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SPACE SHUTTLE

Solid Rocket Motors
Thiokol Corporation

RSRM Top Hat Cover Simulator Lightning Test Final Report

Volume I

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RSRM Top Hat Cover Simulator Lightning Test
Final Test Report

Volume I

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ABSTRACT

The test sequence was to measure electric and magnetic fields induced inside a redesigned solid rocket motor case when a simulated lightning discharge strikes an exposed top hat cover simulator. The test sequence was conducted between 21 June and 17 July 1990. The test sequence was performed at the Thiokol Corporation Lightning Test Complex in Wendover, Utah.

Thirty-six high rate-of-rise Marx generator discharges and eight high current bank discharges were injected onto three different test article configurations. Attach points included three locations on the top hat cover simulator and two locations on the mounting bolts.

Top hat cover simulator and mounting bolt damage (surface pitting and melting) and grain cover damage (fiberglass top was damaged and frayed at arc attachment point) was observed. Overall electric field levels were well below 30 kilovolts/meter. Electric field levels ranged from 184.7 to 345.9 volts/meter and magnetic field levels were calculated from 6.921 to 39.73 amperes/meter.

It is recommended that the redesigned solid rocket motor top hat cover be used in Configuration No. 1 or Configuration No. 2 as an interim lightning protection device until a lightweight cover can be developed.

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INTRODUCTION

This report documents the procedures, performance, and results obtained from the evaluation of simulated lightning discharges to an RSRM test article. The test sequence was conducted following WTP-0245, Rev A. There were three purposes of this test.

a. Measure the electric field levels inside the redesigned solid rocket motor (RSRM) case when a simulated lightning discharge is injected onto the top of the test article. The fields should not exceed 30 kilovolts per meter (kV/m) (1/10 the dielectric breakdown of the propellant) inside the case.

b. Determine if any arcing occurs between the case, handling ring, grain cover, segmented ring, or top hat cover simulator.

c. Evaluate methods of detecting a lightning attachment to a segment while in the vertical transportation mode at Kennedy Space Center (KSC).

This test sequence was accomplished by injecting simulated lightning discharges onto a top hat cover simulator, mounting bolts, and a grain cover, and then evaluating the measured electric fields and calculated magnetic fields inside the empty RSRM case.

The test article was placed between two horizontal grids of a peaking capacitor (Figure 1). The peaking capacitor has a 9-m distance between two parallel grids. The two parallel 2,500-m^2 wire grids (upper and lower) make up two plates of a 2.5-nano-farad (nF) capacitor.

The Marx generator discharges were by direct arc attachment to the top hat cover simulator, the mounting bolts, and the grain cover. The Marx discharges

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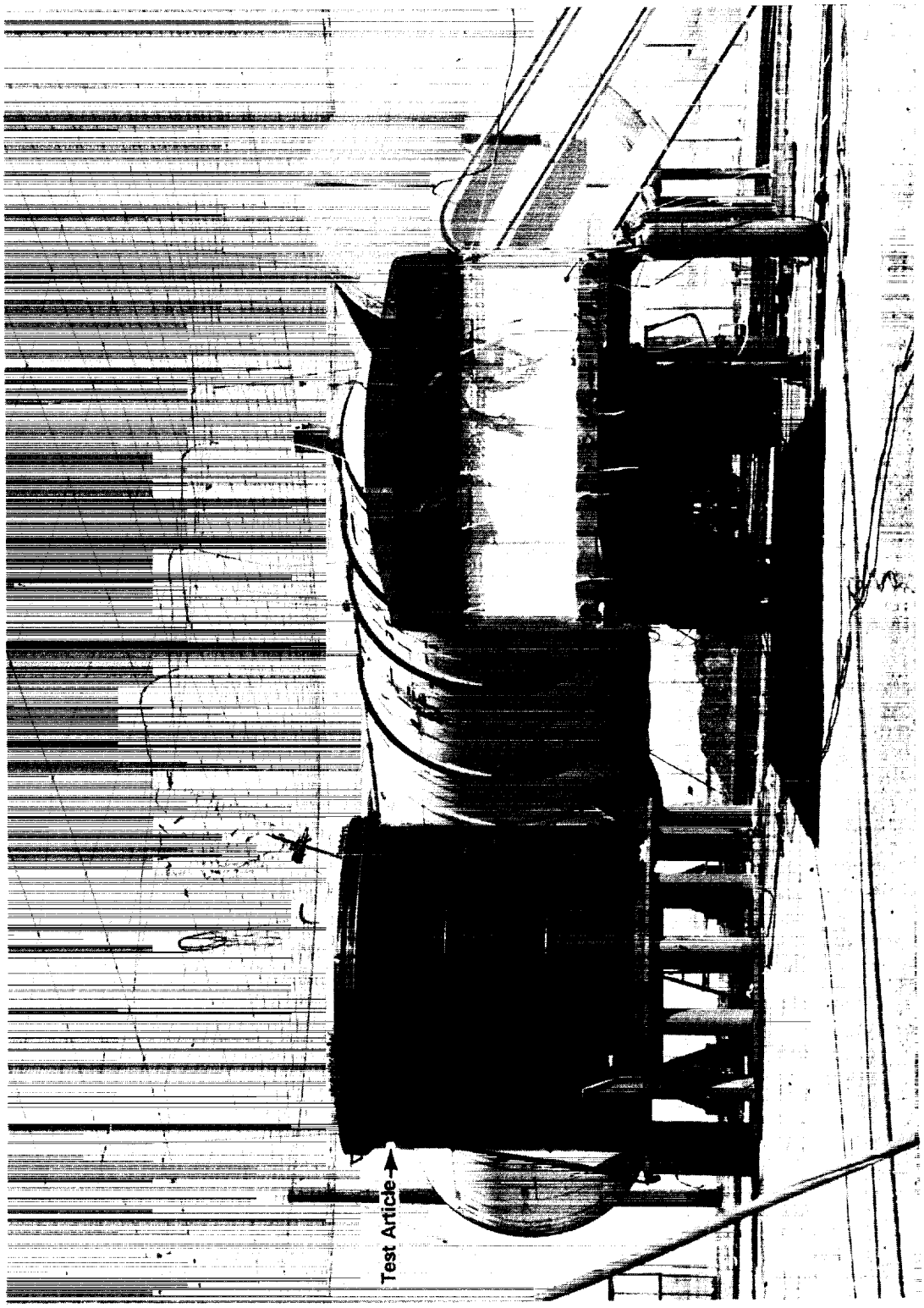

Figure 1. RSRM Top Hat Cover Simulator Test Article

simulated the fast rise in current with respect to time of a worst-case lightning discharge to unprotected flight hardware on the ground (Figure 2, points A - B), as defined in NSTS 07636, Rev D.

The high current bank (HCB) simulated lightning discharges were by direct arc attachment to the top hat cover simulator and the mounting bolts. The HCB simulated the peak current of a worst-case lightning discharge to unprotected flight hardware on the ground (Figure 2, points B - C), as defined in NSTS 07636, Rev D.

The test sequence was completed on 17 July 1990. Simulated lightning discharge testing was performed at the Thiokol Corporation Lightning Test Complex in Wendover, Utah. Testing complied with JSC 20007 and NSTS 07636, Rev D. This test was part of an ongoing lightning test program to evaluate the effects of lightning strikes on the complete RSRM and Space Transportation System.

1.1 TEST ARTICLE DESCRIPTION

All hardware components used in the test article configurations are included in this test article description except those that had no effect on the results. Deviations from the configurations listed in WTP-0245, Rev A, were approved by the Integration Engineer and Program Manager. Three test article configurations were tested using the Marx generator and the HCB. Table 1 indicates the number of discharges per configuration and the total number of discharges for each current bank.

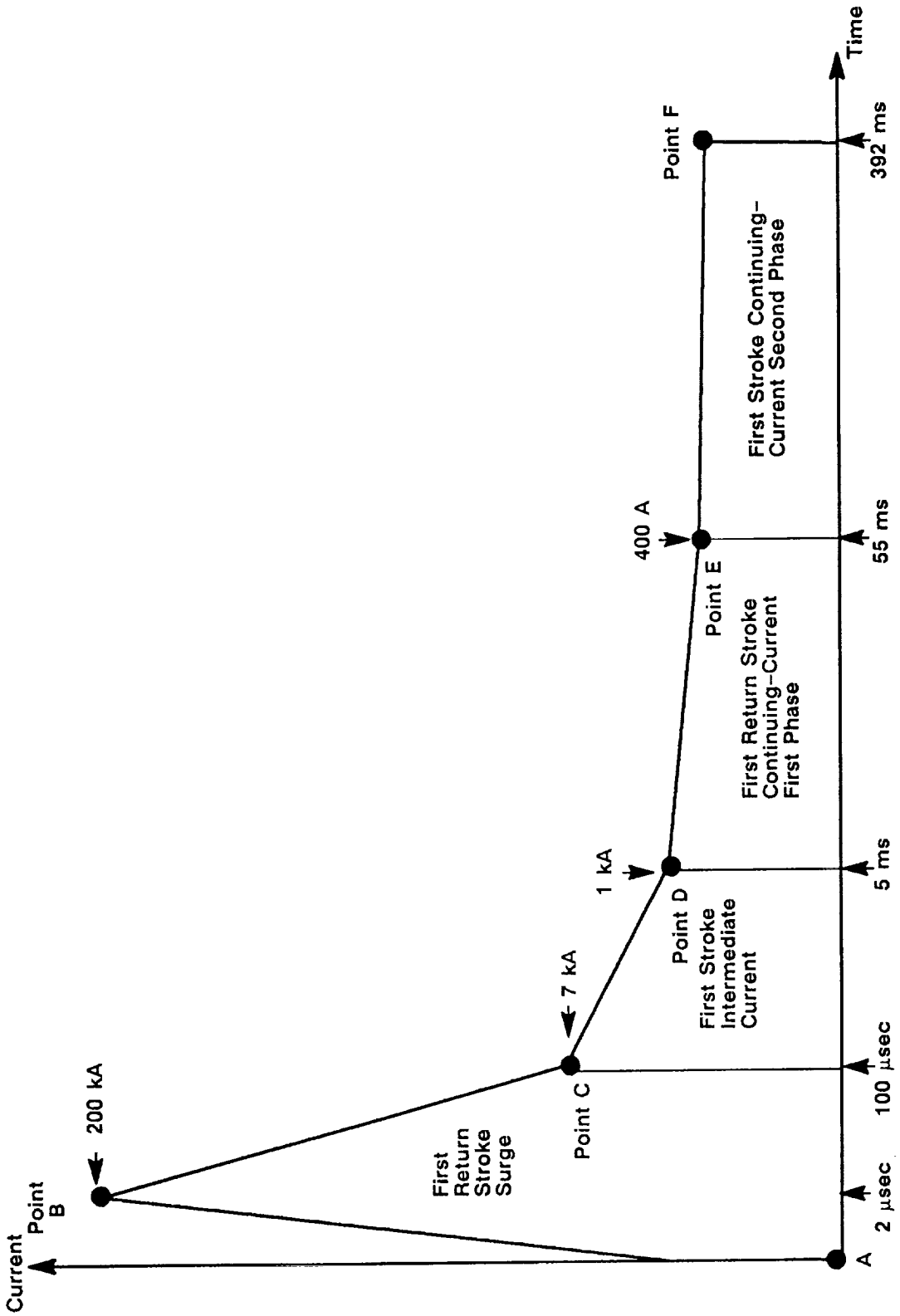

Figure 2. Worst-Case Model of Lightning Discharge

Table 1. Total Discharges

	Number of Discharges	
Configuration No.	Marx Current Bank	High Current Bank
2	26	3
3	6	4
4	4	1
Total	36	8

Configuration No. 1 listed in WTP-0245, Rev A, was not used because of warping during the manufacturing of the top hat simulator. This warping prevented the top hat simulator from making complete contact with the handling ring when all of the bolts were installed. Configurations No. 2 and 3 were considered worst-case situations. The rationale was that if the worst-case configuration could survive the test, then the nominal configuration could survive the test. The fourth configuration listed in this document was not listed in WTP-0245, Rev A, but was added to the test sequence for evaluation purposes.

1.1.1 Configuration No. 2

Test article Configuration No. 2 consisted of a test stand placed on the lower capacitor grid with an empty RSRM case segment (1U50715-02) mounted vertically. Installed around the top edge of the case was a handling ring (8U50943-03), grain cover (8U75816-01), and segmented ring (8U50929-03). Mounted above the grain cover onto the handling ring was a top hat cover simulator (Figure 3). WTP-0245 Configuration No. 2 calls for 0.25-in. shims to be placed between the top hat simulator and the handling ring, which was intended to simulate warping of the cover. During the manufacturing process the top hat simulator warped making the use of shims unnecessary.

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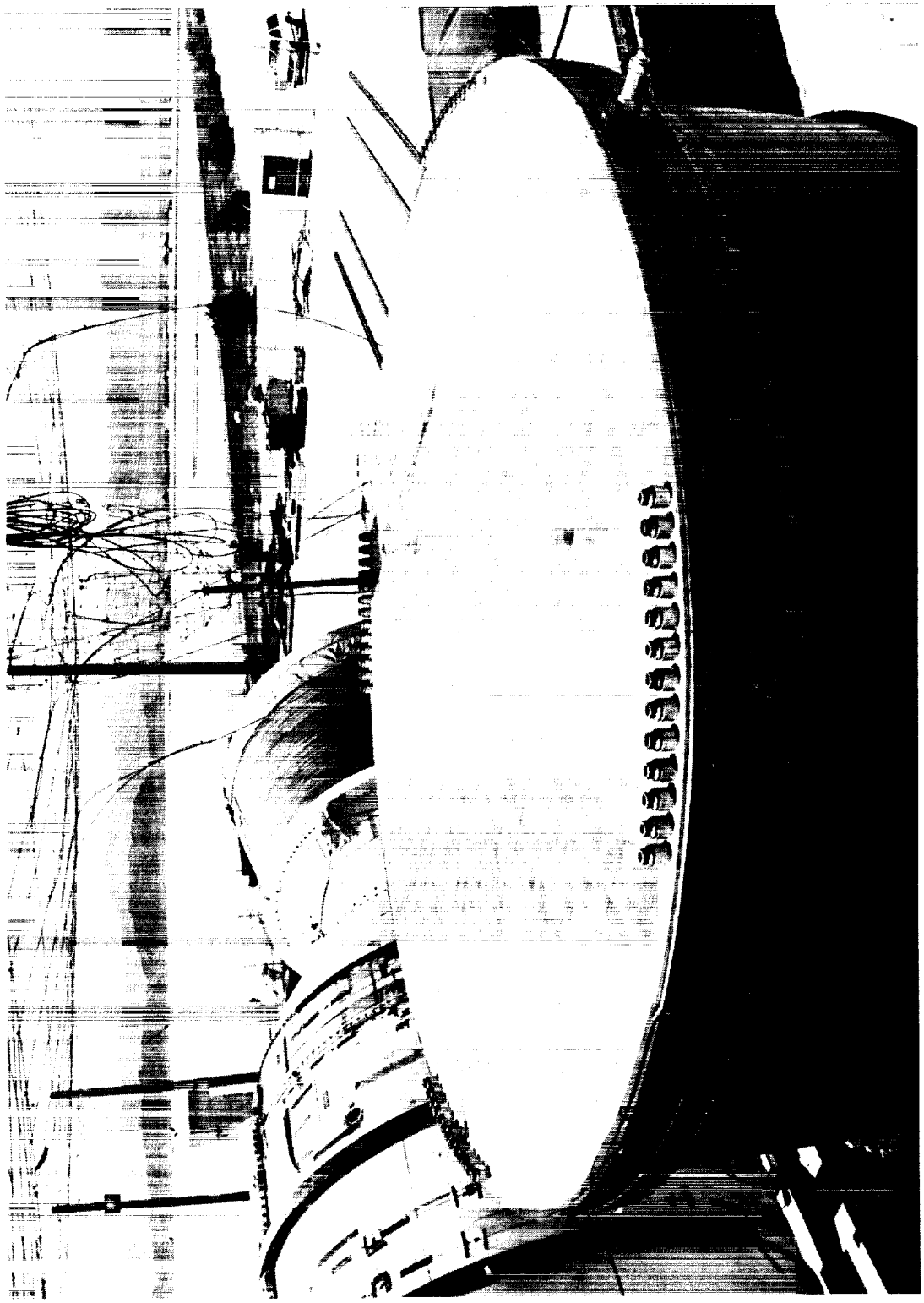

Figure 3. Top Hat Cover Simulator Mounted Onto Test Article

Four lightning detectors (8U76447) were mounted to the case (Figure 4) using a piece of polystyrene foam and olive drab waterproof tape (Permacel No. P672, Thiokol Corporation Stock No. 57-742061). Two of the detectors had sensitivities less than 500 amperes per meter (A/m), and the other two detectors had sensitivities greater than 500 A/m. The detectors were installed for detection 500 A/m during a Marx discharge to the test article.

1.1.2 Configuration No. 3

The next test article configuration consisted of a test stand placed on the lower capacitor grid with an empty RSRM case segment (1U50715-02) mounted vertically. Installed around the top edge of the case was a handling ring (8U50943-03) and segmented ring (8U50929-03). Mounted onto the handling ring was a top hat cover simulator. Non-conductive shims (0.25-in. thick) were to be installed between the handling ring and the top hat cover simulator. However, due to warping during the top hat simulator manufacturing process, shims were not needed or installed. The grain cover was not used.

1.1.3 Configuration No. 4

This test article configuration consisted of a test stand placed on the lower capacitor grid with an empty RSRM case segment (1U50715-02) mounted vertically. Installed around the top edge of the case was a handling ring (8U50943-03), grain cover (8U75816-01), and segmented ring (8U50929-03). The top hat cover simulator was not installed; only the grain cover was used.

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Figure 4. Lightning Detector Mounted Onto Test Article

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OBJECTIVES

The objectives of Test Plan WTP-0245 were:

A. Verify that the induced electromagnetic field levels are less than 30 kV/m when the test article is subjected to a simulated lightning discharge.

B. Verify that no arcing occurs between the case, handling ring, grain cover, or top hat cover simulator when subjected to a simulated lightning discharge.

C. Evaluate methods of detecting a lightning discharge to the RSRM.

3

EXECUTIVE SUMMARY

3.1 SUMMARY

Additional information and details can be found in Section 6 (Results and Discussion).

A total of 36 Marx generator discharges were conducted. A total of eight HCB discharges were conducted. A total of 44 lightning current discharges were made during this test sequence.

The HCB was charged to approximately 36,000 V for each discharge, which resulted in peak currents of approximately 1.75×10^5 amperes (A). The Marx generator was charged to approximately 20,000 V for each discharge, which resulted in peak rise rates of approximately 1.4×10^{11} amperes per second (A/s). The highest rise rate for the Marx generator was 3.9×10^{11} A/s.

None of the discharges resulted in an electric field larger than 345.9 V/m. The largest magnetic field calculated from the surface current data was 39.73 A/m. The data indicates that the electric field levels measured inside the test article are below the limit of 30 kV/m in all configurations. The measured electric field levels were not strong enough to cause dielectric breakdown of the propellant.

The photographic documentation indicates that Configuration No. 2 provides the necessary arcing protection between the test article hardware components. Configurations No. 3 and 4 showed evidence of arcing. Top hat cover simulator and mounting bolt damage (surface pitting and melting) and grain cover damage (fiberglass top damaged and frayed at arc attachment point) was observed.

Two lightning detectors with sensitivities less than 500 A/m detected induced current on the case from a Marx discharge. Two lightning detectors with sensitivities

greater than 500 A/m did not detect the simulated lightning currents from the Marx discharge. The lightning detector performance indicates that the more-sensitive lightning detectors are adequate to detect surface currents induced by the fast rising current portion of the worst-case lightning discharge.

3.2 CONCLUSIONS

The following is a list of conclusions as they relate specifically to the objectives. Additional information about the conclusions can be found in Section (Results and Discussion).

Objectives	Conclusions
A. Verify that the induced electromagnetic field levels are less than 30 kV/m when the test article is subjected to a simulated lightning discharge.	*Verified.* The electric field levels and magnetic field levels were well below the limit. The largest measured electric field being 345.9 V.
B. Verify that no arcing occurs between the case, the handling ring, the grain cover, or the top hat cover simulator when subjected to a simulated lightning discharge.	*Partially Verified.* No arcing was detected between any of the hardware components in Configuration No. 2. Photographic documentation was used to verify this conclusion. In Configuration No. 2 no arcing was detected between the top hat cover simulator and the handling ring during the Marx attachments. During the HCB attachments, arcing was detected between the handling ring and the top hat cover simulator. Arcing was detected between the grain cover and handling ring in Configuration No. 4. Photographic documentation was used to verify these conclusions.

Objectives	Conclusions
C. Evaluate methods of detecting a lightning discharge to the RSRM.	*Evaluated.* Two detectors with sensitivities less than 500 A/m detected the simulated lightning discharge indicating that these detectors can detect the case surface currents induced from the Marx generator. Two lightning detectors with sensitivities greater than 500 A/m did not detect the case surface currents induced by the Marx generator.

3.3 RECOMMENDATIONS

3.3.1 Electromagnetic Fields

No further testing is recommended to determine electric field levels induced within the test article. The levels measured were 1/100 the objective limit (1/1000 of the dielectric breakdown point of the RSRM propellant).

3.3.2 Arcing

Additional testing, to determine if arcing between hardware components occurs, is not recommended. Test article Configuration No. 2 survived 26 Marx discharges and four HCB discharges with no arcing. This indicates that this configuration provides adequate arcing protection between hardware components.

3.3.3 Lightning Detectors

The lightning detectors presently being used to monitor railcar shipments are adequate for the detection of a lightning strike to a segment and should be used for this purpose. However, additional testing with a goal to develop a more practical method of detecting a lightning strike should continue.

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INSTRUMENTATION

Instrumentation used during this test was a Nanofast Electric Field Sensor (model No. EFS1) and two magnetic flux density derivative sensors, EG&G model MGLS5A (B dot sensors). The electric field sensor was calibrated by the manufacturer on 29 June 1990. The B dot sensor was calibrated by the manufacturer before being purchased in 1987, and did not require any new calibrations.

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PHOTOGRAPHY

Still color photographs were taken of the test article assembly and during the simulated lightning discharges. Copies of the photographs (Series 118336, 118337, 118338, 118339, 118340, and 118476) are available from the Thiokol Photographic Services department.

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RESULTS AND DISCUSSION

6.1 TEST ARTICLE ASSEMBLY

The test article was configured three different ways. Each configuration is detailed in the following sections.

6.1.1 Configuration No. 2

The RSRM top hat cover simulator test article was assembled per WTP-0245, Rev A. This configuration consisted of a test stand placed on the lower parallel peaking capacitor grid, an empty RSRM segment mounted vertically on the test stand, a segmented ring, a handling ring, a grain cover, and a top hat cover simulator. Due to warping there was a gap in excess of 0.25 in., so the nonconductive shims were not used.

6.1.2 Configuration No. 3

This configuration consisted of a test stand placed on the lower parallel peaking capacitor grid, an empty RSRM segment mounted vertically on the test stand, a segmented ring, a handling ring and a top hat cover simulator. This configuration did not include the grain cover. The 0.25-in. shims were not installed between the top hat cover simulator and the handling ring. The shims were not installed because the gap between the top hat cover simulator and the handling ring was a minimum of 0.25 in. at several locations around the circumference of the test article (Figure 5).

6.1.3 Configuration No. 4

This configuration consisted of a test stand placed on the lower parallel plate peaking capacitor grid, an empty RSRM segment mounted vertically on the test stand, a

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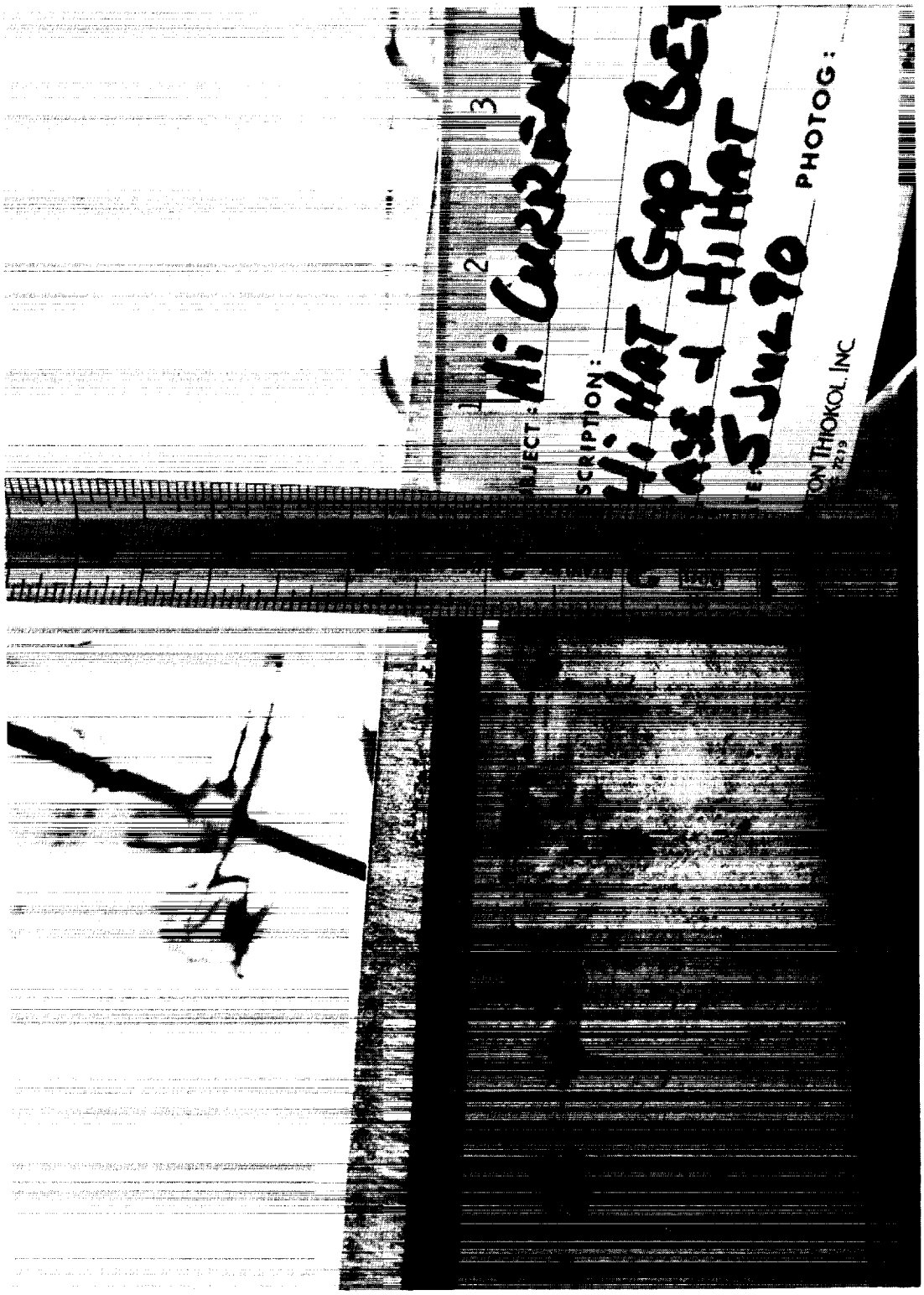


Figure 5. Gap Thickness Between Top Hat Cover Simulator and Handling Ring

segmented ring, a handling ring, and a grain cover. This configuration did not include the top hat cover simulator.

6.2 SIMULATED LIGHTNING TEST

6.2.1 Discharge Locations/Modes

The discharge down-conductor was positioned on the top of each test article configuration in the following five locations (Figure 6).

Location No. 1: At 1-ft radial distance in from the RSRM case edge

Location No. 2: On the mounting bolt at 0 deg

Location No. 3: At 2-ft radial distance from the centerline of the RSRM case

Location No. 4: At the RSRM case centerline position

Location No. 5: On the mounting bolt at 180 deg

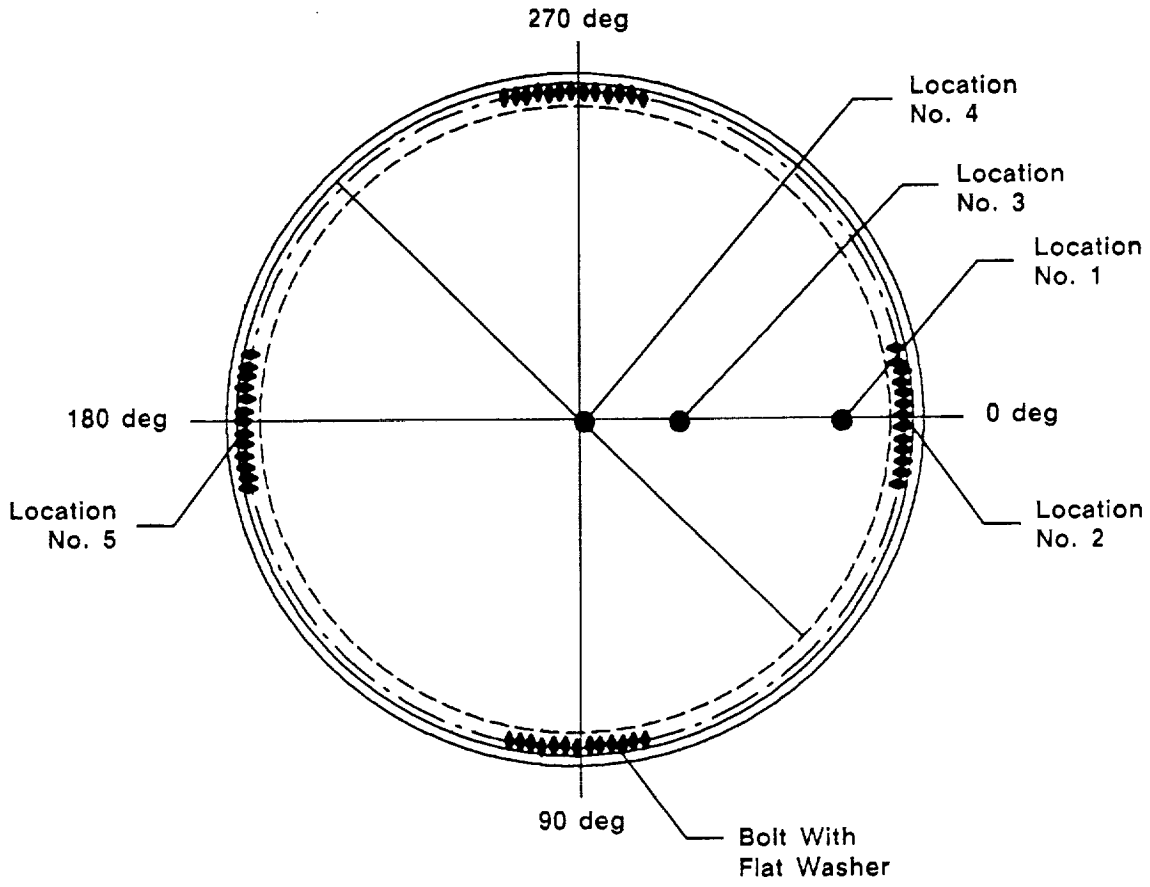
A total of 36 Marx generator discharges were conducted. A total of eight HCB discharges were conducted. A total of 44 electrical current discharges were conducted during this test sequence.

The discharge down-conductor was positioned on the top hat cover simulator, the mounting bolts, and the grain cover (Figure 6). The Marx generator was charged to approximately 26,000 V for each discharge, which resulted in peak current rise rates of 2×10^{11} A/s.

The discharge down-conductor was positioned on the top hat cover simulator, the mounting bolts, and the grain cover (Figure 6). The HCB was charged to 36,000 V (for most shots) and 45,000 V (for one shot) for each discharge, resulting in peak currents of approximately 175,000 to 200,000 A. Action integrals of the discharges were approximately 2×10^6 (A^2).

6.2.2 Test Sequence

Table 2 identifies each set of discharges with respect to each configuration.



Top View of Test Article

Figure 6. Attach Point Diagram

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Table 2. Configuration Test Sequence

	Discharge Set No.	
Configuration No.	Marx Current Bank	High Current Bank
2	26	3
4	0	1
3	6	2
4	4	0
3	0	2

There were 26 Marx discharges and three HCB discharges injected onto the test article in Configuration No. 2 for a total of 29 discharges. The simulated lightning injection waveform and the interior electric field were measured. The interior magnetic field was calculated.

Following the testing in Configuration No. 2, the test article was configured with only the handling rings and grain cover installed. This was to allow the testing of the present handling configuration, which had never been done. Two shots were attempted, but only the first was successful. Since the field sensor had been dropped and damaged previously, only the magnetic field data were collected on this shot.

After the discharges were completed for Configuration No. 4, the test article was assembled to Configuration No. 3. In this configuration six Marx discharges and two HCB discharges were injected onto the test article before the HCB was damaged.

The test article was assembled to Configuration No. 4. A total of four Marx discharges were injected onto the test article in this configuration and one HCB.

The test article was reassembled to Configuration No. 3. When the test article and the HCB were ready for testing, two HCB discharges were injected onto the test

The test article was reassembled to Configuration No. 3. When the test article and the HCB were ready for testing, two HCB discharges were injected onto the test article completing the RSRM top hat cover simulator lightning test.

6.2.2 Data Recovery

Data plots of the injected waveforms, the derivative of the injected waveforms (Marx attachments only), the interior electric fields, and the interior magnetic fields were made, following each strike (Volume II).

Of the 44 electrical current discharges conducted, the electric field measurements during the first eight discharges failed because the fiber optic data transmission line was disconnected to the data acquisition system. During discharges No. 15 through No. 29 an analog integrator was installed on the B dot sensor fiber optic transmission line. It was discovered after looking at the data that the integrator was faulty. The data were unrecoverable and cannot be used for analysis.

6.3 TEST ARTICLE INSPECTION AND RESULTS

6.3.1 Electromagnetic Fields

None of the discharges resulted in electric fields exceeding the 30 kV/m objective. The electric field levels were approximately 1,000 times lower than the dielectric breakdown level of the RSRM propellant and approximately 100 times lower than the 30-kV/m objective level specified in WTP-0245, Rev A. Magnetic field levels were 10 times lower than the electric field levels.

6.3.2 Arcing

Arcing was observed between hardware components in Configurations No. 2 and No. 3. Arcing was observed between the handling ring and top hat cover simulator in Configuration No. 3 during the last two HCB discharges. Top hat cover simulator and mounting bolt damage (surface scorching, pitting, and melting) was observed (Figures 7 and 8).

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Figure 7. Surface Pitting Caused by HCB Discharge to Mounting Bolts and Top Hat Cover Simulator

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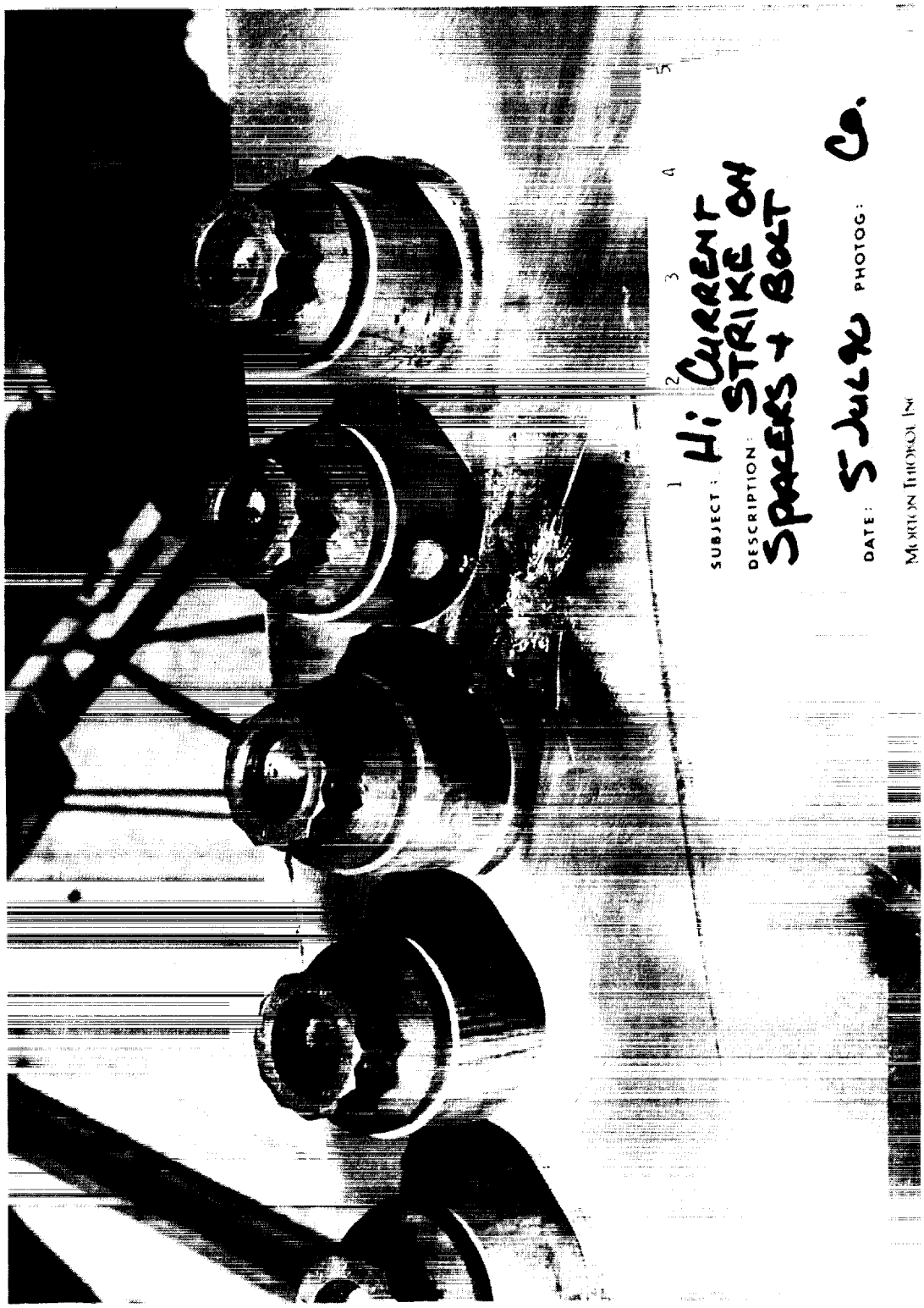

Figure 8. Surface Pitting Inflicted Upon Top Hat Cover Simulator

Arcing was observed between the grain cover and the handling ring during the HCB discharges injected onto the test article in Configuration No. 4 (Figure 9). Damage to the grain cover is shown in Figure 10. During HCB discharges injected directly to the grain cover, the fiberglass top was damaged and frayed at the arc attachment point.

6.3.3 Lightning Detectors

Two detectors with sensitivities less than 500 A/m detected the simulated lightning discharge indicating that these detectors can detect the case surface currents induced from the Marx generator.

Two lightning detectors with sensitivities greater than 500 A/m did not detect the case surface currents induced by the Marx generator.

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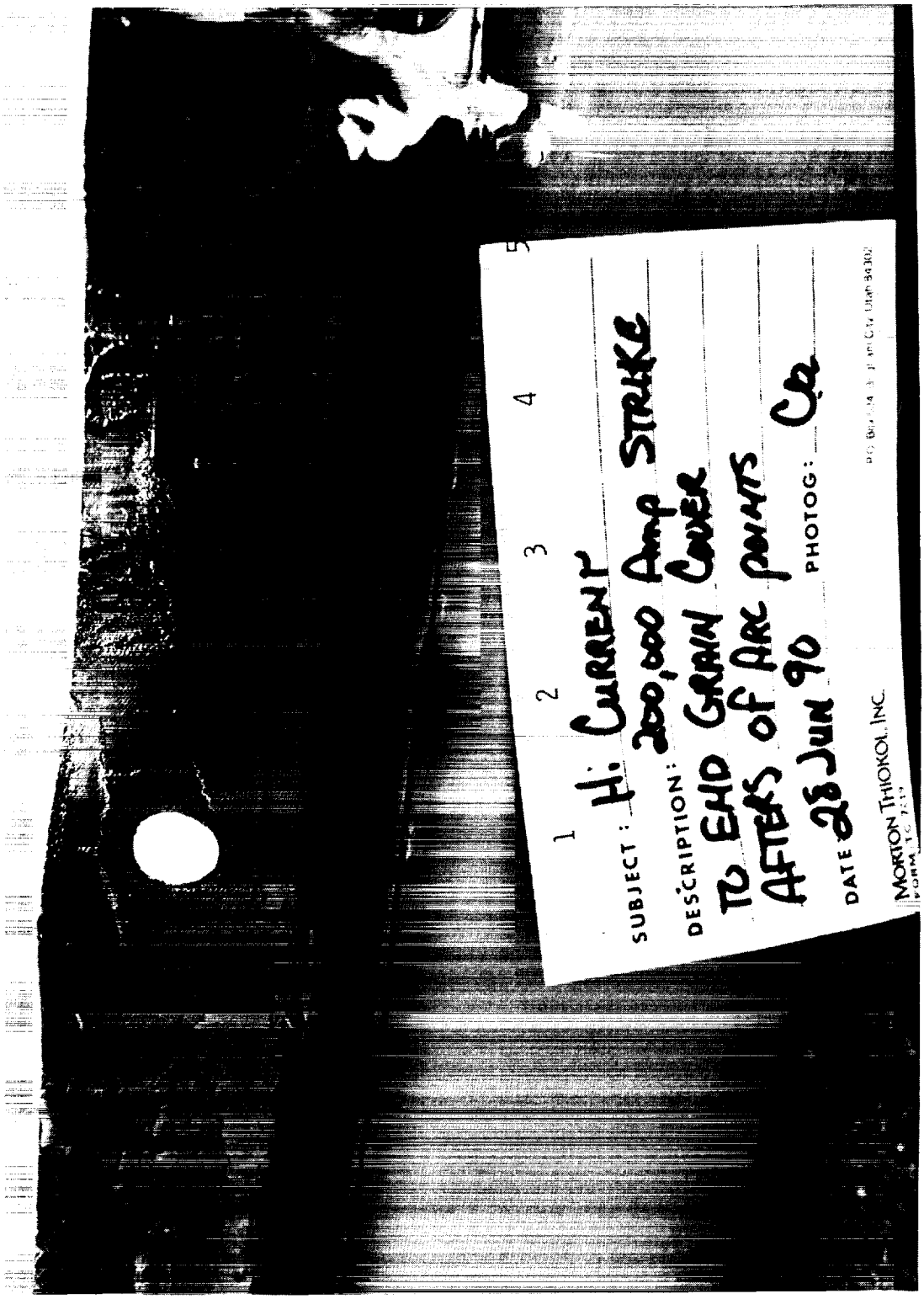

Figure 9. Carbon Spot on Grain Cover Proving Unwanted Arcing Occurred (noticed after removal from test article)

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Figure 10. Damage to Grain Cover After Subjection to HCB Discharge

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APPLICABLE DOCUMENTS

Document No.	Title
NSTS 07636 Rev D	Lightning Protection Criteria Document
JSC 20007	Lightning Protection Verification Document
WTP-0245	RSRM Top Hat Cover Simulator Lightning Test Plan
STW7-500	Marking Methods, Identification

Drawing No.

8U76447	Sensor--Magnetic Field, Passive
8U50943	Handling Ring--Solid Rocket Motor
8U50929	Ring, Segmented, Clevis Joint, Rocket Motor
1U50715	Case Segment, Stiffener--Lightweight
8U50816	Tie-Down Assembly, Cover Assembly--Railcar, Heavy Duty

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