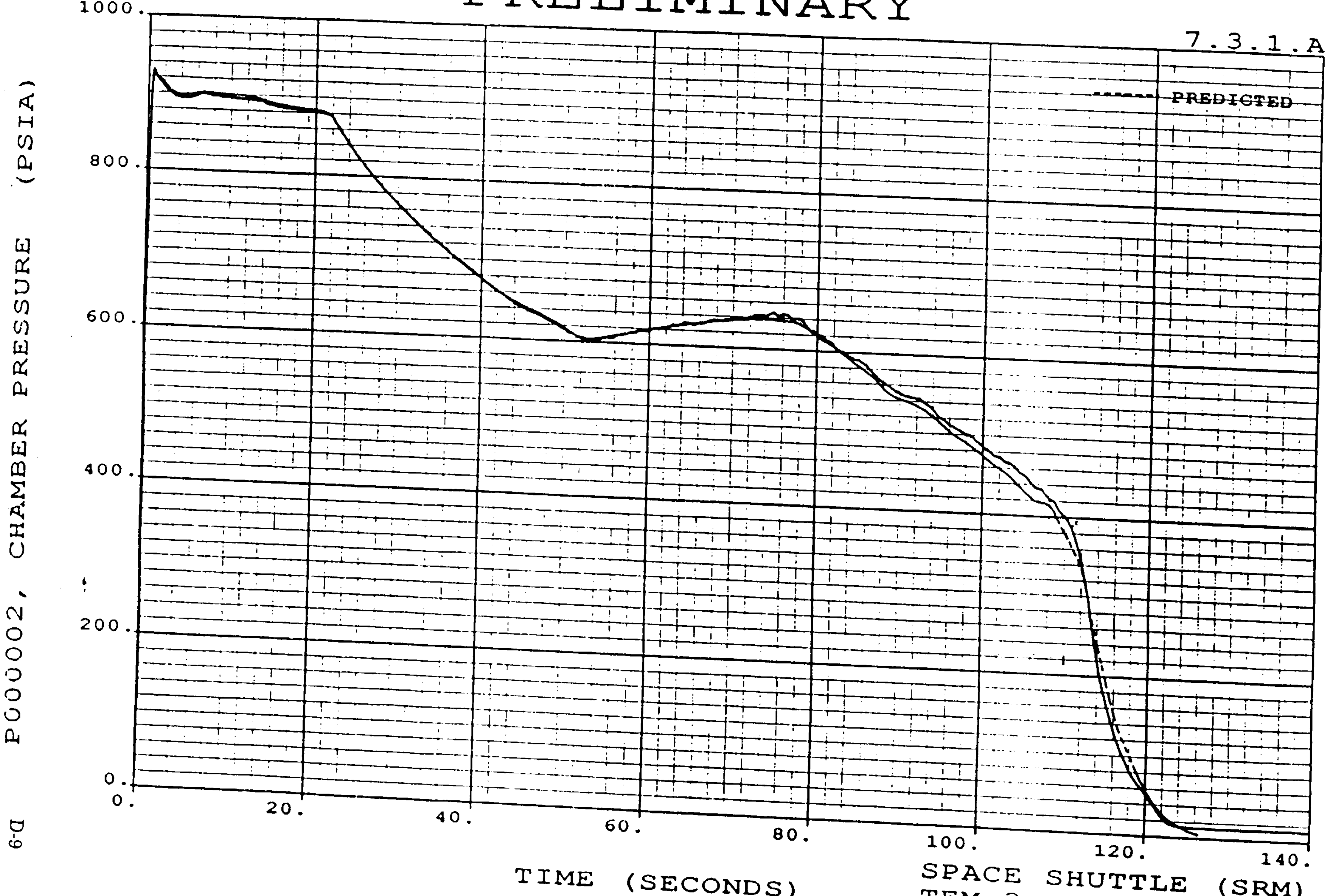
F. Rittenhouse
Project Engineer

TABLE I
TEM-03 PERFORMANCE SUMMARY *
2 HOUR QUICK LOOK

	SPEC LIMITS ADJUSTED FROM 60 °F TO 70 °F (VACUUM CONDITIONS)	PREDICTED** (VACUUM) . (70 °F) .	DELIVERED (VACUUM) . (70 °F).
WEB TIME (SEC)	104.9 - 116.0	110.5	111.8
ACTION TIME (SEC)	114.1 - 130.0	122.7	121.9
MOP HEAD-END (PSIA)	868.2 - 988.9	928.2	929.7
MOF (MLBF) ***	3.15 - 3.56	3.36	N/A
WEB TIME AVERAGE HEAD-END PRESSURE (PSIA)	632.7 - 703.5	668.2	667.5
WEB TIME AVERAGE THRUST (MLBF)	2.48 - 2.76	2.62	N/A
WEB TIME PRESSURE INTEGRAL (PSIA-SEC)	N/A	73885.	74600
WEB TIME TOTAL IMPULSE (MLBF*SEC)	286.1 - 291.9	290.0	N/A
ACTION TIME AVERAGE HEAD-END PRESSURE (PSIA)	N/A	618.5	622.9
ACTION TIME AVERAGE THRUST (MLBF)	N/A	2.43	N/A
ACTION TIME PRESSURE INTEGRAL (PSIA-SEC)	N/A	75746.	75900
ACTION TIME IMPULSE (MLBF*SEC)	293.5 - 299.4	297.7	N/A
ISP AVERAGE DELIVERED (LBF*SEC/LBM)	265.4 - 269.1	268.3	268.2
IGNITION INTERVAL (SEC), TIME TO 563.5 PSIA	0.170 - 0.340	0.232	0.228
MAXIMUM PRESSURE RISE RATE (PSI/10-MSEC)	X < 109.0	90.5	88.6
BURN RATE (IN/SEC)	N/A	0.371	0.371
IGNITER MAXIMUM PRESSURE	N/A	1929	1964
LOADED PROPELLANT WEIGHT (INCLUDING IGNITER) (LB)	X > 1,104,714	1,109,386****	

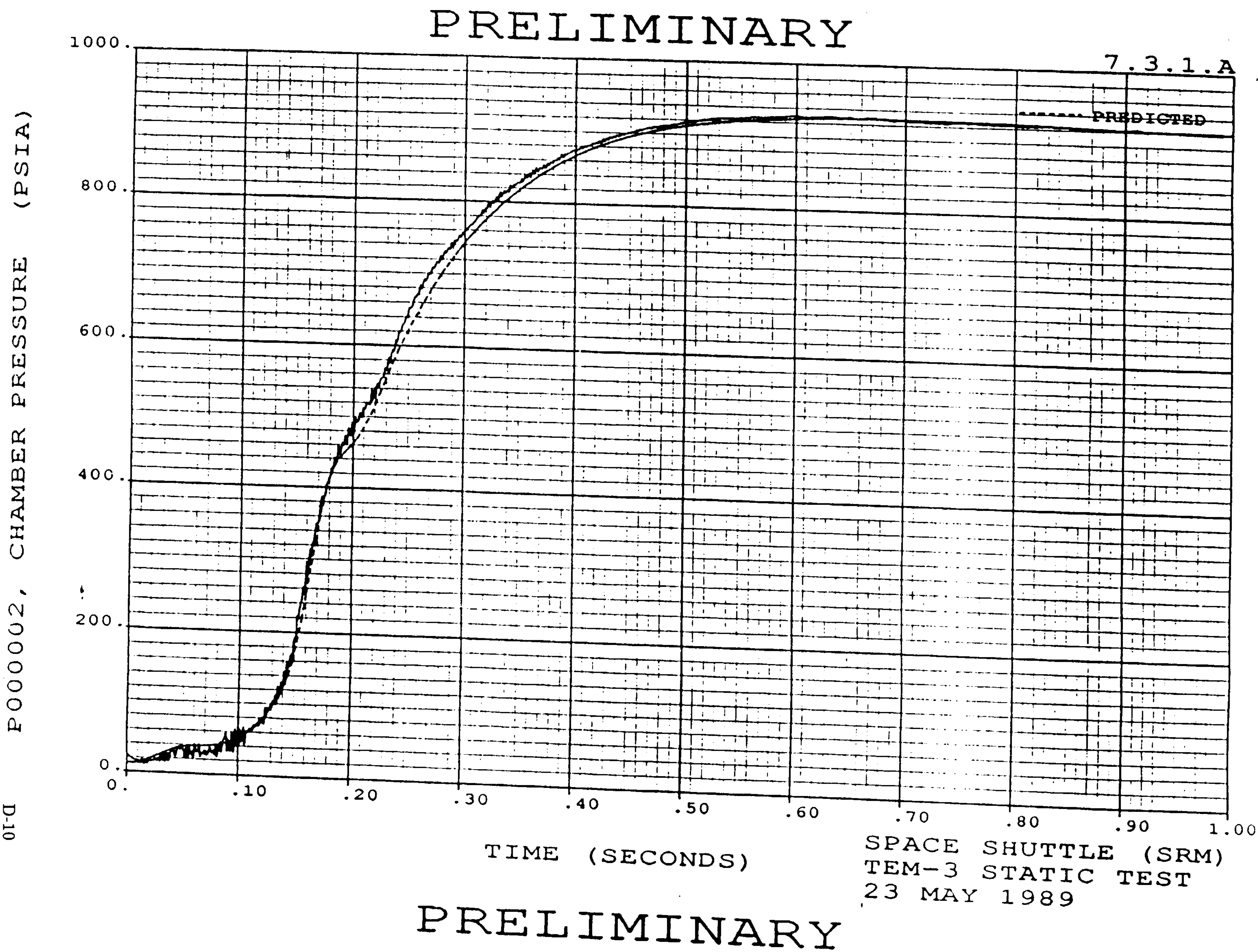
* TEM-03 PREDICTION BASED ON THE FOLLOWING MOTOR SEGMENTS
FWD: SRM-31B, CF: SRM-29A, CA: SRM-27A, AFT: SRM-30B
** BASED ON BURN RATE OF 0.368 IN/SEC AT 60 DEG F, 625 PSIA
*** SPEC. LIMIT ADJUSTED FROM SEA LEVEL THRUST (14.7 PSIA) AND 60 ° F
**** BASED ON NOMINAL PROPELLANT WEIGHTS

PRELIMINARY

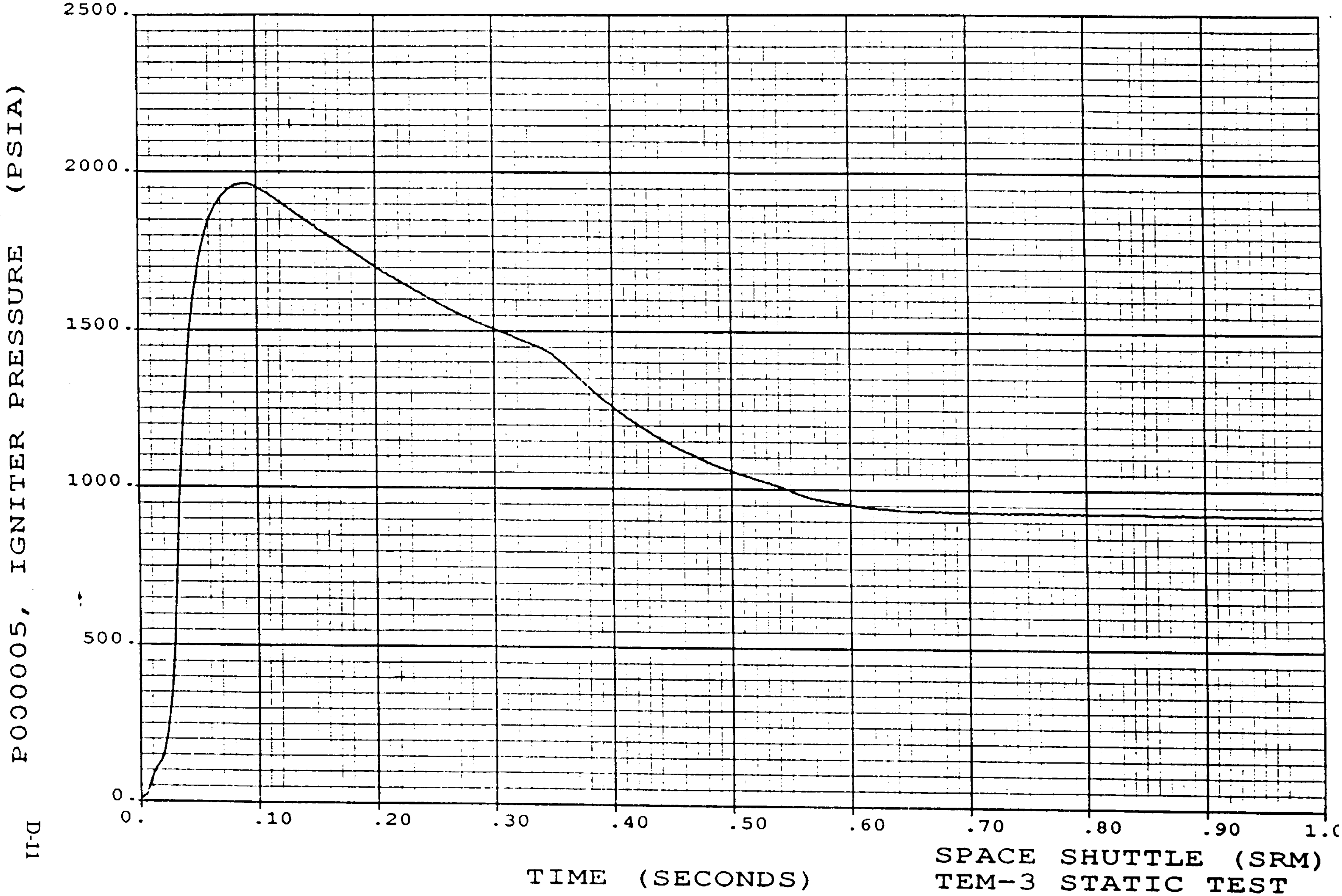


SPACE SHUTTLE (SRM)
TEM-3 STATIC TEST
23 MAY 1989

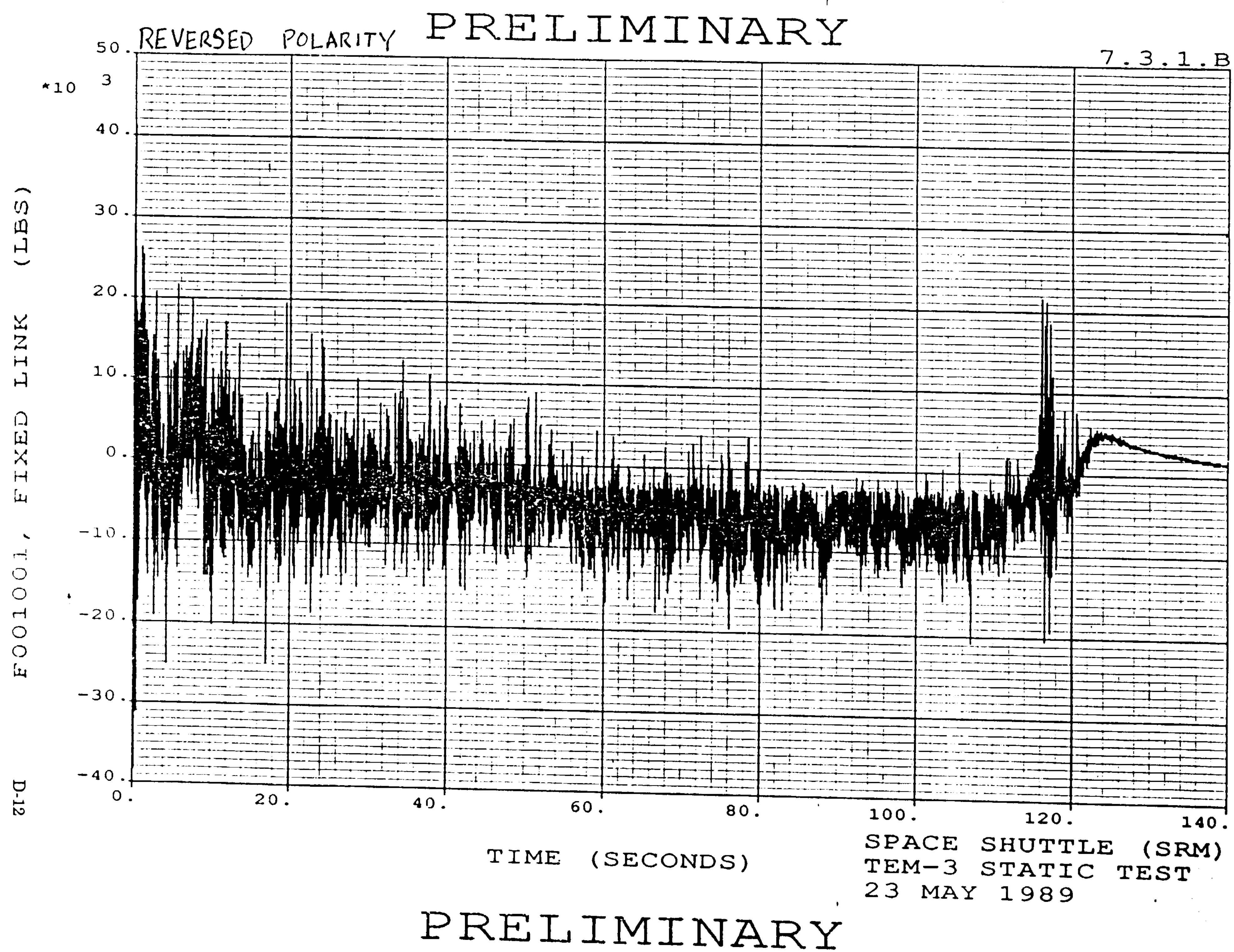
PRELIMINARY


PRELIMINARY
7.3.1.A
------- PREDICTED
P000002, CHAMBER PRESSURE (PSIA)
1000.
800.
600.
400.
200.
0.
0.
.10
.20
.30
.40
.50
.60
.70
.80
.90
1.00
TIME (SECONDS)
SPACE SHUTTLE (SRM)
TEM-3 STATIC TEST
23 MAY 1989
PRELIMINARY

PRELIMINARY



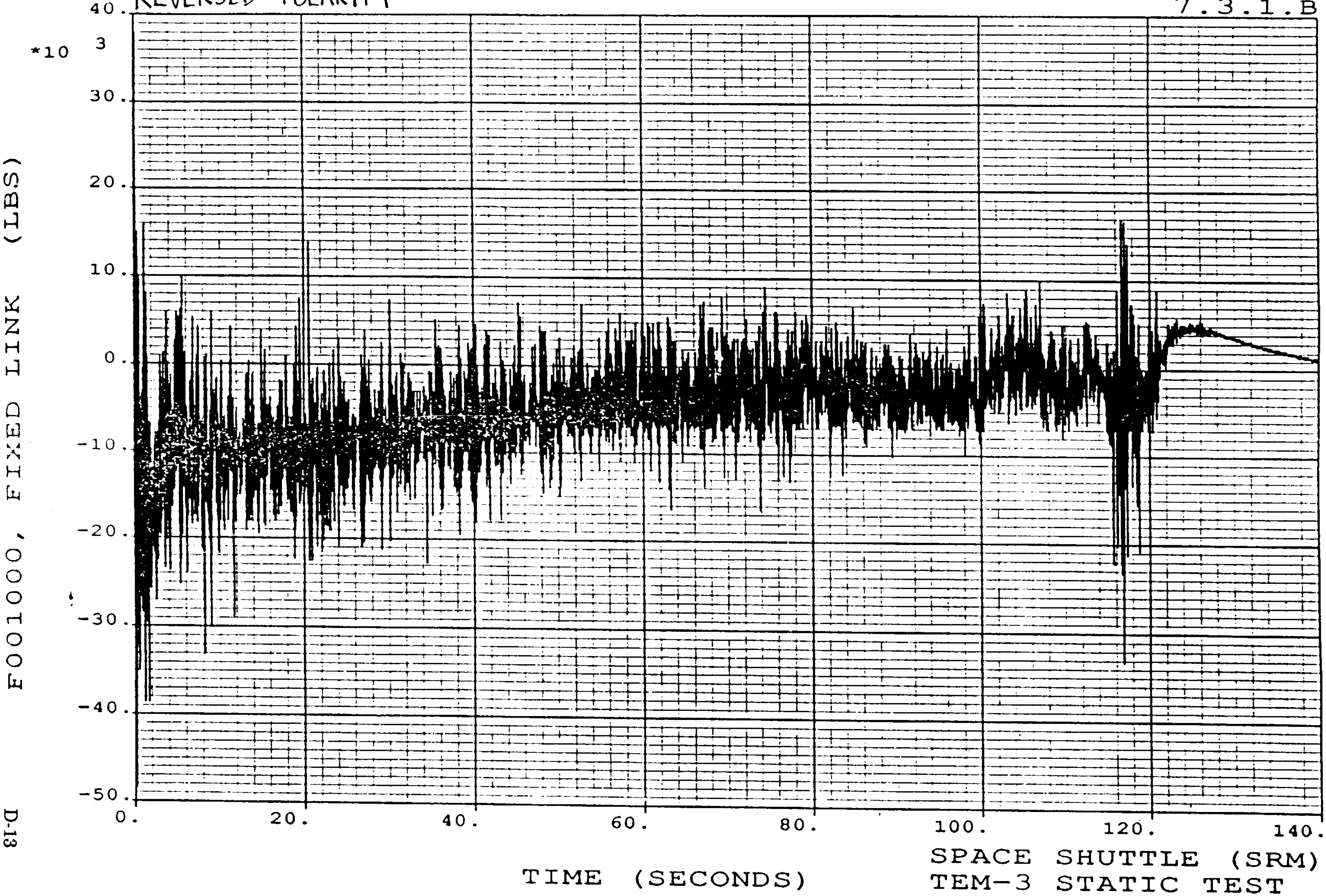
PRELIMINARY



REVERSED POLARITY
PRELIMINARY
7.3.1.B
*10 3
50.
40.
30.
20.
10.
0.
-10.
-20.
-30.
-40.
F00100L, FIXED LINK (LBS)
0.
20.
40.
60.
80.
100.
120.
140.
TIME (SECONDS)
SPACE SHUTTLE (SRM)
TEM-3 STATIC TEST
23 MAY 1989
PRELIMINARY

PRELIMINARY

REVERSED POLARITY

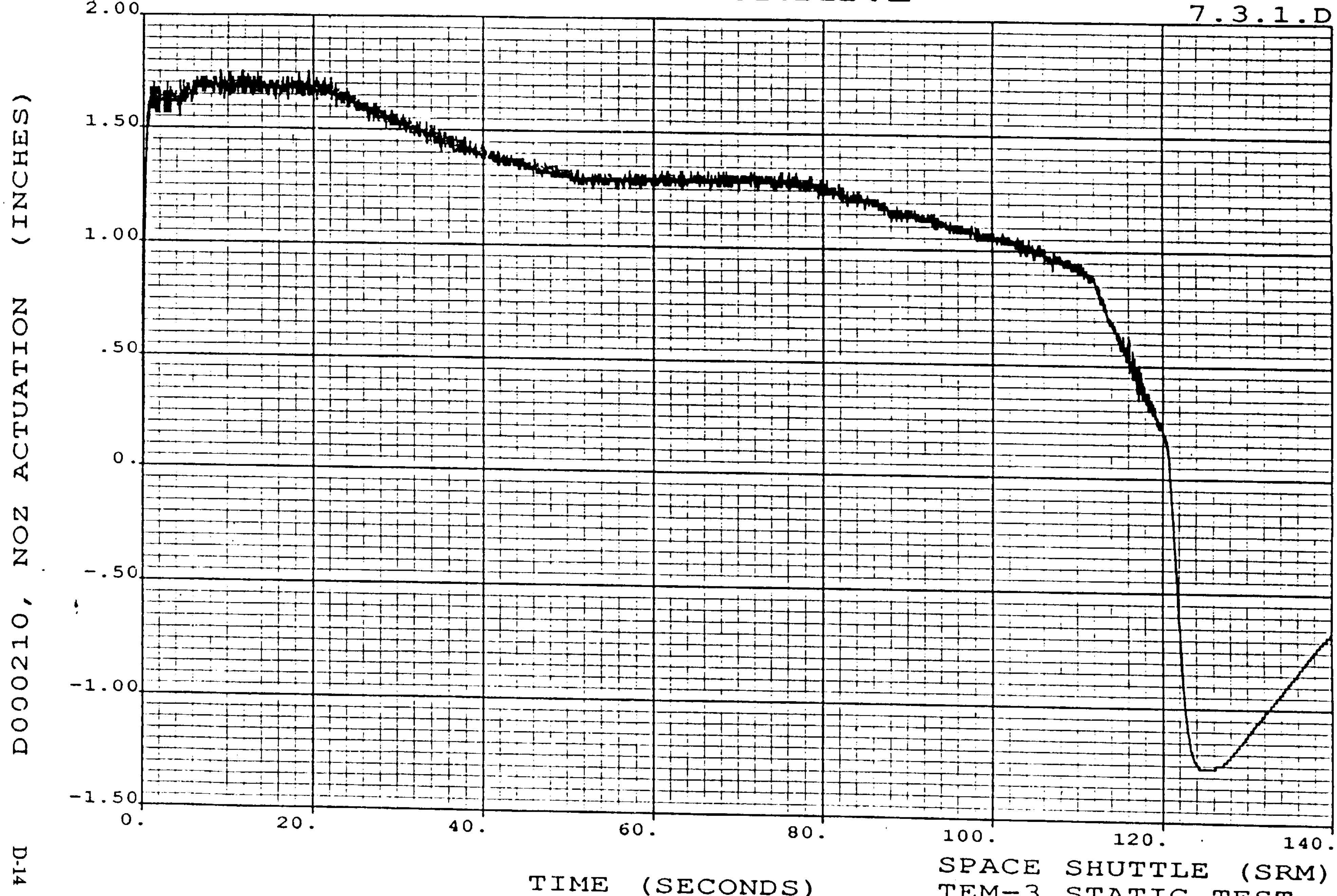


SPACE SHUTTLE (SRM)
TEM-3 STATIC TEST
23 MAY 1989

PRELIMINARY

MF

PRELIMINARY



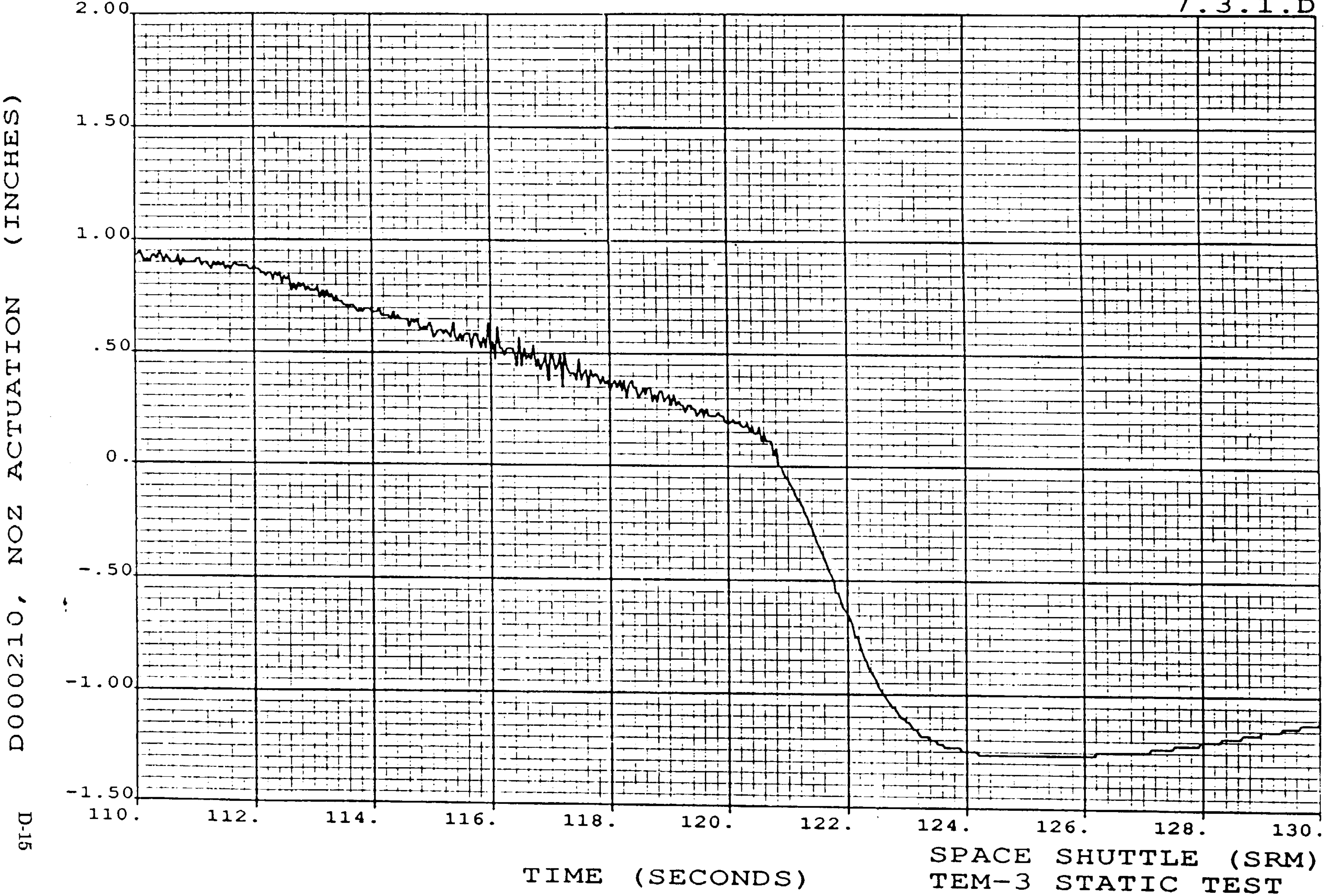
SPACE SHUTTLE (SRM)
TEM-3 STATIC TEST
23 MAY 1989

PRELIMINARY

MG

PRELIMINARY

7.3.1.D

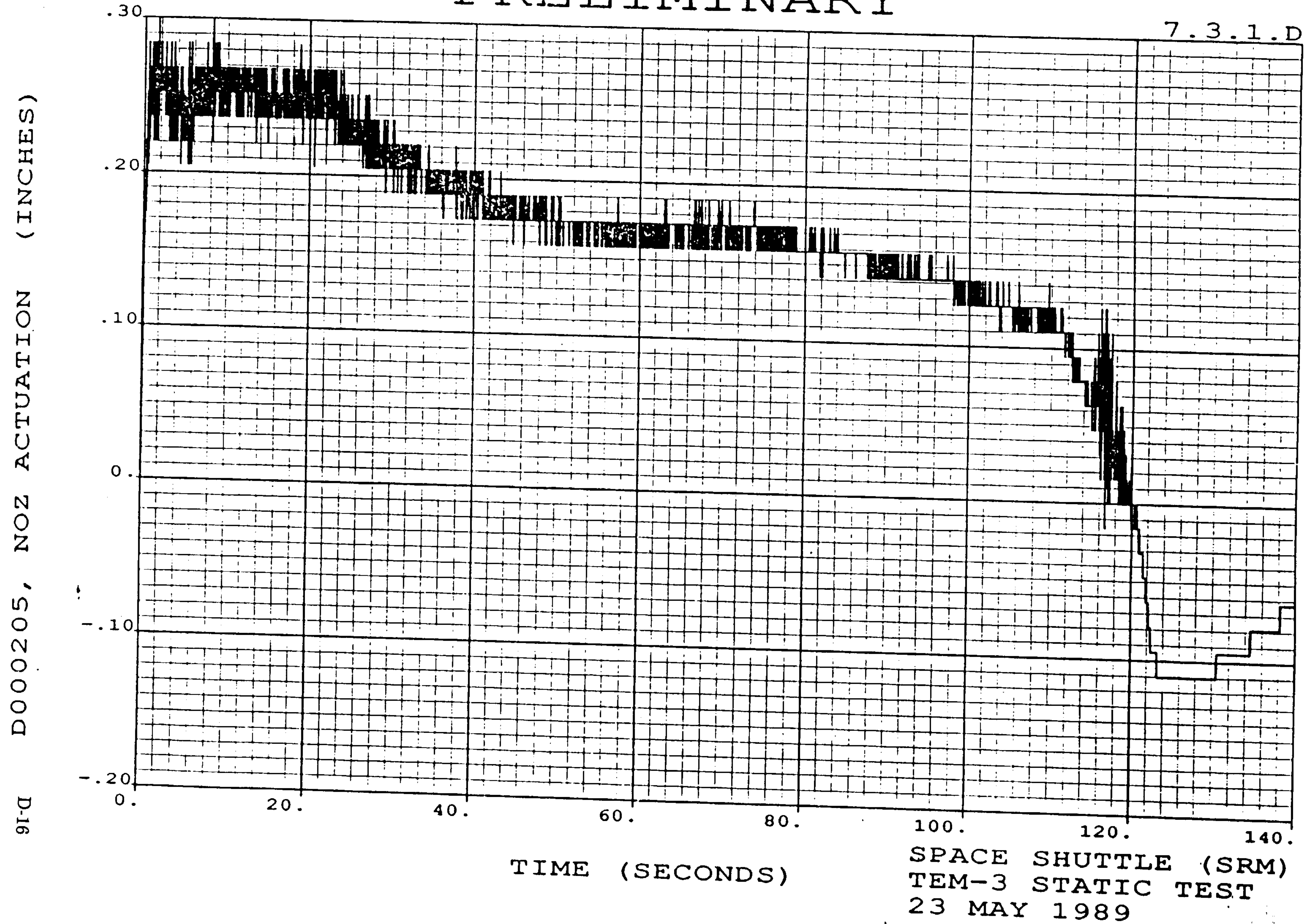


SPACE SHUTTLE (SRM)
TEM-3 STATIC TEST
23 MAY 1989

PRELIMINARY

ME

PRELIMINARY

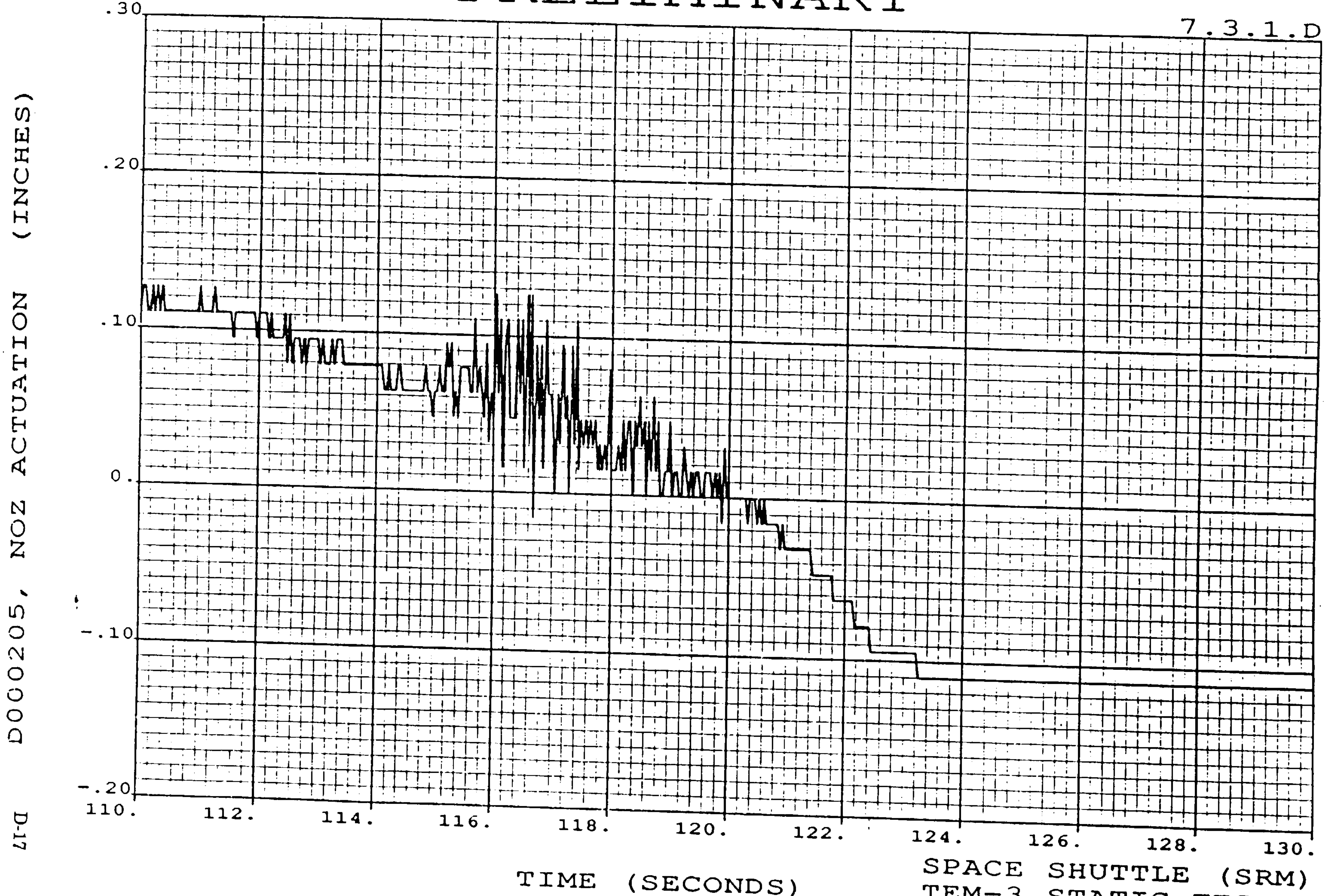


PRELIMINARY

ME

PRELIMINARY

7.3.1.D

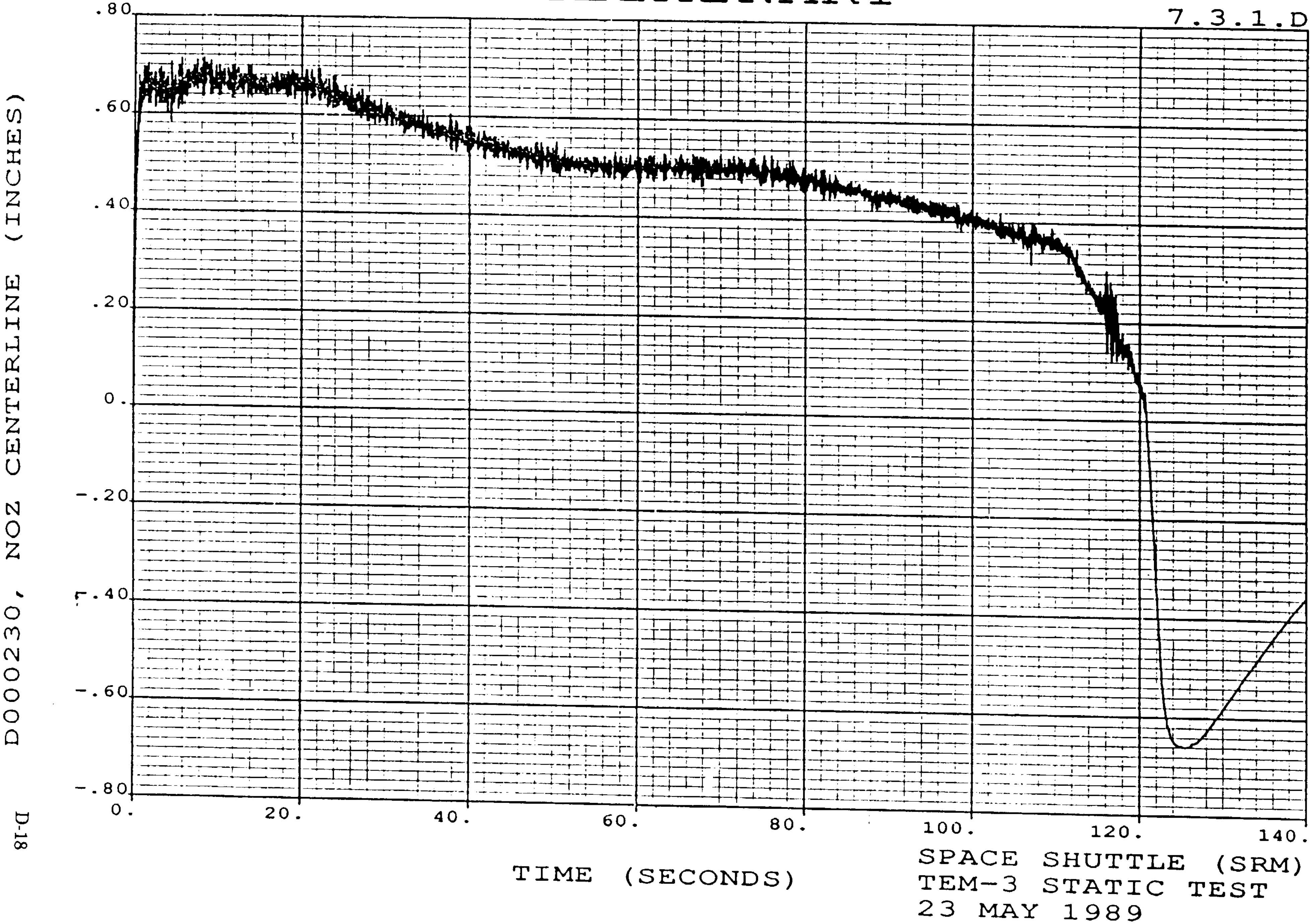


SPACE SHUTTLE (SRM)
TEM-3 STATIC TEST
23 MAY 1989

PRELIMINARY

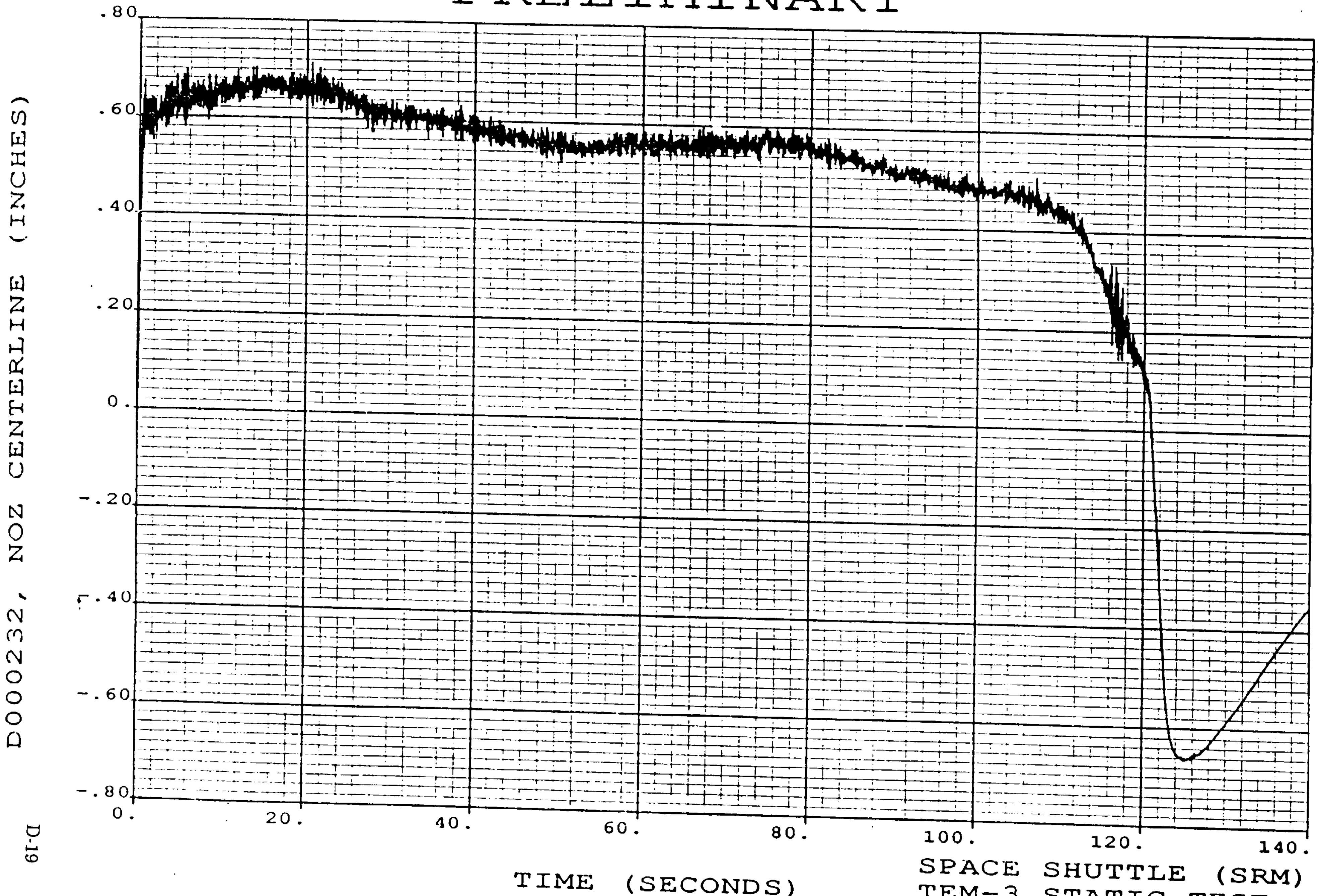
ME

PRELIMINARY



PRELIMINARY

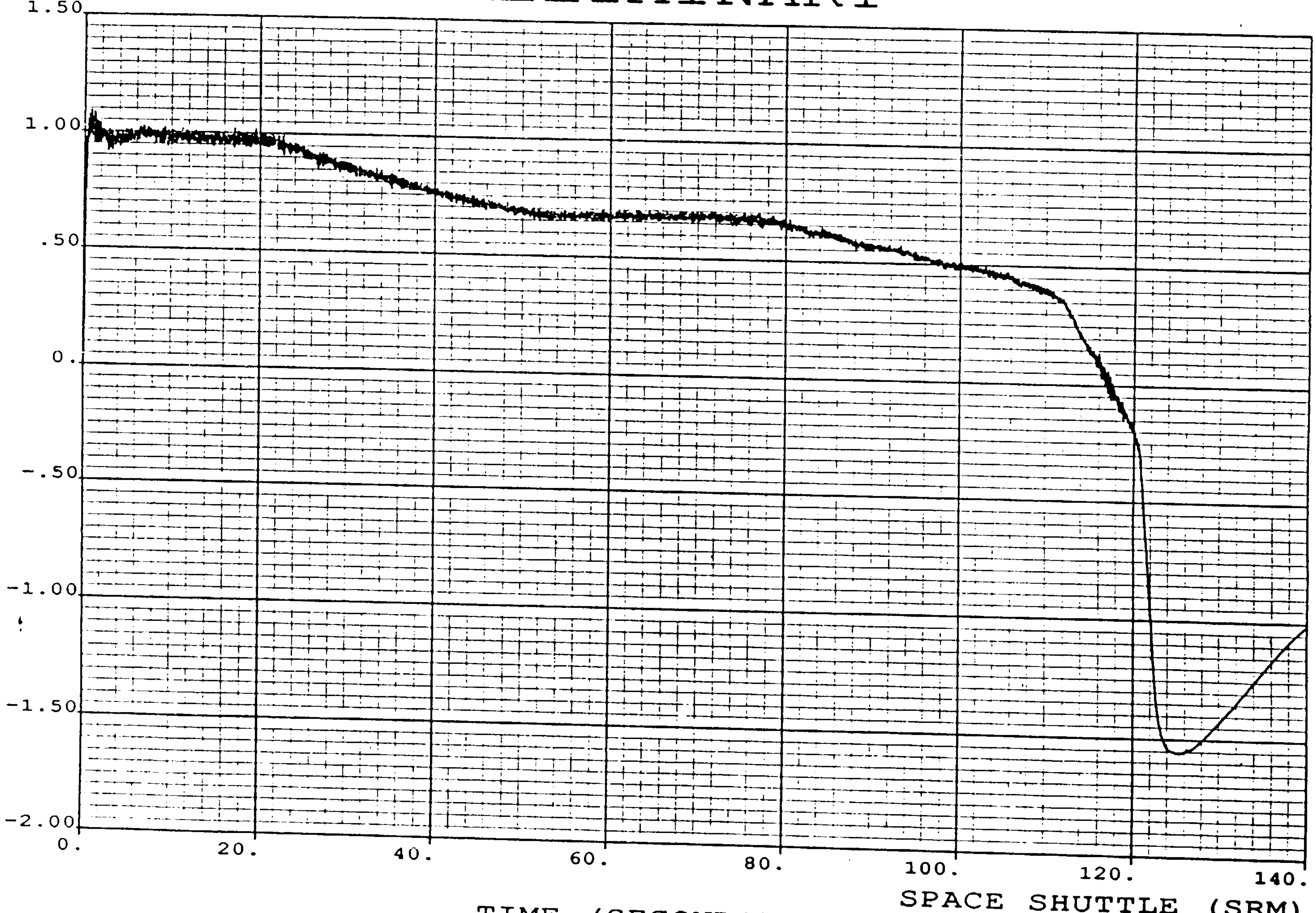
PRELIMINARY



SPACE SHUTTLE (SRM)
TEM-3 STATIC TEST
23 MAY 1989

PRELIMINARY

PRELIMINARY

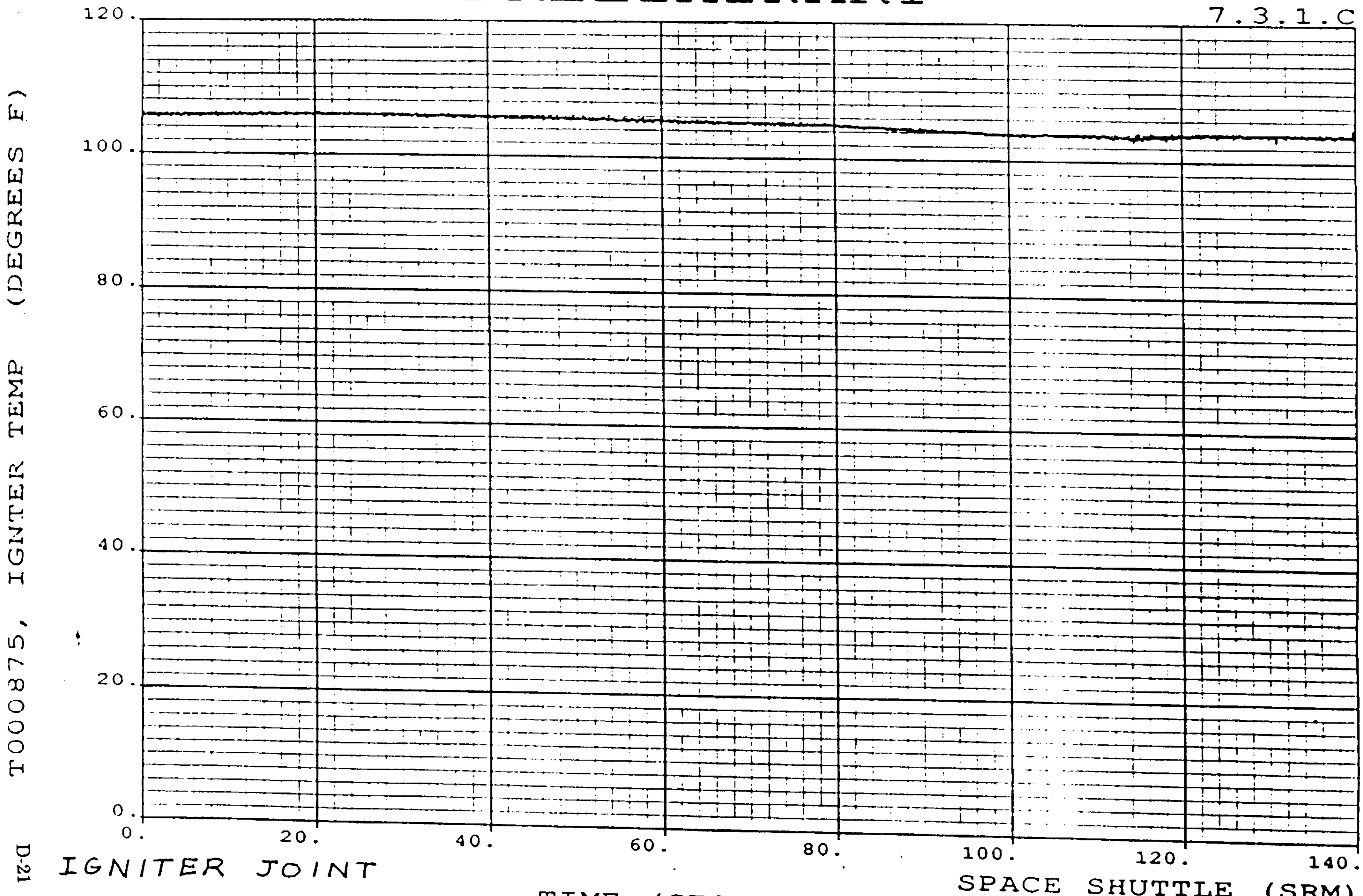


SPACE SHUTTLE (SRM)
TEM-3 STATIC TEST
23 MAY 1989

PRELIMINARY

PRELIMINARY

7.3.1.C

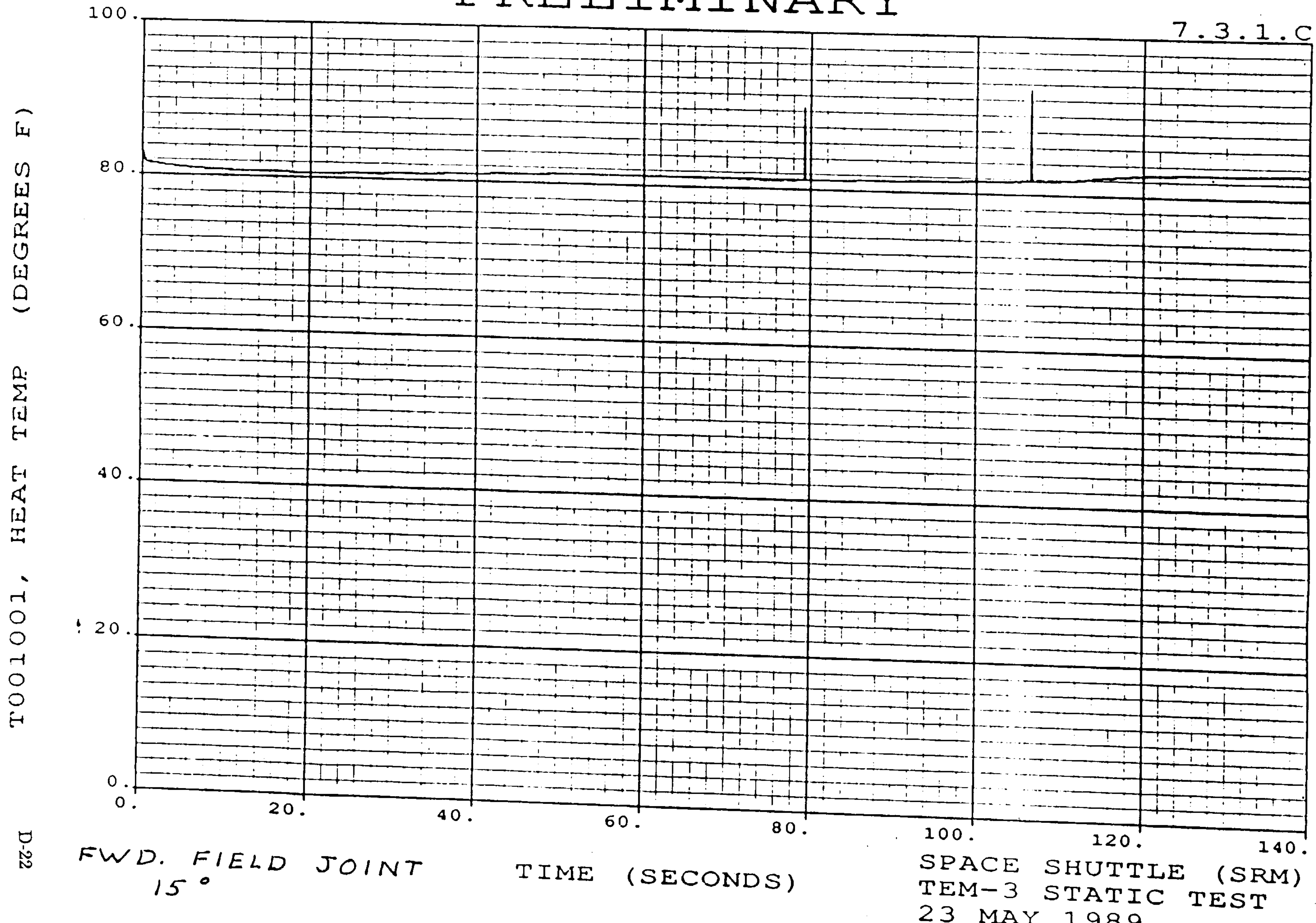


IGNITER JOINT

SPACE SHUTTLE (SRM)
TEM-3 STATIC TEST
23 MAY 1989

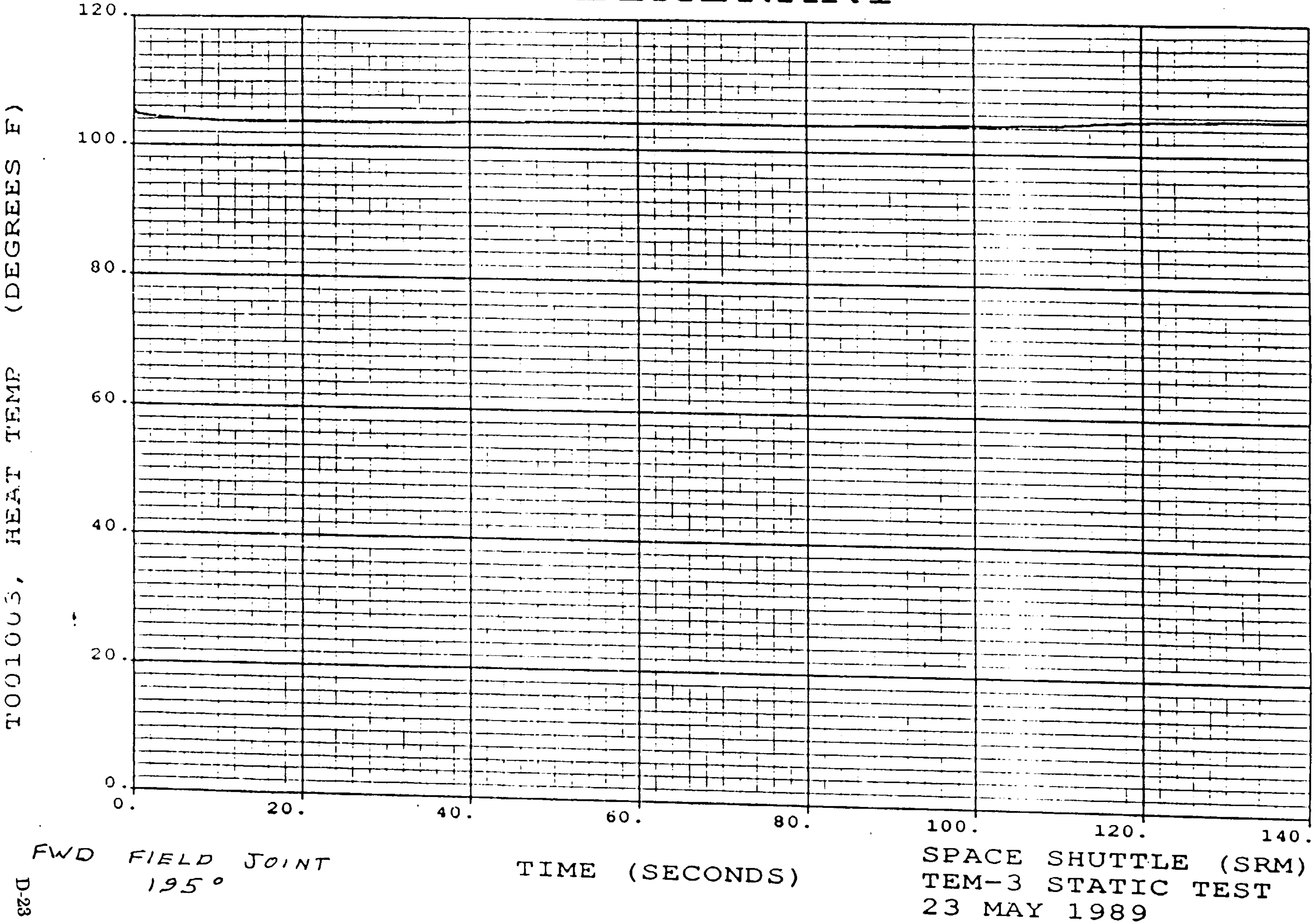
PRELIMINARY

PRELIMINARY



PRELIMINARY

PRELIMINARY

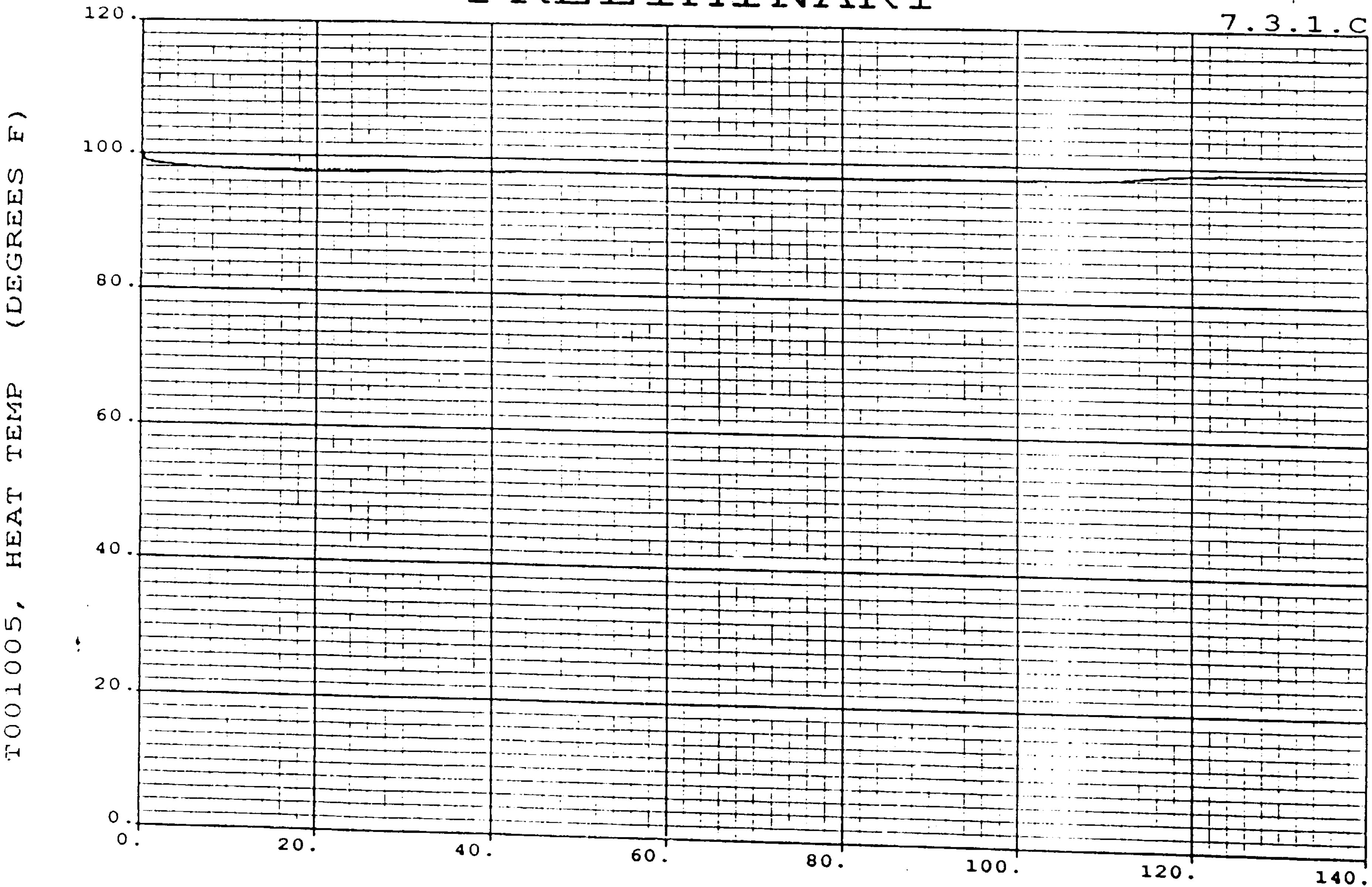


FWD FIELD JOINT
195°

PRELIMINARY

PRELIMINARY

7.3.1.C

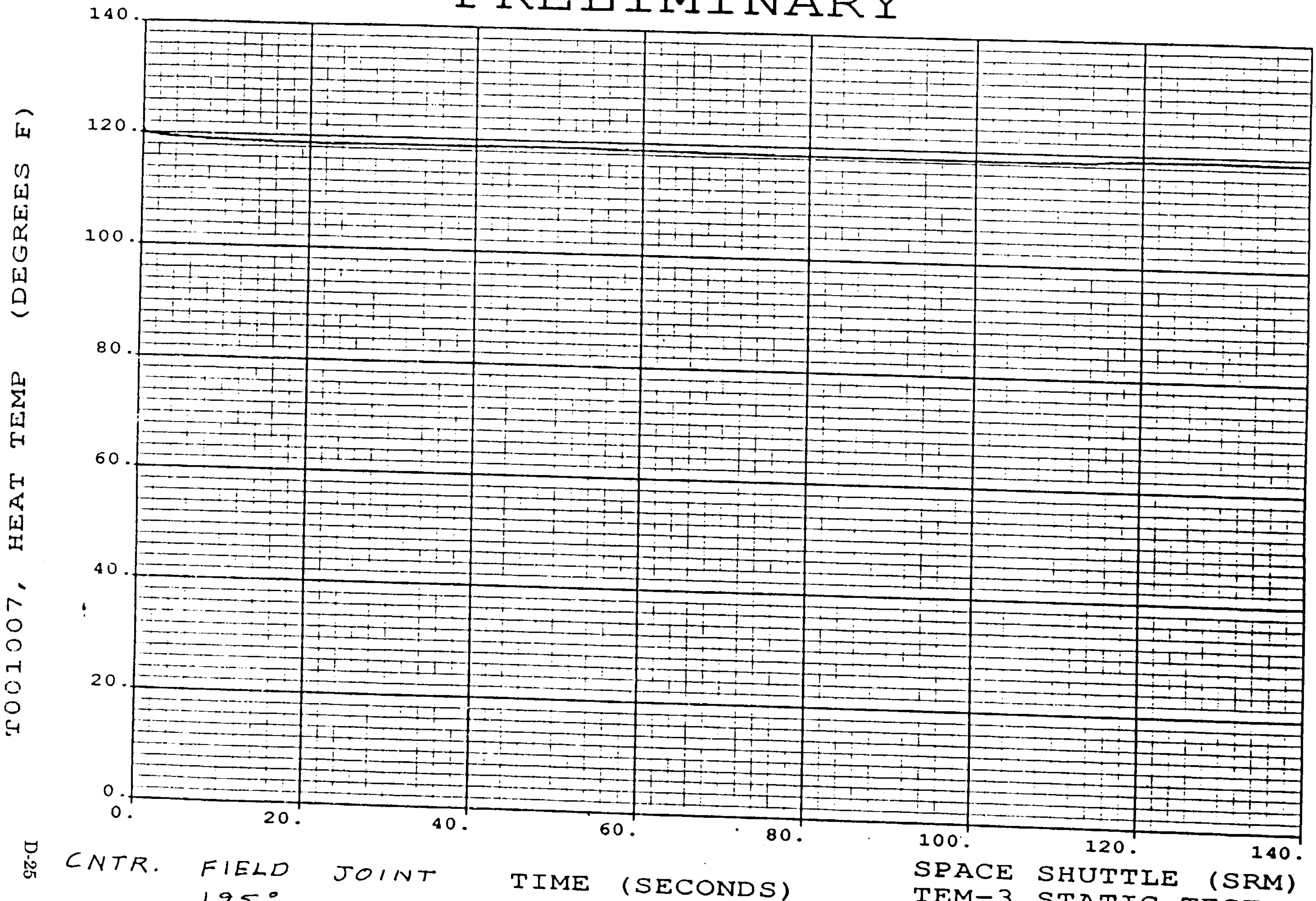


CNTR FIELD JOINT
15°

SPACE SHUTTLE (SRM)
TEM-3 STATIC TEST
23 MAY 1989

PRELIMINARY

PRELIMINARY

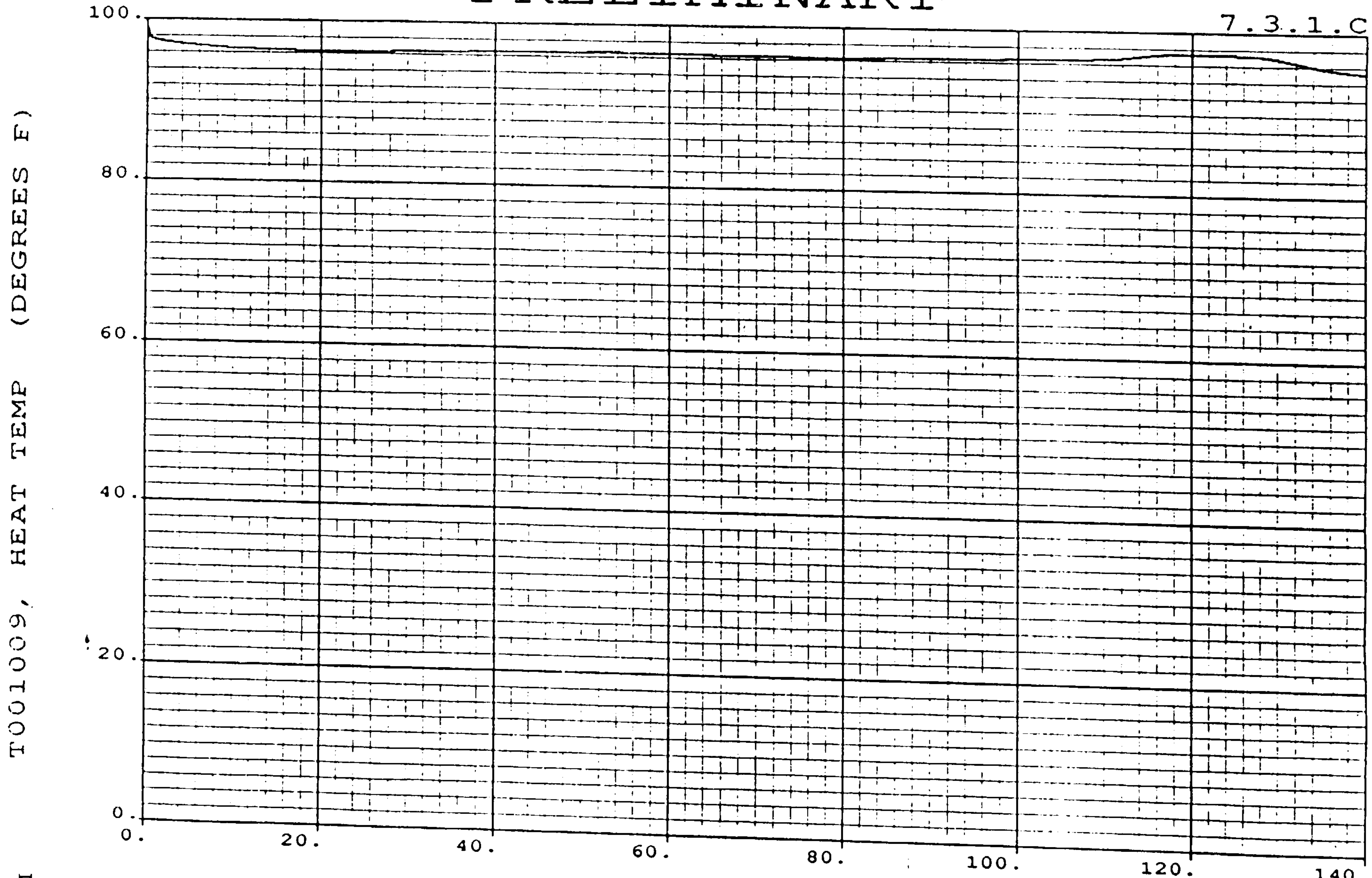


SPACE SHUTTLE (SRM)
TEM-3 STATIC TEST.
23 MAY 1989

PRELIMINARY

PRELIMINARY

7.3.1.C

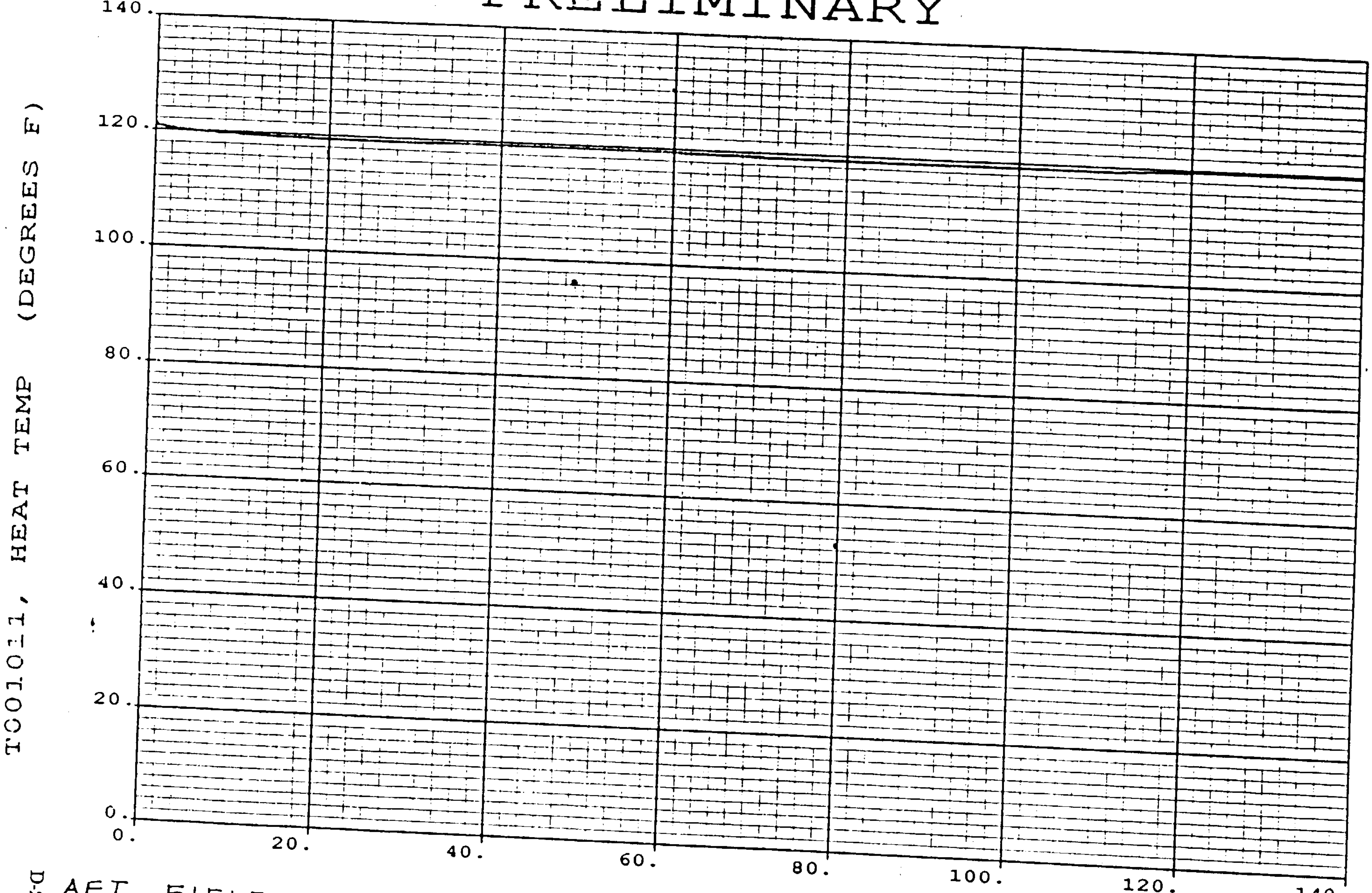


AFT FIELD JOINT
15°

SPACE SHUTTLE (SRM)
TEM-3 STATIC TEST
23 MAY 1989

PRELIMINARY

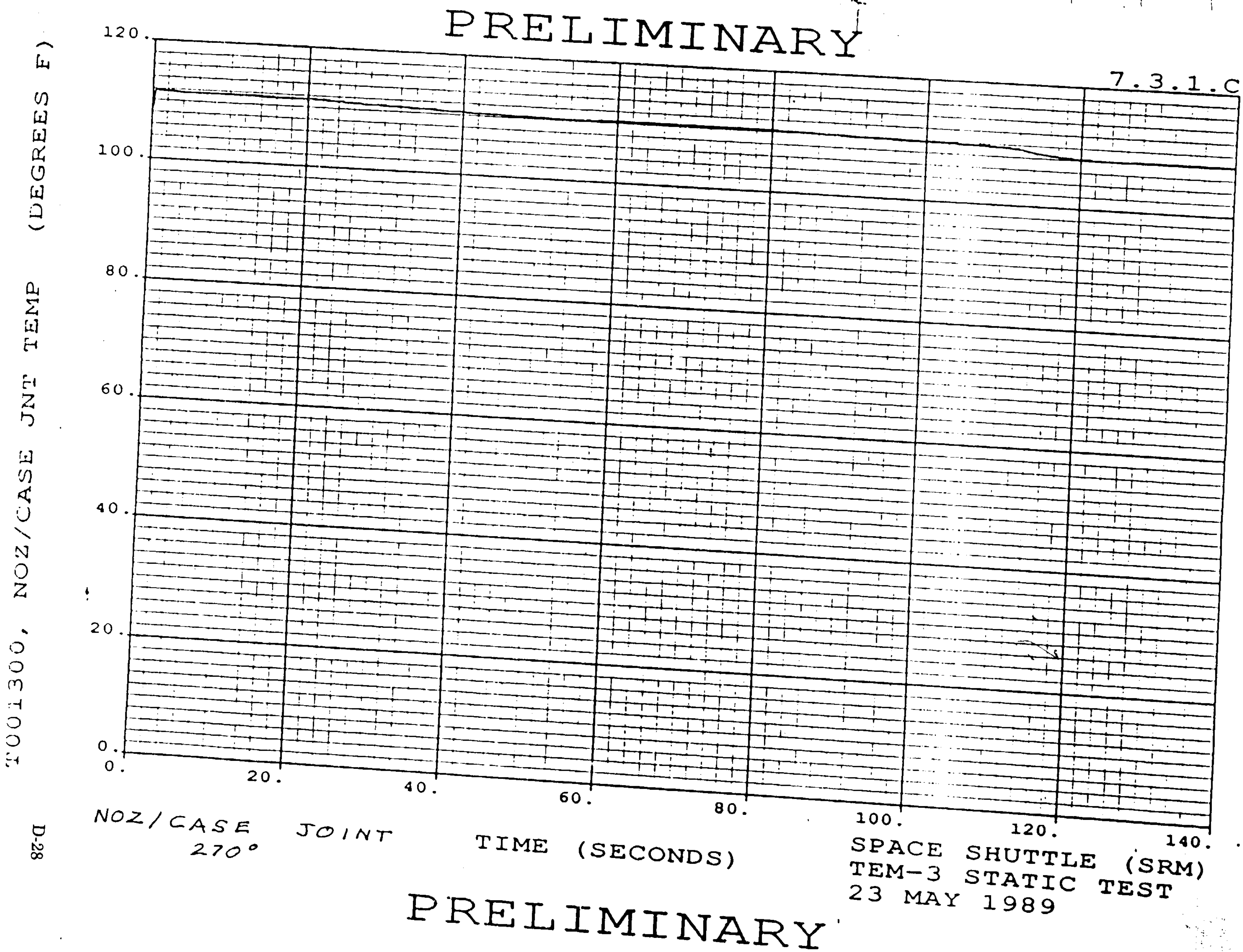
PRELIMINARY



AFT FIELD JOINT
195°

SPACE SHUTTLE (SRM)
TEM-3 STATIC TEST
23 MAY 1989

PRELIMINARY


PRELIMINARY
7.3.1.C
120.
100.
80.
60.
40.
20.
0.
0.
20.
40.
60.
80.
100.
120.
140.
T001300, NOZ/CASE JNT TEMP (DEGREES F)
NOZ/CASE JOINT
270°
TIME (SECONDS)
SPACE SHUTTLE (SRM)
TEM-3 STATIC TEST
23 MAY 1989
PRELIMINARY

Thiokol CORPORATION
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