AD/A-001 676

SHRIKE AND SPARROW MISSILE BASELINE COOKOFF TESTS

Anthony San Miguel, et al

Naval Weapons Center

Prepared for:

Naval Missile Center

October 1974

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FOREWORD

This work was accomplished under AIRTASK A03P-5323/054-C/4W4736-0001 and directed by the Naval Missile Center, Point Mugu, Calif.

This report was jointly prepared by the Naval Missile Center and the Naval Weapons Center, China Lake, Calif., and has been reviewed by Mr. R. W. Slyker and LCDR J. N. Kindig, USN, of NAVMISCEN and by Dr. Arnold Adicoff of NAVWPNSCEN. The cover of this report bears a series number from both Centers.

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NWC Technical Publication 5672
NMC Technical Publication 74-36

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Collation . . . . Cover, 111 leaves
First printing . . . . 130 unnumbered copies

UNCLASSIFIED
SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

AD/A - 001676

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: NWC TP 5672, NMC TP 74-36	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle): SHRIKE AND SPARROW MISSILE BASELINE COOKOFF TESTS		5. TYPE OF REPORT & PERIOD COVERED: Research Report, June 1973–January 1974
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s): Anthony San Miguel, Naval Weapons Center; Paul McQuaide, Naval Missile Center		8. CONTRACT OR GRANT NUMBER(s): AIRTASK A03P-5323/054-C/4W4736-0001
9. PERFORMING ORGANIZATION NAME AND ADDRESS: Naval Weapons Center, China Lake, CA 93555		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS: Naval Weapons Center, China Lake, CA 93555		12. REPORT DATE: October 1974
		13. NUMBER OF PAGES: 224
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS. (of this report): UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release, distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Cookoff
Solid Propellant
Explosives

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(U) *SHRIKE and SPARROW Missile Baseline Cookoff Tests*, by Anthony San Miguel, Naval Weapons Center, and Paul McQuaide, Naval Missile Center. China Lake, Calif., Naval Weapons Center, October 1974. 202 pp. (NWC TP 5672, NMC TP 74-36, publication UNCLASSIFIED.)

(U) Baseline cookoff tests of the SHRIKE (AGM-45A/B) and SPARROW (AIM-7E) missile systems were conducted at the Naval Weapons Center (NWC). China Lake, under the direction of the Naval Missile Center (NAVMISCEN), Point Mugu, between 28 June 1973 and 15 January 1974.

(U) The purpose was to determine the fast-cookoff characteristics of SHRIKE and SPARROW missiles when exposed to a JP-5 fuel fire. Time to cookoff reaction, type of reaction, and time/temperature data were obtained for each test. These data were analyzed and a hypothesis of the events leading to cookoff of the test items was formulated. These results are being used in the design of retrofit thermal protection systems for in-service missiles. These results are also applicable to the design of thermal protection systems for new missiles

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ACKNOWLEDGMENT

A major portion of the credit for obtaining the base-line data used in this report is due to the efforts of Mr. Ben L. Tozer, Head of Naval Weapons Center Safety Test Section, Code 45335. Mr. Tozer, who is responsible for cookoff test operations at NWC Safety Test Facility CT-4, coordinated all tests in the SHRIKE/SPARROW Baseline series and conducted those tests which occurred at CT-4.

INTRODUCTION

Catastrophic fires aboard the aircraft carriers *USS Forrestal*, July 1967 and *USS Enterprise*, January 1969 vividly demonstrated the hazards associated with the exposure of naval air-launched weapons to enveloping jet fuel fires. The Naval Missile Center was tasked by Reference 1, as the lead Naval Field Activity in 1969 for the Weapons Cookoff Improvement Program because of its engineering cognizant function on in-service weapons. The work summarized in this report was accomplished in accordance with Phase I of Reference 2.

The report contains three major sections: introduction, main body, and appendixes. The introduction delineates the objectives of the SHRIKE/SPARROW baseline cookoff test effort, and presents the findings. The body of the report describes the test facilities and instrumentation, summarizes the SHRIKE/SPARROW tests, and presents the retrofit recommendations. The appendixes (A through D) include complete descriptions of the SHRIKE (A) and SPARROW (B) missiles and detailed description and analysis of the individual tests (C, D).

OBJECTIVES

The objectives of these baseline cookoff test series were to determine the time to cookoff, type of reaction, transient-temperature data, critical heat-paths, and vulnerabilities of SHRIKE and SPARROW missiles when exposed to jet-fuel fires. Transient-temperature data were obtained to estimate the magnitudes and directions of heat-flux in all vulnerable missile components. These data were used together with audio/video recordings to determine time to and type of reaction.

The overall cookoff improvement objectives are to obtain a five minute minimum time to reaction (cookoff time) of missile systems when engulfed in jet-fuel fires, reduce the violence of reactions, and decrease or eliminate propulsive reactions of motors.

A complete program plan is presented in Section 3.0 of Reference 2.

THE FINDINGS

Time to cookoff reaction, type of reaction, and transient temperature data for various events were obtained for SHRIKE and SPARROW missiles when exposed to JP-5 fuel fires. The data are given in Tables 1 and 2, which are found in the cookoff summaries. The results are being used in

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the design of retrofit thermal protection systems for in-service missiles. The results are also applicable to the design of thermal protection systems for new missiles.

Analysis of the test data suggests that heating within a jet-fuel fire initiates exothermic reactions at various interfaces within the missile components. It is hypothesized that this apparent behavior in turn accelerates reaction of both propellants and explosives, with consequent acceleration of chemical reaction within the affected component, and hence premature ignition. It is further hypothesized that if adequate venting is not available to release the pressure of the burning gases, then cracking of the explosive/propellant will occur. Burning at these new surfaces causes excess pressures which explode the component.

Various retrofits are proposed. Among these are venting to reduce the degree of over-pressurization to a point at which the violence of cookoff would be lessened to that of a deflagration. Other proposals deal with chemical modification of he explosive/propellant/liners and insulation of the explosive/propellant against heat. These are described under the SPARROW and SHRIKE cookoff improvement recommendations.

CRITERIA FOR, AND DEFINITIONS OF COOK-OFF REACTIONS OF GUIDED MISSILES

The most recent standard of criteria and test procedures for ordnance exposed to an aircraft fuel fire (MIL-STD-1648 AS of March 1974) defines two cookoff criteria/requirements which air-launched ordnance should meet.

The first requirement involves burning of energetic materials such as explosives and solid propellant During burning the enclosure may open up and vent. The missile remains in position, although it may fall due to structure failure. The burning reaction should present a minimal hazard to fire-fighting personnel.

The second requirement addresses rapid combustion and rupture of the enclosure (deflagration). The test item or major parts thereof may be thrown up to 50 feet by the reaction. There must be no damage due to blast effects or fragmentation. The process may endanger or inhibit fire-fighting personnel because of fire expansion and burning material or parts thrown about.

Ordnance is judged by the standard to have passed the fuel-fire test if during the first five minutes of the test, the severity of the reaction is not greater than that for a burning reaction (as described above) Burning reactions are acceptable any time during the test. After the first five minutes and until the test ordnance returns to ambient temperature, the severity of the reaction shall not be greater than that for a deflagration reaction (as described above).

The test series reported herein was completed and most analyses conducted prior to publication of the above-mentioned MIL-STD-1648 AS. For this reason Definitions of Reactions for Guided Weapons form NAVORD OP 5, Volume 1, Third Revision as listed below apply to reactions described in this report.

DEFINITIONS OF REACTIONS (FOR GUIDED WEAPONS)

Detonation (cookoff). Munition performs in design mode. Maximum possible air shock is formed. Essentially all of case is broken into small fragments. Blast and fragment damage is at maximum. Severity of blast causes maximum ground crater or flight-deck hole capable by the munition involved.

Partial Detonation (cookoff). Only part of total explosive load in munition detonates. Strong air shock and small as well as large case fragments produced. Small fragments are similar to those in normal munition detonation. Extensive blast and fragmentation damage to environment. Amount of damage and extent of breakup of case into small fragments increases with increasing amount of explosive detonated. Severity of blast could cause large ground crater, or large flight-deck hole on carrier if munition is large bomb: hole size depends on amount of explosive that detonates.

Explosion (cookoff). Violent pressure rupture and fragmentation of munition case with resulting air shock. Most of metal case breaks into large pieces which are thrown about with unreacted or burning explosive. Some blast and fragmentation damage to environment. Fire and smoke damage as in deflagration. Severity of blast could cause minor ground crater, or small depression on flight-deck or carrier if munition is large bomb.

Deflagration (cookoff). Explosive in munition burns. Case may rupture or end-plates blow out; however, no fragmentation of the case. No fragments are thrown about. Damage to environment due only to heat and smoke of fire. No discernible damage due to blast or fragmentation.

FAST-COOKOFF TEST FACILITIES

Two test sites were used for this series of baseline cookoff tests. These were the Safety Test Facility, CT-4 and Skytop Test Facility, Bay 5, both located at the Naval Weapons Center, China Lake, California.

CT-4 employs an open fuel pit 24 ft square or 24 ft octagon shape, located about 50 yds from an underground bunker containing conditioning and recording equipment with lead wires to the test item (Figure 1). The transducer leads that protrude from the test item to the ground in the test pit were insulated with a one-eighth-inch-thick layer of white felt (WPR-X-AQ), Refractory Products, Inc., which was held in place by glass reinforced tape. Then a one-and-one-half-inch layer of EAGLE PICHER "Super 66" insulative cement was added.

This pit was filled with 1,000 gallons of JP-5. The test item was supported above the ground by an A-frame so that the distance from the fuel surface to the horizontal centerline of the test component was 36 inches. The bottom of the fuel pit was leveled to provide an even depth of the fuel, with a polyethylene plastic liner to prevent fuel loss by seepage into the ground. Thirty (30) gallons of gasoline were poured over the fuel surface to promote rapid fuel ignition, and thermite grenades, placed in each corner of the test site, were electrically initiated to ignite the fuel. A lightweight wind barrier, approximately 3 feet in height, enclosed the pit (Figure 1).

Skytop was designed as a retention structure. The structure (Figures 2 and 3) incorporates two side solid steel-plated firewalls with supporting revetments, and two open screened ends and roof which allow free airflow but restrain missile motors which may react propulsively. The structure is 63 ft long, 47 ft wide and 31 ft high.

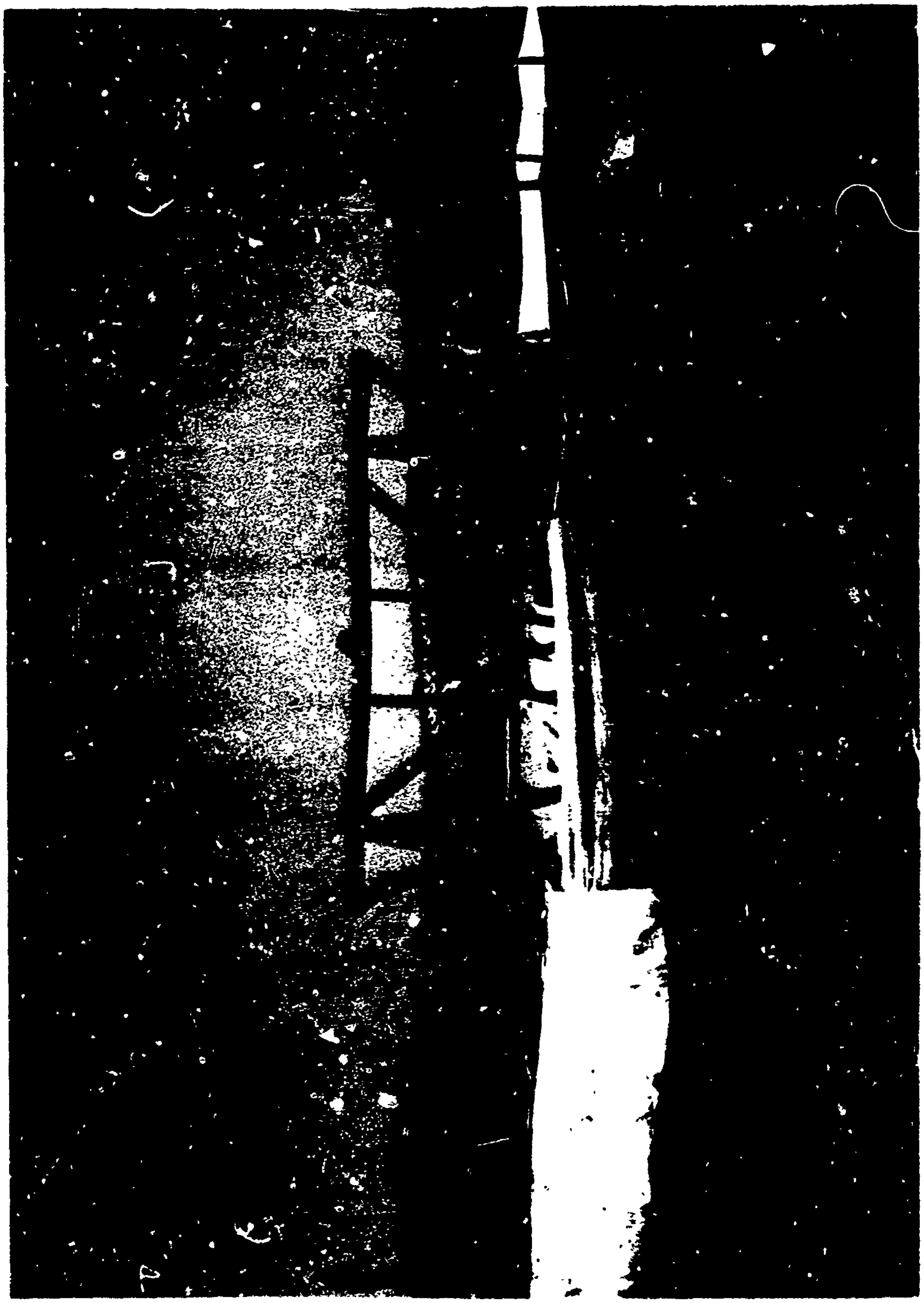


FIGURE 1. CT-4 Open Cookoff Pit Showing A Frame and Asbestos Windscreens.

FIGURE 2. Front View of Skytop Cookoff Retention Facility.

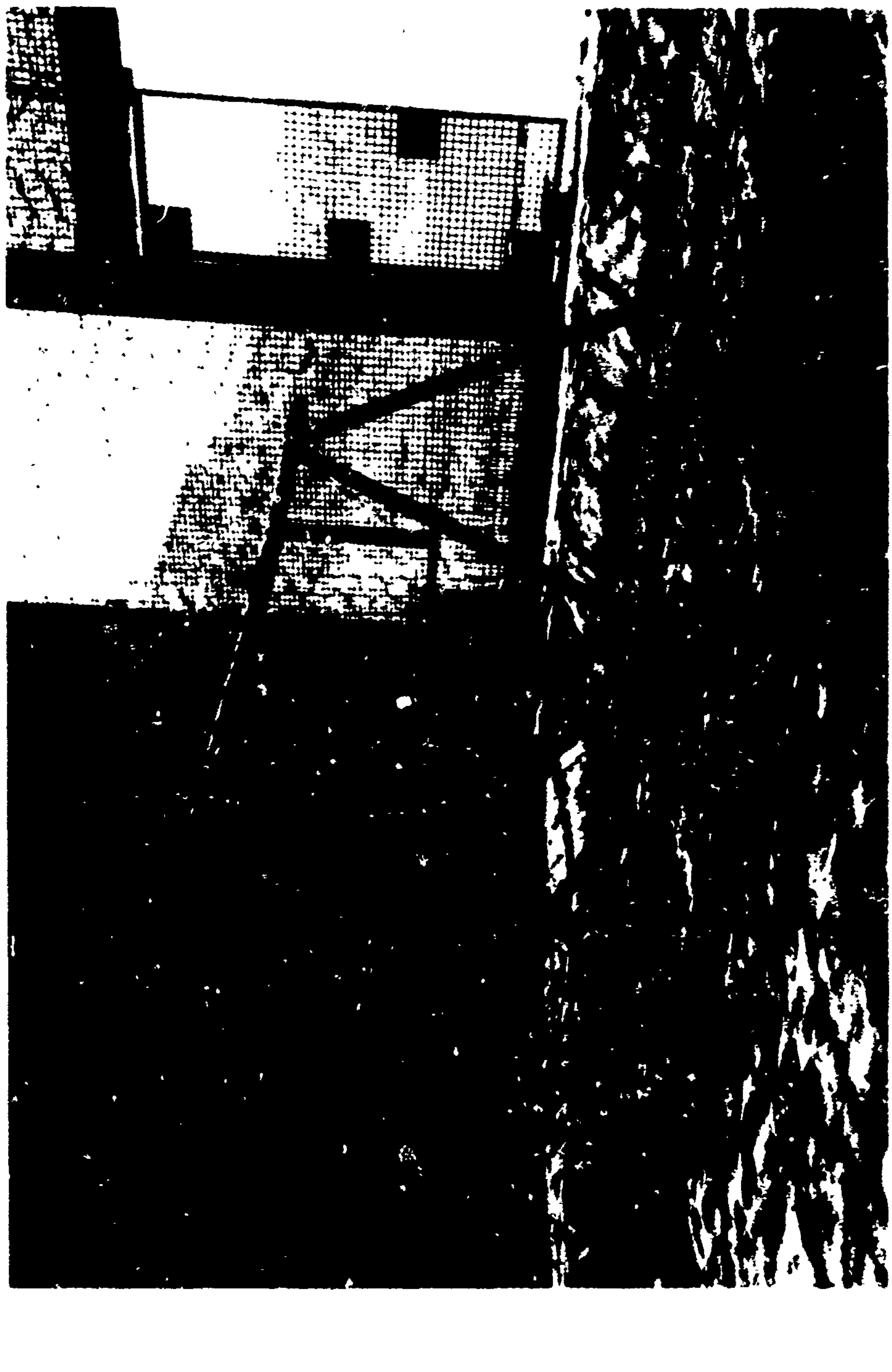


FIGURE 3. Interior View of Skytop Cookoff Retention Facility.

The fuel pit, 24 ft square by 1 ft deep, located in the center of the earth floor, is provided with a polyethylene plastic liner, and holds 1,000 gallons of JP-5 fuel (1,200 gallons where noted).

At the center of the pit is an underground junction box to which test-item transducer leads are connected. Insulation material and procedures to protect these leads from the fire between the junction box and the test item are the same as for the open pit facility. The pit is surrounded by 5- by 3-ft-high 1-inch-thick movable steel witness plates.

INSTRUMENTATION

A Data Acquisition System, consisting of chromel-alumel thermocouples and an analog recorder was used to collect time-temperature data. Thermocouple data were acquired by using a 150°F electric temperature reference junction. Chromel-alumel thermocouples were calibrated to voltage levels which are related to temperatures in the quasistatic sense by use of standard tables. Each thermocouple signal was amplified, conditioned, and recorded on analog tape. A computer program assigned and printed out temperatures at any prescribed time from the digital data obtained using an analog/digital converter. Data from each channel were sampled at intervals as small as 0.002 seconds, printed out, and graphed over various intervals of interest.

Chromel-alumel thermocouples were used to estimate transient temperatures within the various test items and the fuel flames. The details of their size, locations and response are given in Appendixes C and D.

Documentary color slow-speed and real-time motion picture cameras, videotape with audio recorders, still black-and-white cameras, and color slides were used in each test.

FAST-COOKOFF TEST SUMMARIES

SHRIKE

A series of seven baseline SHRIKE cookoff tests was conducted from 28 June 1973 to 21 November 1973. It consisted of one all-up live and one all-up inert missile, and tests of individual motors and warheads. A brief summary of the test item components and test results is given in Table 1. Analyses of all SHRIKE tests and photographs of each test item are contained in Appendix C.

Baseline-test configurations of motors in both the SHRIKE and SPARROW test series were selected which would provide the maximum information on motors with free-standing grains, case-bonded grains, different liner-material thicknesses, and different propellants. Due to the availability of SHRIKE motors and the great similarity among many of the SHRIKE and SPARROW motors, most motor-cookoff data were obtained during SHRIKE testing. Data from motor tests are applicable to both SHRIKE and SPARROW.

Table 1 lists the baseline configurations and critical cookoff events for the SHRIKE tests. Each test configuration is given an SH-series number followed by the components used to compose the test item. Modifications and event classification for each component are indicated by the superscripts

TABLE 1. SHRIKE Baseline Configurations and Critical Cook-Off Events.

Test item	Modular components						Significant events (seconds)		
	Warhead	Fuze	Motor	Igniter	Control	Guidance	1000°F, flame	Exothermic	Reactions
SH-1A	Mk 68 Mod 0[a]	Mk 330[b]	Mk 39 Mod 7[a]	Mk 274 Mod 1A[b]	Mk 1 Mod 2	Mk 37	58	(W) 60 (M) 80	Liner venting None
SH-7A	None	None	Mk 53 Mod 1[c]	Mk 274 Mod 0[c]	Mk 1 Mod 2	None	46	(W) (M) 54	(D) 54
SH-8A	Mk 80 Mod 0[a]	Mk 330[b]	Mk 78 Mod 0[c]	Mk 274 Mod 1A[b]	Mk 1 Mod 2	None	13	(W) 165 (M) 25	(D) 70
SH-12A	Mk 68 Mod 0[a]	Mk 330[b]	Mk 78 Mod 0[c]	Mk 274 Mod 1A	Mk 1 Mod 2	None	19	(W) 160 (M) 28	(D) 57
SH-13A	Mk 68 Mod 0[c]	Mk 330[b]	Mk 39 Mod 3[b]	Mk 274 Mod 1A[b]	Mk 1 Mod 2	None	32	(W) 113 (M)	(EX) 128
SH-14A	Mk 80 Mod 0[c]	None	Mk 39 Mod 7[b]	Mk 274 Mod 1A[b]	Mk 1 Mod 2	None	34	(W) 84 (M)	(EX) 109
SH-16A	Mk 68 Mod 0[c]	Mk 330[c]	Mk 39 Mod 7[c]	Mk 274 Mod 1A[c]	Mk 1 Mod 2	Mk 37	96	(W) 104 (M) 104	(EX) 169 (EX) 122

[a] Crystal white stucco sand (≈30 mesh) replaces solid propellant or explosive
[b] Empty
[c] Signifies live
(W) Signifies warhead
(M) Signifies motor
(D) Signifies deflagration
(EX) Signifies explosion

explained in the table. Three significant events for each test are also summarized in the table. The first is the time it takes for all four flame thermocouples (forward, starboard, aft and port) to reach or exceed an indicated temperature of 1000°F. The second is the minimum time it takes to observe a definitely apparent exothermic reaction as indicated by thermocouples in the liner/steel case region of the rocket motor (M) or the potting material/cavity paint/steel case region of the warheads (W). The third event is the time to reach deflagration (D) or explosion (EX).

Interpretation of the events occurring during the tests relied upon data obtained from the instrumentation system used and post-test inspection of the test items and site. Reference was made to data from earlier tests (References 3, 4, 5, 6, 7) and also to Harm, Agile and Condor tests for assurance of consistency. It is emphasized that the hypothesis presented below needs further evaluation to identify and quantify many of the uncertain aspects intrinsic to fast-cookoff testing.

The SHRIKE warheads tested were the Mk 68 Mod 0 and the Mk 80 Mod 0. A detailed description for these warheads is included in Appendix A. They exhibit internal exothermic reactions in the region between the steel and the potting material and/or cavity paint area before 165 sec (e.g., SH-16A, 60 sec; SH-8A, 165 sec; SH-12A, 160 sec; SH-13A, 113 sec; SH-14A, 84 sec; SH-16A, 104 sec). Regions where apparent liner-exothermic reactions occur prior to burning of the explosive are around the cubes within the steel liner, the foam in the forward cone, and the lower aft region where the cavity paint separates the explosive from the steel casing.

The exothermic heating produced from the potting material and/or cavity paint ignites the explosive sooner than if only heating by conduction from the fire existed without chemical reactions. The explosive is shown burning at the aft end in Figure 4a.

The failure of the SHRIKE warhead is hypothesized to be due to over-pressurization within the steel casing, which causes the crack as shown in Figure 4b. Inadequate venting exists for the SHRIKE warhead, and it explodes before 169 sec, e.g., SH-13A, 128 sec; SH-14A, 109 sec; SH-16A, 169 sec. If the excess explosive-gas can be vented, then there may be deflagrations instead of explosions. Both types of reaction are illustrated in Figures 4c and 4d.

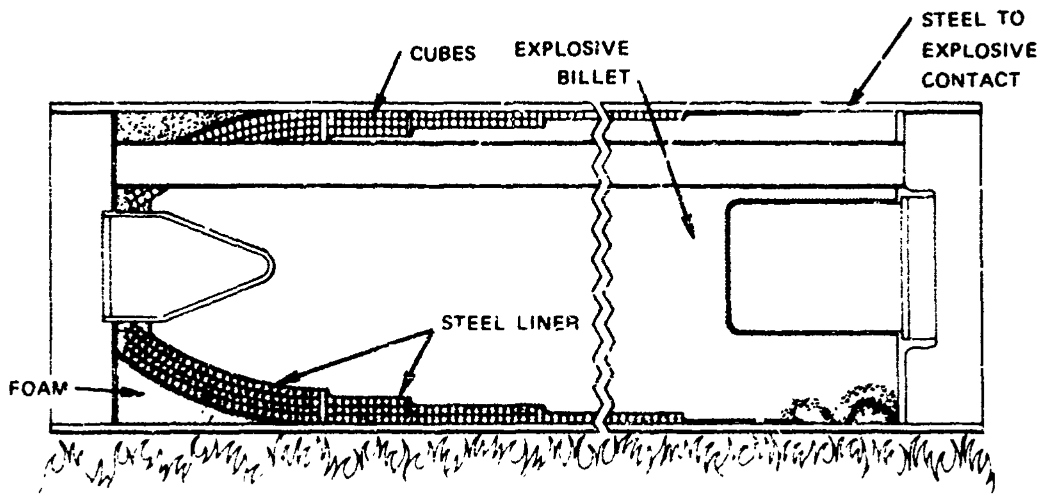
The SHRIKE rocket motors tested were the Mk 53 Mod 1, Mk 78 Mod 0 and the Mk 39 Mod 7. Descriptions of these motors are included in Appendix A. They exhibited internal exothermic reactions in the steel/liner region before 104 sec (e.g., SH-1A, 80 sec; SH-7A, 54 sec; SH-8A, 25 sec; SH-12A, 28 sec; SH-16A, 104 sec). The region where apparent exothermic reactions occur prior to burning of the propellant is between the lower steel case and liner. The exothermic heating produced from the liner and/or other material used to prepare the inside of the steel case for graining ignites the propellant sooner than if only heating by conduction from the fire existed without chemical reactions. The solid propellant is shown burning at the lower surface in Figure 5a.

The failure of the SHRIKE rocket motor is hypothesized to be due to over-pressurization within the steel casing, which causes solid propellant cracks (Figure 5b). If the excess propellant gas can be vented (e.g., SH-7A, SH-8A, SH-12A) then the reaction will be one of deflagration; otherwise an explosion may result (e.g., SH-16A). Both types of reactions are illustrated in Figures 5c and 5d.

The Mk 78 Mod 0 in tests SP-7A and 12A initiated deflagration at 70 and 57 sec, respectively. The Mk 53 Mod 1 deflagrated in an abnormal manner (because of internal instrumentation) at 54 sec. The Mk 39 Mod 7 in test SP-16A probably exploded at 122 sec.

SPARROW

A series of five baseline SPARROW cookoff tests was conducted from 18 July 1973 to 15 January 1974, consisting of tests of one all-up live and one all-up inert missile, and tests of an



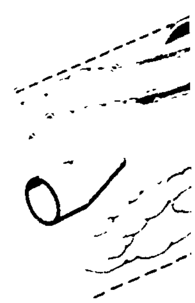


FIGURE 4a. SHRIKE Warhead Explosive Igniting at Lower Aft End.

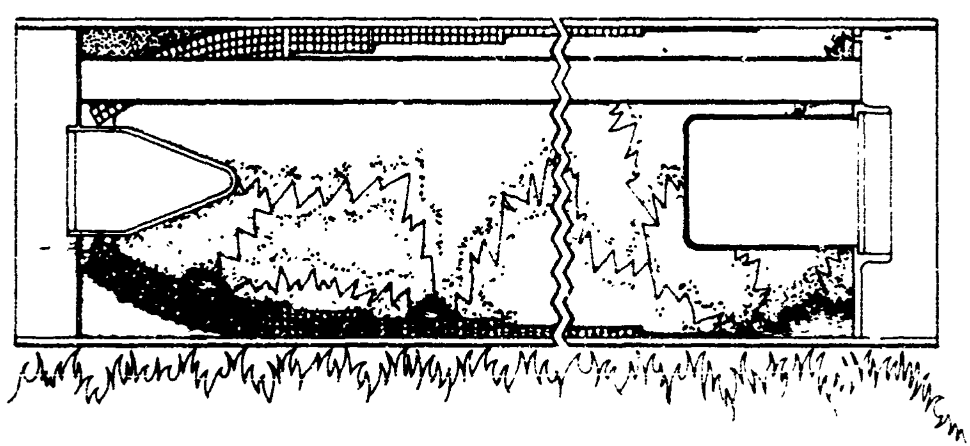
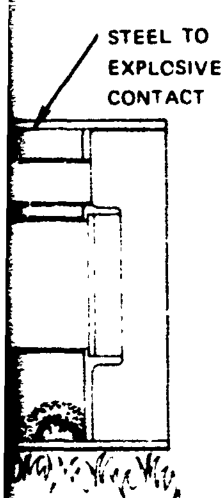


FIGURE 4b. Possible SHRIKE Warhead Explosive Cracking Creating New Burning Surfaces.

FIGURE 4 Possible SHRIKE Warhead Reactions During Fast



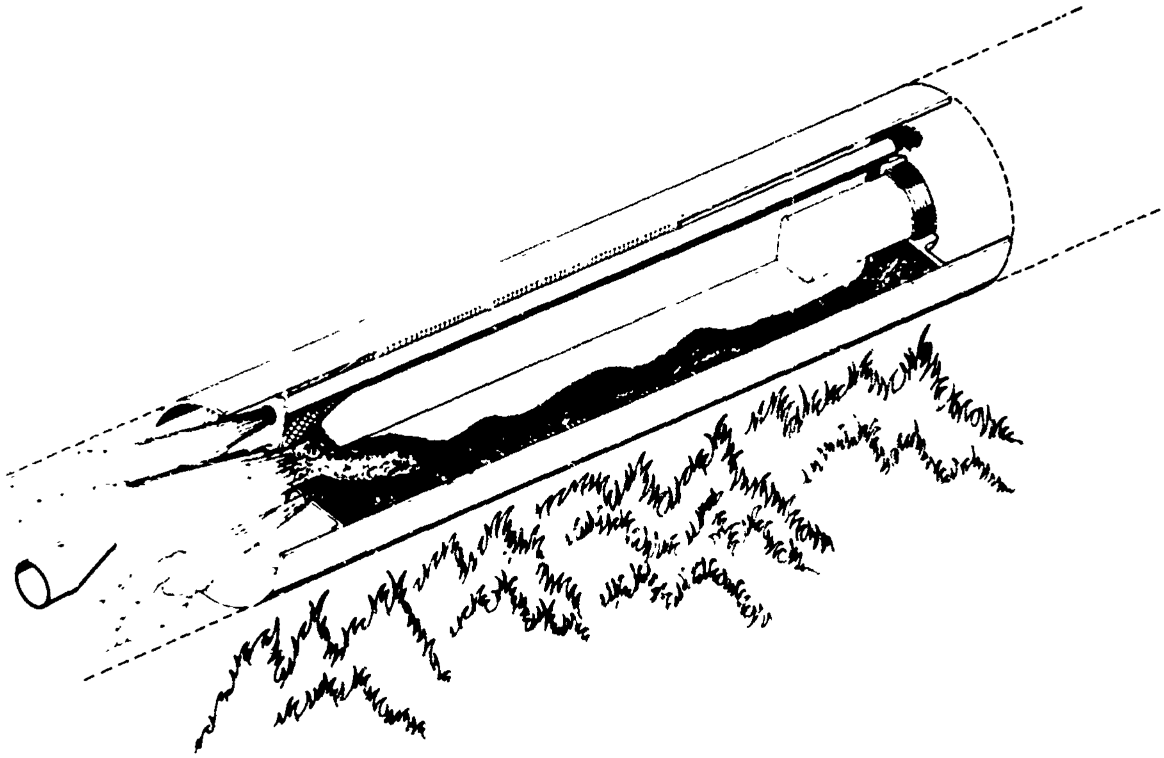
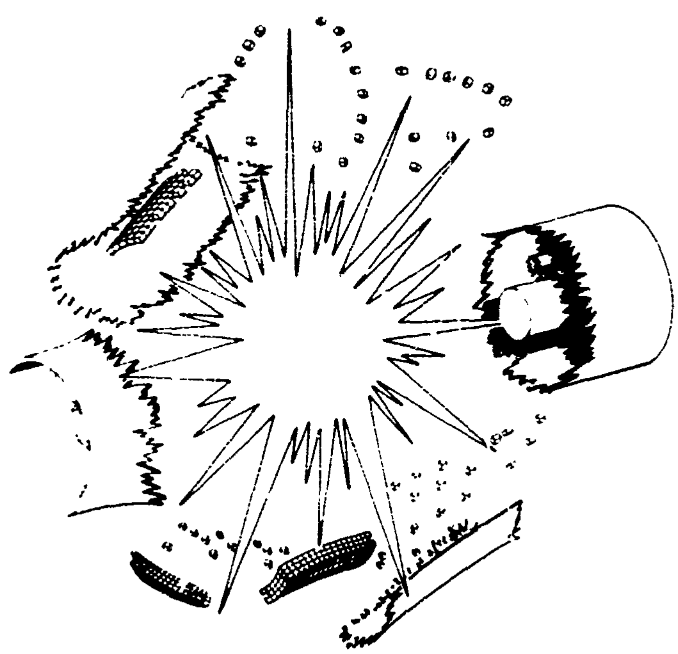
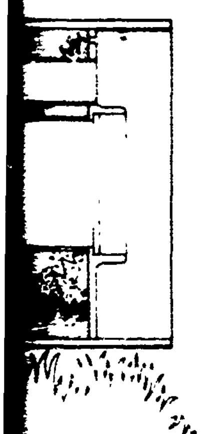


FIGURE 4c. Possible SHRIKE Warhead Venting.





Surfaces.

FIGURE 4d. Possible SHRIKE Warhead Explosion Due to Overpressurization.

Possible SHRIKE Warhead Reactions During Fast Cookoff

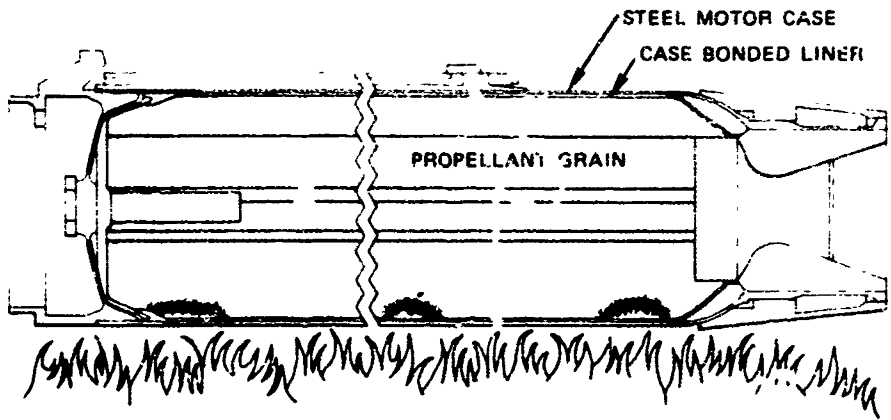
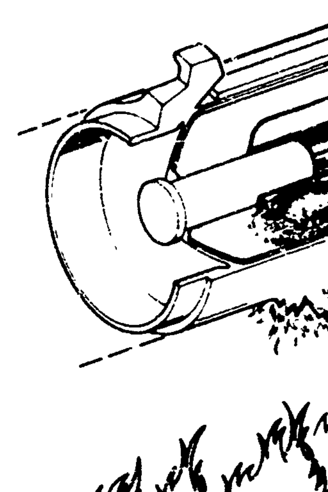


FIGURE 5a. SHRIKE Motor Propellant Igniting at Lower Surface.



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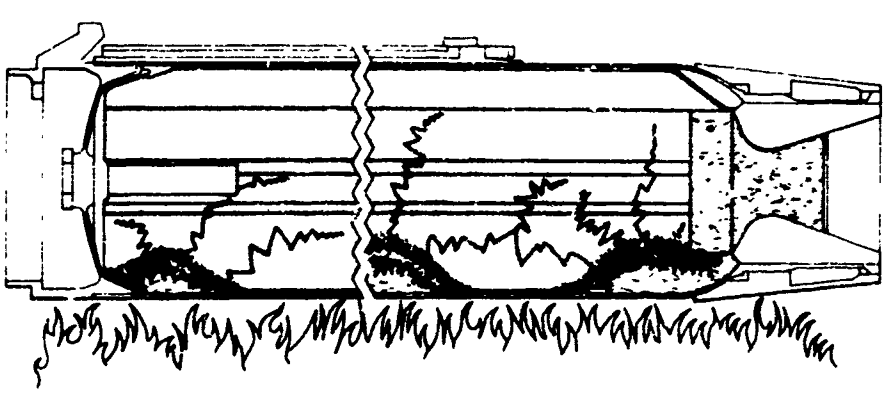
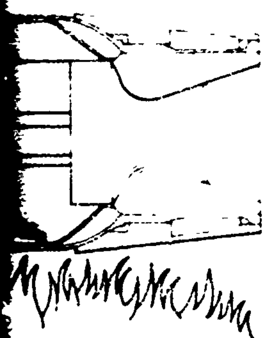


FIGURE 5b. Possible SHRIKE Motor Propellant Grain Cracking Creating New Burning Surfaces.

FIGURE 5

FIGURE 5. Possible SHRIKE Motor Reactions During



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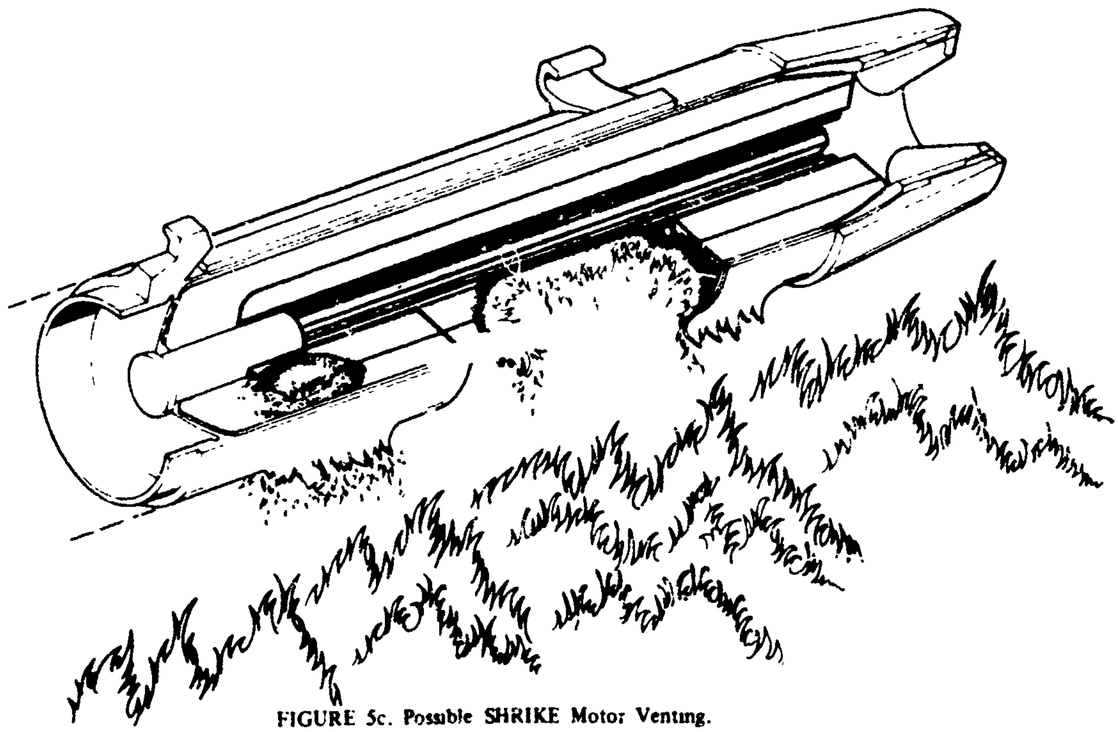
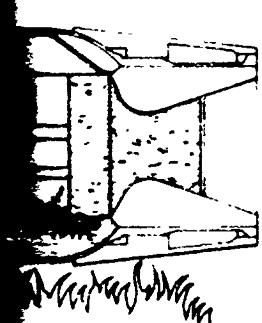


FIGURE 5c. Possible SHRIKE Motor Venting.



New Burning Surfaces.

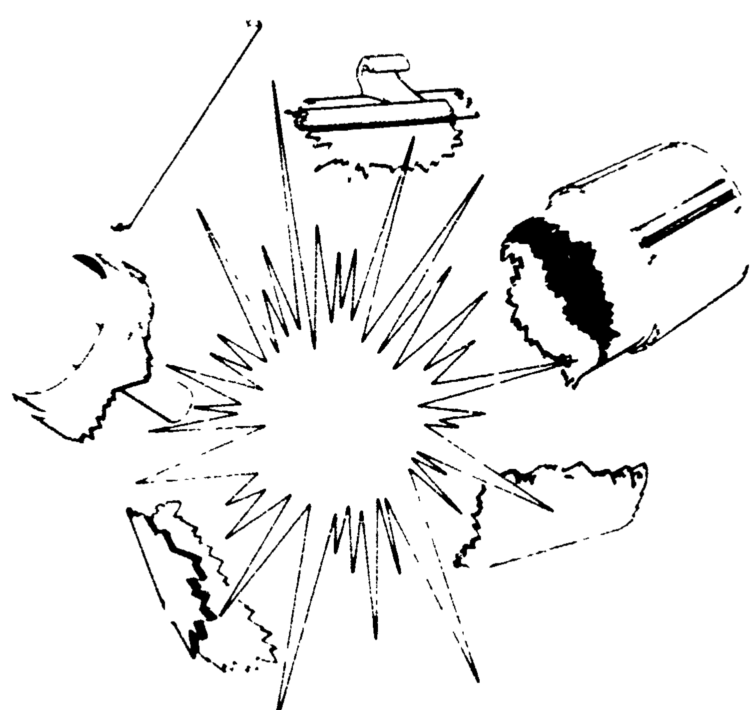


FIGURE 5d. Possible SHRIKE Motor Propellant Explosion Due to Overpressurization.

FIGURE 5 Possible SHRIKE Motor Reactions During Fast Cookoff individual motor and several warheads. Two of these tests incorporated modified warheads (Table 2). Analyses of all SPARROW tests and photographs of test items are contained in Appendix D.

Baseline test configurations of motors in both the SHRIKE and SPARROW test series were selected which would provide the maximum information on motors with a free-standing grain, case-bonded grains, different liner materials and thicknesses, and different propellants. Due to the availability of SHRIKE motors and the similarity between SHRIKE and SPARROW motors, most motor cookoff data were obtained during the SHRIKE motor testing. During the SPARROW baseline series a live SPARROW motor with a standoff grain configuration and an inert SPARROW motor with case-bonded grain configuration were tested. Data from motor testing of SHRIKE motors are applicable to SPARROW motors (Table 1).

Table 2 lists the baseline configurations and critical cookoff events for the SPARROW tests. Each test configuration is given an SP-series number followed by the components used to compose the test item. Modifications and event clarifications for each component are indicated by the superscripts and explained in the table Three significant events for each test are also summarized: the time it takes for all four thermocouples (forward, starboard, aft and port) to reach or exceed an indicated temperature of 1000°F; the minimum time it takes to observe a definite apparent exothermic reaction as indicated by thermocouples between the liner and steel case region of the motor (M) or in the potting/cavity paint/steel case region of the warhead (W); and the time to reach deflagration (D), ejection of the safe/arm (E), or explosion (EX).

Interpretation of the events occurring during the tests relied upon data obtained from the instrumentation system used and post-test inspection of the test items and site. Reference was made to data from earlier tests (References 3, 4, 5, 6, 7) and also to Harm, Agile and Condor tests for assurance of consistency. It is emphasized that the hypothesis presented below needs further evaluation to identify and quantify many of the uncertain aspects intrinsic to fast-cookoff testing.

The SPARROW warheads tested were the normal and slightly modified Mod 38, Mk 0. A description of these warheads is contained in Appendix B. These warheads exhibit apparent exothermic reactions in the steel/potting material and/or cavity paint interface before 120 sec (e.g., SP-3A, 120 sec; SP-13B, 96 sec; SP-13A, 100 sec; SP-14A, 84 sec). Regions where apparent exothermic reactions of potting material and/or cavity paint are in and around the rod-bundle adjacent to the explosive and magnesium.

Test SP-7B was conducted on a live, modified Mk 38 warhead to determine the effects of increased liner thickness on cookoff time. Due to instrumentation acquisition difficulties no thermocouple data were obtained. Test SP-13B (SP-7X) was conducted on an inert modified Mk 38 warhead and run concurrently with a SIDEWINDER motor test. The modification did not provide an acceptable increase in the time to reaction, but did provide data on the use of internal heat-path interruptors.

The exothermic heating produced from the potting material and/or cavity paint ignites the explosive sooner than if heating only by conduction from the fire existed without chemical reactions. The explosive is shown burning at its ends in Figure 6a.

The reaction of the SPARROW warhead is hypothesized as a deflagration characterized by venting of gas out the forward end if the safe/arm ejects as shown in Figure 6b. On the other hand, if (as with SP-7B) the safe/arm does not eject, the booster eventually explodes, due to heating (Figure 6c), producing over-pressurization and the potential explosion shown in Figure 6d. For SP-7B and SP-14A the safe/arm device exploded within the warhead at 1200 sec and 495 sec, respectively. The reason that the safe/arm did not eject as it did for SP-3A is that the motor either exploded first or its front bulkhead burned through (because of the warhead burning gas) destroying the

TABLE 2. SPARROW Baseline Configurations and Critical Cook-Off Events.

Test item	Modular components						Significant events (seconds		
	Warhead	Safe/Arm	Motor	Igniter	Control	Guidance	1000°F flame	Exothermic	Reac
SP-3A	Mk 38 Mod 0[a]	Mk 35 Mod 1[b]	Mk 38 Mod 4[c]	Mk 265[b]	Wing hub	None	42	(W) 120 (M) 70	(D) 320* Nc
SP-7B	Mk 38 Mod 0[d,e]	Mk 35 Mod 1[e]	Mk 38 Mod 1[b]	Mk 265[b]	None	None	Unknown	(W) . . . (M) . .	(D) 490, (I .
SP-13A	Mk 38 Mod 0[e]	None	Mk 38 Mod 1[b]	Mk 265[b]	Wing hub	None	51	(W) 145 (M) . . .	(D) .
SP 13B	Mk 38 Mod 0[a,d]	None	Mk 38 Mod 1[b]	Mk 265[b]	None	None	52	(W) 96 (M) . . .	(D) 1 .
SP-14A	Mk 38 Mod 0[e]	Mk 35 Mod. 1[e]	Mk 38 Mod 0[e]	Mk 265[e]	Wing hub	None	16	(W) 84 (M) 30	(D) 134, (EX

[a] Wood billet replaced warhead explosive.
[b] Empty casing.
[c] Crystal white stucco sand (#30 mesh) replaces solid propellant.
[d] Warhead modified so as to add thicker potting material between explosive edges and steel rods.
[e] Signifies live.
* Explosion due to detonation of Safe/Arm unit
** Due to magnesium burning.
(W) Signifies warhead.
(M) Signifies motor.
(D) Signifies deflagration.
(E) Signifies ejection of Safe/Arm.
(EX) Signifies explosion reaction.

TABLE 2. SPARROW Baseline Configurations and Critical Cook-Off Events.

Test item	Modular components						Significant events (seconds)		
	Warhead	Safe/Arm	Motor	Igniter	Control	Guidance	1000°F flame	Exothermic	Reactions
SP-3A	Mk 38 Mod 0[a]	Mk 35 Mod 1[b]	Mk 38 Mod 4[c]	Mk 265[b]	Wing hub	None	42	(W) 120 (M) 70	(D) 320**, (E) 360 None
SP-7B	Mk 38 Mod 0[d,e]	Mk 35 Mod 1[e]	Mk 38 Mod 1[b]	Mk 265[b]	None	None	Unknown	(W) . . . (M) . .	(D) 490, (EX)* 1200 . . .
SP-13A	Mk 38 Mod 0[e]	None	Mk 38 Mod 1[b]	Mk 265[b]	Wing hub	None	51	(W) 145 (M) . . .	(D) 220 . . .
SP-13B	Mk 38 Mod 0[a,d]	None	Mk 38 Mod 1[b]	Mk 265[b]	None	None	52	(W) 96 (M) . . .	(D) 195** . . .
SP-14A	Mk 38 Mod 0[e]	Mk 35 Mod 1[e]	Mk 38 Mod 0[e]	Mk 265[e]	Wing hub	None	16	(W) 84 (M) 30	(D) 134, (EX) 495* (EX) 62

[a] Wood billet replaced warhead explosive.
[b] Empty casing.
[c] Crystal white stucco sand (#30 mesh) replaces solid propellant.
[d] Warhead modified so as to add thicker potting material between explosive edges and steel rods.
[e] Signifies live.
* Explosion due to detonation of Safe/Arm unit
** Due to magnesium burning.
(W) Signifies warhead.
(M) Signifies motor.
(D) Signifies deflagration.
(E) Signifies ejection of Safe/Arm.
(EX) Signifies explosion reaction.

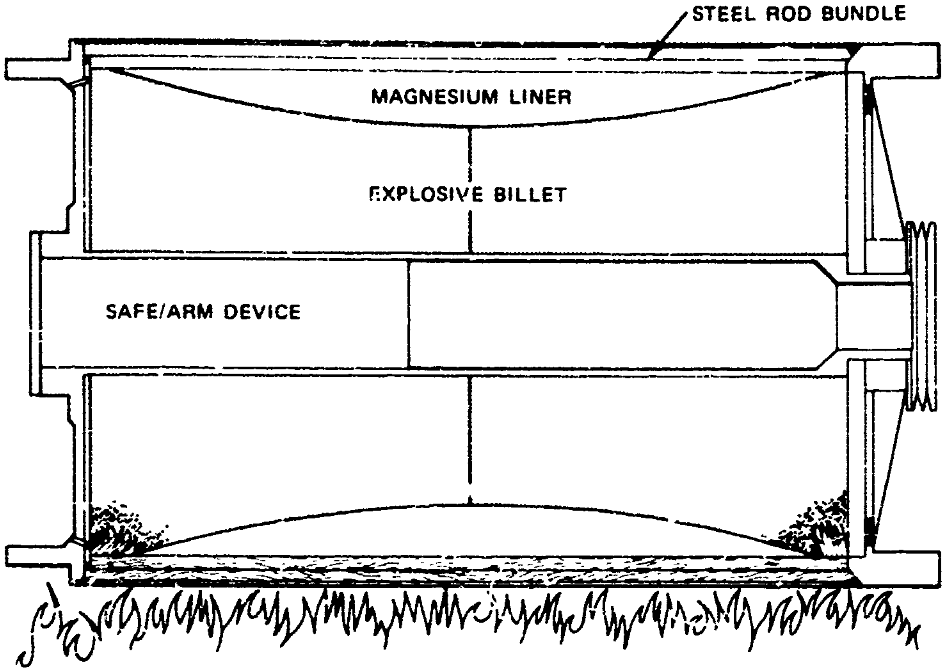


FIGURE 6a. SPARROW Warhead Explosive Igniting on Lower Surface.

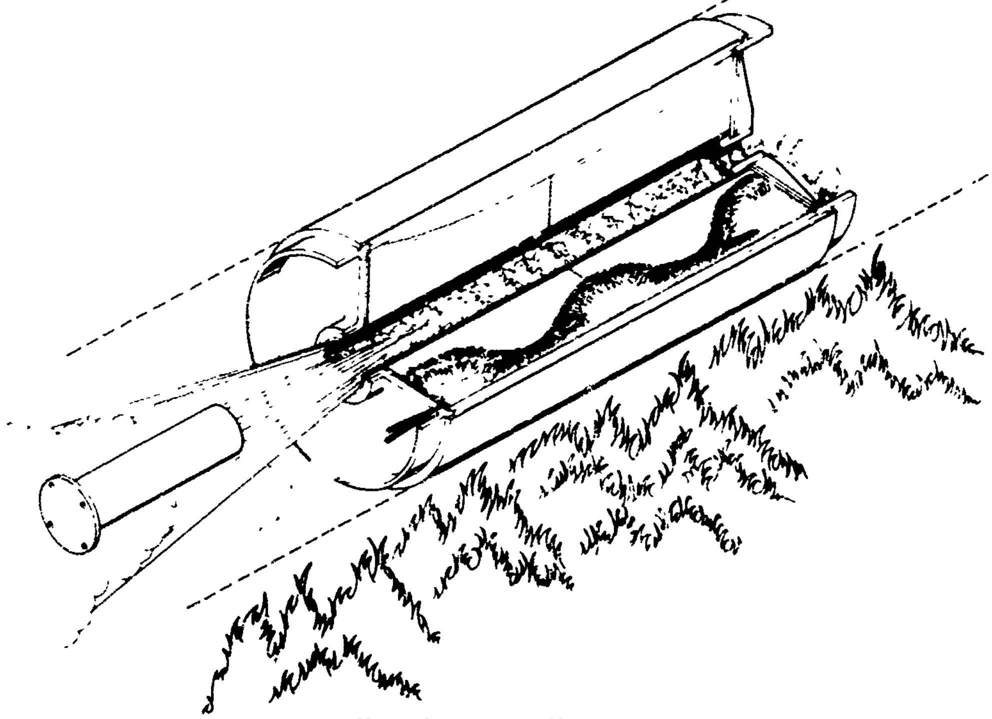


FIGURE 6b. Possible SPARROW Warhead Venting.

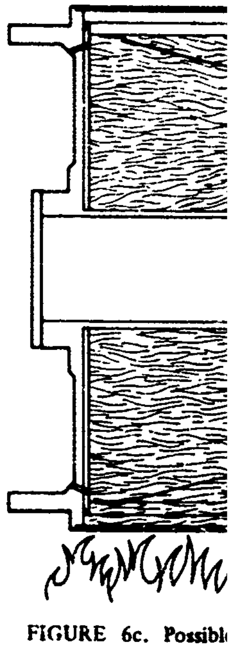
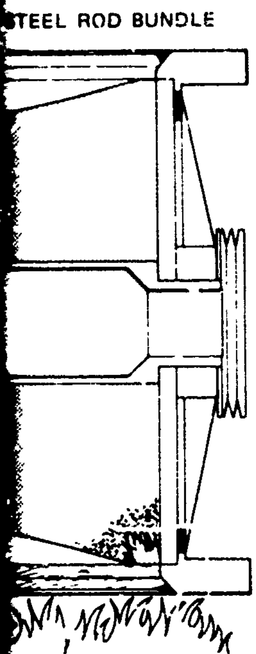


FIGURE 6c. Possibl
Ejected.

FIGURE 6d

FIGURE 6. Possible SPARROW Warhead Reactions During



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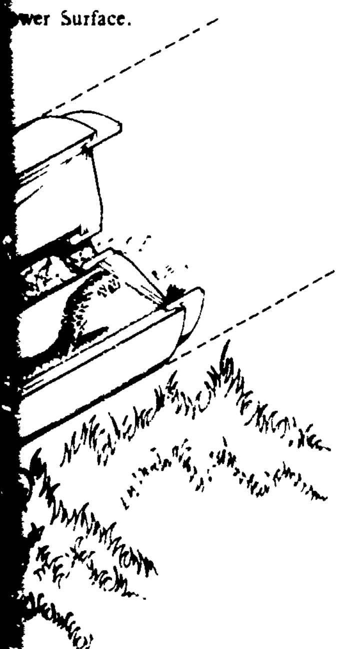

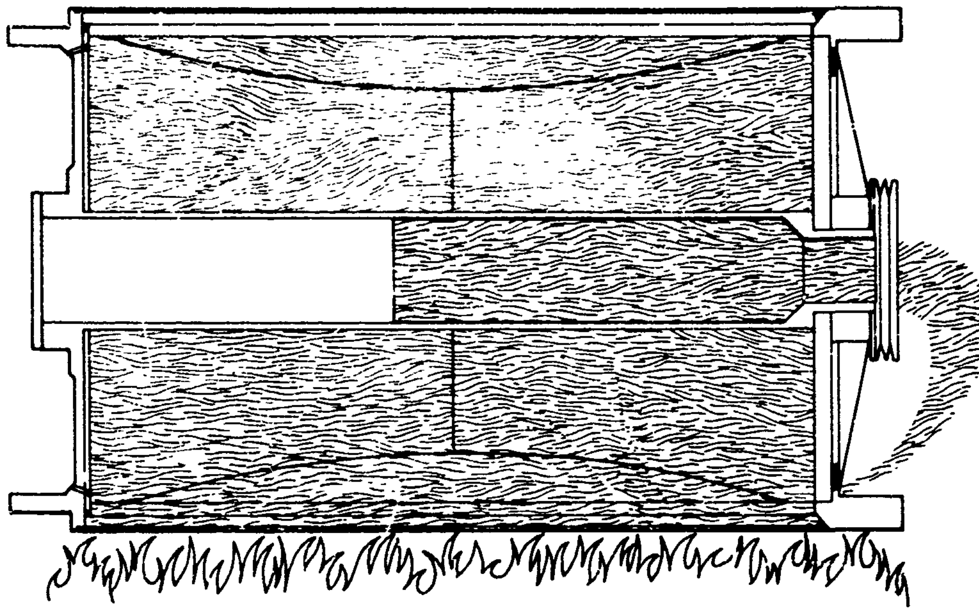

FIGURE 6c. Possible SPARROW Warhead Explosive Completely Burned With Safe/Arm Not Ejected.

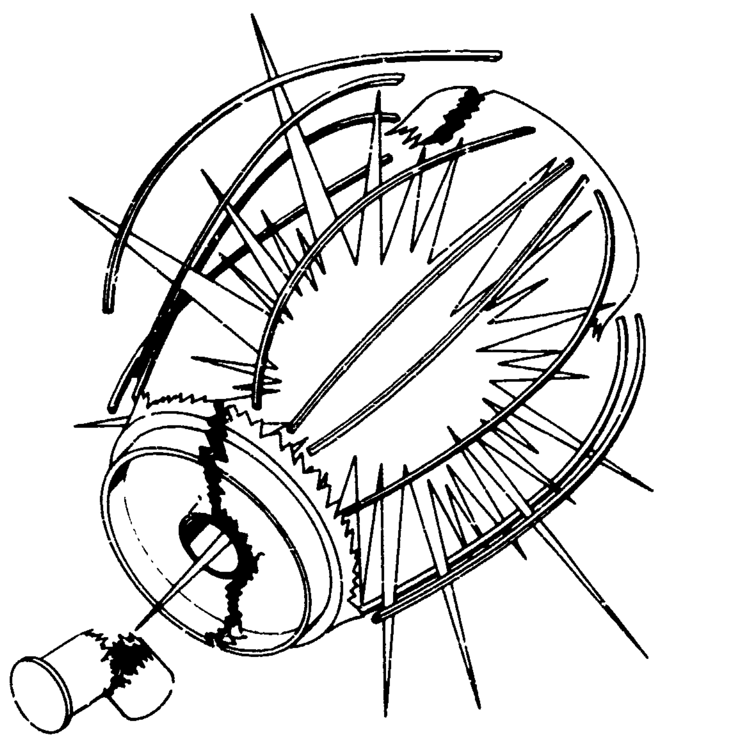

FIGURE 6d. Possible SPARROW Warhead Explosion Due to Safe/Arm Exploding.

FIGURE 6. Possible SPARROW Warhead Reactions During Fast Cookoff.

motor-to-warhead-chamber, so that the pressure needed to eject the safe/arm (Figure 6b) never materialized.

The SPARROW rocket motors tested were the Mk 38 Mod 0, and Mk 38 Mod 4. Description of these motors is contained in Appendix B. Note that the standoff propellant grain is held by nine elastomeric pads. The region between the grain and fiber glass case liner is filled with air. This motor exhibited internal exothermic reactions in the steel-to-liner region at 30 sec (SP-14A).

The exothermic heating produced from the liner and/or other material used to prepare the steel case for graining ignited the propellant sooner than if heating only by conduction from the fire existed without chemical reactions. The solid propellant is shown burning at the lower surface in Figure 7a.

The failure of the Mk 38 Mod 0 SPARROW rocket motor is hypothesized to be due to over-pressurization within the steel casing, which causes the solid propellant to crack, as shown in Figure 7b. If the propellant gas can vent, then the reaction may be one of deflagration, as shown in Figure 7c. Otherwise an explosion may result, as shown in Figure 7d.

COOKOFF IMPROVEMENT RECOMMENDATIONS

The events observed during cookoff of the SHRIKE and SPARROW missiles are so similar that for the purpose of cookoff improvement recommendations they may be discussed together. Based upon these observations a hypothesis to explain cookoff sequence has been formulated. Schematics of the events are given in Figures 4, 5 (SHRIKE) and 6, 7 (SPARROW). The proposed retrofit recommendations are applicable in many cases to both missiles.

THE WARHEADS

The SHRIKE and SPARROW warheads tested react as a result of the chain of events described in the summary. Three critical events occur: the apparent exothermic response of the potting material and/or cavity paint, the build-up of pressure because of burning of the explosive, and either the venting of the burning gas leading to deflagration or the fracturing of the billet leading to explosion.

In the SPARROW warhead the safe/arm device will explode due to heating if it is not ejected by the pressure of the explosive gas vented into the cavity between the warhead and the motor.

Insulation of the entire warhead by super-insulative materials, and/or intumescent or ablative coatings is recommended and is currently being studied as a possible means to interrupt the heat paths and so increase the time to reaction.

Inhibition of any oxidizing agents which may be present in the encapsulating compounds and/or cavity paint is proposed. Such agents may arise by reason of impure materials used in their preparation, or due to the manufacturing process, or by migration from the explosive. Neutralizing materials (as yet unidentified) should also neutralize any reactive materials released by the high temperatures of cookoff.

In the SHRIKE warhead the conditioning substance could (in principle) be introduced through the two cavity holes and/or the anti-compromise device.

In the SPARROW warhead introduction could be done through the aft end by removing the spider and end plate.

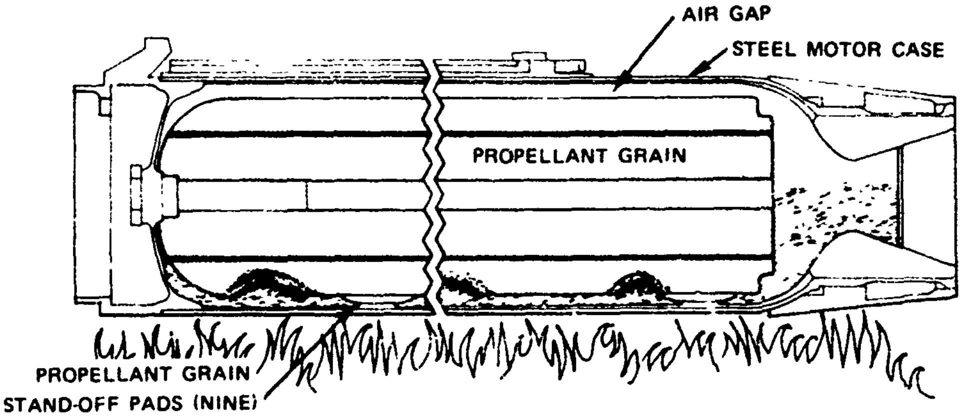

FIGURE 7a. SPARROW Motor Propellant Igniting at Lower Surface.

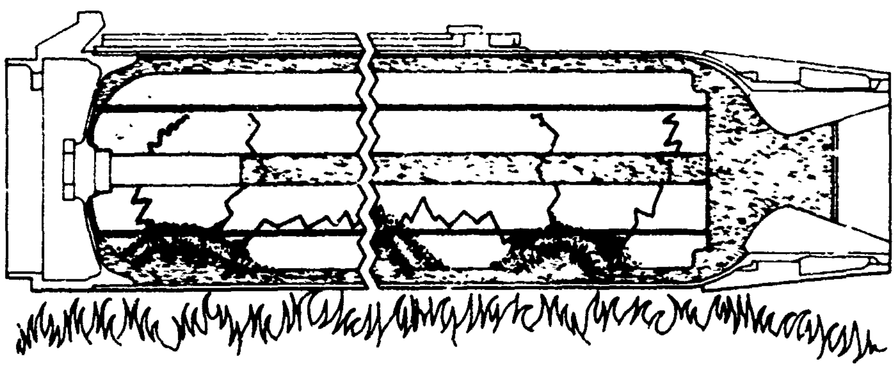

FIGURE 7b. Possible SPARROW Motor Propellant Grain Cracking Creating New Burning Surfaces.

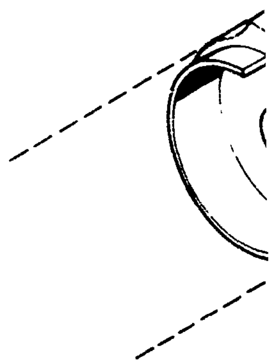

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FIGURE 7. Possible SPARROW Motor Reactions During Fast Cook

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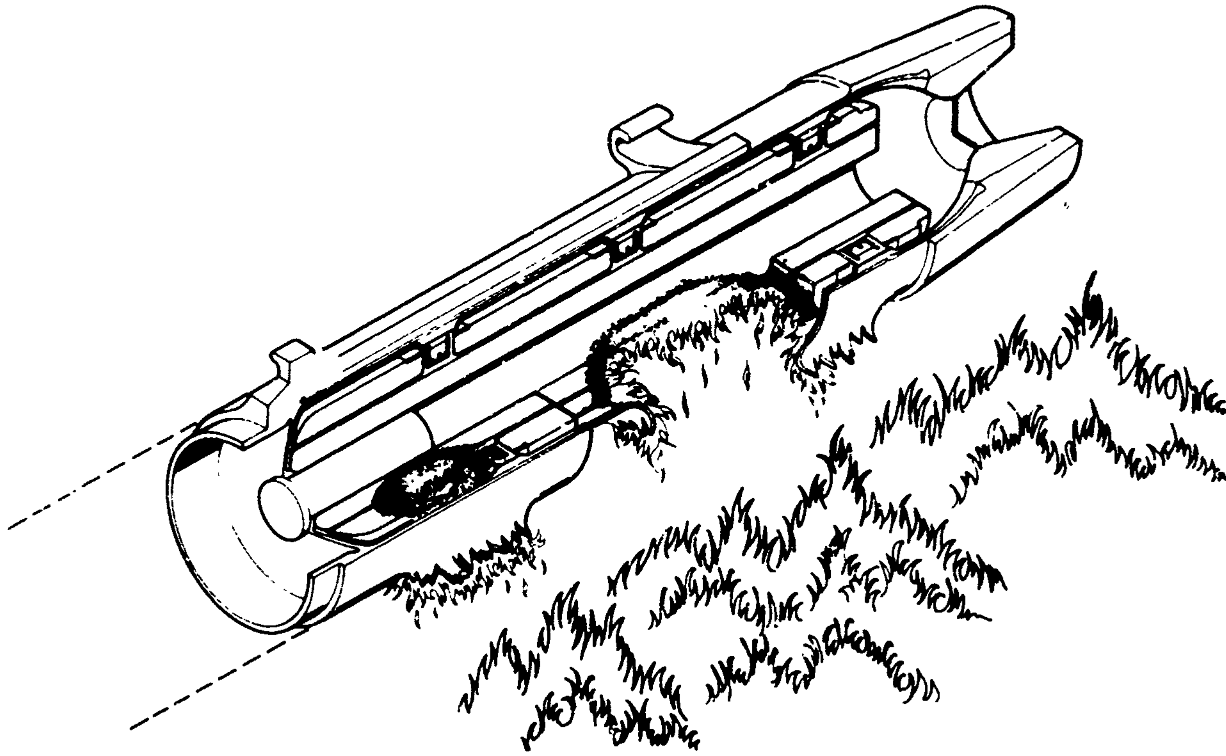

FIGURE 7c. Possible SPARROW Motor Venting.

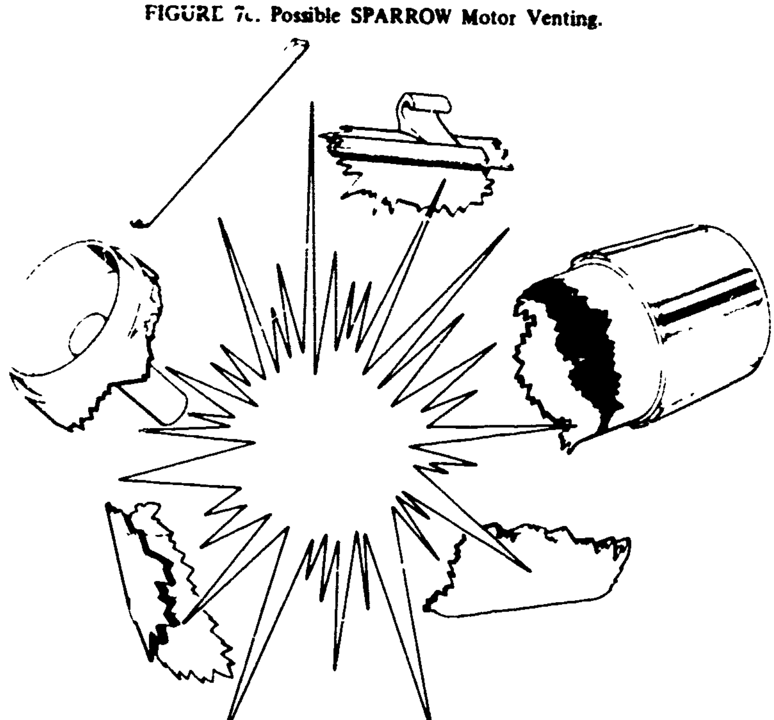

FIGURE 7d. Possible SPARROW Motor Propellant Explosion Due to Overpressurization.

Burning

sible SPARROW Motor Reactions During Fast Cookoff.

Ventilation to relieve and retard pressure build-up is also recommended. Pressure reliefs could be machined or chemically milled into the bulkheads not penetrating into the explosive. These should then be filled with a resin to provide a smooth finish. In both missiles the bottom portion of the warhead casing should be weakened in a similar manner, and a smooth-finished composite doubler applied to maintain its ambient strength. The doubler would quickly lose strength in a fire, allowing the warhead to vent.

In the SHRIKE warhead section such ventilation is recommended, particularly for the aft bulkhead and also in the steel casing itself. Also the forward cone should be uncrimped and refastened with an adhesive. The aft fuze cavity should be removed by chemically milling the weld joint, and refastened with a suitable adhesive. Holes could also be drilled in the fuze booster cup itself, which should then be relined with a suitable sealant.

In the SPARROW warhead section the same procedure is recommended. Holes should be made in the bulkheads and in the weld fillets on the interior periphery of the warheads. Further venting could be attained by weakening the flange attachment of the safe/arm device by use of plastic screws. Venting of the center cavity also appears feasible.

THE MOTORS

The SHRIKE and SPARROW motors tested react as a result of the chain of events described in the summary. Three critical events occur: the apparent initial exothermic response in the liner to case region, the build-up of pressure in this region because of burning of the propellant, and either the venting of the burning gas leading to deflagration or the fracturing of the grain leading to explosion.

Insulation of the entire motor section by superinsulative materials, and/or intumescent or ablative coatings is recommended and is being investigated within the Navy.

Ventilation of the bottom portion of the rocket motor case is recommended and can be realized by machining or chemical milling, which would weaken the casing at high temperatures. A glass/resin doubler with suitable heat diffusion filler would then be applied to maintain its external configuration and low-temperature strength. This retrofit is applicable to both the SHRIKE Mk 39 Mod 7 and SPARROW Mk 39 Mod 0 motors.

Surface modification of the propellant grain by chemical means is recommended to reduce the mechanical modulus near the surface at areas of stress concentration. The fiberglass liner of the SPARROW Mk 38 Mod C motor is functional, and chemical modification does not seem warranted. However, mechanical venting is recommended. The existing epoxy liner could be coated with a chemically inert material with longitudinal grooves to conduct any gases from the epoxy liner aft through the weather seal.

In the SHRIKE Mk 39 Mod 7 the liner might be treated to increase exothermic behavior by introducing exothermic materials directly into the liner, and thus lead to early propellant ignition, burn-through, and venting. This could possibly be done either through the propellant or through the aft and forward liner enclosures, or during motor regrain operation.

The SHRIKE motor Mk 78 Mod 0 burned and then deflagrated mildly so no retrofit is recommended as this reaction is acceptable. It is hypothesized that the liner experiences exothermic behavior very soon (Table 1), ignites the solid propellant which burns through the motor casing, and thus provides adequate venting (Figure 5c).

It is emphasized that these retrofits are *proposed*, and except for the insulative, intumescent, and ablative coatings, their feasibility has yet to be demonstrated.

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4. Russell, L. H. and J. A. Canfield. "Experimental Measurement of Heat Transfer to a Cylinder Immersed in a Large Aviation-Fuel Fire," J. of Heat Transfer, Aug. 1973, pp. 397-404.

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Appendix A

SHRIKE (AGM-45A/B) MISSILE DESCRIPTION

LIST OF FIGURES

SHRIKE (AGM-45A/B) MISSILE DESCRIPTION

GENERAL

Surface Attack Guided Missile (SHRIKE) (Figure A-1) is a passive air-to-ground antiradar missile. Models AGM 45A/B are assembled from four sections: guidance, warhead, control with wings, and rocket motor with fins (Table A-1). The AGM-45A uses the Mk 5 (Mods 0 and 1), Mk 68 (Mod 0) or Mk 86 (Mods 0 and 1) warhead. The rocket motor used with the AGM-45A is a Mk 39 (Mod 3-5, 7) or Mk 53 Mod 1. The AGM-45B employs the Mk 5 Mod 1 or Mk 86 Mod 1 warhead and the dual thrust Mk 78 Mod 0 rocket motor. The guidance and control sections are common to the assembly of either guided missile.

COMPONENT DESCRIPTION

Warhead Section

Warhead sections Mk 86 (Figure A-2) and Mk 5 (Figure A-3) are made up of a Mk 58 or Mk 80 warhead, Mk 330 fuze, Mk 44 fuze booster, and an armament cable assembly. In the Mk 5 warhead section only a Mk 4 smoke canister containing 5.5 pounds of allotropic red phosphorous fits forward of the fuze cavity.

The Mk 68 and Mk 80 warheads are eight inches in diameter. They are constructed of a 1/4-inch thick outer fragmenting case which houses 22,000 preformed 1/4-inch cube fragments, and the main explosive charge of approximately 50 pounds of PBXN-101.

The preformed cube fragments are distributed in varying numbers of layers around the explosive charge so that the explosive is separated from the outer fragmenting case for nearly the forward three-quarters of the warhead's length. The cube fragments are encapsulated in Type D insulating compound, and separated from the main explosive charge by a 0.035-inch-thick steel liner and 0.020-inch of MIL-P-22332 cavity paint. The cavity paint is applied to all interior surfaces of the explosive cavity prior to loading. An anti-compromise device, installed in the forward closure of the warhead section, consists of a shaped-charge cone in Mk 86 warhead sections, and a destruct cup in Mk 5 warhead sections.

The Mk 44 booster and the Mk 330 fuze are located along the warhead centerline in the Mk 68/86 and Mk 5 warhead sections. The fuze, hermetically sealed in an aluminum case, is installed in the aft end of the warhead sections. The fuze booster contains 170 grams of CH-6 explosive and attaches to the forward end of the fuze. The armament cable is a molded electrical cable running through the warhead section.

TABLE A-1. SHRIKE Guided Missile and Missile Section Physical Characteristics.

ACM-45 A/B GUIDED MISSILE	
Length	121 inches (approximately)
Diameter	8 inches
Wing span (installed)	36.25 inches
Gross weight	400 pounds (approximately)
GUIDANCE SECTION	
Length	29 inches (approximately)
Diameter	Ogive point to 8 inches
Weight	43 pounds (approximately)
WARHEAD SECTION	
Length	29 50 inches
Diameter	8 inches
Weight	145.5 pounds
Explosive	
Composition	PBXN101
Weight	50 pounds (nominal)
FUZE	
Length (assembled with booster)	4 95 inches
Diameter	
Forward end	3 1 inches
Aft end	3 5 inches
FUZE BOOSTER	
Length (assembled with fuze)	4 95 inches
Diameter	2 85 inches
Explosive	
Weight	170 grams
Composition	CH-6
CONTROL SECTION	
Length	11 15 inches
Diameter	8 inches
ROCKET MOTOR SECTION	
Length	51 8 inches (approximately)
Diameter	8 inches forward end 6 7 inches aft tapered end
Weight	162 to 173 pounds
Igniter explosive weight	117 grams

Rocket Motor Section

Rocket motor sections Mk 39 Mods (Figures A-4, A-5) consist of a solid-propellant propulsion unit, a Mk 265 igniter assembly, igniter cable assembly, safe/arm igniter activator, safety clips, boattail, and forward and aft launch hooks. The rocket motor (8-inch diameter, 51.8-inch long) consists of a 4130 steel shell case with a 0.056-inch nominal wall thickness. This case or combustion chamber assembly includes a rocket-exhaust nozzle, a forward head that holds a motor igniter and in Mods 0, 1, 2, 3 and 5 a propellant grain of RDS507, which is cast on an integral grain-support tube and then inserted into the motor chamber. This grain assembly is separated from the motor case glass/phenolic liner by 12 strips of 0.15-inch thick rubber asbestos strips (R-154 EPT), and by nine support legs terminating in plastic feet which are compression-fitted against built-up sections of the case-wall insulation. Propellant grains of RDS507-86 for other mods of the Mk 39 motor are case-bonded, i.e., they are cast in the motor case in a five-point star configuration and bonded to a rubber/asbestos liner (R-154 EPT) of .070–0.130-inch thickness bonded to the steel case.

The Mk 265 Mod 0 igniter (Figure A-6) used with the Mk 39 motor section consists of an igniter body, motor assembly, crank, plastic perforated basket, and ignition elements.

The ignition elements are, in the order of function: (1) parallel squib circuit, (2) two primary charges in intimate contact with squibs, (3) two secondary charges contained in the rotor assembly, (4) one tertiary charge at the forward end of the plastic basket, and (5) the main igniter charge contained in the perforated basket. Current from the delivery aircraft applied to the igniter starts the sequence which ultimately ignites the rocket motor grain.

Rocket motor section Mk 53, Mod 1 (Figure A-7) is similar in design to case-bonded Mk 39 motor sections. This alternative section consists of a solid-propellant propulsion unit, a Mk 274 Mod 0 safe/arm igniter assembly, wiring harness assembly, safe/arm lock assembly, safety clip, fin stabilizer attachment, and forward and aft launch hooks. The composit internal-burning, case-bonded propellant grain is cast in a five-point-star configuration. This ANB-3109-1 propellant is separated from and bonded to the steel motor chamber by an SD 864-4 copolymeric liner approximately 0.250 inch thick. The igniter Mk 274 safe/arm assembly (Figure A-8) and wiring harness assembly are mounted in the forward head closure of the combustion chamber, and secured in place by a snap ring and sealed with a preformed packing. The igniter assembly consists of an igniter-chamber assembly containing the main pyrotechnic charge, an igniter-adapter containing a sliding control-piston, a safe/arm rod, a dual-delay squib initiator, and associated seals and retaining rings. During normal operation, a 10-ampere current from the delivery aircraft applied to the igniter starts the train which ultimately ignites the rocket motor.

Rocket motor section Mk 78 Mod 0 (Figure A-7), which is used primarily for SHRIKE Missile AGM-45B, consists of a solid-propellant, dual-thrust propulsion unit, a safe/arm actuator assembly, Mk 274 Mod 1 igniter assembly, wiring harness assembly, arming key assembly, fin-stabilizer attachment, and forward and aft launch hooks. The propulsion unit is 8.00 inches in diameter and 51.75 inches long. The chamber is made of 4130 steel with a minimum wall thickness of 0.057 inch. The solid-propellant grain is a mixture of ammonium perchlorate, aluminum, and catalytic agents (Boost–ANP-3146-2, Sustain–ANP-3196-1) which are specifically formulated to provide two levels of motor thrust. The components of the grain are case-bonded to the chamber. A polyurethane liner material (0.053 inch thick) separates the propellant grain from the steel motor chamber. The igniter, safe/arm assembly and wiring harness assembly are located inside the forward head closure of the motor. Their main function is to carry the ignition current to the igniter which in turn ignites the main propellant grain.

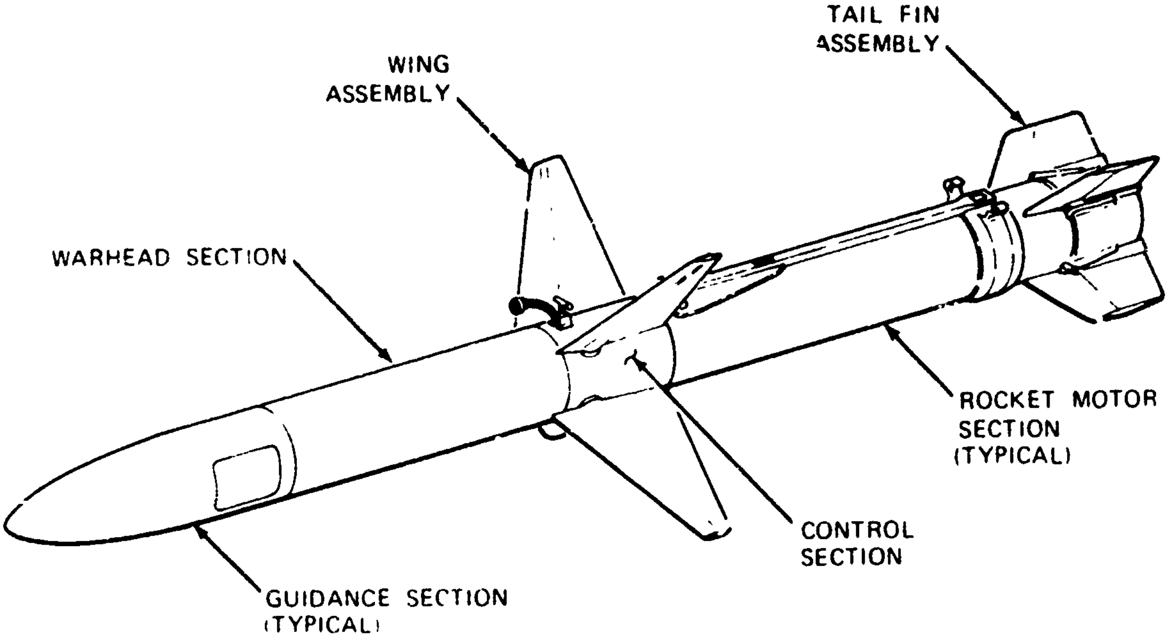

FIGURE A-1. SHRIKE Guided Missile AGM 45A/B.

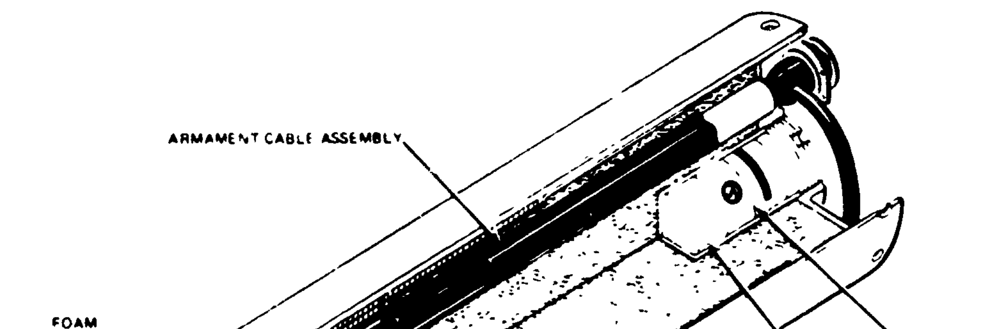

FIGURE A-2. SHRIKE Mk 68 Mod 0 Warhead

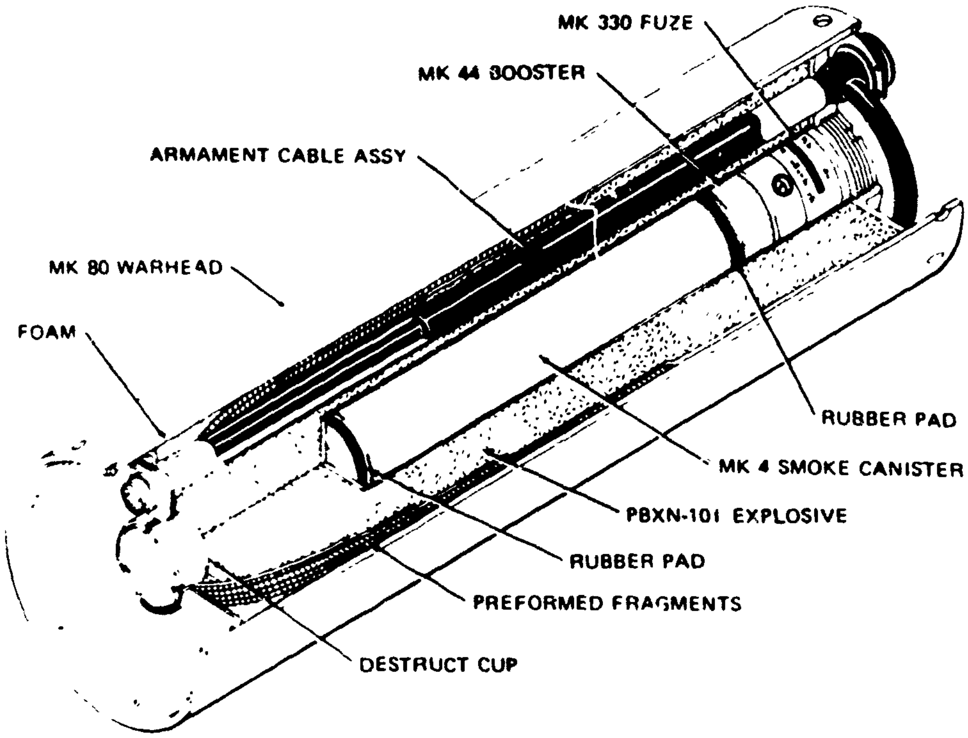

FIGURE A-3. SHRIKE Mk 5 Mod 0 Warhead

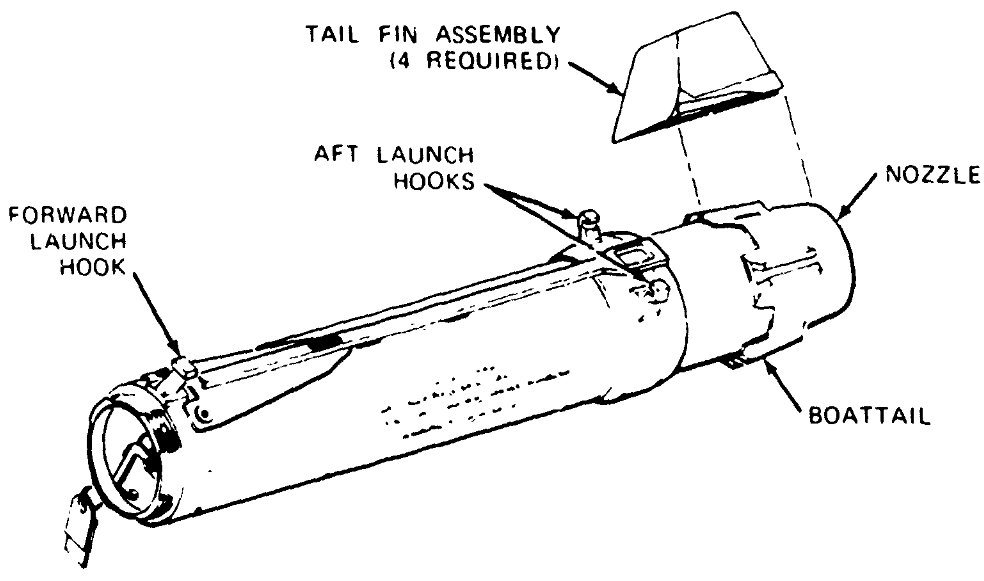

FIGURE A-4. SHRIKE Rocket Motor Section Mk 39 Mod 0 3 W/Tail Fin Assembly

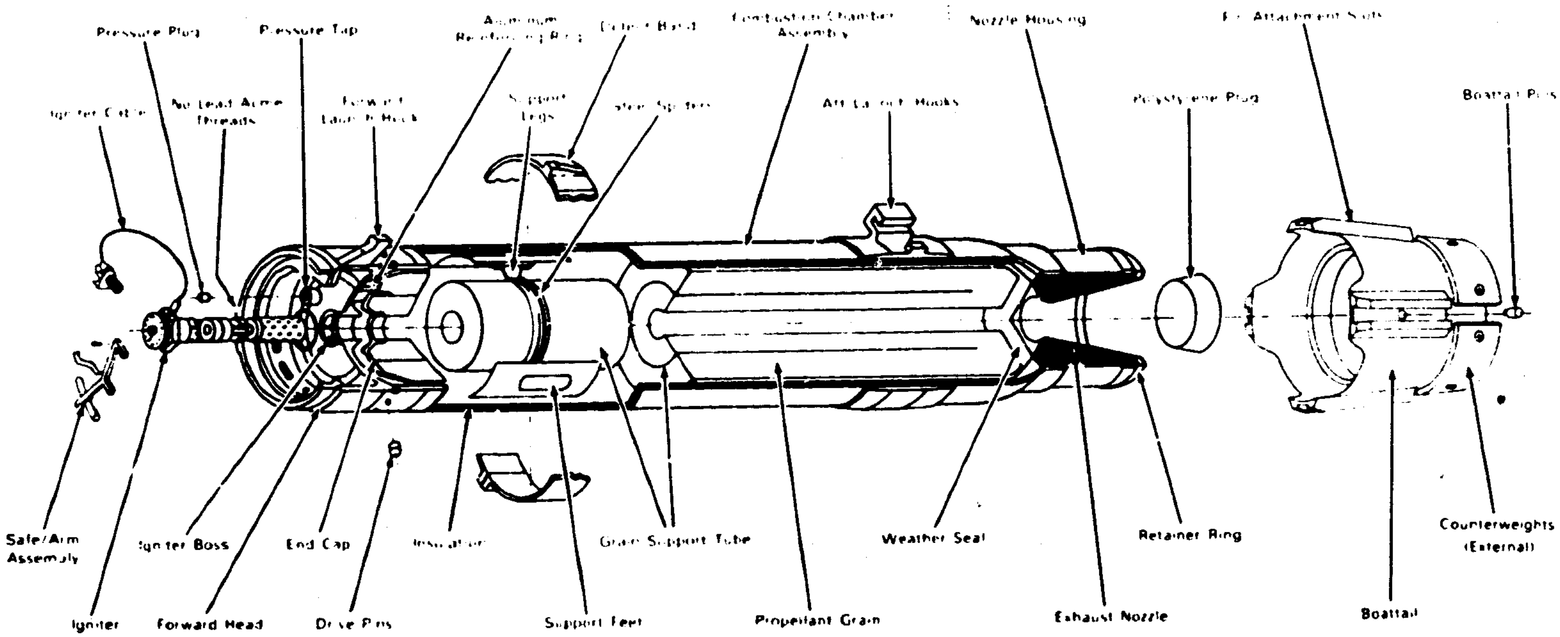

FIGURE A-5. Rocket Motor Section Mk 39 Mods 0, 1, 2, 3 and 5. Exploded View.

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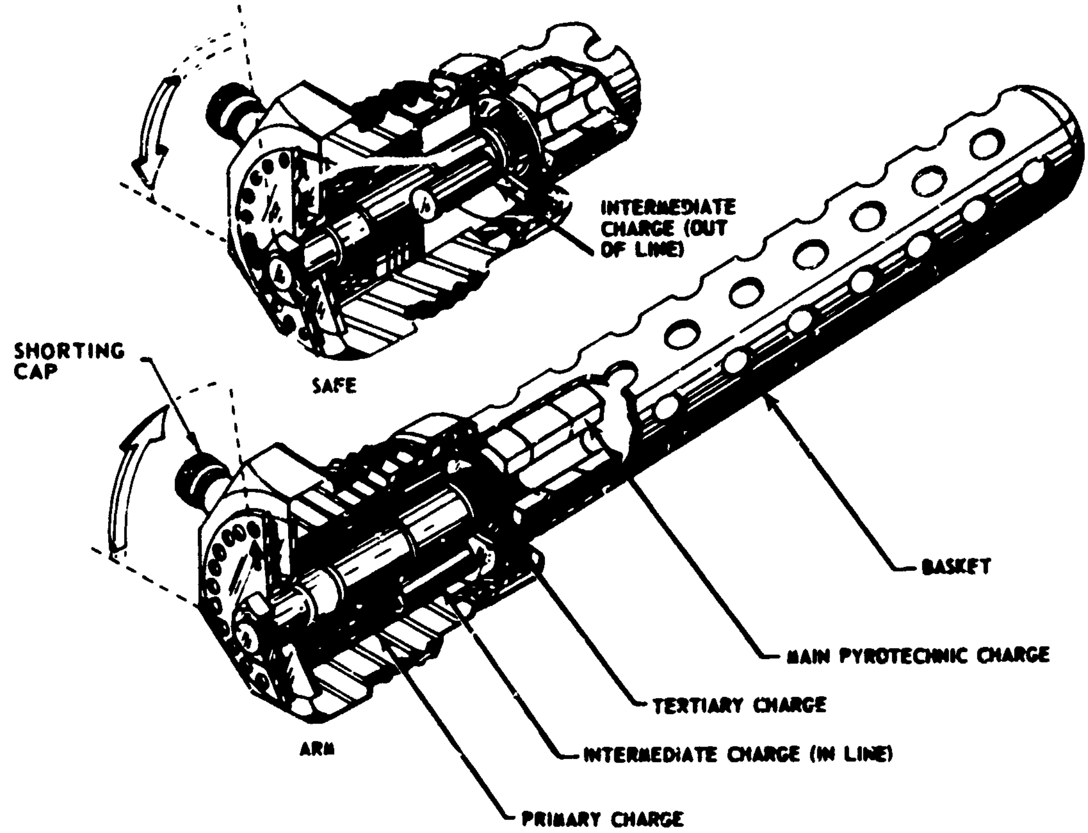

FIGURE A-6 Igniter Mk 265 Mod 0, Cutaway

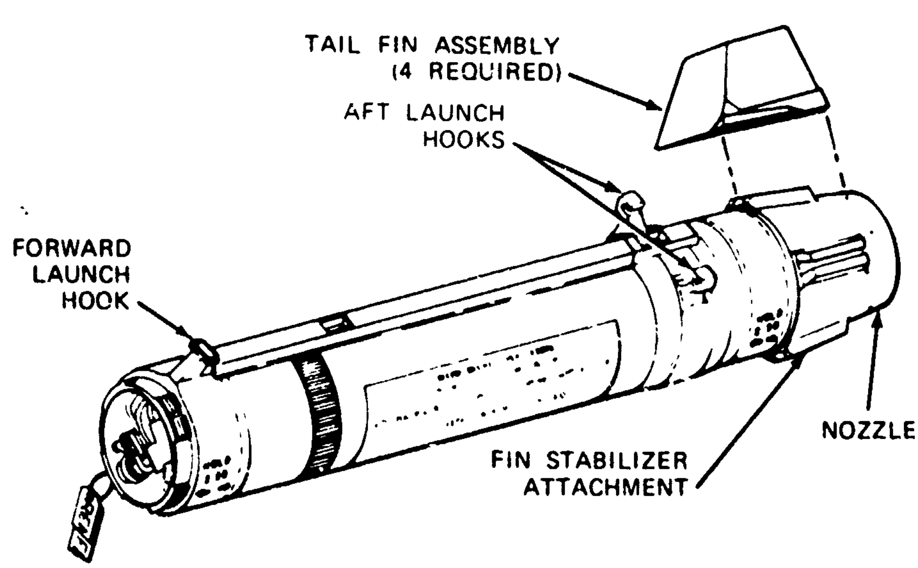

FIGURE A-7 Rocket Motor Section Mk 53 Mod 1 and Mk 78 Mod 0 With Tail Fin Assembly

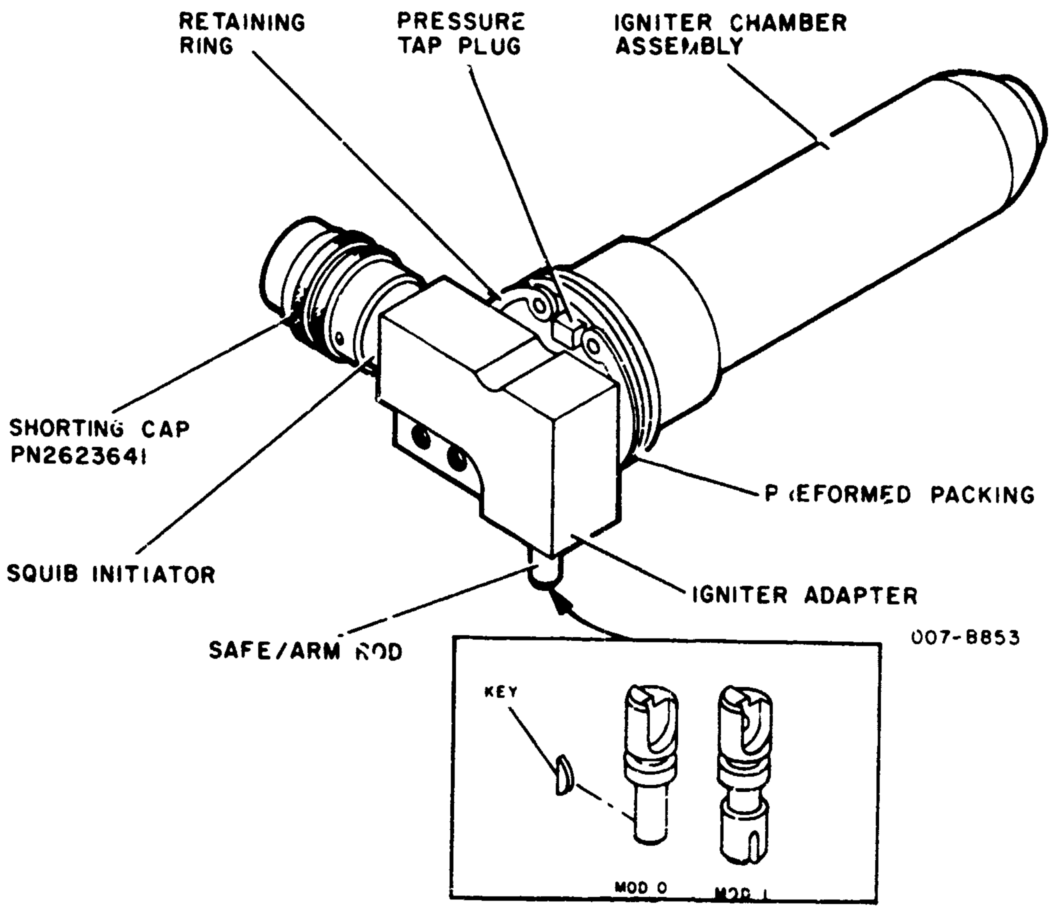

FIGURE A-8. SHRIKE Mk 274 Safe/Arm Igniter Assembly.

Appendix B

SPARROW (AIM-7E AND AIM-7E-2) MISSILE DESCRIPTION

LIST OF FIGURES

SPARROW (AIM-7A AND AIM-7E-2) MISSILE DESCRIPTION

GENERAL

Guided missile models AIM-7E and AIM-7E-2 (Figure B-1) are supersonic, air-to-air, boost-glide missiles, composed of three major functional sections: guidance control, warhead, and rocket motor (Table B-1). The AIM-7E and AIM-7E-2 use the Mk 38 Mod 4 or Mk 52 (Mods 1 and 2) motor.

TABLE B-1. SPARROW Guided Missile and Missile Section Physical Characteristics

AIM-7E/E-2 GUIDED MISSILE	
Length (AIM-7E/E-2)	145.2 inches
Diameter	8 inches
Wing span (installed)	40.3 inches
Tail fin span (installed)	32.2 inches
Gross weight (AIM-7E/E-2)	430 pounds (approximately)
GUIDANCE & CONTROL SECTION (AN/DPN-72)	
Length	80.4 inches
Diameter	8 inches
Weight	155 pounds (approximately)
WARHEAD SECTION (MK 38)	
Length	13 inches
Diameter	8 inches
Weight	69.4 pounds
Explosive	
Composition	PBXN-104
Weight	20 pounds
FUZE (MK 5-35)	
Length (assembled with fuze booster)	7.85 inches
Diameter	1.46 inches
FUZE BOOSTER (MK 38)	
Length (assembled with fuze)	0.75 inch
Diameter	1.29 inches
Explosive	
Weight	26.3 grains
Composition	CH-6
ROCKET MOTOR SECTION (MK 38, 52)	
Length	51.8 inches
Diameter	6.38 inches aft tapered end
Weight (Mk 38, 52)	155.5 pounds
Igniter (Mk 265, 274)	
Explosive weight	116.2 grains

COMPONENT DESCRIPTION

Warhead

The Mk 38 warhead (Figure B-2) located between the control section and the rocket motor is cylindrical in shape and forms part of the missile structure. It is of the insulated continuous-rod type, using 20 pounds of PBXN 104 explosive initiated by a Mk 5 Mod 2 or Mod 0 safe/arm device (Figure B-3) and is approximately 8 inches in diameter and 14 inches long. The case is constructed of a continuous rod bundle 0.375 max. inch thick, 7.25 inches in diameter and 11.7 inches long. The outside of the bundle is protected by a 0.024-inch thick steel skin. Two halves of the PBXN 104 billet are assembled into a magnesium liner and this assembly is then inserted into the rod-bundle assembly. Potting resin fills the voids between the lined explosive billet and the rod bundle. Forward and aft gaskets, 0.125 inch thick, insulate the billet from the warhead end closures.

The safe/arm device is mounted in the central axis of the warhead. Its functions are to maintain the warhead in an unarmed condition until the missile has traveled a safe distance from the launching aircraft, and then to arm the warhead. The length of each safe/arm device is approximately 8 inches with the Mk 38 booster attached.

Rocket Motor Section

Rocket motor sections Mk 38 Mods (Figures B-4 and B-5) consist of a solid propellant propulsion unit, a Mk 265 igniter assembly, igniter cable assembly, safe/arm igniter activator, safety clips, boattail, and forward and aft launch hooks. The rocket motor (eight inches in diameter and 51.8 inches long) consists of a 4130 steel case with a 0.056 nominal wall thickness. This case or combustion chamber assembly includes a rocket-exhaust nozzle, a forward head that holds a motor igniter, and a propellant grain. The Mk 38 Mods 0, 1 and 2 motor contain a free-standing propellant grain of RDS 507, cast on an integral grain-support tube and then inserted into the motor chamber. The grain assembly is separated from the motor case by a 0.10- to 0.38-inch thick glass phenolic liner and by nine support legs terminating in plastic feet which are compression-fitted against built-up sections of the case-wall insulation. Propellant grains of RDS 507-86 for Mk 38 Mods 3 and 4 motor are case-bonded, i.e., they are cast in the motor case in a five-point-star configuration and bonded to a rubber/asbestos liner (R-154 EPT) of 0.056 to 0.074 nominal-inch thickness which is bonded to the steel case.

The Mk 265 Mod 0 igniter (Figure B-6), which is used with the Mk 38 motor section, consists of an igniter-body motor assembly, crank, plastic perforated basket, and ignition elements.

The ignition elements are, in the order of ignition: (1) parallel squib circuit, (2) two primary charges in intimate contact with squibs, (3) two secondary charges contained in the rotor assembly, (4) one tertiary charge at the forward end of the plastic basket, and (5) the main igniter charge contained in the perforated basket. Current from the delivery aircraft applied to the igniter starts the train which ultimately ignites the rocket motor grain.

Rocket motor section Mk 52 Mod 1 and 2 is similar in design to case-bonded Mk 38 motor sections and SHRIKE Mk 53 motor sections. This alternate rocket motor section, which is 8.0 inches in diameter and 51.8 inches long, consists of a chamber and grain assembly, a safe/arm igniter assembly, a nozzle assembly and a fin-stabilizer attachment. The composite, internal-burning case-bonded propellant grain is cast in a five-point-star configuration. The propellant, ANB-3109-1, is separated from and bonded to the 4335 steel motor chamber by an approximately 0.050-inch thickness of SD 864-4 copolymer liner.

The igniter, Mk 274 safe/arm assembly (Figure B-7) and wiring harness assembly are mounted in the forward head closure of the combustion chamber. The igniter and safe/arm assembly are secured in place by a snap ring and sealed with preformed packing.

The igniter assembly consists of an igniter chamber assembly containing a sliding control piston, a safe/arm rod, a dual-delay squib initiator, and associated seals and retaining rings. During normal operation a 10-ampere current from the delivery aircraft, when applied to the initer starts the train, which ultimately ignites the rocket motor.

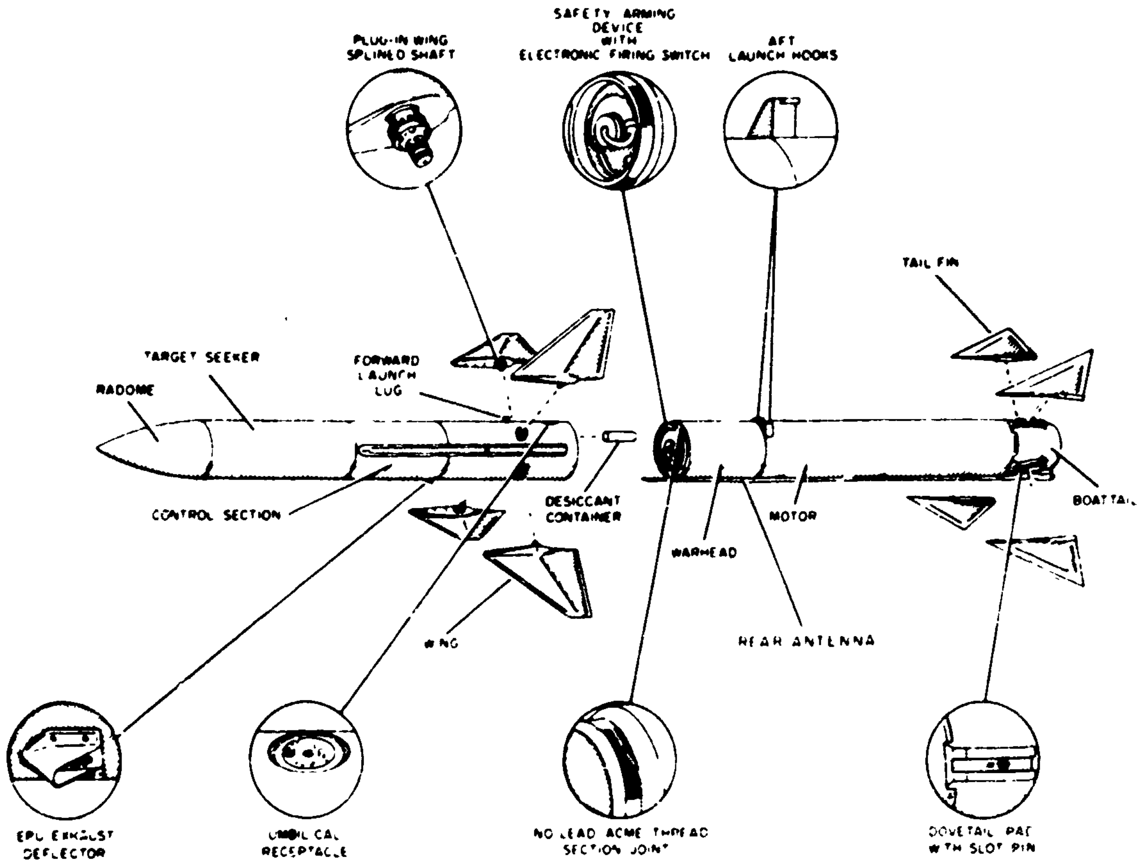

FIGURE B-1. SPARROW Missiles AIM-7E and AIM-7E2 (Exploded View)

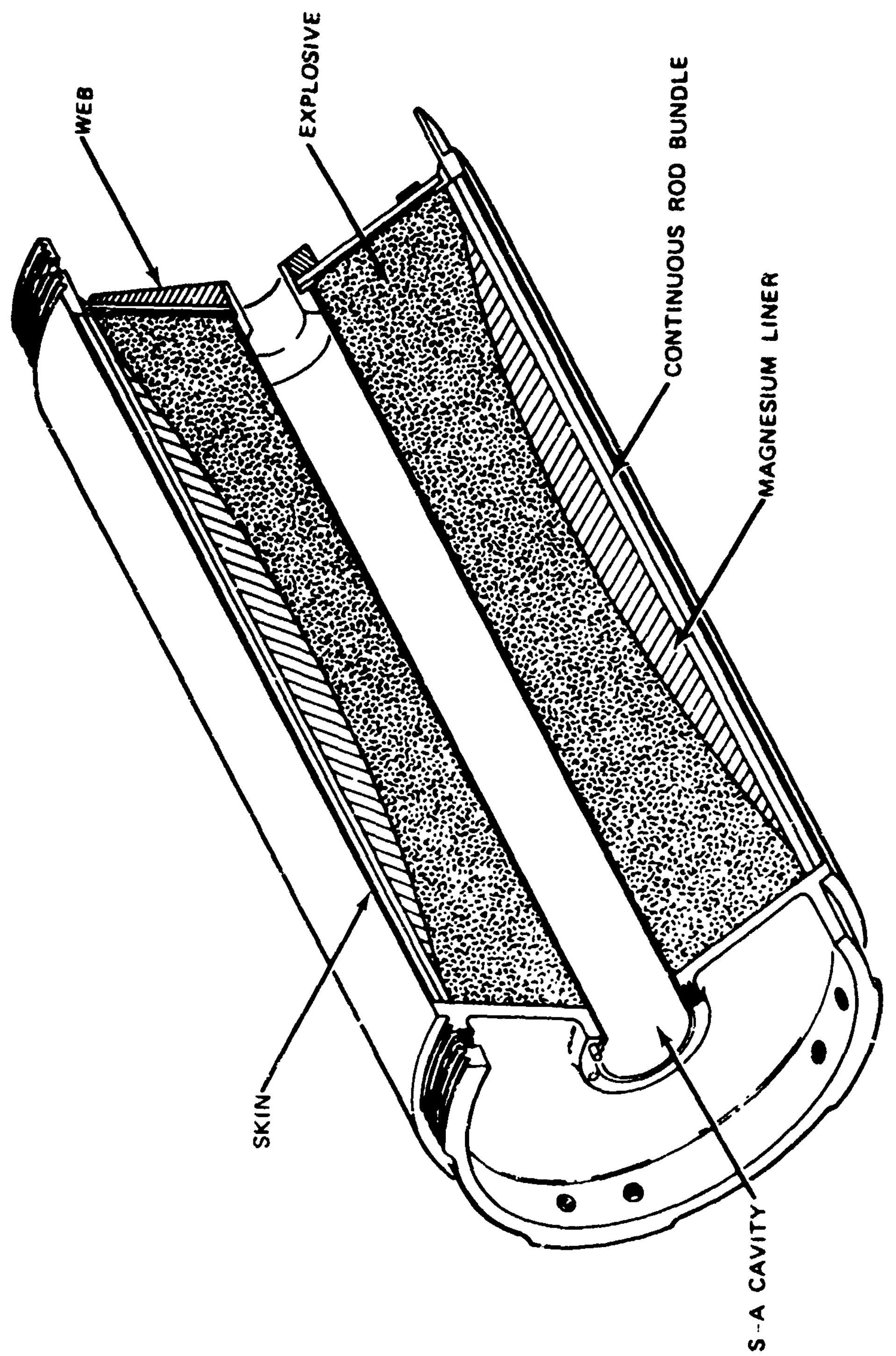

FIGURE B-2. SPARROW Mk 38 Mod 0 Warhead

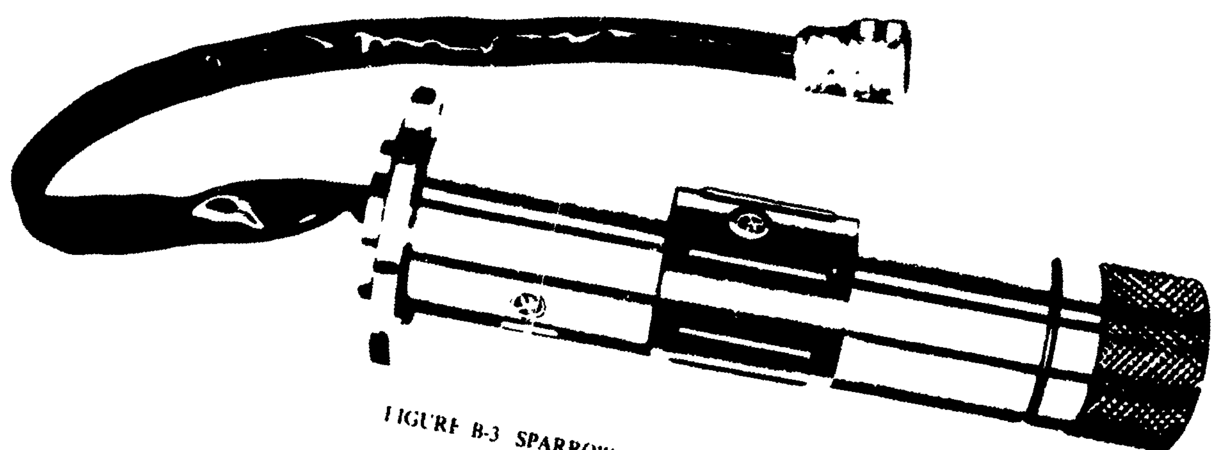

FIGURE B-3 SPARROW Safe/Arm Device.

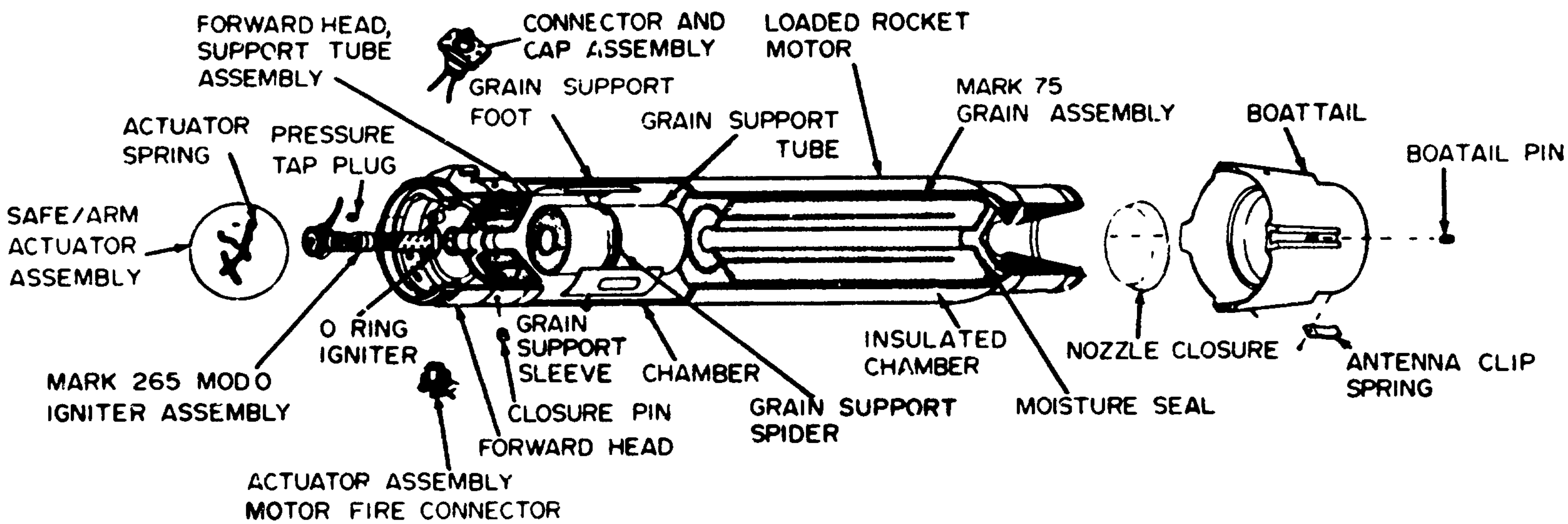

FIGURE B-4 Mk 38 Mods 0, 1 and 2 SPARROW Rocket Motor Section

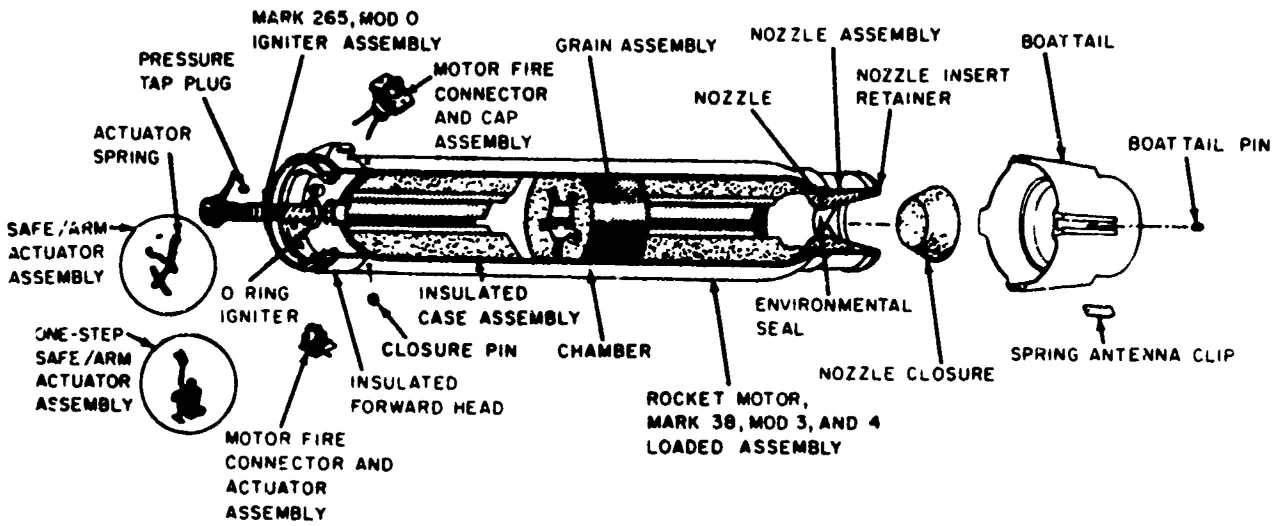

FIGURE B-5. Mk 38 Mods 3 and 4 SPARROW Rocket Motor Section

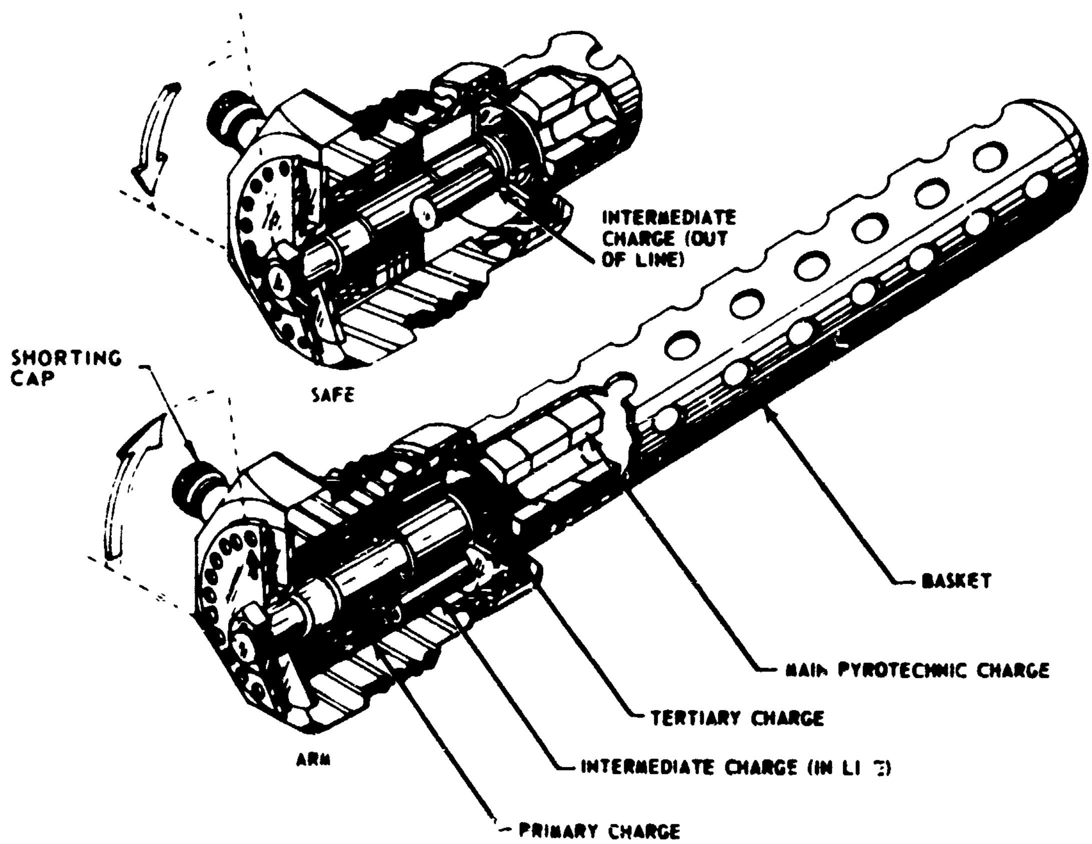

FIGURE B-6. Igniter Mk 265 Mod 0, Cutaway

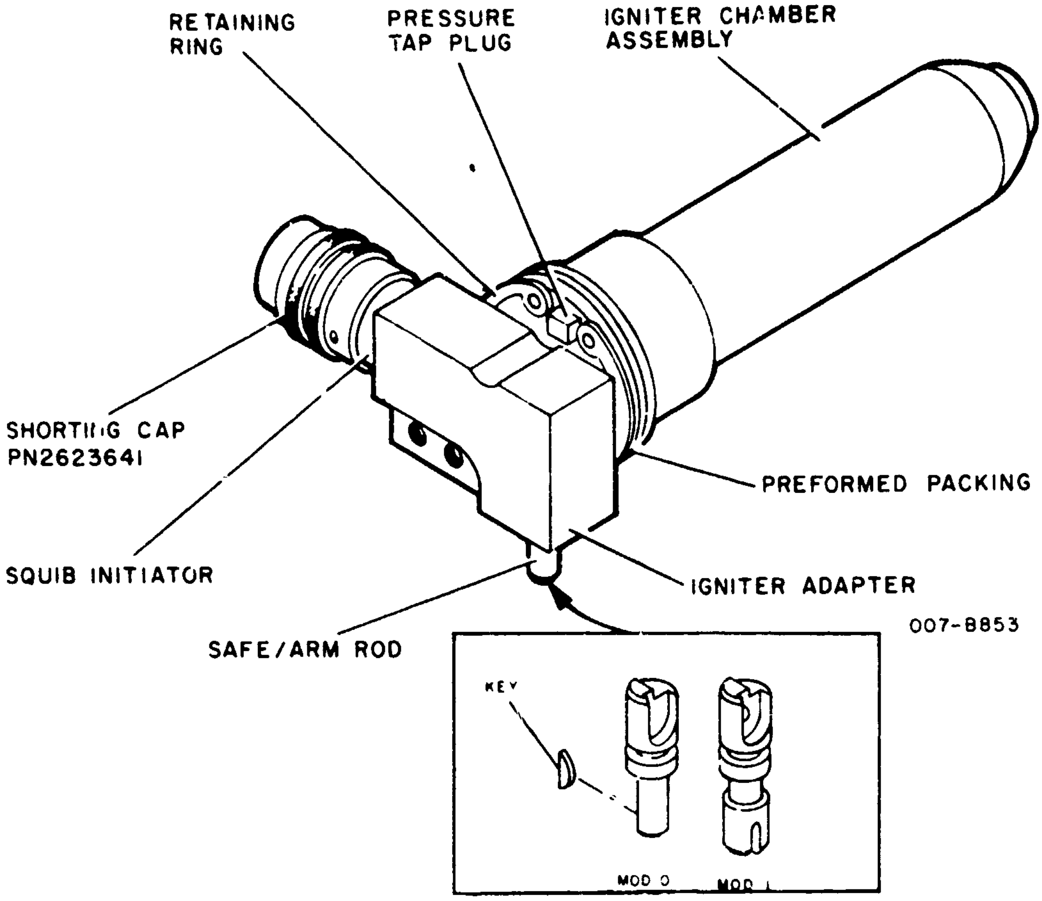

FIGURE B-7 Safe/Arm Igniter Assembly Mk 274 Mods

Appendix C

SHRIKE MISSILE
DETAILED TEST DESCRIPTION

LIST OF FIGURES

SHRIKE MISSILE
DETAILED TEST DESCRIPTION

Each of the seven SHRIKE baseline cookoff tests is described separately. The format for all reports is the same. General Results, Detailed Description of the Test Item, Thermocouple Locations, Characterization of the Fire, and Graphs of Uncorrected Transient Thermocouple Data. The components used to configure the various test items have already been listed in Table 1 of the body of the report. Although an attempt was made to use complete production hardware (Appendix A) wherever feasible, in many instances secondary hardware was either simulated or not used at all. The meteorological conditions varied from test to test, and are shown in Table C-1. The test set-ups are shown in Figures C-1, C-12, C-21, C-32, C-43, C-50 and C-58, which also show the heavily insulated lead-wires and flame-thermocouples.

The primary hardware, i.e., motors and warheads, were modified in that thermocouples were embedded during test-item assembly. Thermocouples (24-28 gauge) were used to minimize breakage during handling and processing. Care was taken to minimize intrinsic thermocouple installation errors. Unfortunately the size of the thermocouples precluded quantitative analysis because of the well known uncertainties associated with transient-temperature and lead errors which are large because of the good thermal insulative properties of propellants, explosives and liners. Therefore the interpretation of the thermocouple data obtained in these tests was only qualitative.

The data from each test are given as received by the recorder. It is important to note that the recorded temperature is that of the thermocouple bead, which can conceivably move during the test. Heat entering the leads from a different area and other circumstances can also warm the bead. A discontinuity can occur anywhere along the leads as a result of mechanical fracture or of burn-through caused by explosive/propellant burning. Electrical arcing across the frayed leads can also lead to spurious EMF readings.

TABLE C-1. SHRIKE Test Meteorology

Test no.	Temp, F	Humidity (Rel.)	Wind
SH 1A	95	Near 0	Calm, slight airs
7A	45	Near 0	1-3 knots S/SW
8A	70	Near 0	2 knots, SW
12A	28	30	1 knot SE
13A	100	Near 0	1 knot, E
14A	84	Near 0	6-8 knots NW
16A	75	Near 0	Calm. Occasional gusts to 3 knots

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No attempt was made to separate data as valid or invalid. Such a judgment would be purely subjective. For example, it was observed by separate test that fractured thermocouple leads will arc in a fire, and give an EMF which could erroneously be attributed to some other bead located elsewhere. Another example is the apparent exothermic behavior observed at steel case/organic liner interfaces. If the liner is properly cured it could be argued that endothermic behavior should first occur there. On the other hand, exothermic liner behavior could certainly explain the apparently premature ignition of explosive/propellants. Thermocouple data (if quantitatively correct) taken between liner and explosive/propellant suggest that auto-ignition temperatures are generally not reached prior to deflagration or explosion. Therefore, until future laboratory tests examine such phenomena, abnormally high heating of a thermocouple bead is called "apparent exothermic behavior" in these test descriptions.

Other pertinent data are times to unusually loud sounds, and light flashes recorded on audio/video tape. Post-test observations are also given. Noise intensity cannot be directly correlated to quantitative hazard or explosion analysis. Also, post-test observations by different investigators were generally not in exact agreement. Hence only those observations made in common are listed. Some information was lost in that it was difficult to reconstruct from only post-test photographs possible alternative events which conceivably could explain some of the responses indicated by the transducers

SUMMARY OF SH-1A TEST

Results

All three flame thermocouples reached an indicated flame temperature of 1000°F by 58 sec. Apparent exothermic reaction was indicated in the warhead/steel liner region by 80 sec. The potting material vented into the sand through the lower aft end of the warhead steel liner by 60 sec. Thermocouples located between the motor case and liner indicated that apparent exothermic reactions occurred by 80 sec. Many thermocouples were lost between 198 and 216 sec. Significant structural yielding of the motor casing was attributed to the weight of the sand.

Test Item Description

The item consisted of an inert motor, a control section, an inert warhead, and a guidance section (Figure C-1).

The motor casing, with a case-bonded liner, was filled with crystal-white stucco sand (#30 mesh). Ten 24-gauge chromel-alumel thermocouples (TC 1-10) were located within the motor casing (Figure C-2). The leads were routed through the sand, the aft nozzle seal, and out to the support A-frame (Figure C-1)

The inert warhead (a Mk 68 Mod 0 casing) was filled with crystal-white stucco sand (30 mesh). Fifteen 24-gauge chromel-alumel thermocouples (TC 12-26) were located as shown in Figure C-3. The internal thermocouple leads were routed aft through the upper aft bulkhead. The forward exterior thermocouple leads were routed aft through the longitudinal armament tunnel. All thermocouple leads exited through the control-section umbilical hole to the A-frame.

One thermocouple, TC 11, was attached to the outer surface of the inert motor igniter (Figure C-2). Another thermocouple, TC 27, was mounted on the fuze base (Figure C-3)

SH-1A Fire

Thermocouples were placed at the centerline plane, about six inches from the test item at the forward (TC 28), starboard (TC 29), and aft (TC 30) regions. The uncorrected output of the flame thermocouples is shown in Figures C-4a, b, and c. The fire was abornormally cool at the forward end between 86 and 92 sec.

Post-Fire Commentary

The test item is shown after the test in Figure C-5. The guidance section had fallen into the pit. A noticeable amount of structural bending was evident, suggesting that the weight of the sand in the unit was sufficient to distort the steel at fuel-flame temperatures.

The outputs of TC 1, 2, and 11, located in the forward end of the motor, are shown in Figure C-6. Apparent exothermic behavior at the head end, between the steel and liner is evidenced by TC 1 and 2 before 80 sec. By comparison, TC 11, which is on the outside of the igniter, suggests normal (non-exothermic) heat-transfer behavior up to about 260 sec, when excess heating became apparent.

The outputs of TC 3-10 in the motor are shown in Figure C-7. Apparent exothermic behavior of TC 3 and 4 (located between the steel and liner) similar to that of TC 1 and 2 is observed. TC 5-10 indicated normal heat-transfer behavior for the first 80 sec. Then apparent violent exothermic reaction or thermocouple failure is indicated for TC 5 at 419°F and 190 sec, for TC 8 at 341°F and 212 sec, for TC 9 at 184°F and 212 sec, TC 10 at 412°F and 210 sec, TC 7 at 487°F and 214 sec, and TC 6 at 448°F and 216 sec

The outputs of TC 12-15, located on the outside of the warhead, facing the guidance section, are shown in Figure C-8. The erratic output between 120 and 240 sec is attributed to venting of the potting material through two forward fill holes. After 274 sec it is possible that the guidance section was beginning to fall off the warhead, thus causing the significant rise of TC 12-14

The responses of TC 16-22 are shown in Figure C-9. A general characteristic of TC 16-19 is their double-S mode The expected thermocouple response, in the absence of exothermic-endothermic phenomena is a single-S mode In view of the responses shown in Figure C-9 it is suspected that potting material and/or cavity paint decomposition is the cause of the apparent exothermic response. This possibility is reached by noting that TC 16-19 show pronounced exothermic behavior, while TC 20 and 21, which are not on the steel liner, exhibit only the single-S shape The behavior of TC 22 is not readily explained. Sometime after 60 sec the liner weld-joint vented, as confirmed by post-test inspection of the warhead interior. The thermal response of the aft end of the warhead (Figure C-3) is shown by TC 23-26 in Figure C-10. TC 24-26 are well-behaved, and suggest that explosive auto-ignition temperatures are not reached at the aft warhead bulkhead during the first five minutes. However, TC 23 does not warm as fast as TC 19 or 21, which again suggests that exothermic reactions are occurring within the warhead liner. TC 23 indicates that events occurred at 198 sec, and again at 358 sec. The response of TC 27, located on the wall of the aft fuze well is shown in Figure C-11. An apparent event occurred around 290 sec.

SUMMARY OF SH-7A TEST

Results

All four flame thermocouples reached or exceeded an indicated temperature of 1000°F by 46 sec. The motor became propulsive at 54 sec, and all data after this time were lost. Data prior to this time were unusual, and all perhaps invalid. The manner in which the instrumentation was installed caused motor-case venting at five locations. Ignition of the grain port occurred, which is unusual in fast-cookoff tests. No pressure was evident in the port prior to ignition. The motor igniter was ejected.

Test Item Description

The item consisted of a live motor Mk 53 Mod 4 rocket (Figure C-12). Five 28-gauge chromel-alumel thermocouples (1-5) were located as shown in Figure C-13. Four of the thermocouple leads were routed through tunnels in the propellant, the port, the nozzle seal, and out to the A-frame (Figure C-12). Copper tubes were used to channel any possible gas generation from the liner region to a pressure transducer. A second pressure transducer was exposed to the grain port at the forward end of the motor through a motor-igniter attachment screw-hole (Figure C-14).

SH-7A Fire

Thermocouples were placed at the centerline plane, six inches from the test item at the forward (TC 6), starboard (TC 7), aft (TC 8), and port (TC 9) regions. The uncorrected thermocouple output of flame temperatures is shown in Figures C-15a, b, c, and d.

Post-Fire Commentary

The motor became propulsive and moved the A-frame 8 ft from the center of the pit (Figure C-16). The forward legs were buried in dirt, and the aft tie rod of the A-frame legs was bent over the ground junction. This suggests that the A-frame was airborne, pivoted about its front legs, and fell back on top of the ground junction.

Holes were burned through the motor casing at the point where the internal radial instrumentation was embedded (Figures C-17 and -18).

In Figure C-19 the motor igniter is seen. It was ejected with the pressure transducers, and hit the steel windscreen.

All the thermocouple data are shown in Figure C-20. Only TC 1 and 4, which were attached to the steel case, responded prior to failure of all the thermocouples in 54 sec The pressure-transducer data showed no increase in pressure until the last second, when the motor became propulsive.

Audio-visual observations suggested that the motor ignited at 54 sec, and continued to burn until 70 sec. Flames visible at the aft end indicated burning through the nozzle. The ejection of the igniter (some 15 ft) helped reduce the forward thrust. A round fragment was observed in the port side of the control section, as if it had been penetrated from the outside by a 30 cal bullet or similar object.

SUMMARY OF SH-8A TEST

Results

All four flame thermocouples reached or exceeded an indicated temperature of 1000°F by 13 sec Apparent exothermic reactions were indicated at the motor-case/liner region by 25 sec. A report heard at 70 sec may have been the motor venting. Propellant burn-out through a casing vent hole is believed to have been initiated at 70 sec. The deflagration reaction of the Mk 78 Mod 0 rocket was mild

Test Item Description

The item consisted of a live Mk 78 Mod 0 rocket, a control section, and an inert warhead (Figure C-21) Sixteen 28-gauge chromel-alumel thermocouples (TC 1-16) were located as shown in Figure C-22 The thermocouple leads were routed through the liner, the nozzle seal, and out to the A-frame

The inert warhead was a Mk 80 Mod 0 casing filled with crystal-white stucco sand (30 mesh) Fifteen 24-gauge chromel-alumel thermocouples (17-31) were located as shown in Figure C-23 The leads of TC 21-27 were routed through a hole in the upper aft bulkhead Leads of TC 17-20 were routed aft through the armament tunnel

SH-8A Fire

Thermocouples were placed at the centerline plane six inches from the test item at the forward (TC 32), starboard (TC 33), aft (TC 34), and port (TC 35) regions. The uncorrected thermocouple outputs of flame temperatures are shown in Figures C-24a, b, c and d The forward flame thermocouple was abnormally cool between 130 and 140 sec. TC 32 and 33 failed at 155 sec

Post-Fire Commentary

The bottom of the rocket motor was consumed, as shown in Figures C-25 and -26 In Figure C-26 the nozzle section of the motor, still containing its seal, is shown lying on the ground The warhead section is shown, held by the A-frame at one end, and lying on the ground at the other. Figure C-25 shows the extent to which the motor casing was consumed.

The responses of the thermocouples in the motor and at the boundary are shown in Figures C-27 and -28. Apparent exothermic reaction after some 25 sec is indicated by TC 3 and 4. The double-S response, TC 2 and 5, suggested exothermic behavior. These thermocouples had been welded to the motor case adjacent to the liner. This apparent exothermic behavior is not observed for TC 6 to 9. All the boundary thermocouples, which were between the liner and the propellant, failed by 100 sec.

Internal thermocouples 10-16 (Figure C-28), located in the motor port region, exhibited a small response after 60 sec. All failed by 155 sec. The output of TC 1, attached to the outer motor bulkhead, is shown in Figure C-27. Its heating rate is less than that of TC 2-5.

The double-S mode exhibited by TC 21 and 23-27 are not attributed to exothermic reaction in the liner, although this could have occurred, because the intense heating was primarily generated by the deflagration of the motor. Note that the heating rates of the thermocouples are much greater than those of their counterparts in the SP-3A tests.

Outputs from warhead thermocouples 17-20 are shown in Figure C-29. Apparent exothermic responses from TC 17 and 18 may be attributed to gases from potting material decomposition, venting through the two cube loading holes adjacent to the warhead cup. These thermocouples failed by 220 sec (Figure C-30). The outputs of the warhead thermocouples 28-31 which failed at 235 sec, are given in Figure C-31.

A sound was heard at 70 sec, which may have been the motor venting. A burning sound was also heard between 150 and 155 sec.

SUMMARY OF SH-12A TEST

Results

All four flame thermocouples reached or exceeded an indicated temperature of 1000°F by 19 sec. Apparent exothermic reactions were indicated at the motor-case/liner interface by 28 sec. A report heard at 57 sec may have been the motor venting. No significant grain-bore pressure build-up was recorded. Transient local heat-flux measurements reached an uncorrected value of 4 BTU/ft^2-sec. and were in phase with a temperature rise-rate of the flame thermocouple. By 90 sec the propellant was burning. Apparent exothermic reaction in the inert warhead liner region was indicated before 120 sec. The deflagration reaction of the Mk 78 Mod 0 motor was mild.

Test Item Description

The test item (Figure C-32) was made up of a live motor (Mk 78, Mod 0), a control section, and an inert warhead. Sixteen 28-gauge chromel-alumel thermocouples (1-16) were located, as shown in Figure C-22 of test SH-8A The leads were routed through the liner, the nozzle seal, and out to the A-frame. A pressure transducer was attached to the igniter to sense bore pressure. A heat-flux transducer was attached to the side of the motor case.

The inert warhead was a Mk 68 Mod 0 casing filled with crystal-white stucco sand (30-mesh).

Fifteen 24-gauge chromel-alumel thermocouples (TC 17-31) were located as shown in Figure C-23 of test SH-8A. Leads of TC 17-20 were routed aft through the armament tunnel. The leads of TC 21-27 were routed through a hole in the upper aft bulkhead. All the leads were routed out the umbilical hole to the A-frame.

SH-12A Fire

Thermocouples were placed at the centerline plane six inches from the test item at the forward (TC 32), starboard (TC 33), aft (TC 34), and port (TC 35) regions. The uncorrected outputs of flame temperatures are shown in Figures C-33a, b, c and d. The forward thermocouple was abnormally cool between 48 and 58 sec, and again between 74 and 86 sec. The starboard thermocouple was lost at 138 sec. The aft thermocouple was abnormally cool at 36 sec, again between 58 and 74 sec, and again between 138 and 166 sec. The port thermocouple was lost at 108 sec.

Post-Fire Commentary

The bottom of the rocket motor (propellant and case) was consumed (Figures C-34 and C-35). The warhead section is shown held by the A-frame at one end, and lying on the ground at the other.

The responses of the thermocouples in the motor are given in Figures C-36 and C-37. Apparent exothermic reaction is indicated by TC 2 and 4 which were welded to the motor case adjacent to the liner. Failure of TC 2-9 occurred before 104 sec, and was probably due to lead-wire burn-through. TC 8 was the first to fail, and did so at 66 sec.

Thermocouples 10-16 (Figure C-37) located in the motor port region showed a small response at 56 sec, but after 128 sec began to fail.

Outputs from TC 17-20, located at the forward bulkhead of the warhead, are shown in Figure C-38. The response of TC 18 is unusual, and is not understood, unless the warhead cup had caused a mechanical interference. The responses of TC 21-27 (Figure C-39) are similar to those in Figure C-30 in test SH-8A. Outputs from warheads TC 28-31 are given in Figure C-40.

The output of the port pressure transducer is shown in Figure C-41. The response at 57 sec corresponds to a loud report heard at that time. The second response was at 130 sec. The motor was audibly burning between 90 and 127 sec. Chuffing and visible motor burning occurred between 127 and 150 sec. At 187 sec a loud metal-striking-metal sound was heard. There was no significant pressure in the grain bore during the time to burn-through.

The output of the miniature heat-flux transducer is shown in Figures C-42a, b, and c. It became detached from the motor case at 57 sec, suggesting that venting occurred. This corresponds to the pressure transducer, and the sound heard at 57 sec.

SUMMARY OF SH-13A TEST

Results

All four flame thermocouples reached or exceeded an indicated temperature of 1000°F by 32 sec. By 113 sec apparent exothermic reaction was initiated at the warhead explosive/liner region. All data were lost after 128 sec, when a loud explosion was heard. The reaction of the Mk 68 Mod 0 warhead was considered to be an explosion.

Test Item Description

The item consisted of an empty motor case, an incomplete control section, and a live Mk 68 Mod 0 warhead (Figure C-43). Fifteen 24-gauge chromel-alumel thermocouples 1-15 were located as shown in Figure C-44. The leads for TC 1-4 were routed aft through the armament tunnel. The leads for TC 5-11 through the upper aft bulkhead. A thermocouple TC 16 was placed on the outer face of the fuze on the threads of the fuze cavity. TC 17 was on the forward end of the igniter. All the thermocouple leads were led out of the control section to the A-frame.

SH-13A Fire

Thermocouples were placed at the centerline plane six inches from the test item, at the forward (TC 18), port (TC 19), aft (TC 20) and starboard (TC 21) of the warhead. The uncorrected outputs are shown in Figures 45a, b, c and d The fire was abnormally cool until 128 sec, when the thermocouples failed.

Post-Fire Commentary

The warhead exploded at 128 sec. Figure C-46 showed the cloth windscreens blown down, with the empty motor case lying on the left The penetration of shrapnel through the windscreen is shown in Figure C-47, and a sample collection of the larger shrapnel in Figure C-48. The data for TC 1-13 are shown in Figure C-49. Apparent exothermic behavior is observed for TC 2, 6, 7, and 13, beginning at 113°. All thermocouples were lost at 128 sec.

The heating of TC 2 may be attributed to the venting of potting material decomposition gases through the two holes in the forward bulkhead. The accelerated heating of TC 6 and 7 is also attributed to exothermic potting material decomposition Note that TC 8 is hotter than either TC 4 or TC-12. Only exothermic reaction of the potting material/cavity paint can account for this.

All the missile components separated. The control section was in large fragments, but the motor case was fairly intact. One large (full-length quarter circumference) warhead case fragment was found 30 ft to port, and a small section under the A-frame. The warhead inner liner was scattered about. Some explosive fragments were strewn to port and forward. The guidance section was found 60 ft in front of the A-frame.

SUMMARY OF SH-14A TEST

Results

All four flame thermocouples reached or exceeded an indicated temperature of 1000°F by 34 sec. By 84 sec an apparent exothermic reaction was initiated in the warhead/liner region. All data were lost after 109 sec when a loud noise was heard. The reaction of the Mk 80 Mod 0 warhead was considered to be an explosion.

Test Item Description

The item, shown in Figure C-50, consisted of an empty motor case, an incomplete control section, and a live Mk 80 Mod 0 warhead. Sixteen 24-gauge chromel-alumel thermocouples (1-16) were located as shown in Figure C-51. The leads for TC 1-4 were routed through the armament tunnel and then through the umbilical hole to the A-frame.

SH-14A Fire

Thermocouples were placed at the centerline plane, some eight inches from the test item at the forward (TC 17), starboard (TC 18), aft (TC 19), and port (TC 20) sides of the warhead. The uncorrected thermocouple outputs are shown in Figures C-52a, b, c, and d. Because of the prevailing wind the fire was abnormally cool to the time of the explosion. The top of the A-frame was in view during the whole period.

Post-Fire Commentary

The warhead exploded at 109 sec, and blew away the windscreens with the aid of the prevailing wind (Figure C-53). The empty motor casing is seen 40 ft from the A-frame on the right. A sample of shrapnel scatter is viewed on the ground in Figure C-54, and a collection of the larger shrapnel is shown in Figure C-55 The data for TC 1-4, shown in Figure C-56, are well-behaved. Differing from the other tests, TC 2 shows no response to possible venting of potting material through the two manufacturing holes. It is not known if TC 1 and TC 2 were insulated when they were attached to the destruct-cup (cone). The thermocouple data for TC 5-9, 11 are shown in Figure C-57. TC 10 gave no data. Apparent exothermic behavior of TC 8 and TC 11 began at 84 sec. All thermocouples were lost at 109 sec, coinciding with the visible explosion occurring at that time The responses of TC 12-16 are shown in Figure C-58 The heating rates of TC 8 and TC 11 are much greater than that of TC 12, suggesting exothermic behavior by the potting material and/or cavity paint

All the missile components separated The motor case, with part of the control section attached, was thrown directly aft, about 40 ft from the A-frame. The partial guidance section, and the remains of the control section were in the pit forward of the A frame. Many large fragments, approximating one-half of the warhead body, were found. The forward bulkhead was found (crumpled) in one piece Also found were the armament tunnel and the canister fuze well. The floor of the pit was littered with individual frag cubes, and two clusters of cubes about 1.5-inch square were also found. All the explosive had been consumed The A-frame showed no frag cube damage, but the asbestos cloth around the pit showed numerous impacts.

SUMMARY OF SH-16A

Results

All four flame thermocouples reached or exceeded an indicated flame temperature by 96 sec. By 104 sec apparent exothermic reaction in the motor-case/liner region was evident At about the same time it appeared that exothermic reaction had begun at the warhead steel liner/potting material/cavity paint interface regions. A loud explosion occurred at 122 sec, when all data were lost. It is probable that this explosion occurred in the rocket motor. The chain of events that might have taken place is speculative. However, it is probable that the Mk 39 Mod 7 rocket motor ignited at 104 sec, and at 122 sec exploded with sufficient thrust to move the A-frame and break all the thermocouples leading to the recording facility. At 169 sec the Mk 68 Mod 0 warhead may have exploded. At 316 sec another explosion occurred, which may have been the Mk 330 fuze.

Test Item Description

The item (Figure C-59) consisted of a guidance section, a live warhead, a control section, and a live motor (a grain case-bonded Mk 39 Mod 7). Sixteen 24-gauge chromel-alumel thermocouples (1-11 and 28-32) were located as shown in Figure C-60. The leads were routed through the liner, the nozzle seal, and out to the A-frame

The live warhead was a Mk 68 Mod 0. Fifteen 24-gauge chromel-alumel thermocouples (12-26) are located as shown in Figure C-9 The internal thermocouple leads were routed through the upper aft portion of the bulkhead. The forward exterior thermocouple leads were routed aft through the longitudinal armament tunnel All thermocouple leads exited through the umbilical hole to the A-frame.

A thermocouple (TC 27) was mounted on the fuze-face threads.

SH-16A Fire

Thermocouples were placed at the centerline plane about six inches from the test item, at the forward (TC 32), starboard (TC 33), aft (TC 34), and port (TC 35) regions. The uncorrected thermocouple output of flame temperatures is shown in Figures C-61a, b, c, and d. It took 96 sec for all the thermocouples to reach or exceed an indicated temperature of 1000°F, denoting a relatively slow and cool heating period.

Post-Fire Commentary

The test item exploded violently (Figures C-62–C-67). The A-frame is seen overturned in Figure C-62. Heavy steel windscreens were turned over, and the test chamber littered with debris. The guidance section was ejected forward and entwined in the submarine netting (Figure C-63). An external view of damage to the test cell is seen in Figure C-64. The control section was found in a corner of the pit (Figure C-65). The aft end of the motor was ejected, and intercepted by the steel windscreens (Figure C-65). Chunks of explosive and warhead parts are shown gathered in Figure C-67.

Apparent exothermic reaction in the motor steel case/liner region (before loss of all thermocouples at 122 sec) is evidenced by TC 2 and TC 3 in Figure C-68. TC 1 shows thermocouple failure at 104 sec, which may indicate that the propellant had auto-ignited before that time, producing the heat necessary to cause the thermocouple leads to fail. None of the thermocouples between the liner and propellant (TC 5-8) indicated liner degradation or significant heating to suggest propellant auto-ignition.

The only other thermocouple in the motor to respond prior to thermocouple failure at 122 sec was TC 29 (Figure C-69), showing an apparent exotherm.

Data from thermocouples in the warhead are shown in Figures C-70 and C-71. Significant exothermic behavior is not obvious. Again it is observed that a thermocouple between the explosive and steel case, i.e., TC 20, is significantly warmer than thermocouples attached directly to the steel case, i.e., TC 15 and TC 23. All the thermocouples were well-behaved, rising monotonically with time until all the thermocouples failed at 122 sec.

Visual and audio recordings registered a very loud explosion at 122 sec. A smaller but still loud explosion registered at 169 sec, a small noise at 245 sec, and a sharp explosion with light emission at 316 sec.

Large warhead fragments (long strips) totalling about one-half of the warhead case, were scattered at the north end of the bay. One fragment was embedded in the north windscreen. About 12 pounds of explosive (Figure C-67) were recovered at the north end of the bay.

The guidance section, Figure C-63, exhibited little fire damage. The aft two-thirds of the motor case was at the northwest edge of the pit, while the control section with the forward eight inches of motor case, was lying at the southwest corner.

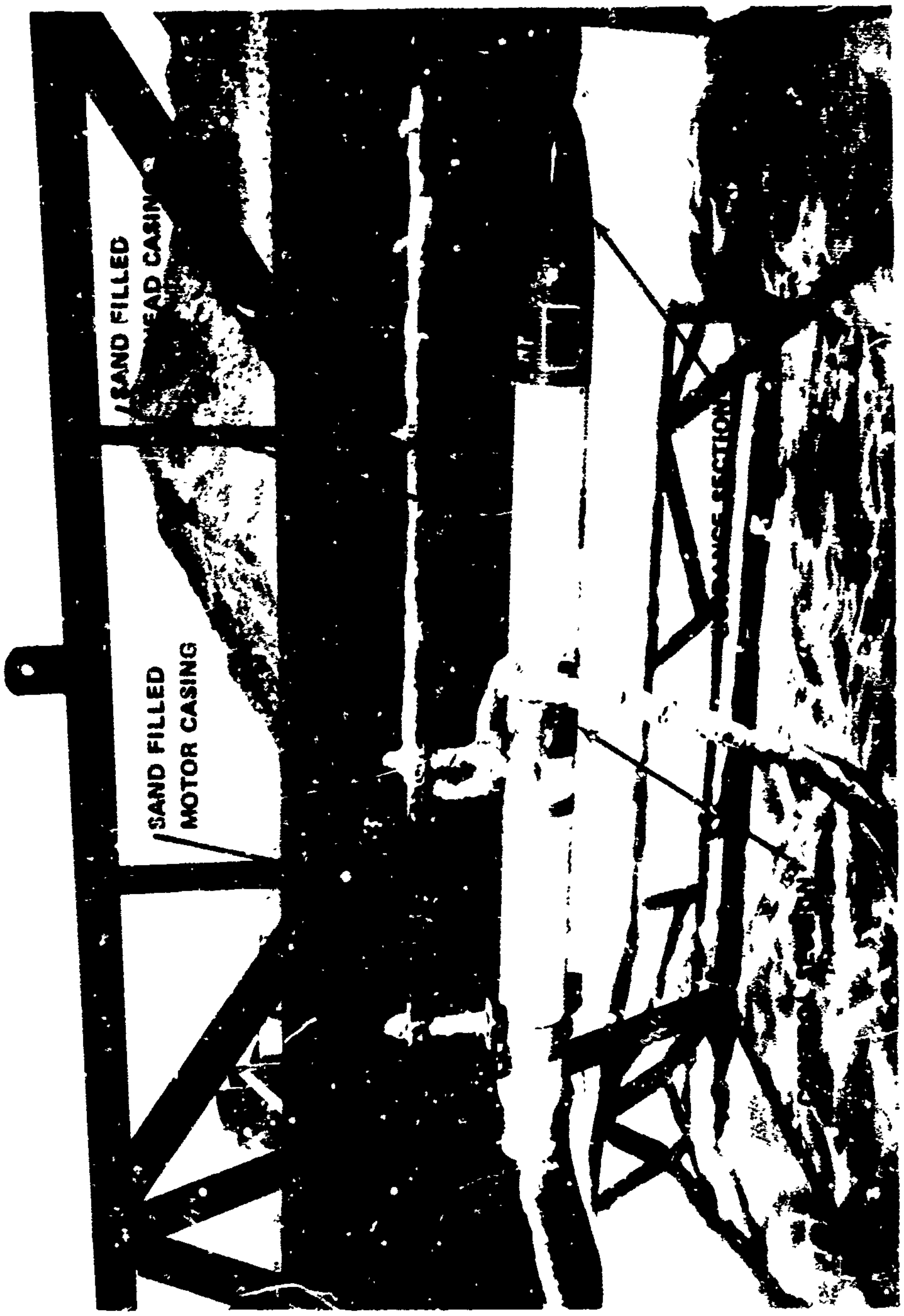

FIGURE C-1. SHRIKE SH-1A Test Configuration.

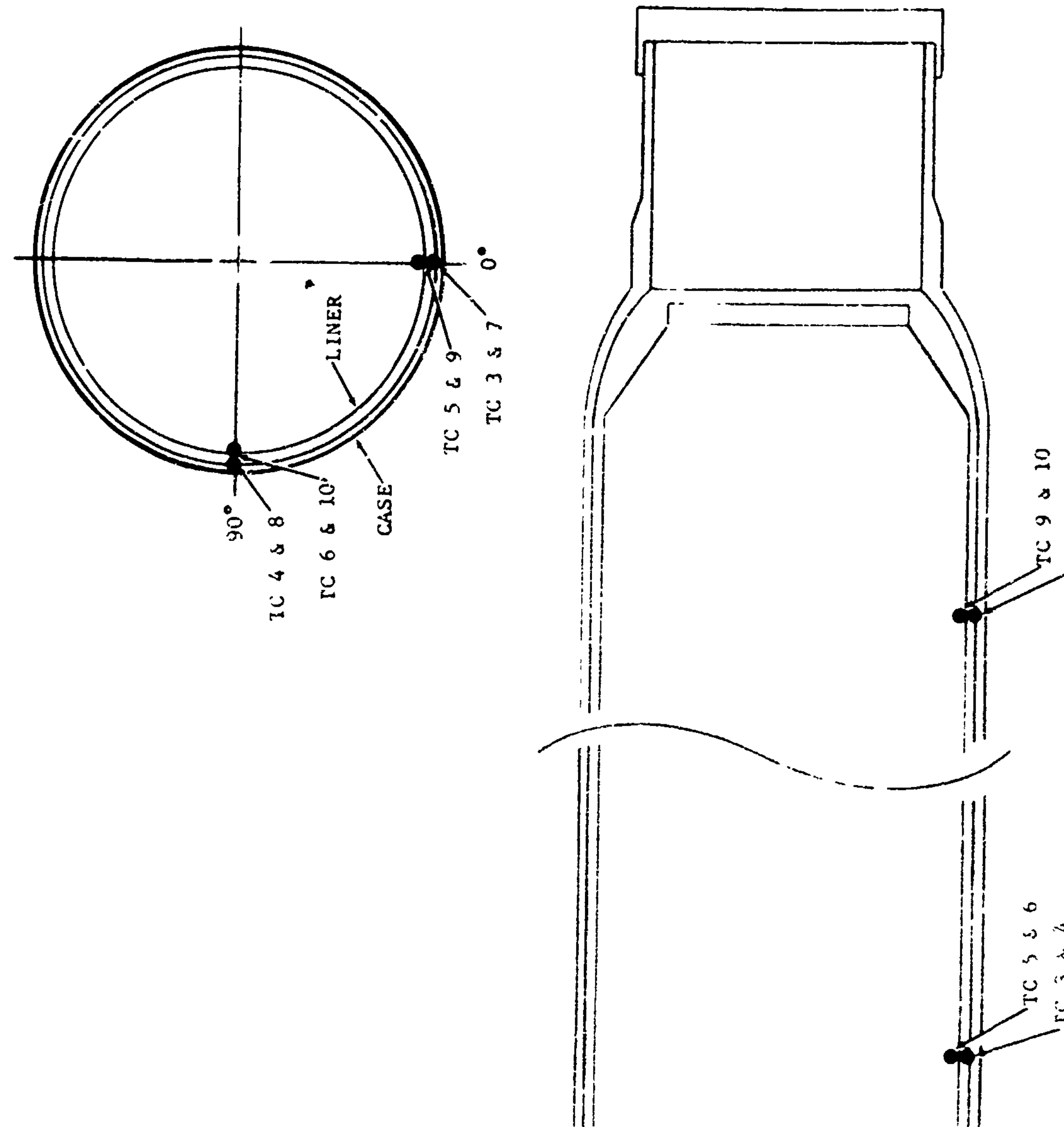

FIGURE C-2. MK 39 Mod 7 Motor Thermocouple Locations

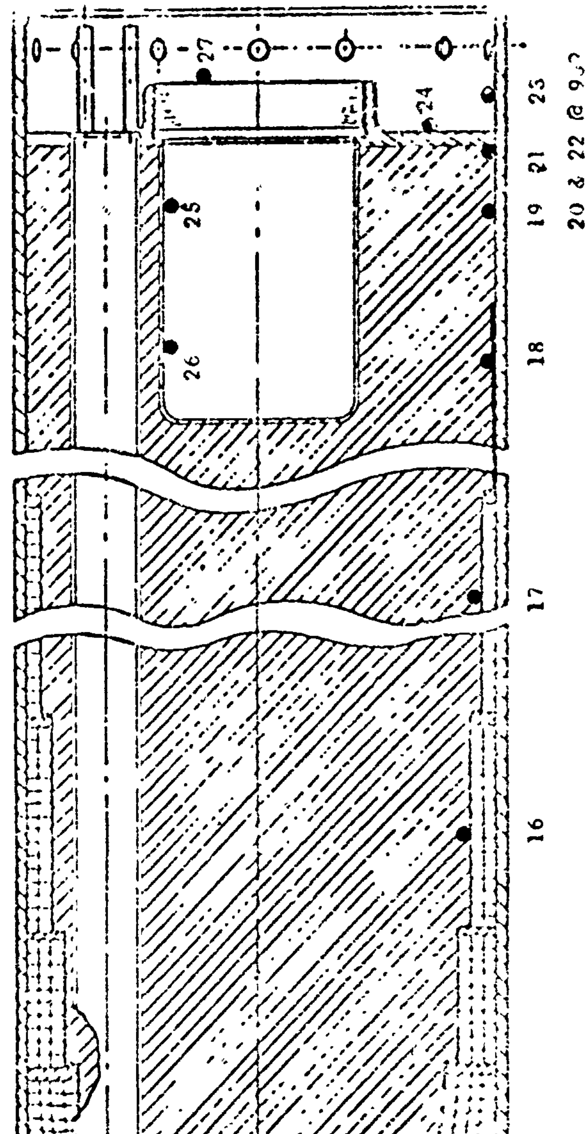

FIGURE C-5. Mk 68 Mod 0 Warhead Thermocouple Locations.

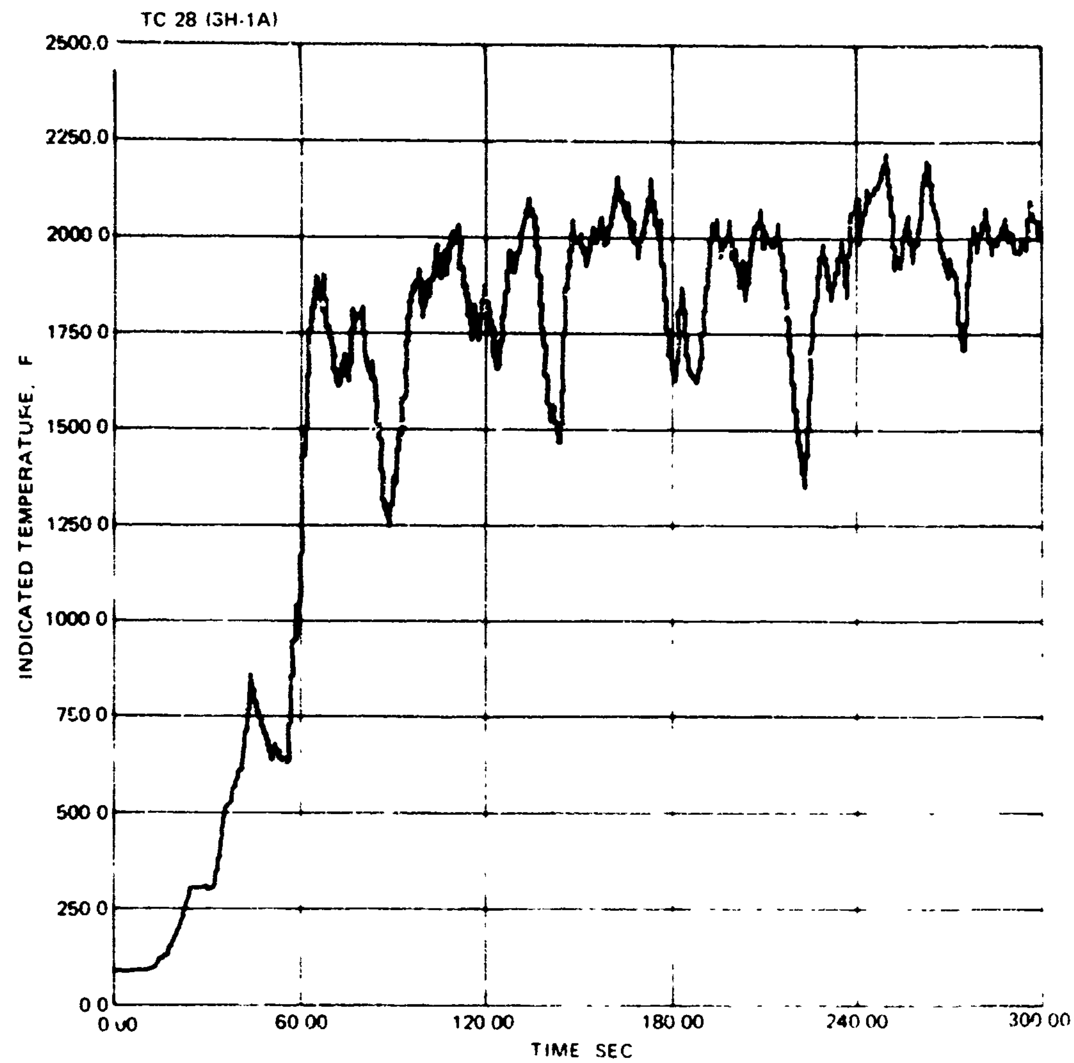

FIGURE C-4a. TC 28, Forward Flame Thermocouple SH-1A

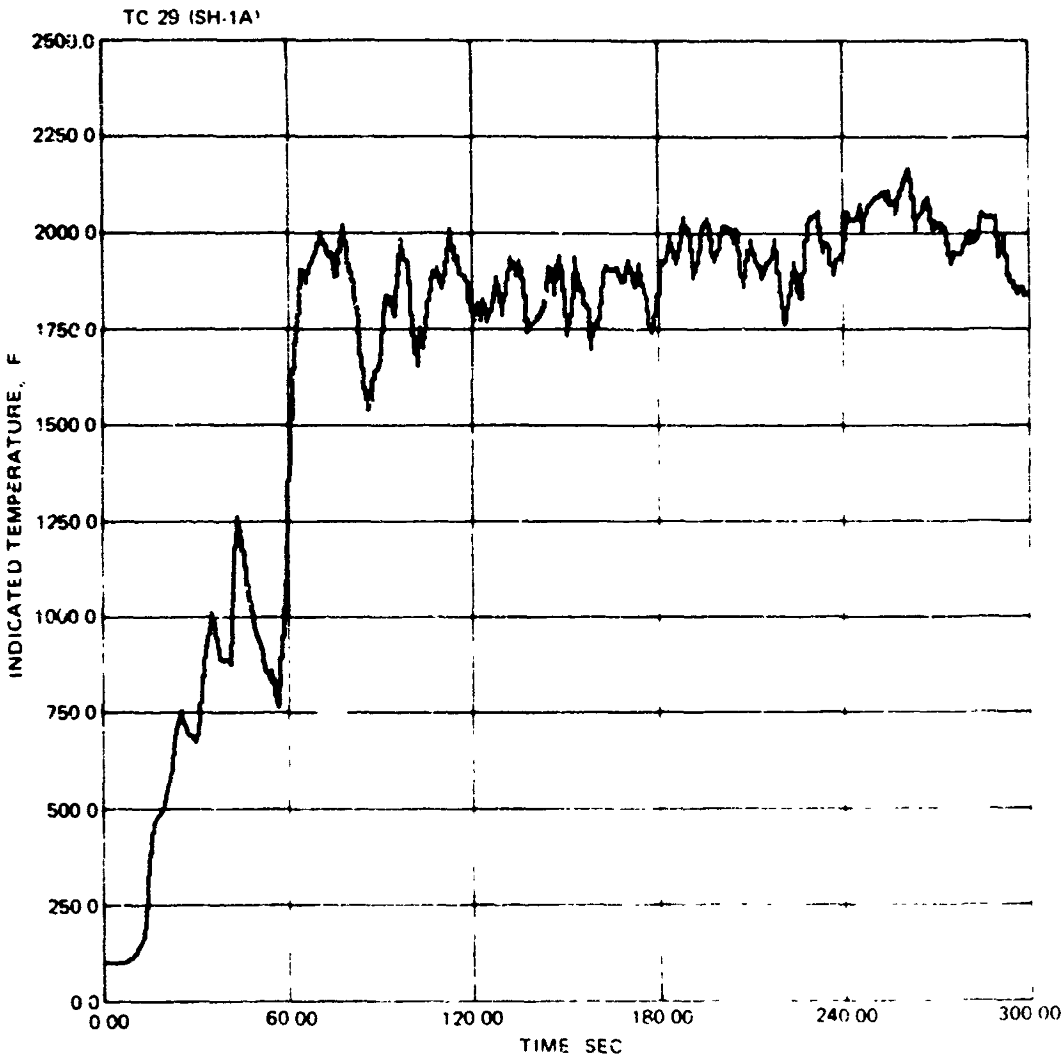

FIGURE C-4b. TC 29, Starboard Flame Thermocouple SH-1A.

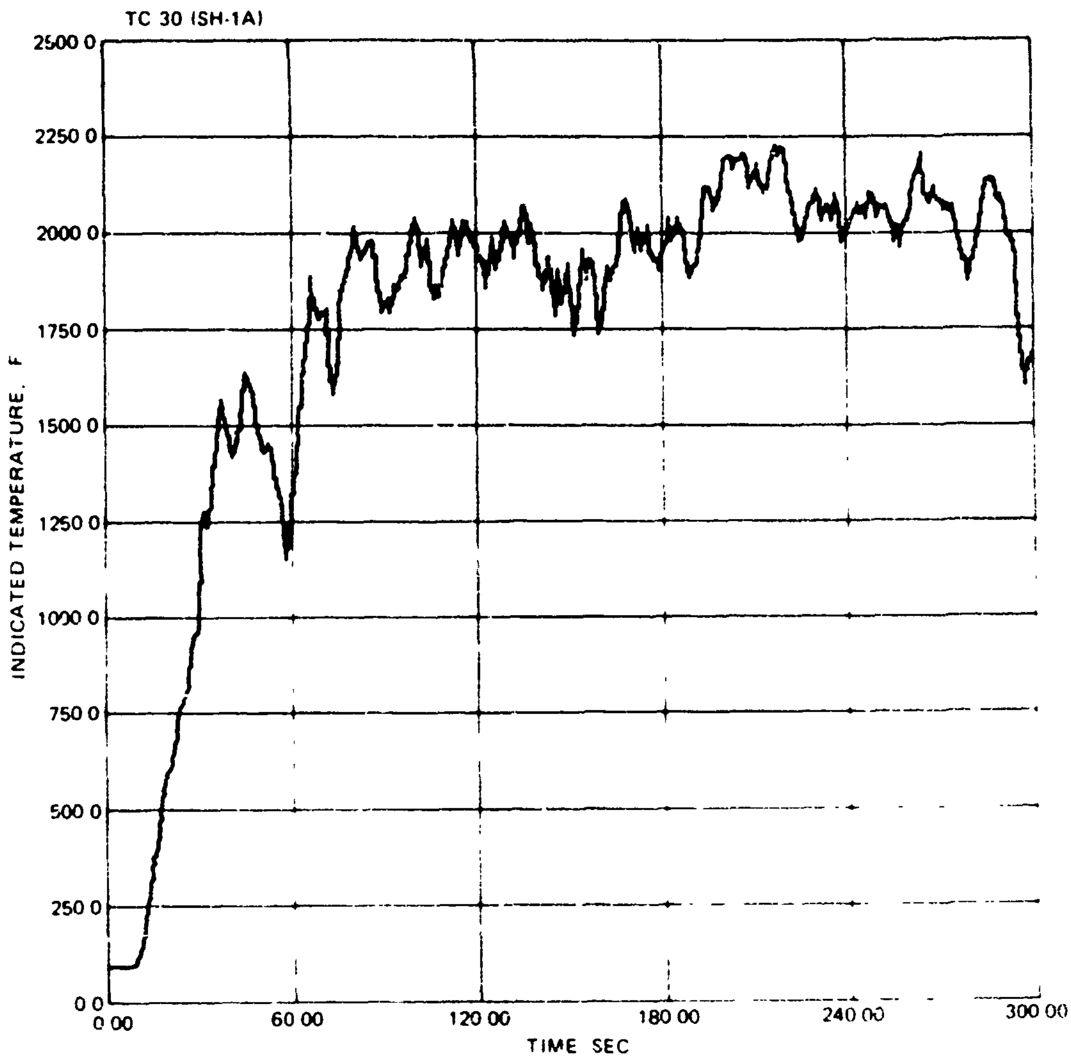

FIGURE C-4c. TC 30, Aft Flame Thermocouple SH-1A

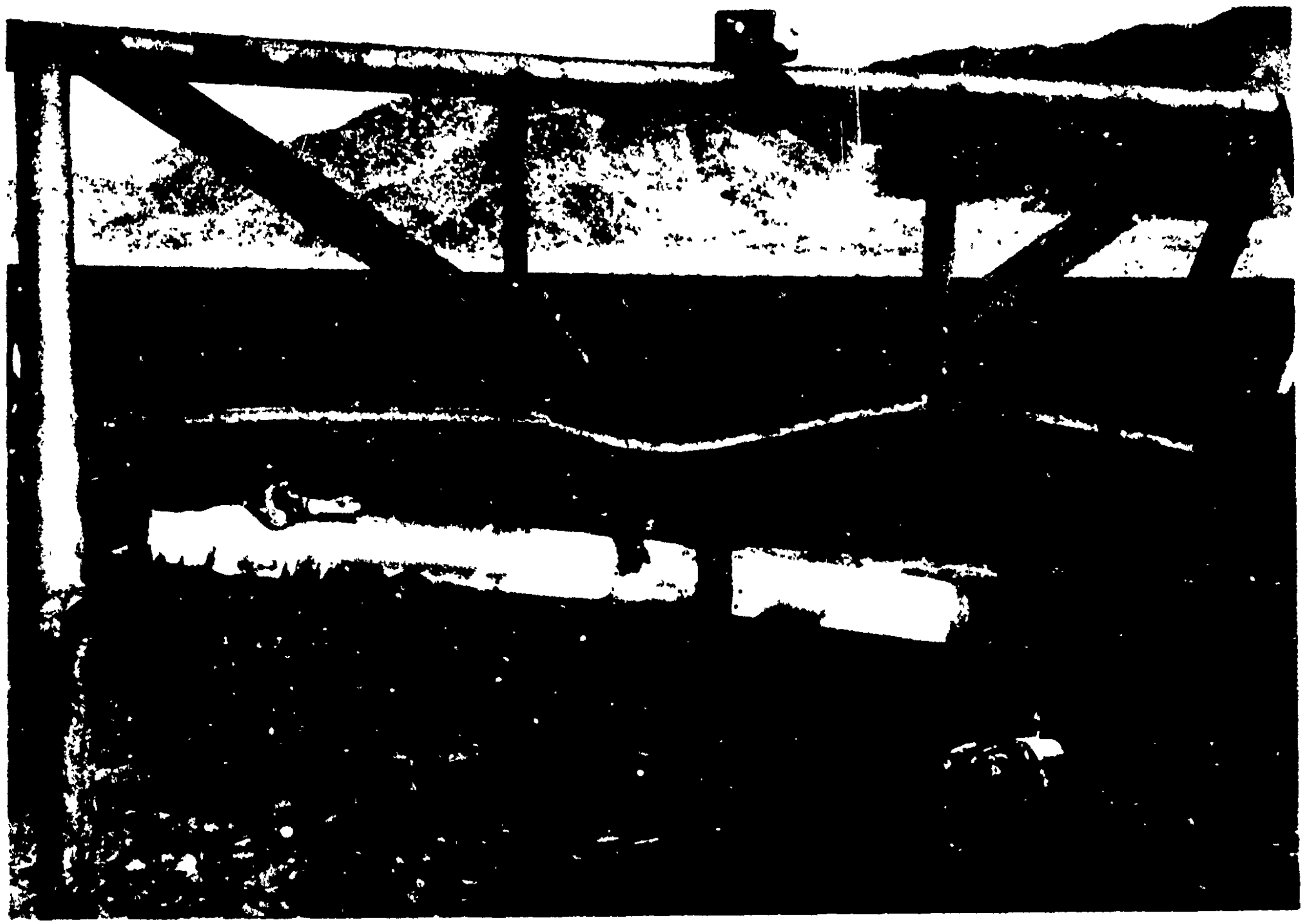

FIGURE C-5. SHRIKE SH-1A Post Test Configuration

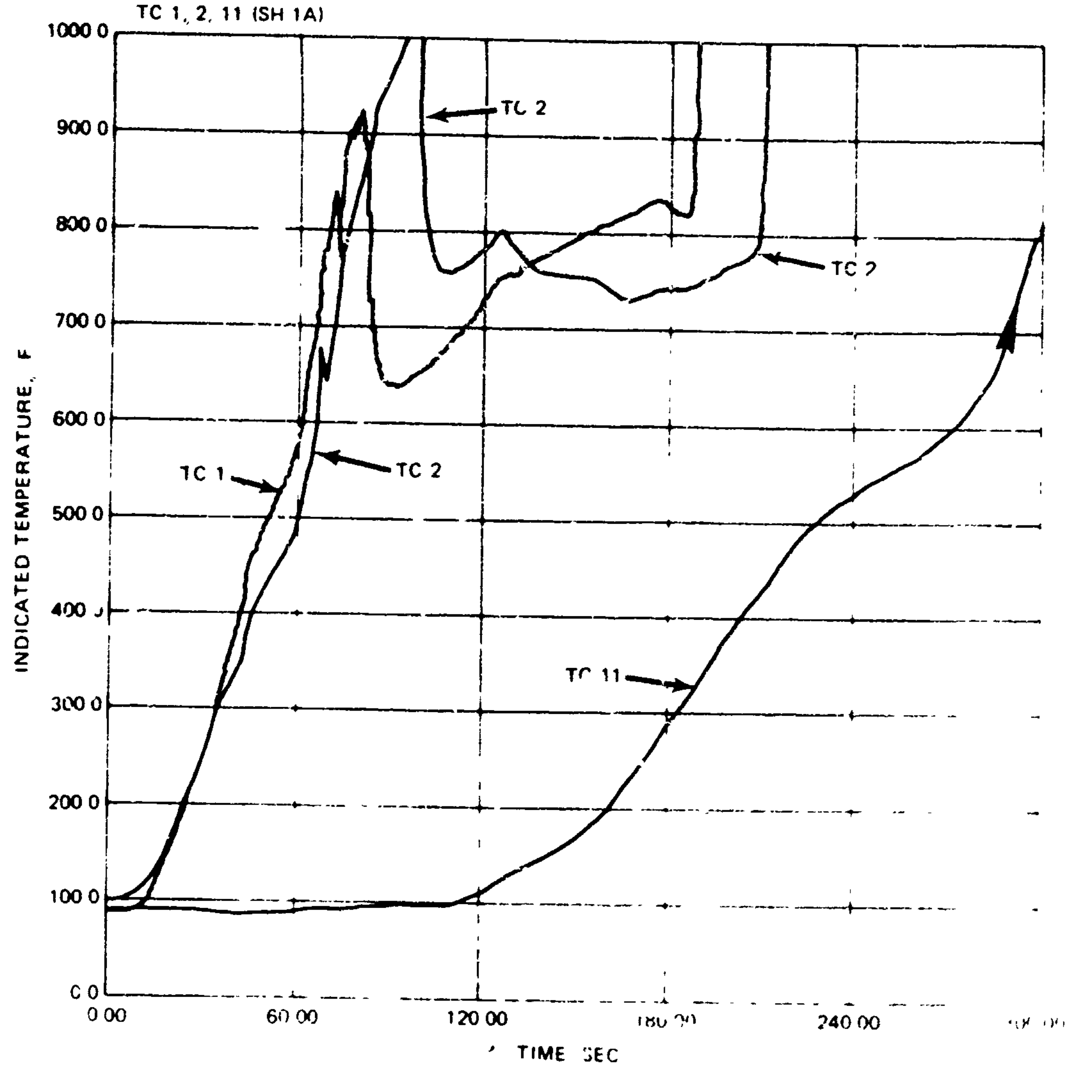

FIGURE C-6. TC 1, 2, 11 Response, SH-1A

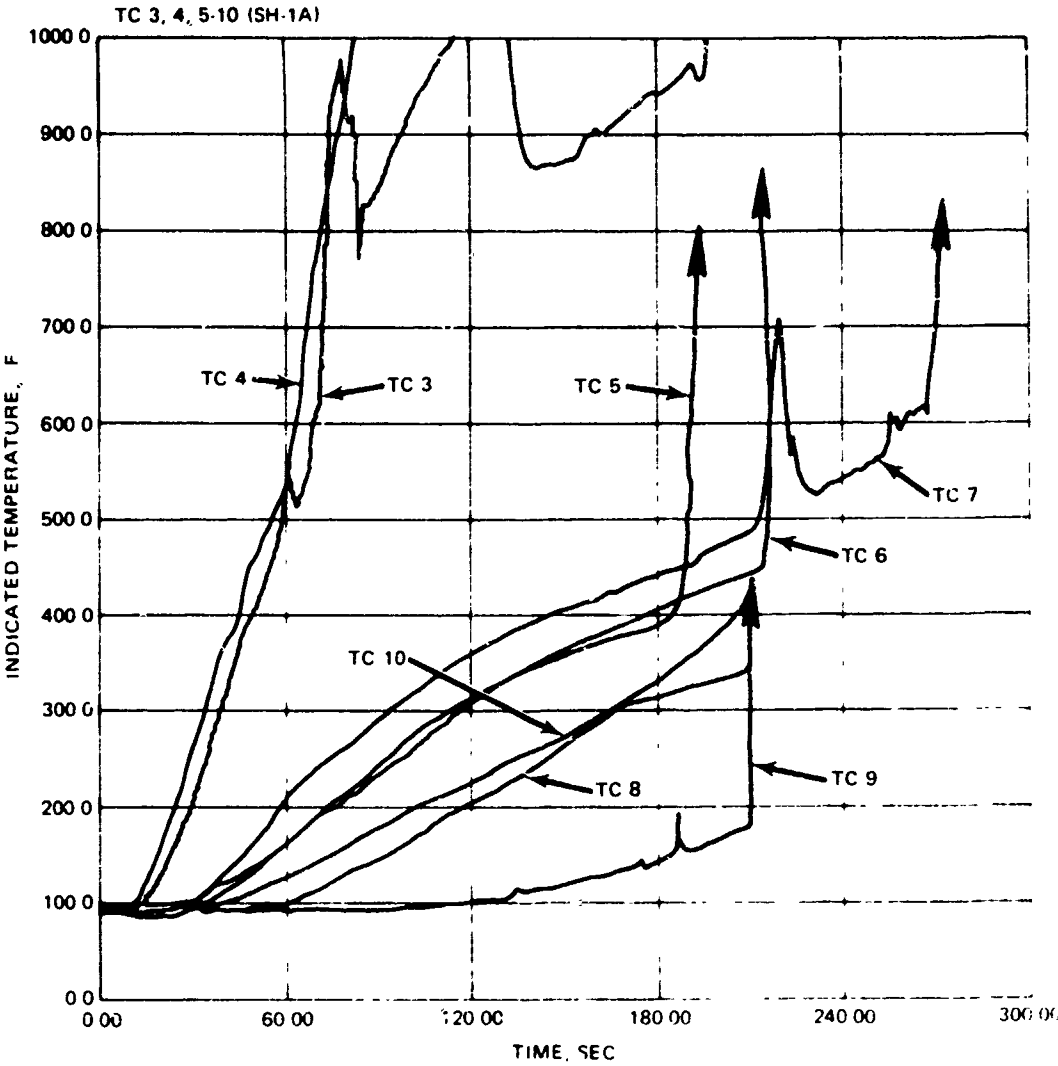

FIGURE C-7. TC 3-10 Response, SH-1A

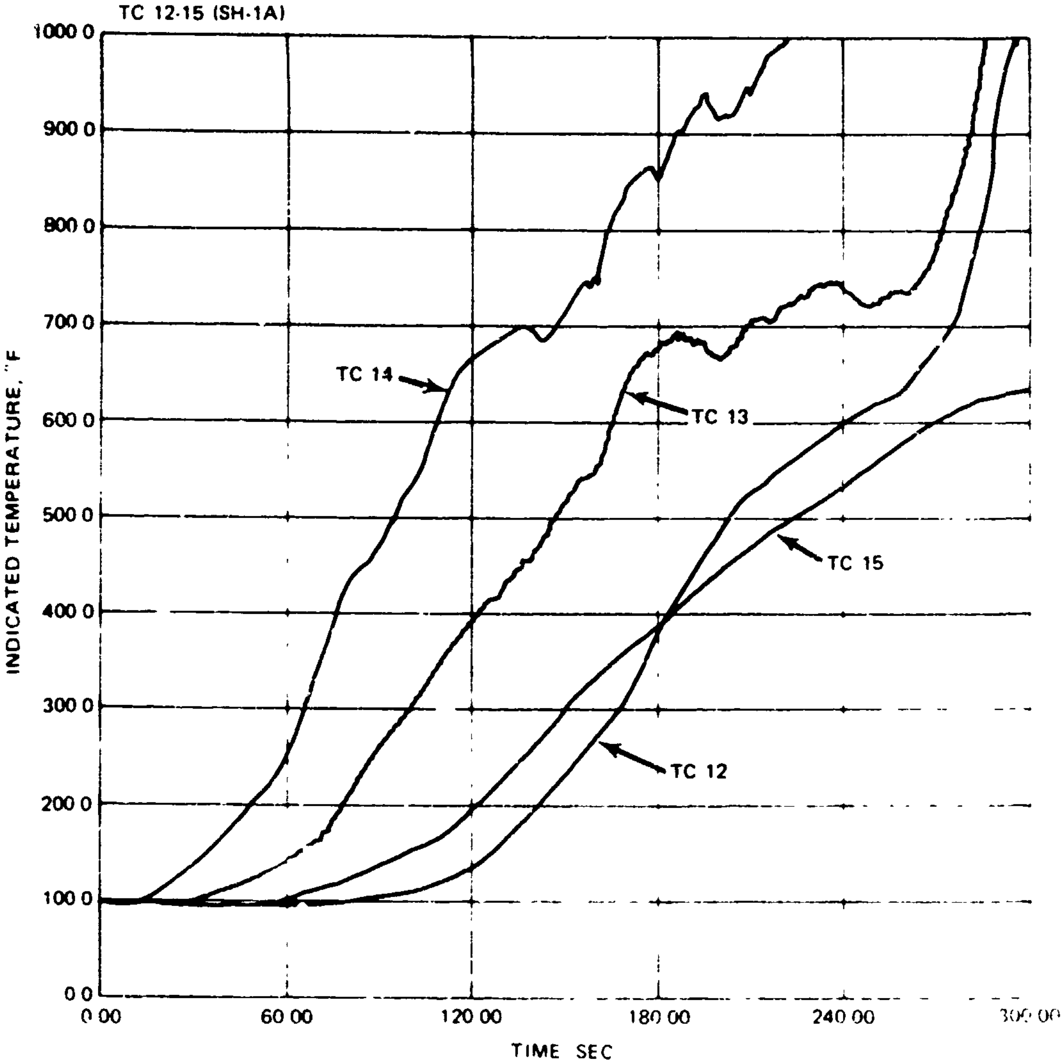

FIGURE C-8 TC 12-15 Response, SH-1A

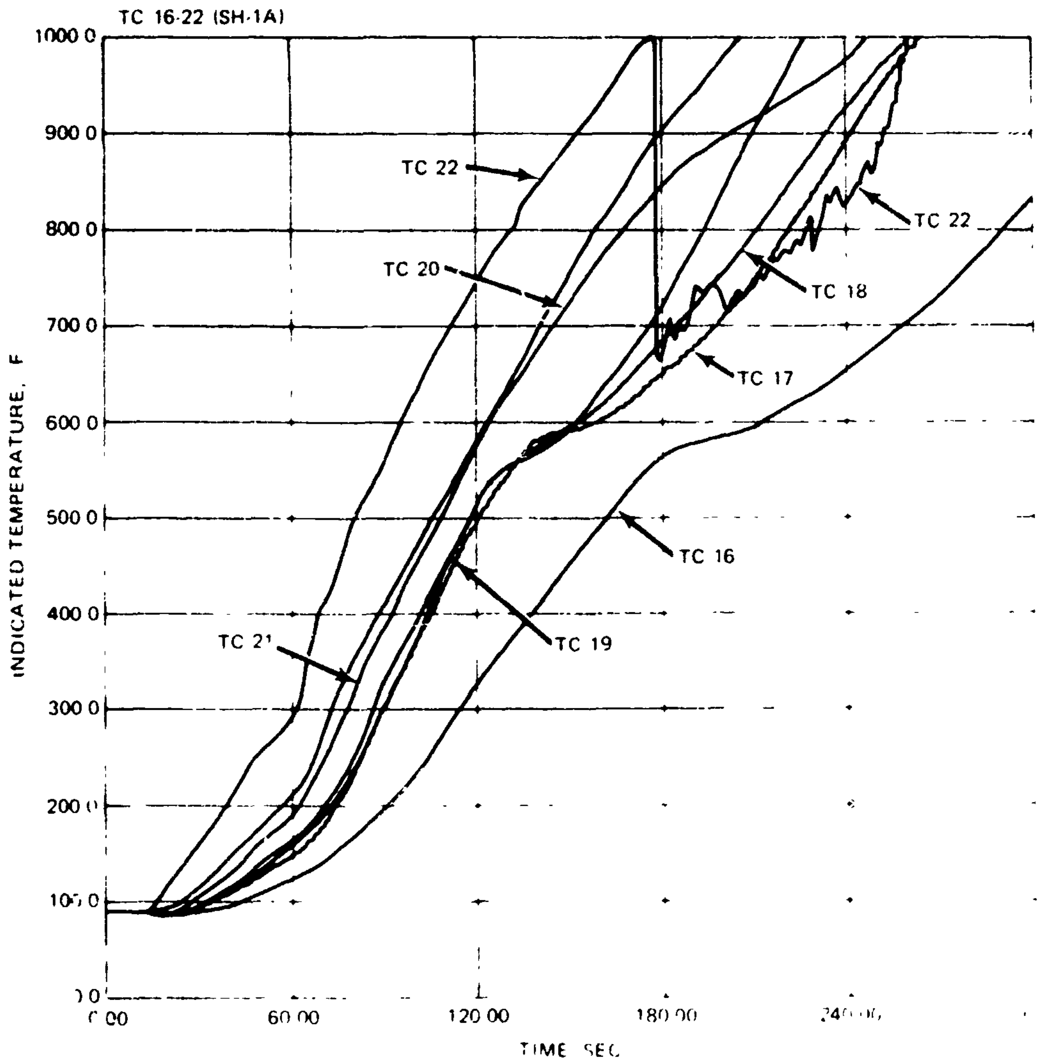

FIGURE C-9. TC 16-22 Response SH-1A

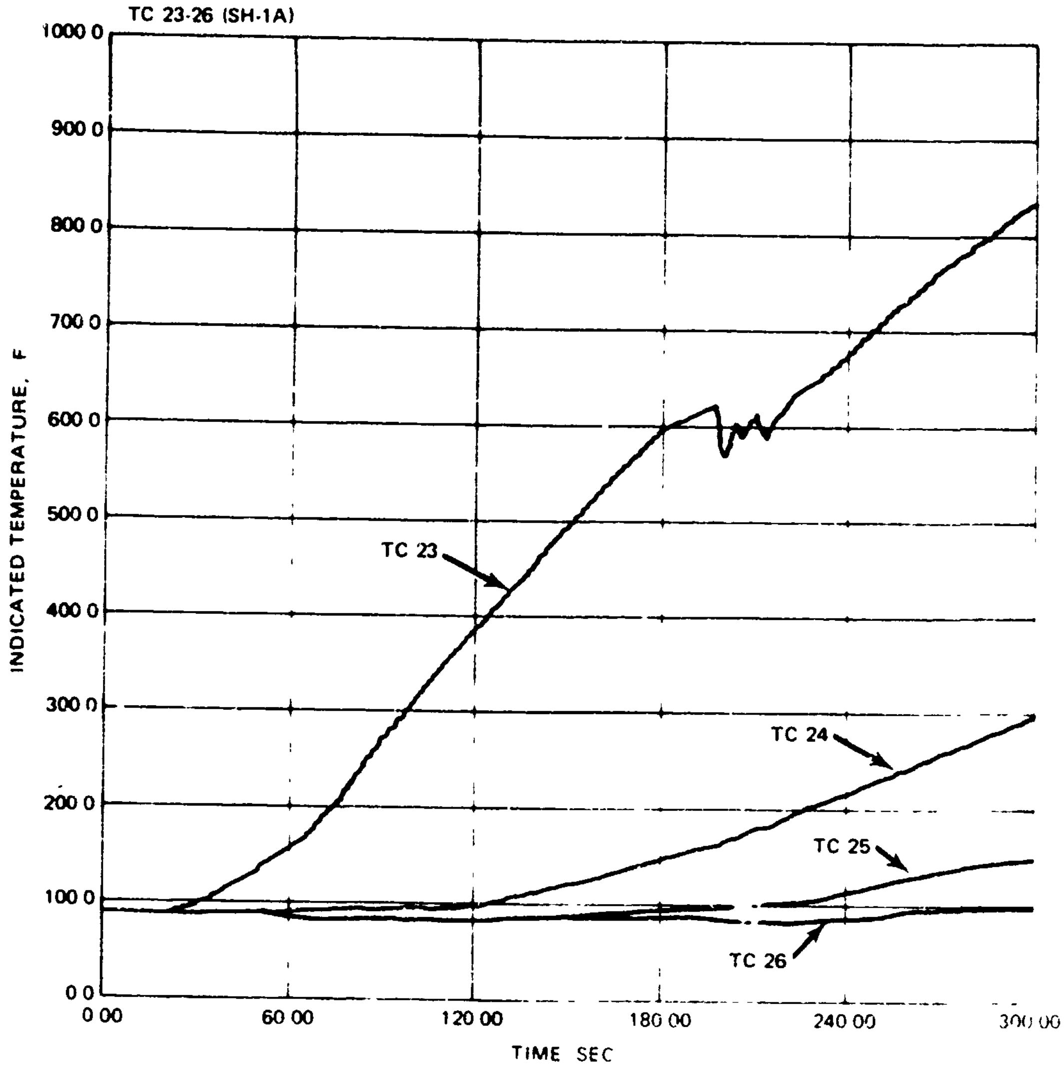

FIGURE C-10 TC 23-26 Response, SH-1A

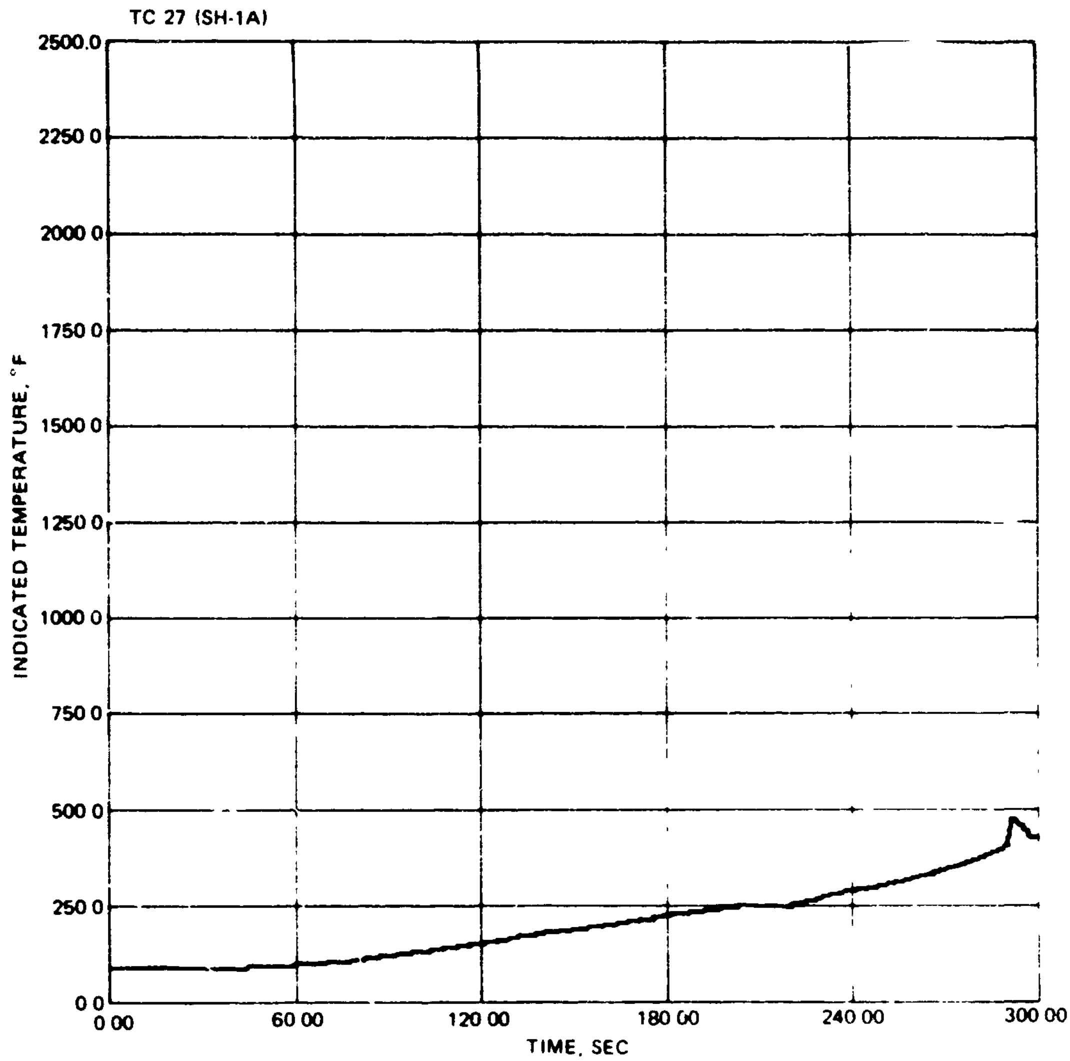

FIGURE C-11. TC 27 Response, SH-1A

FIGURE C-12. SHRIKE SH-7A Test Configuration.

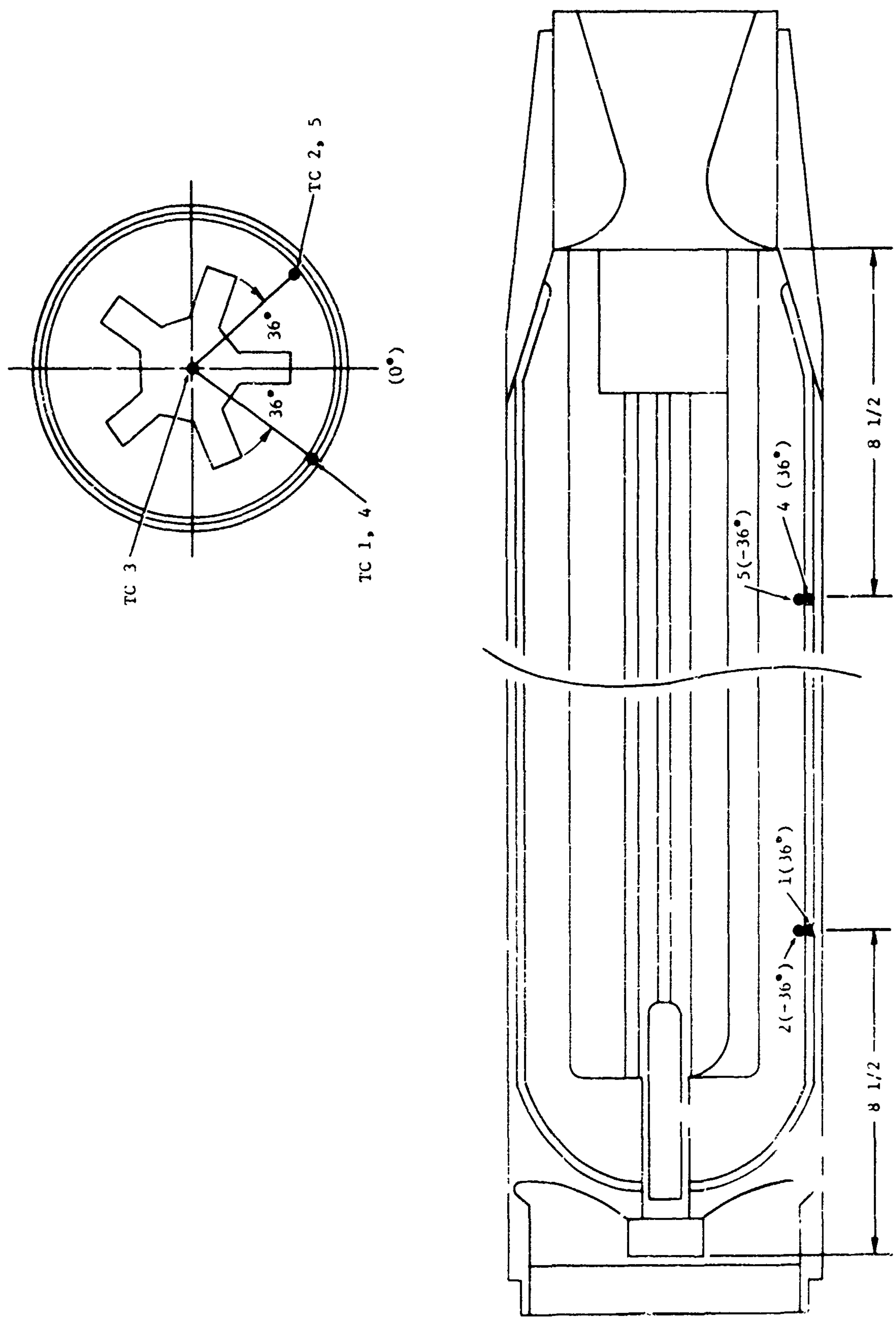

FIGURE C-13. Mk 53 Mod 4 Motor Thermocouple Locations.

FIGURE C-14. Pressure Transducer Installation in Forward Motor Bulkhead

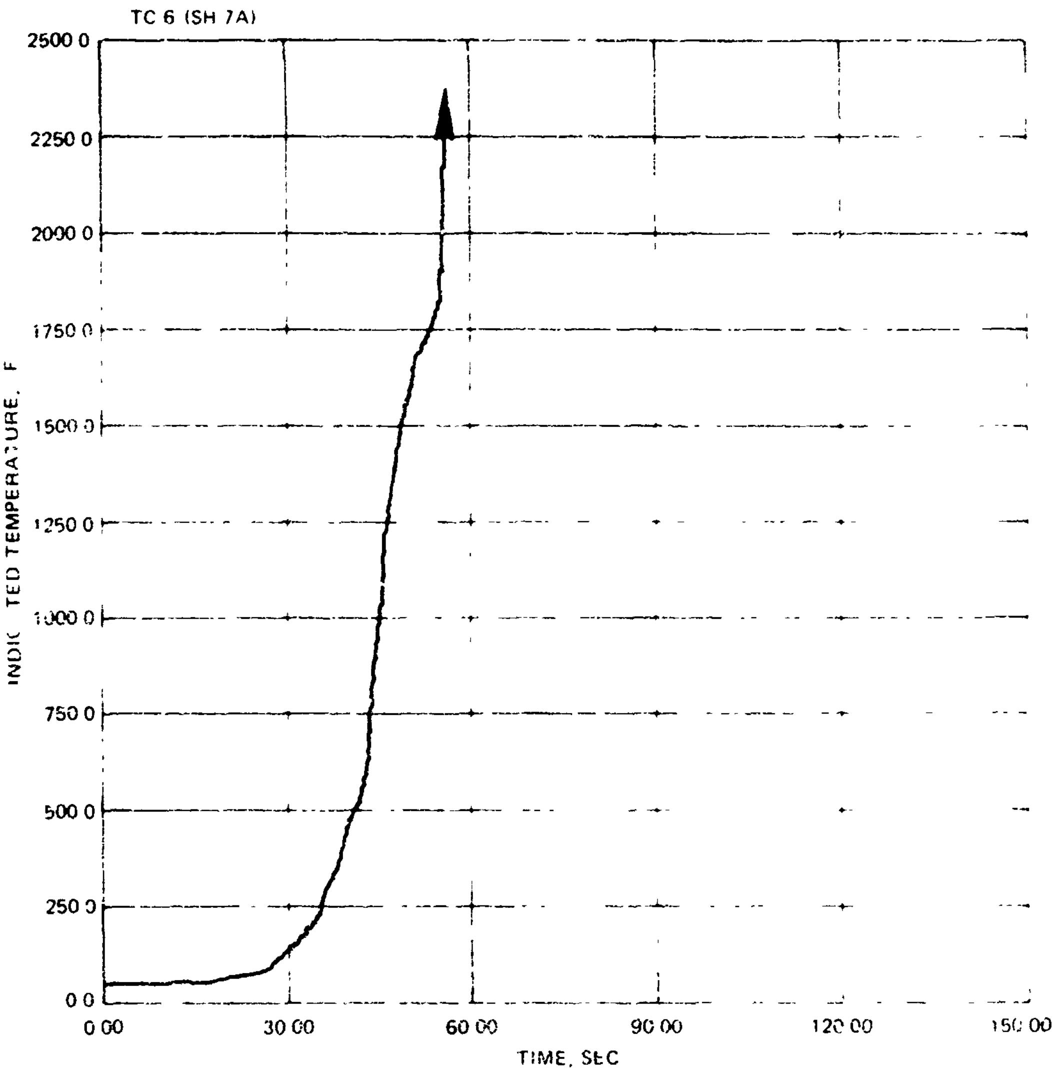

FIGURE C-15a TC 6, Forward Flame Thermocouple SH-7A

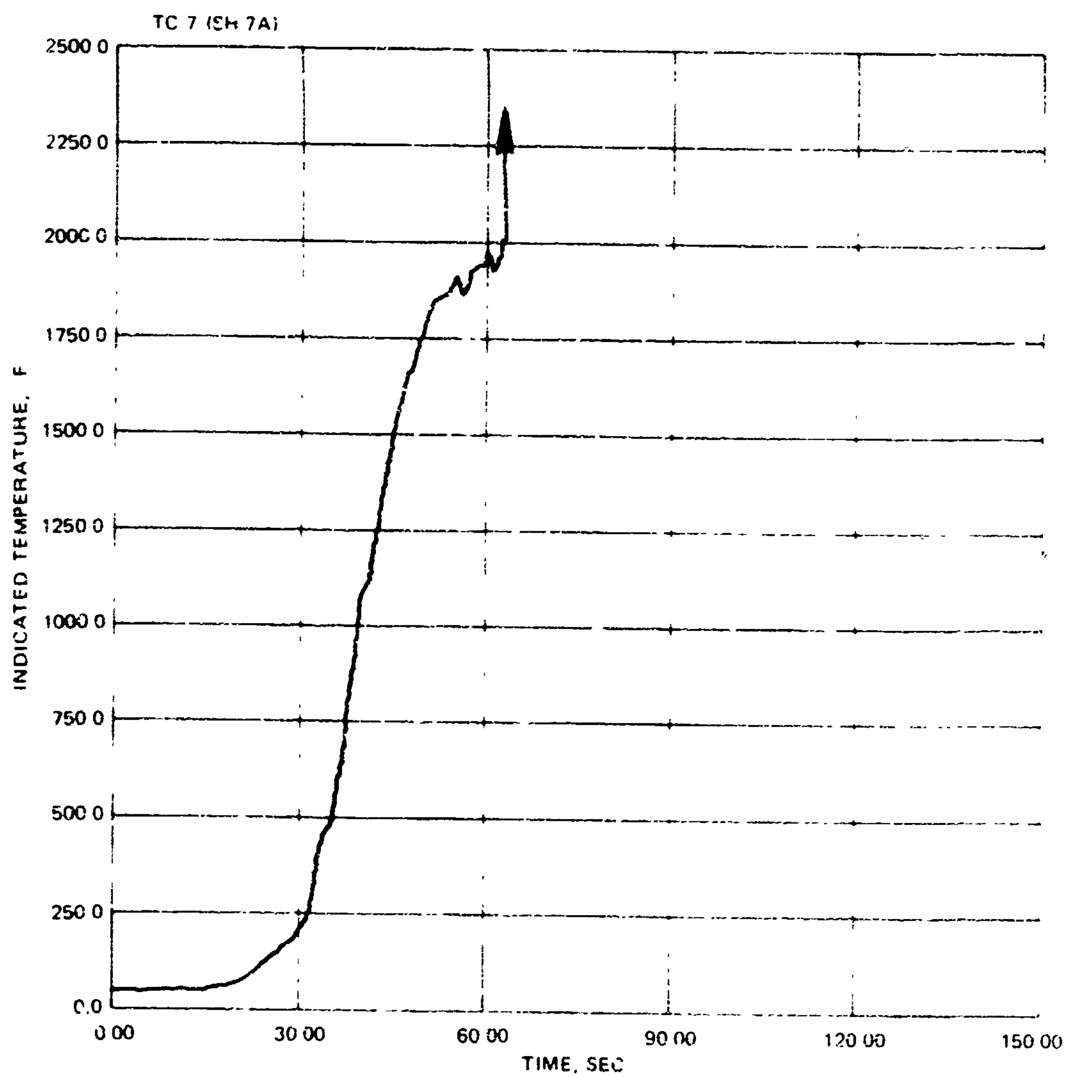

FIGURE C-15b TC 7, Starboard Flame Thermocouple, SH 7A

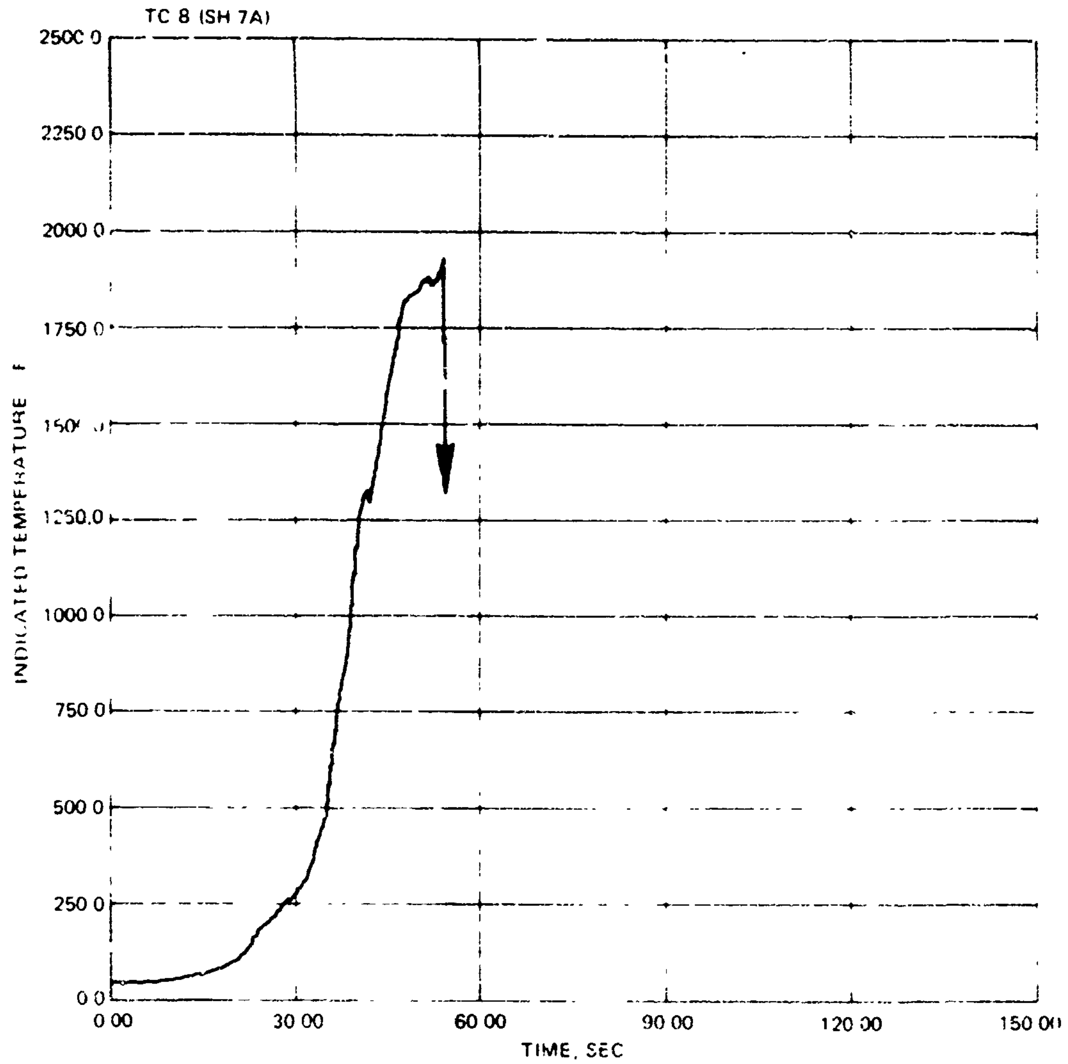

FIGURE C-15c TC 8, Aft Flame Thermocouple, SH-7A

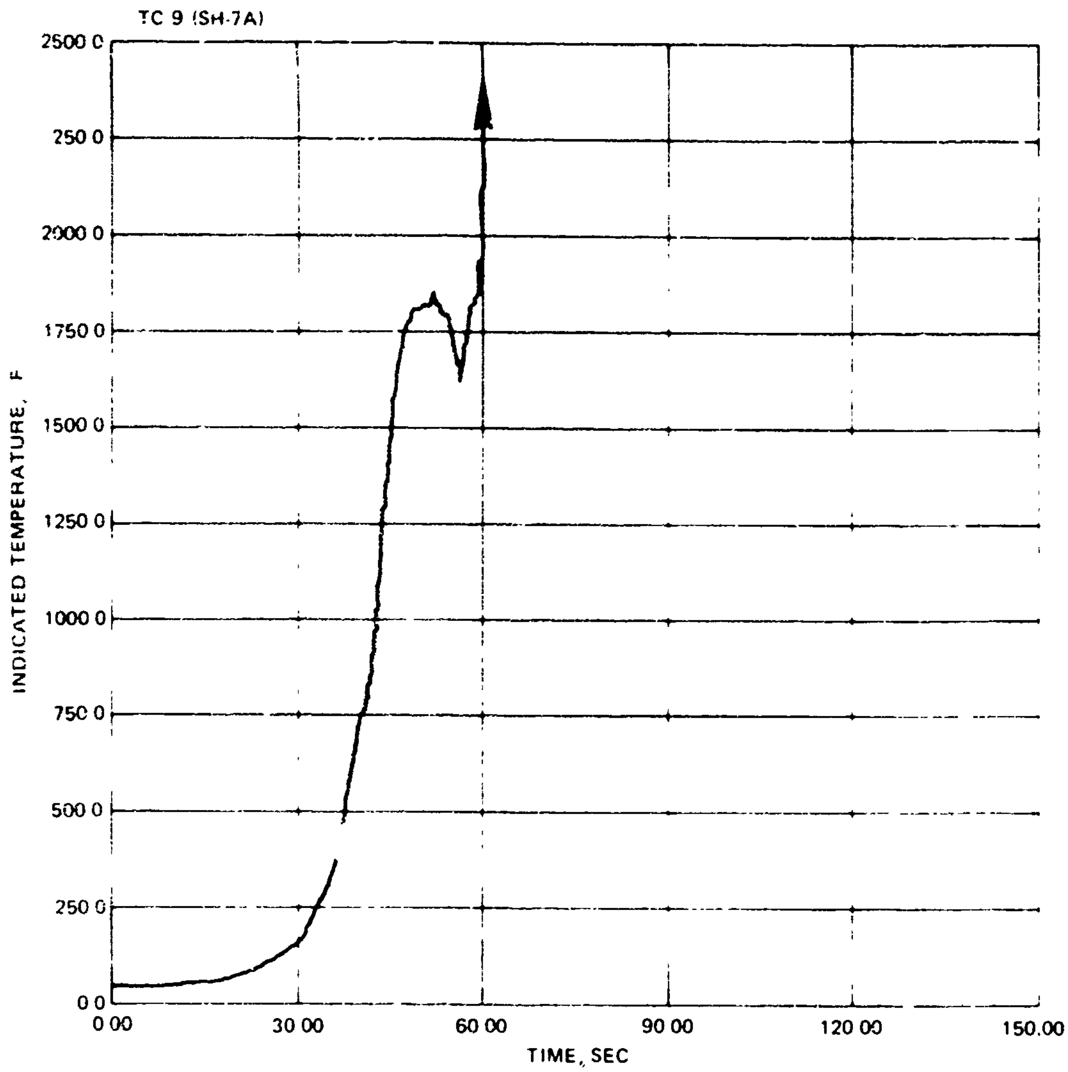

FIGURE C-15d TC 9, Port Flame Thermocouple, SH-7A

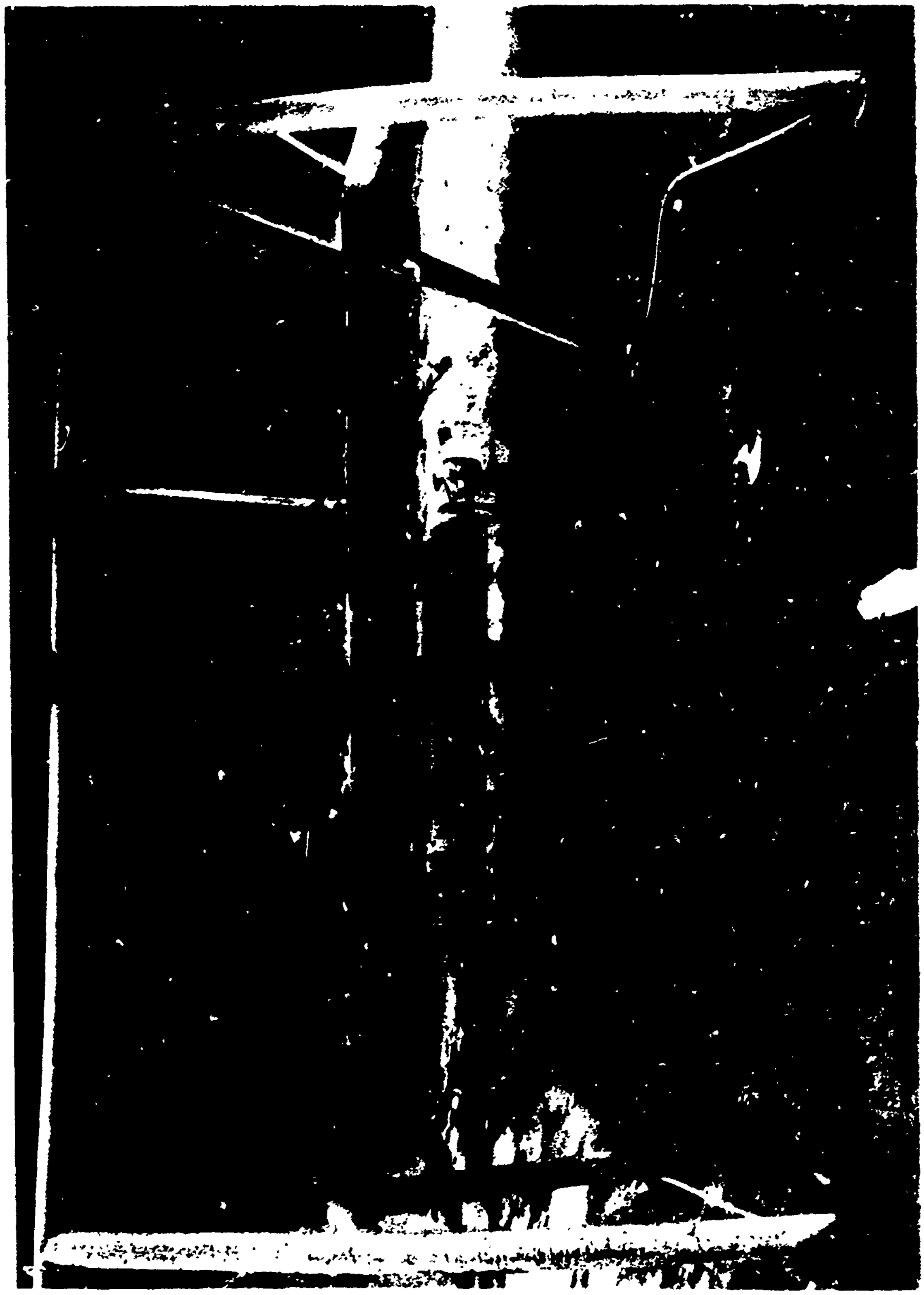

FIGURE C-16. SHRIKE SH-7A Post Test Configuration

FIGURE C-17. Aft Motor Case Vent Holes

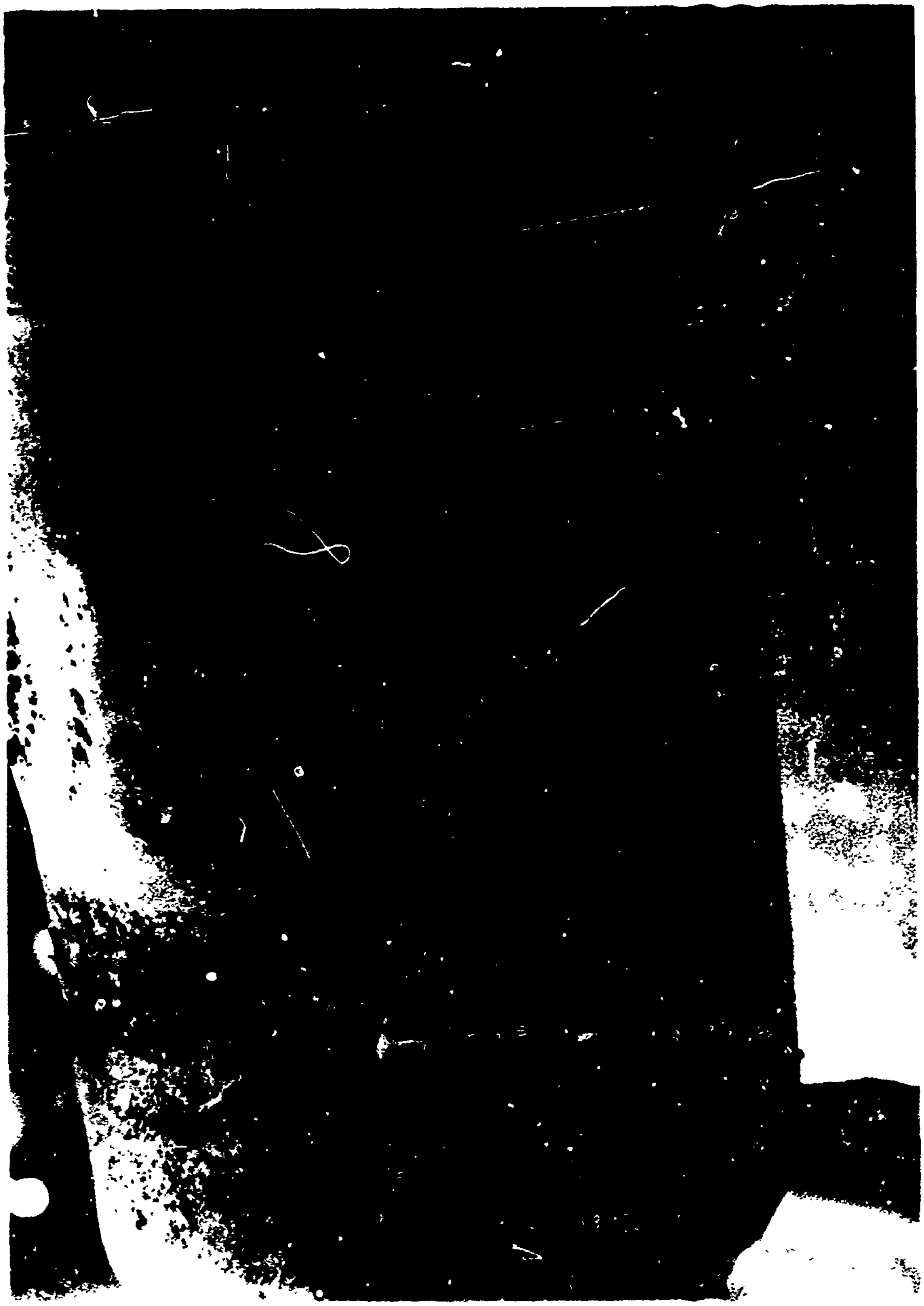

FIGURE C-18. Forward Motor Case Vent Holes

FIGURE C-19. Ejected Igniter With Attached Pressure Transducer.

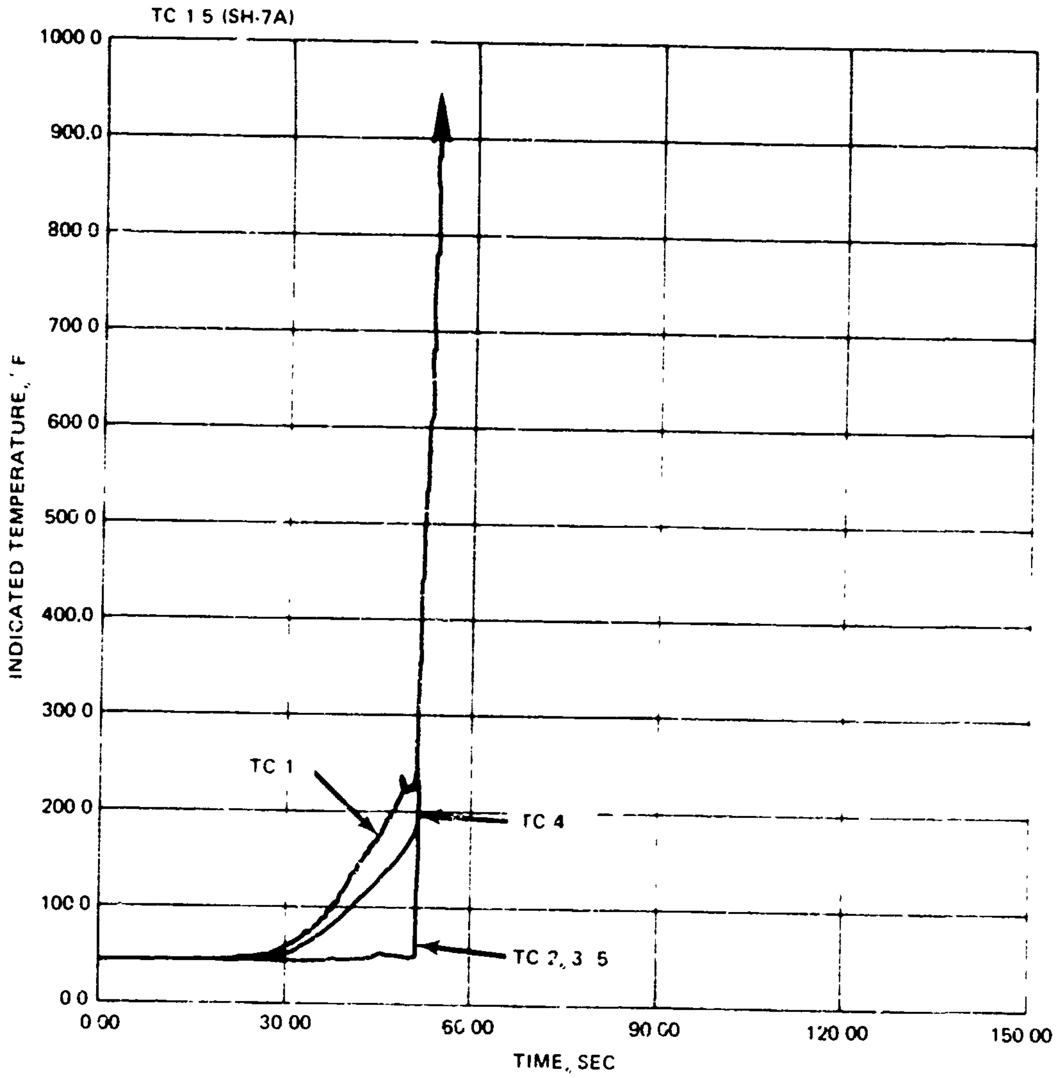

FIGURE C-20 TC 1-5 Response, SH-7A

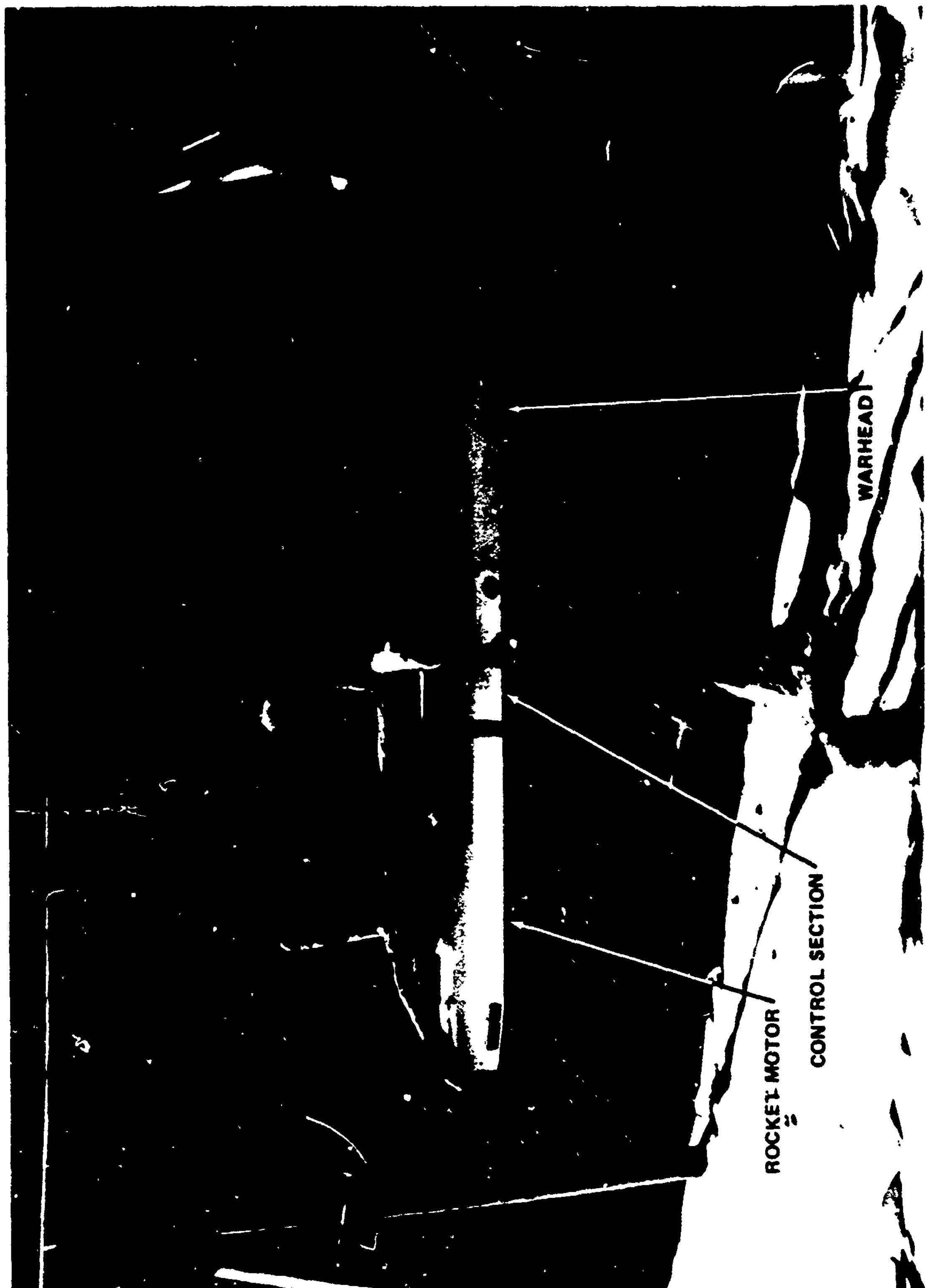

FIGURE C-21. SHRIKE SH-8A Test Configuration

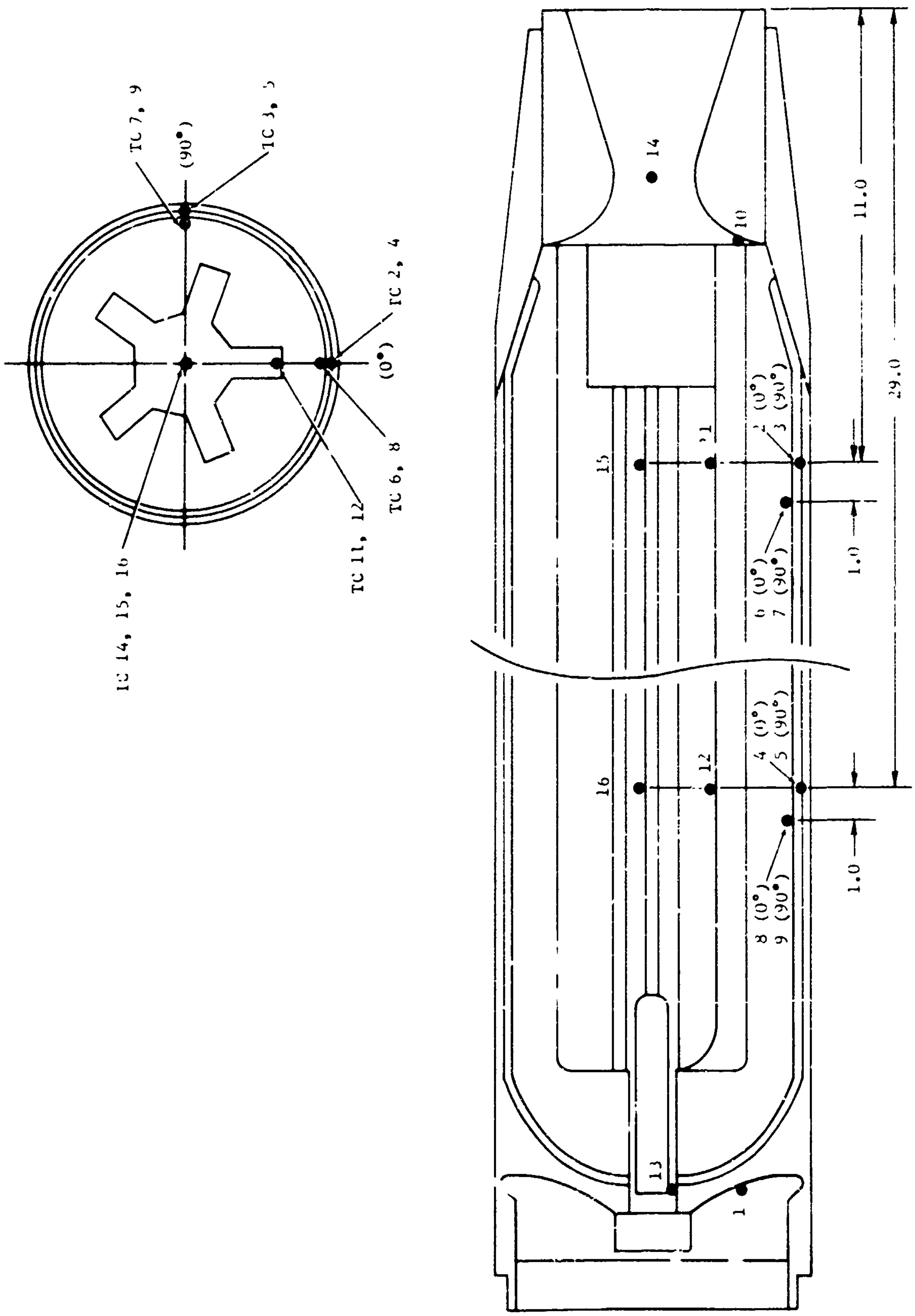

FIGURE C-22. MK 78 Mod 0 Motor Thermocouple Locations

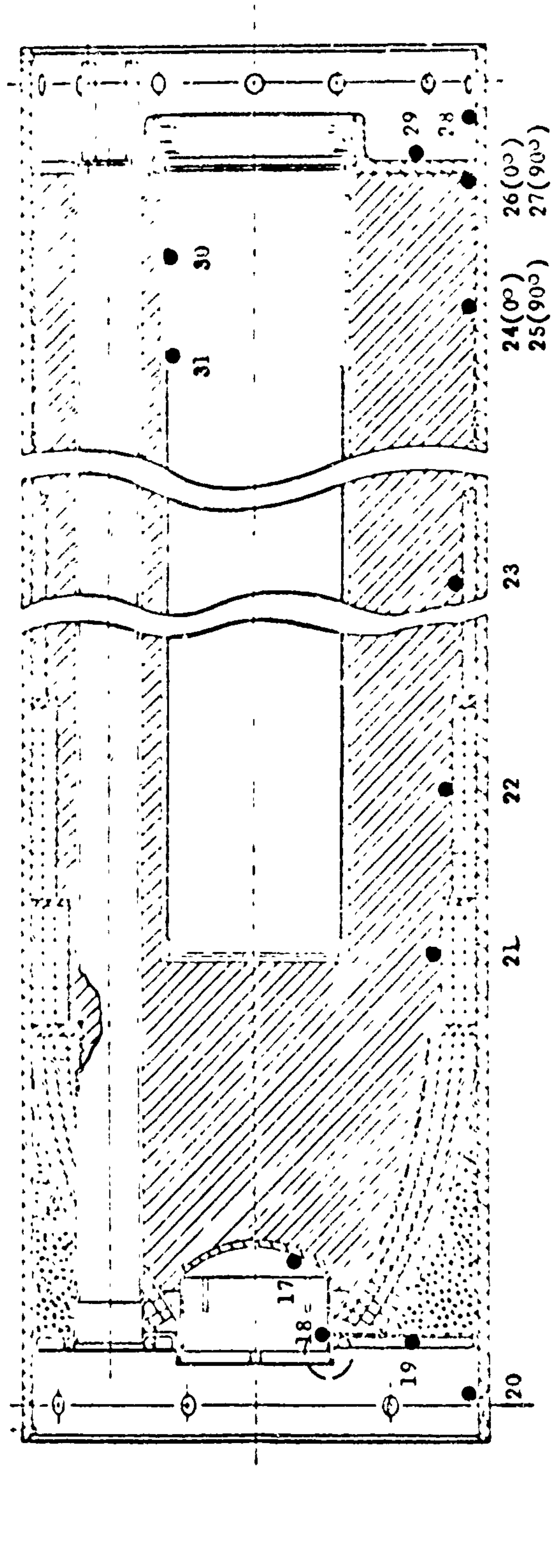

FIGURE C-23. Mk 80 Mod 0 Warhead Thermocouple Locations

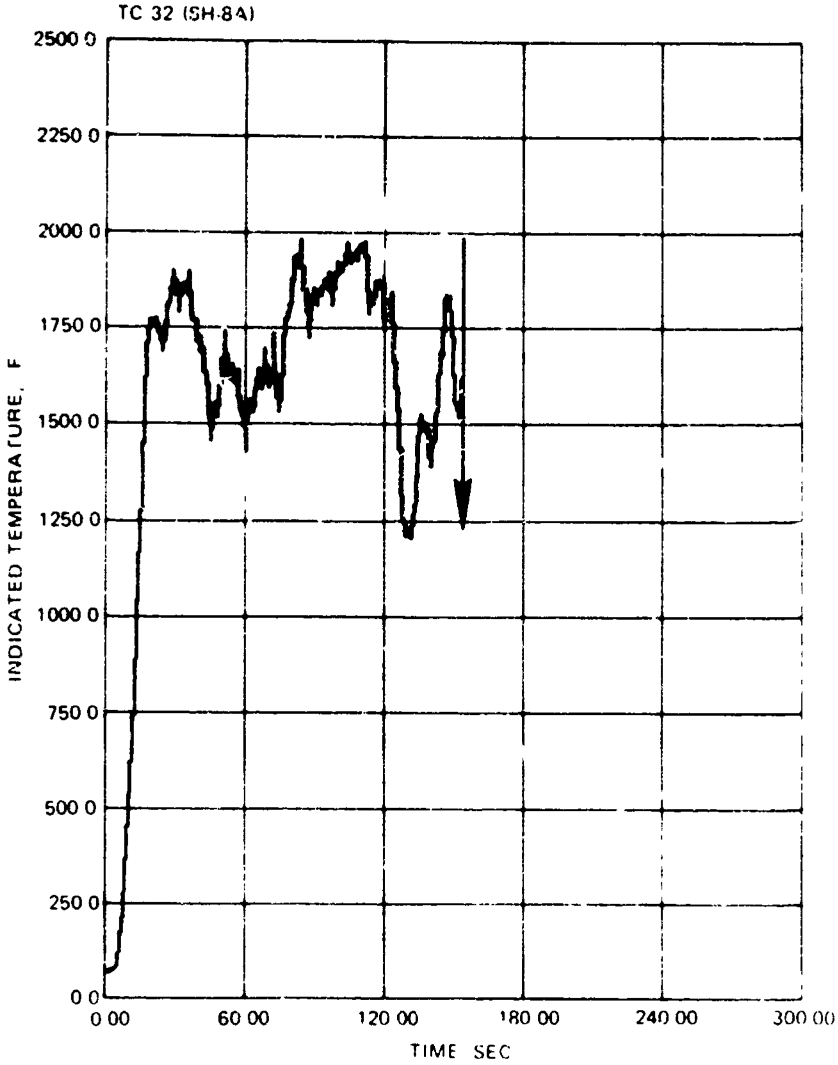

FIGURE C-24a. TC 32, Forward Flame Thermocouple, SH-8A.

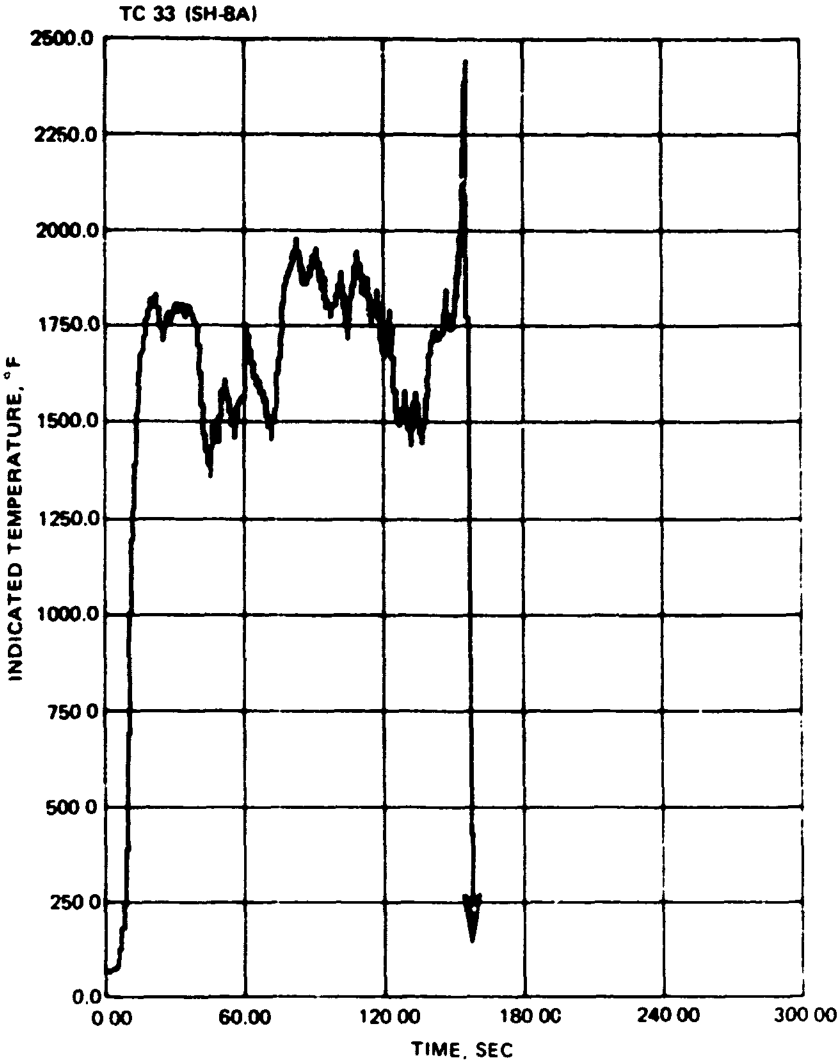

FIGURE C-24b. TC 33, Starboard Flame Thermocouple, SH-8A.

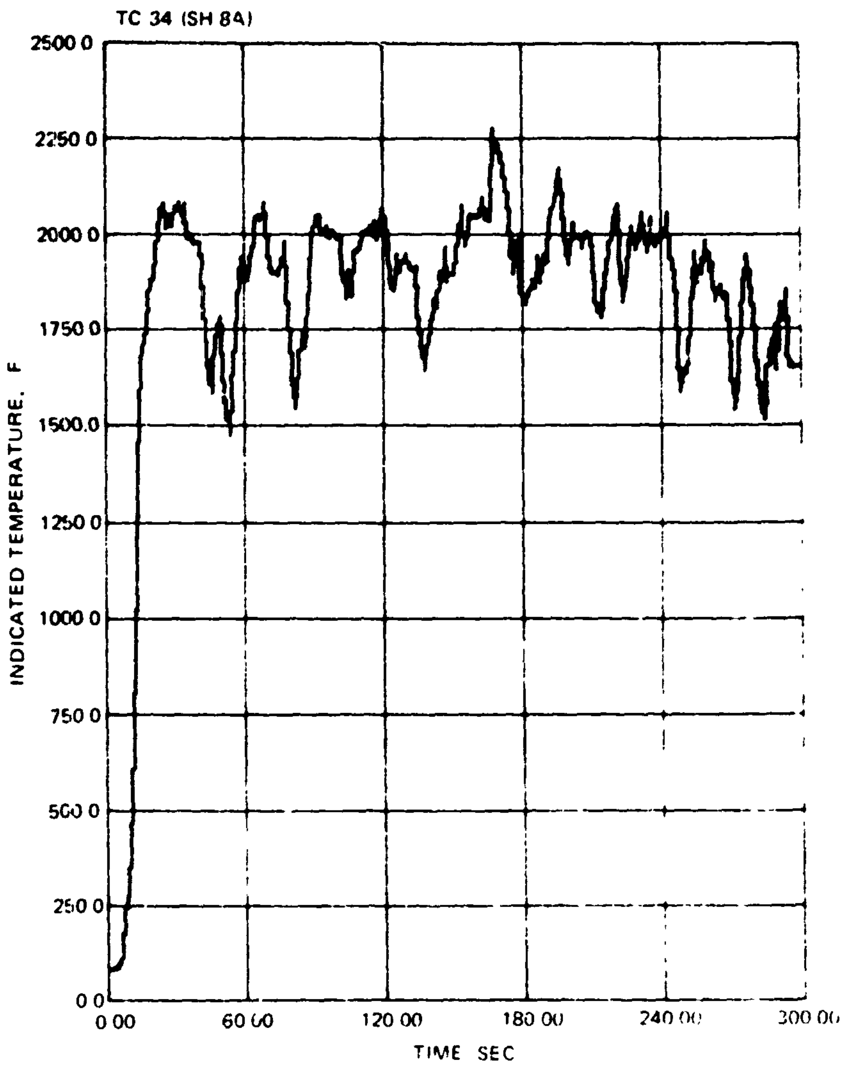

FIGURE C-24c. TC 34, Aft Flame Thermocouple, SH-8A

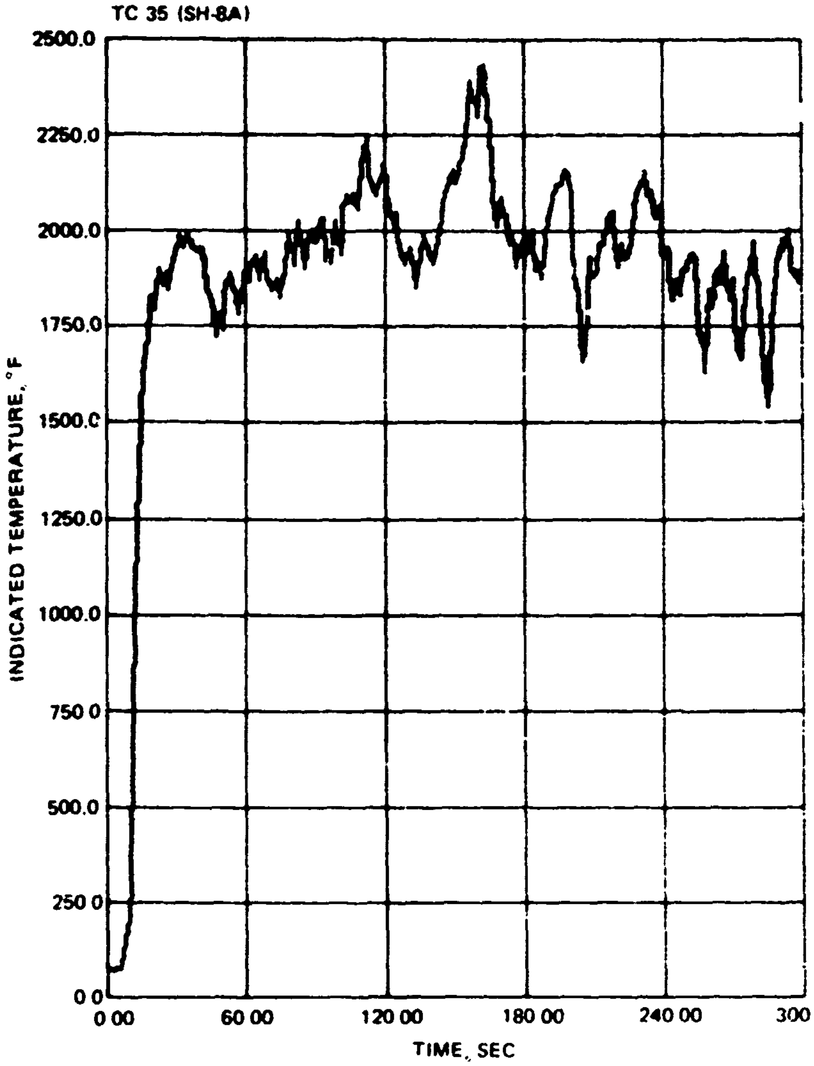

FIGURE C-24d. TC 35, Port Flame Thermocouple, SH-8A.

FIGURE C-28. Unburned Motor Case, SH-8A.

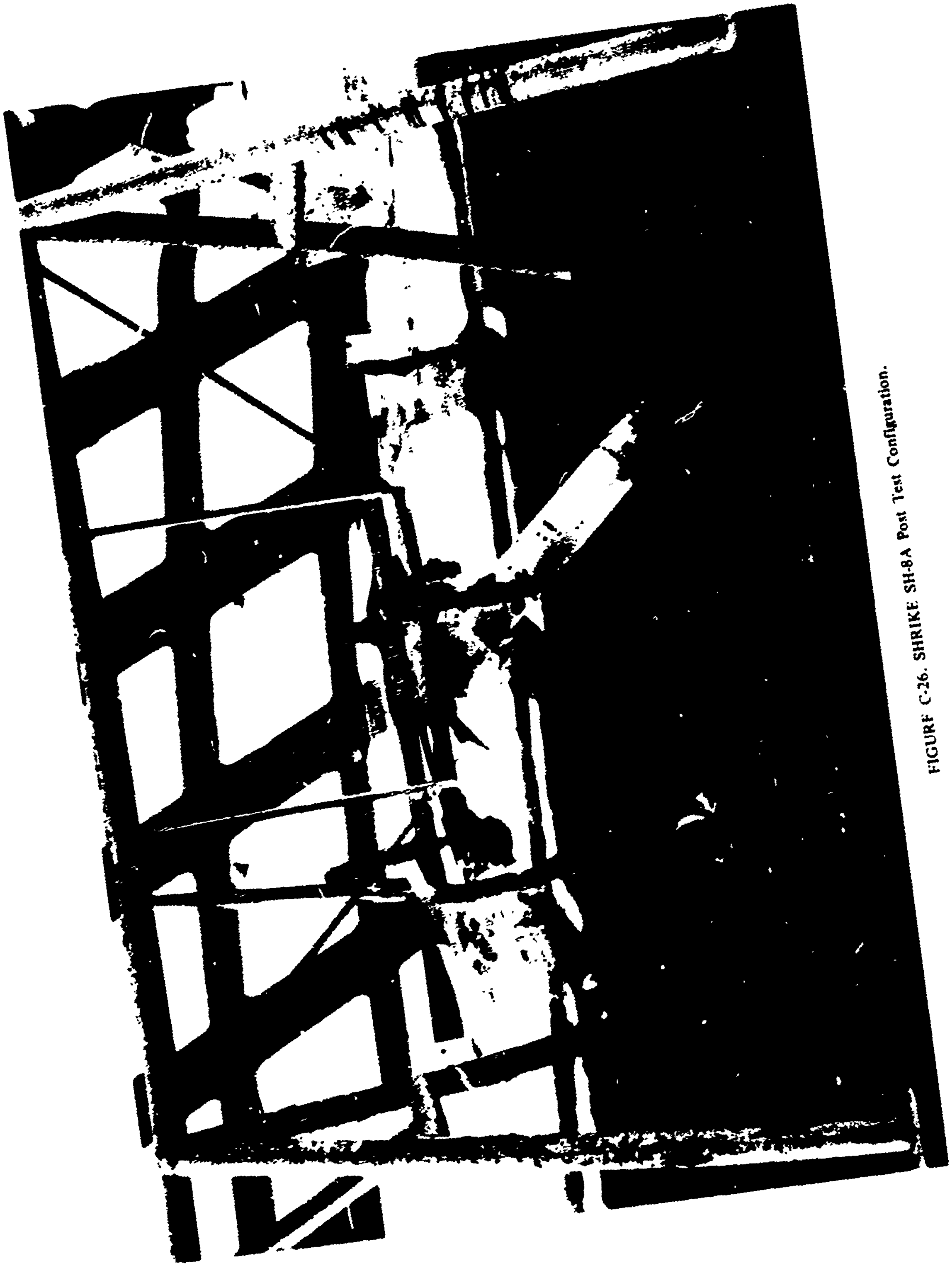

FIGURE C-26. SHRIKE SH-8A Post Test Configuration.

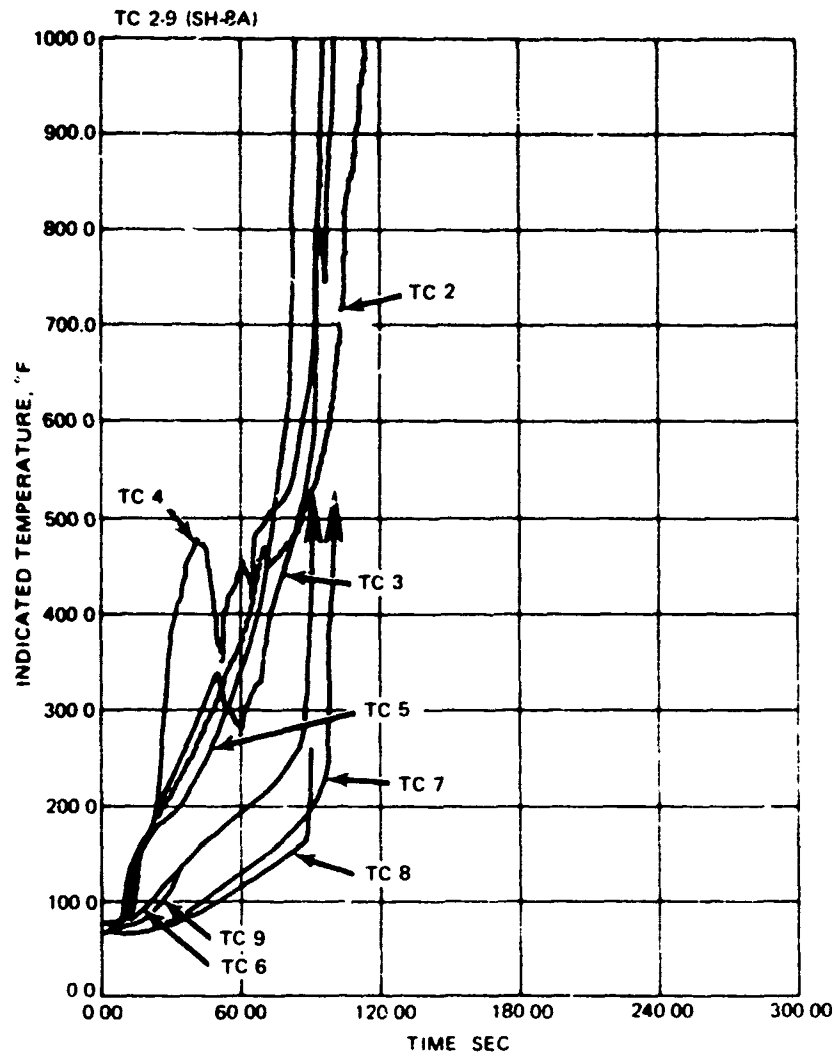

FIGURE C-27. TC 2-9 Response, SH-8A.

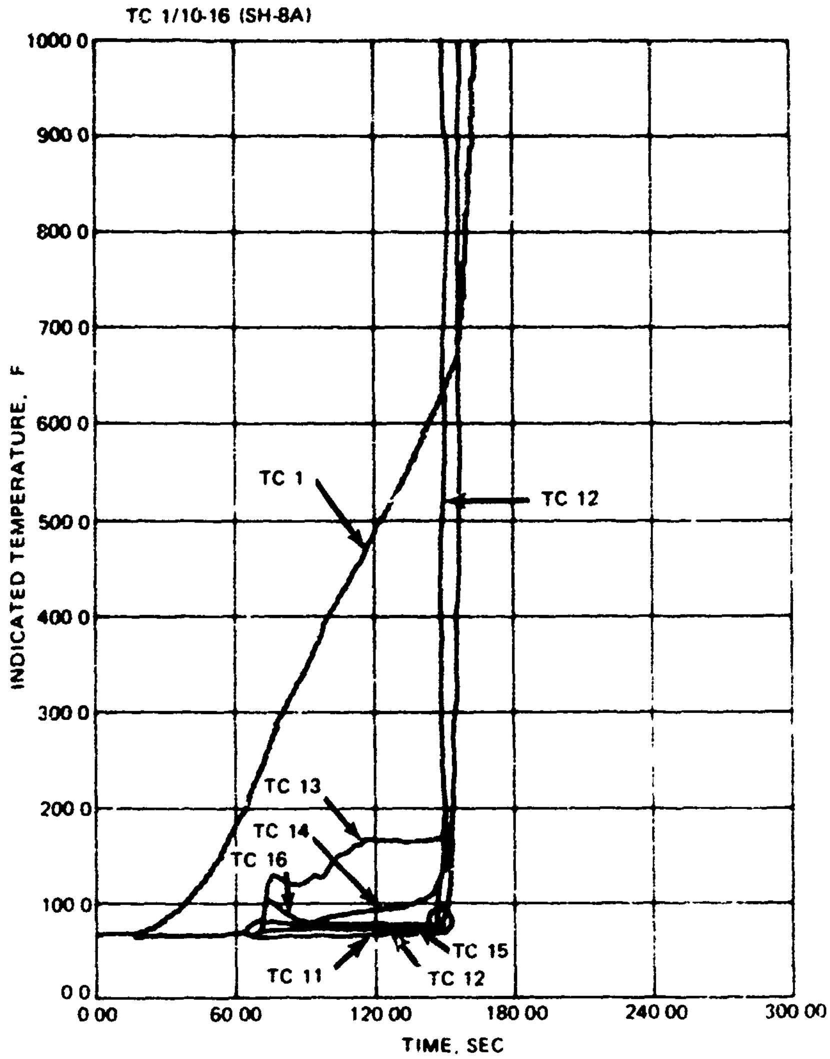

FIGURE C-28. TC 1/10-16 Response, SH-8A

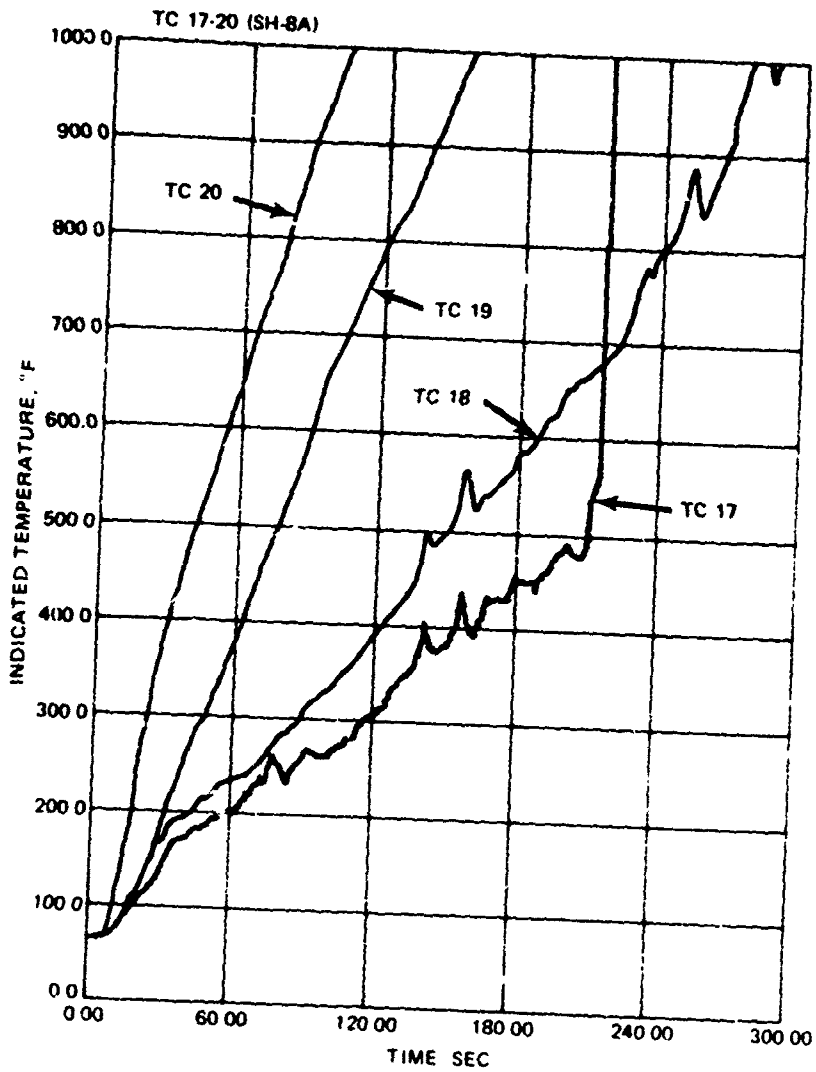

FIGURE C-29. TC 17-20 Response, SH-8A.

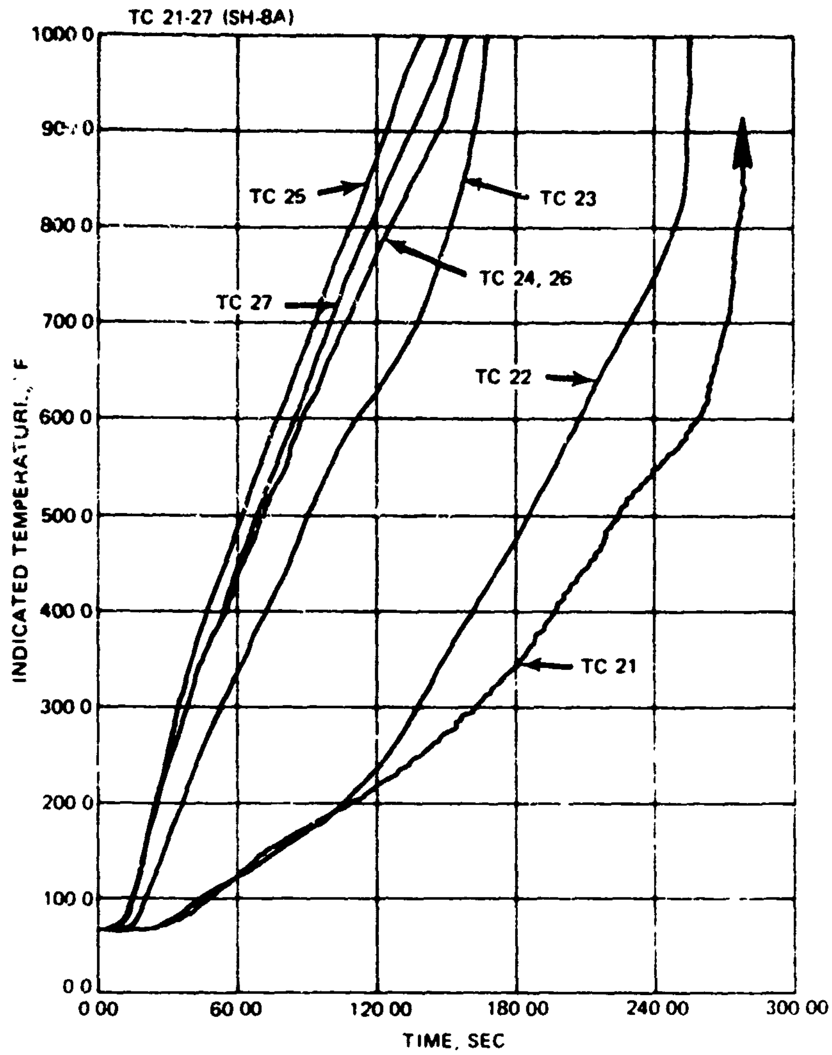

FIGURE C-30. TC 21-27 Response, SH-8A.

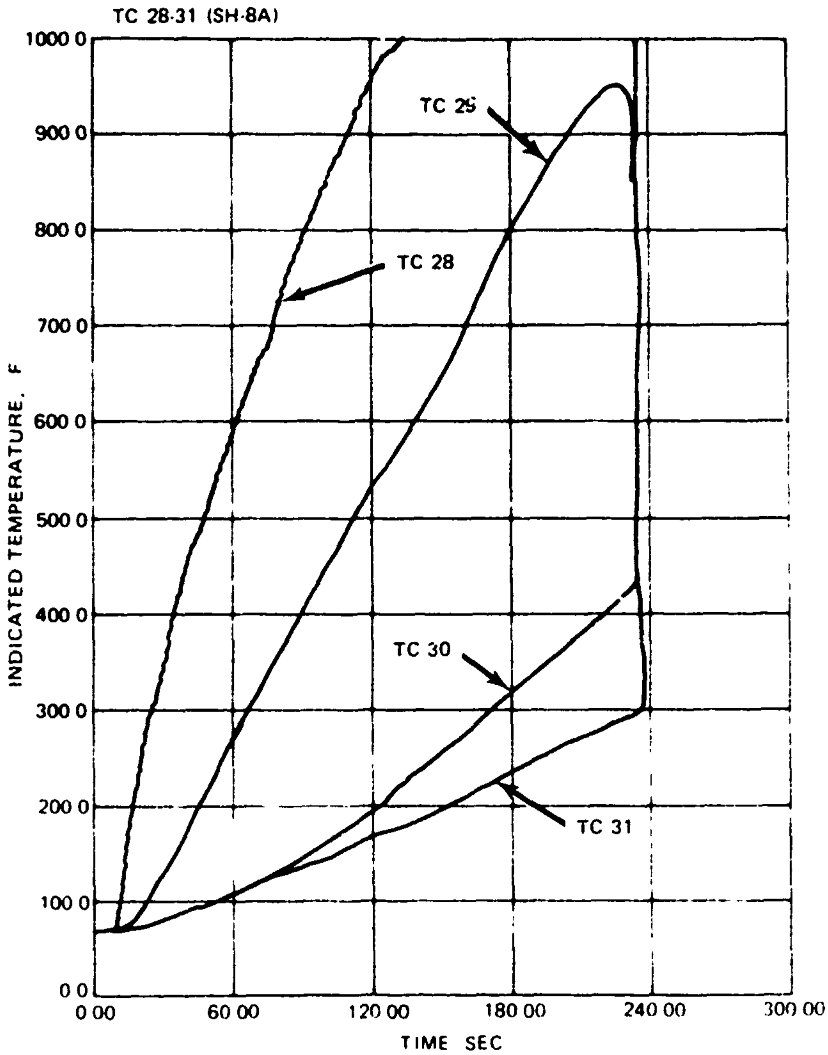

FIGURE C-31 TC 28-31 Response, SH-8A

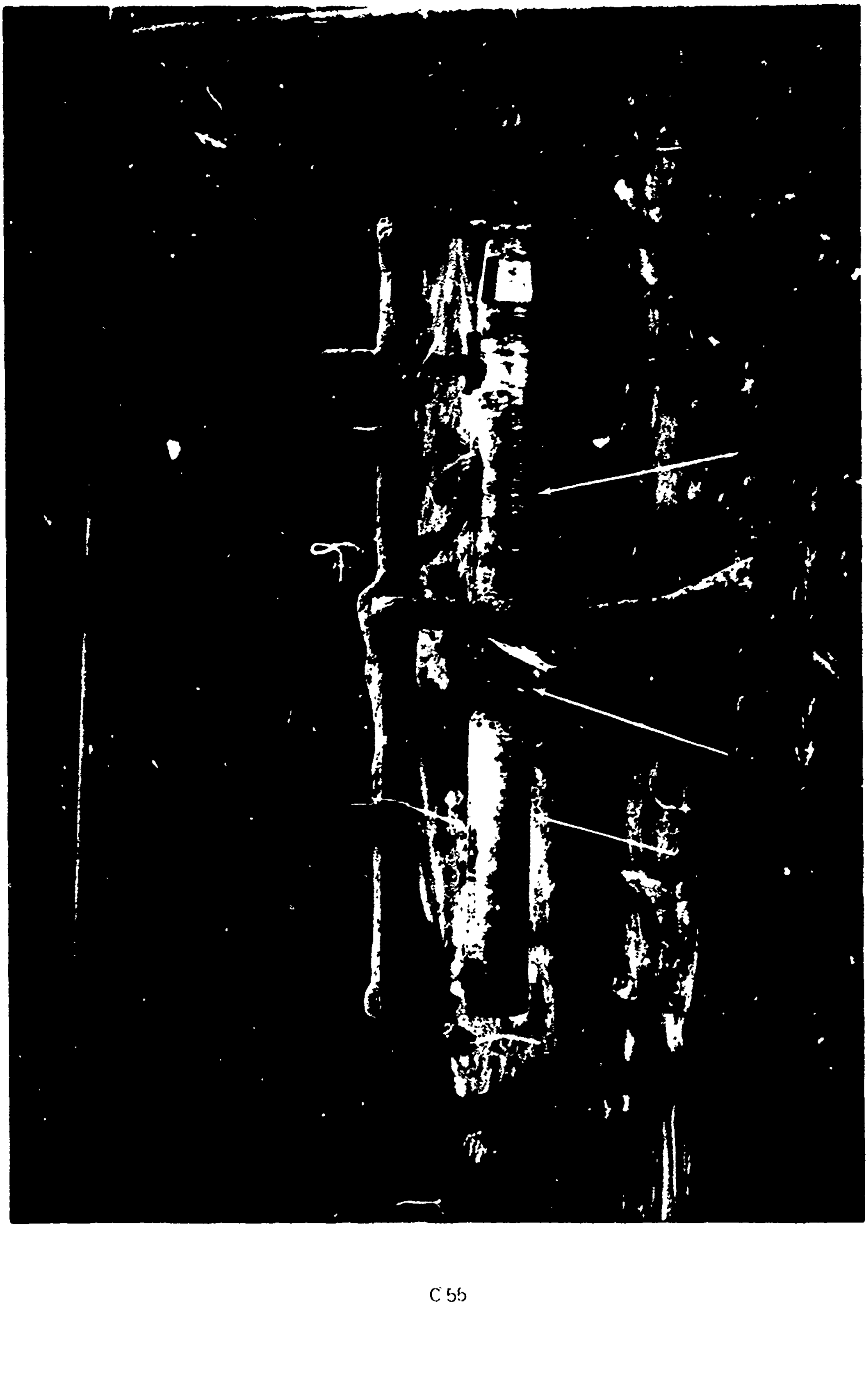

FIGURE C-32. SHRIKE SH-12A Test Configuration.

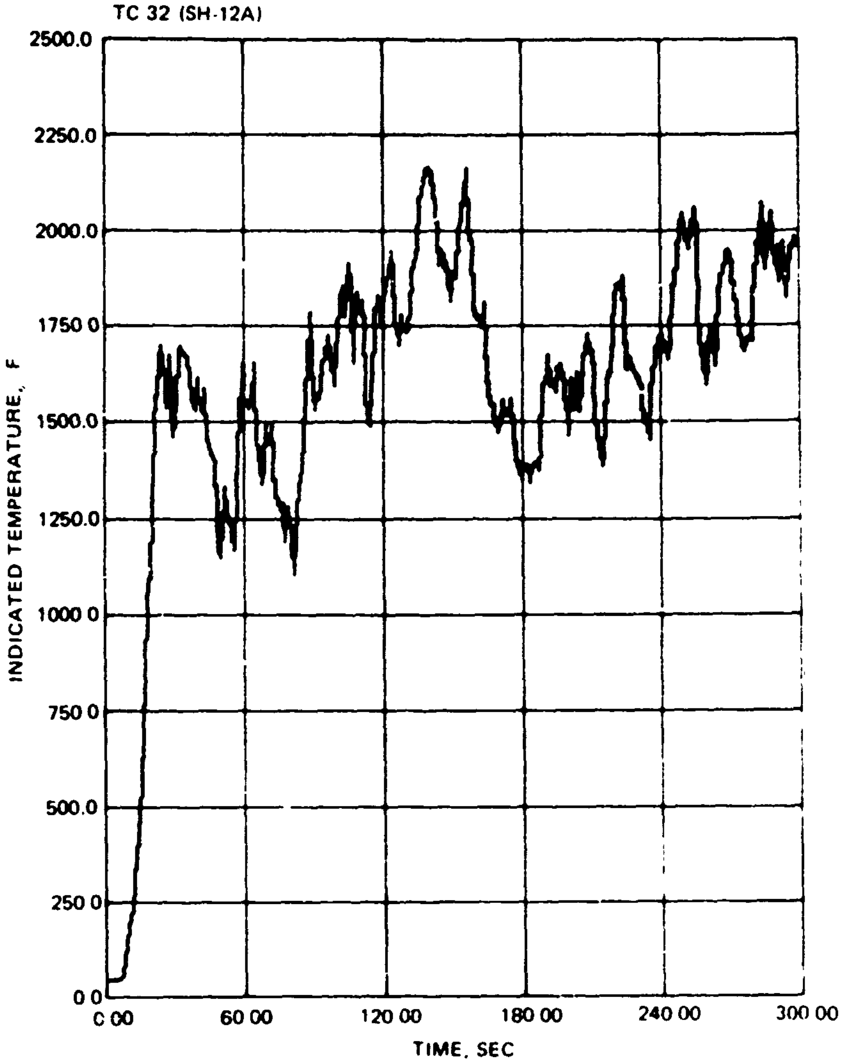

FIGURE C-33a. TC 32, Forward Flame Temperature, SH-12A.

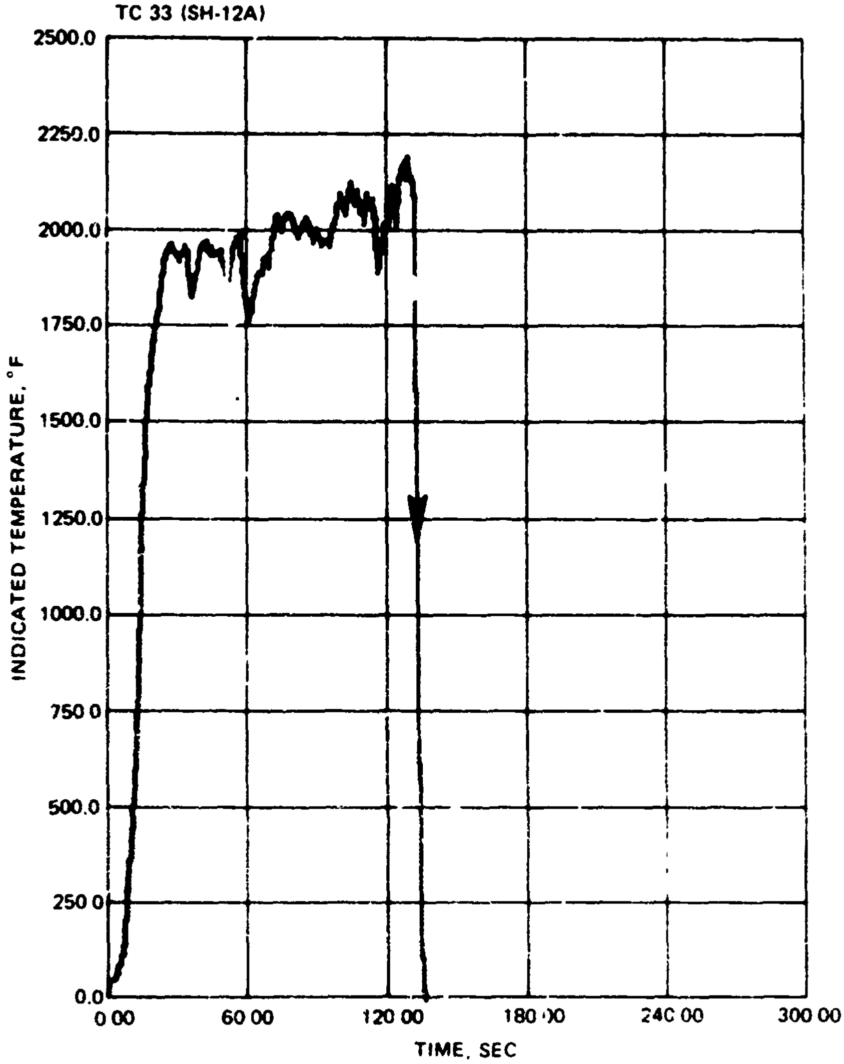

FIGURE C-33b. TC 33 Starboard Flame Temperature, SH-12A.

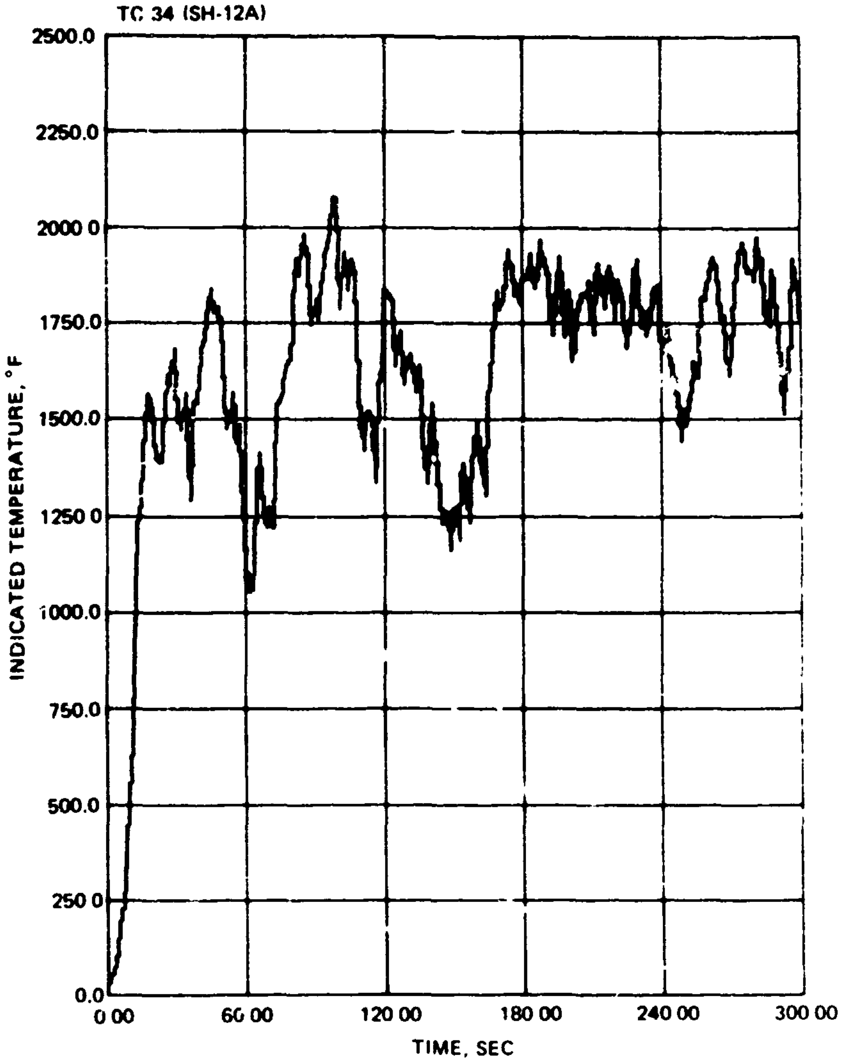

FIGURE C-33c. TC 34, Aft Flame Temperature, SH-12A.

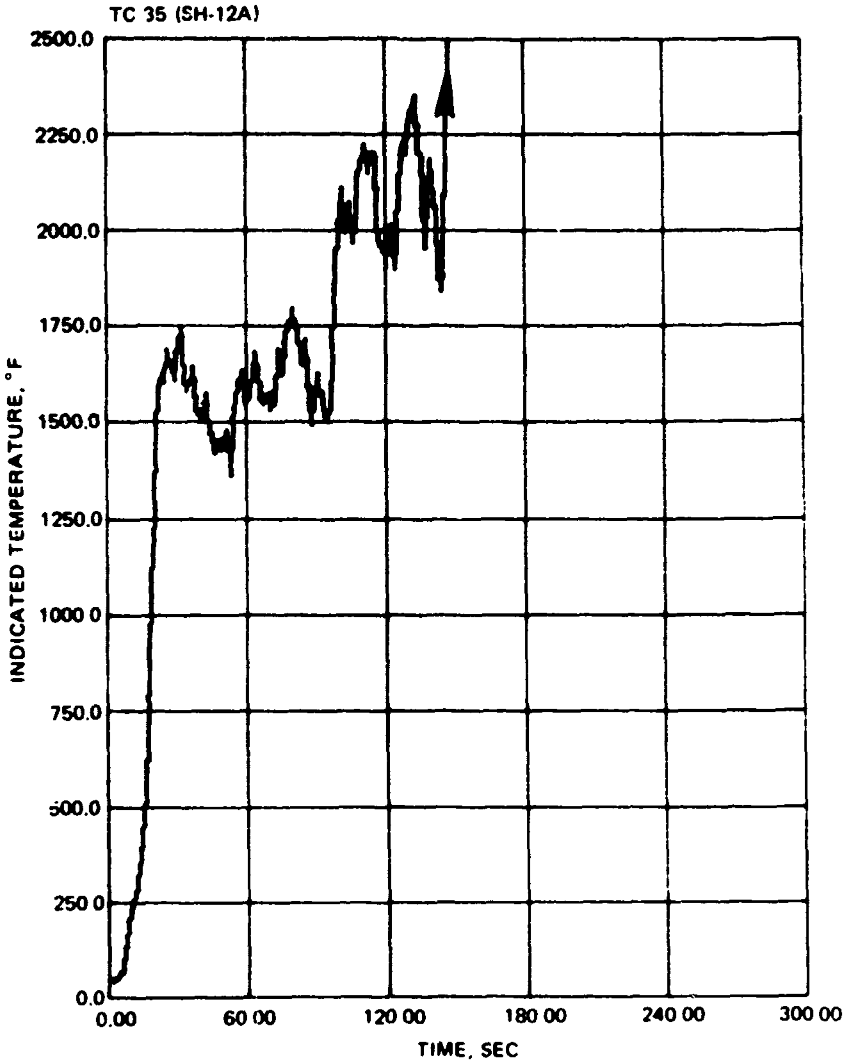

FIGURE C-33d. TC 35, Port Flame Temperature, SH-12A

FIGURE C-34. SHRIKE SH-12A Post Test Configuration (Forward View)

FIGURE C-35. SHRIKE SH-12A Post Test Configuration (Side View).

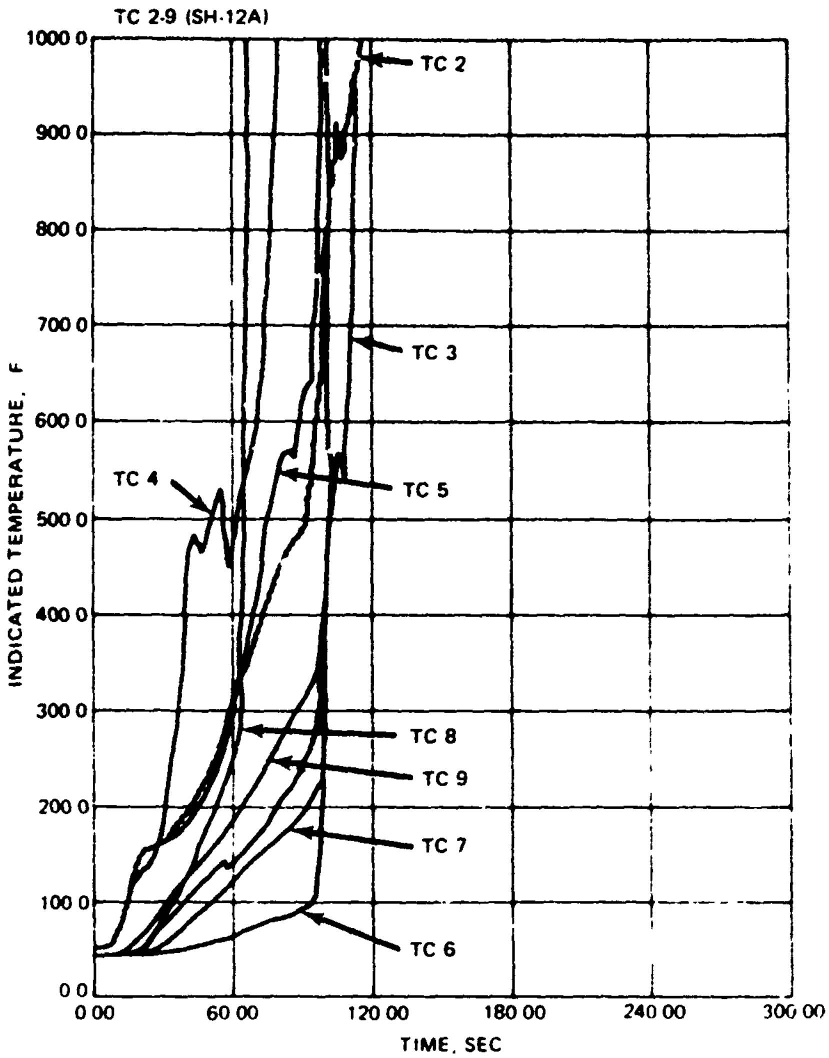

FIGURE C-36. TC 2-9 Response, SH-12A

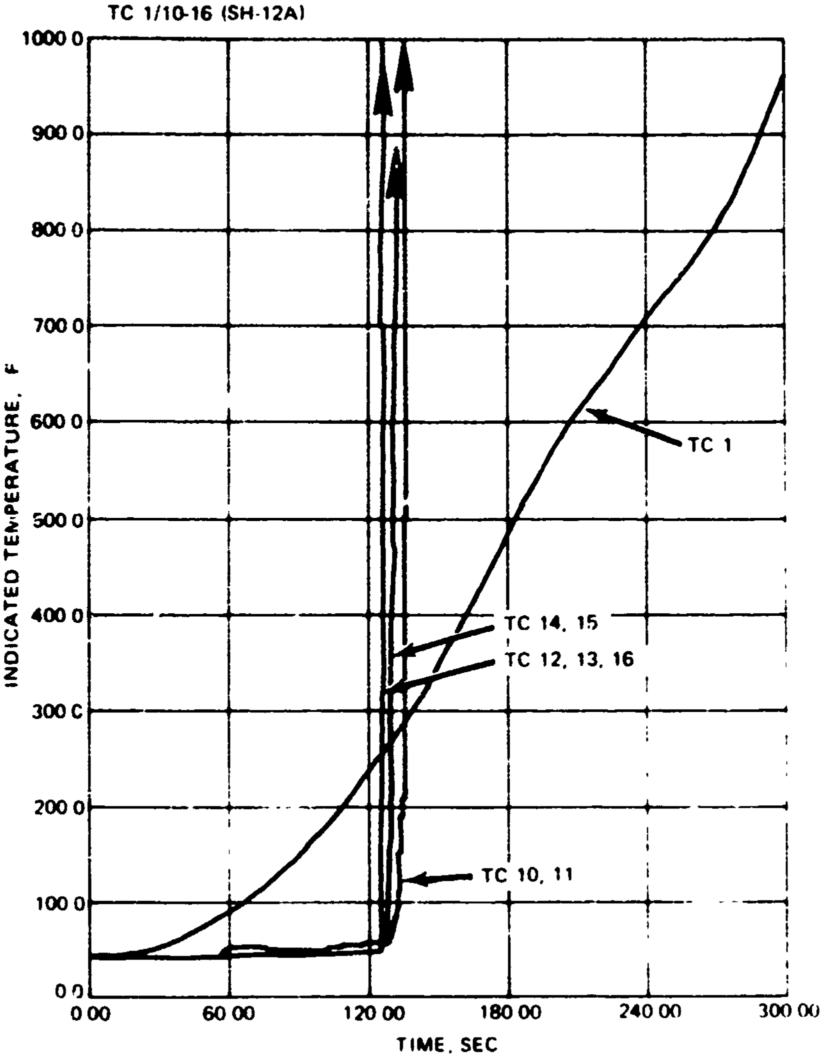

FIGURE C-37. TC 1/10-16 Response, SH-12A

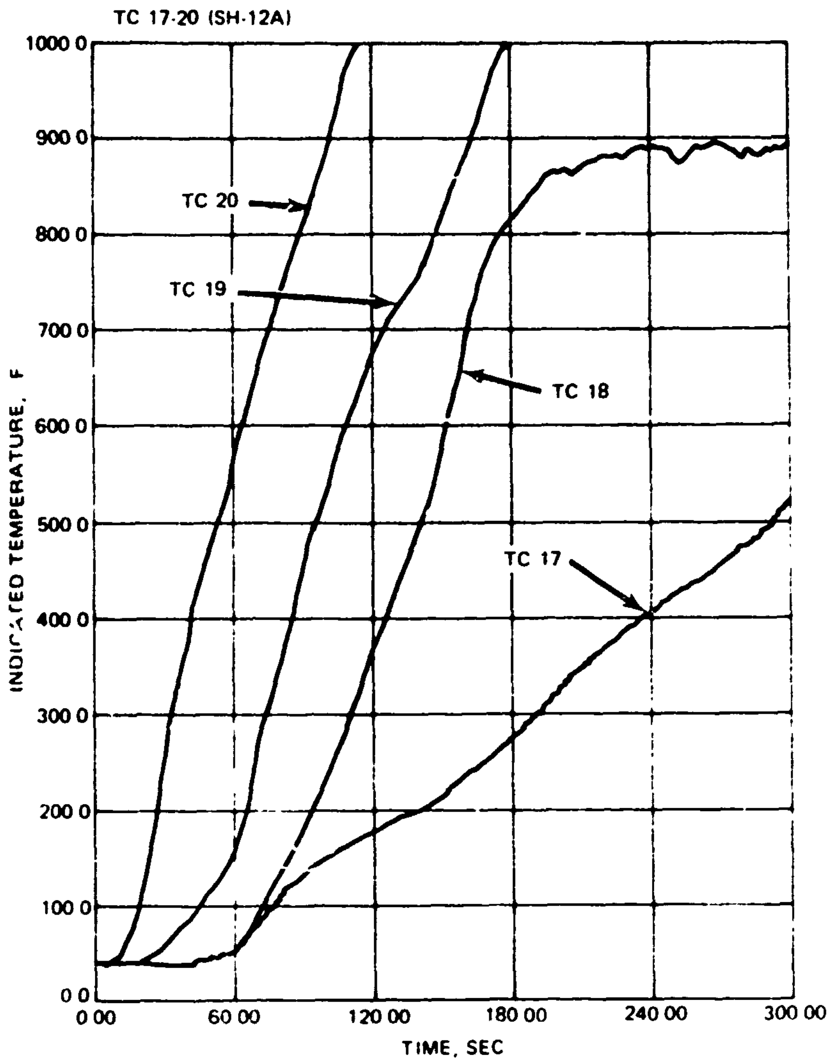

FIGURE C-38 TC 17-20 Response, SH-12A.

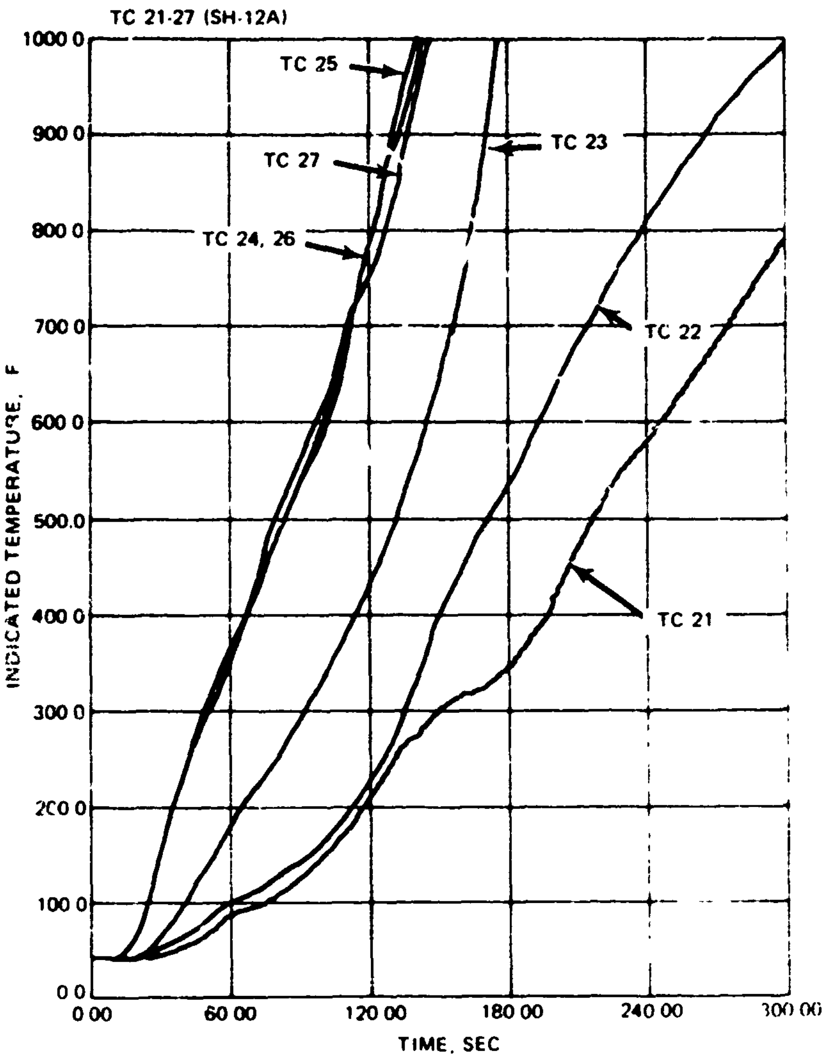

FIGURE C-39. TC 21-27 Response, SH-12A

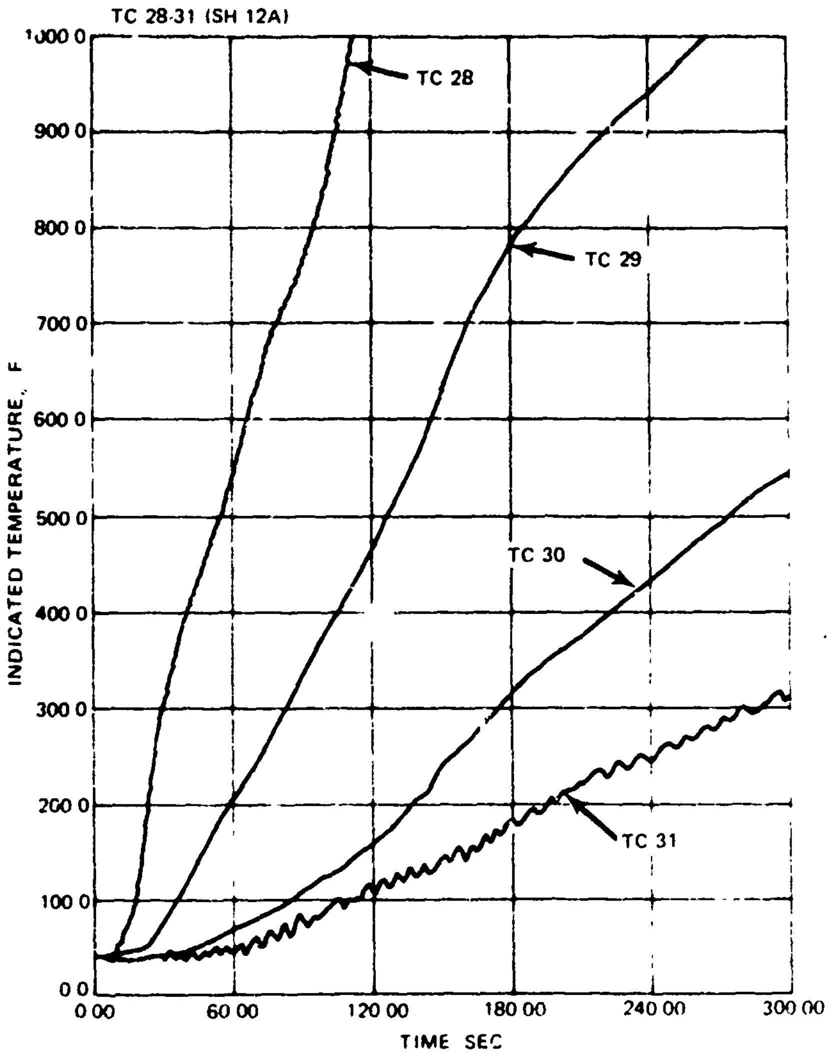

FIGURE C-40. TC 28-31 Response, SH-12A

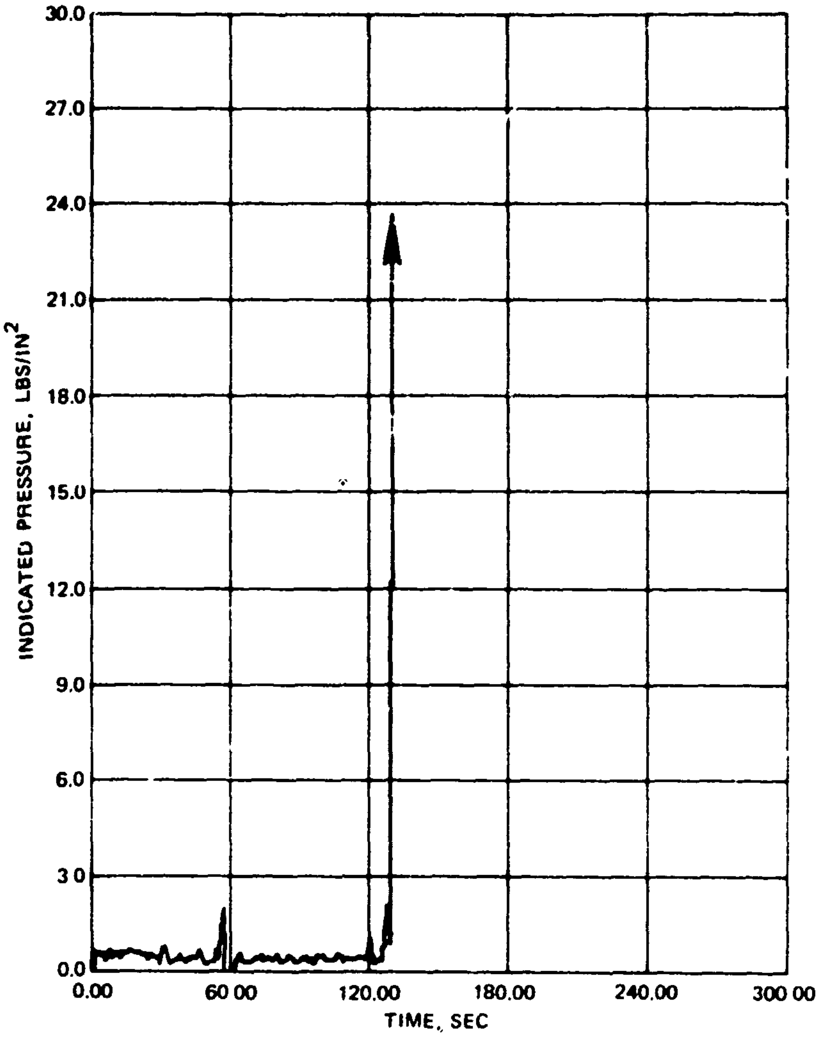

FIGURE C-41. Propellant Port Pressure, SH-12A

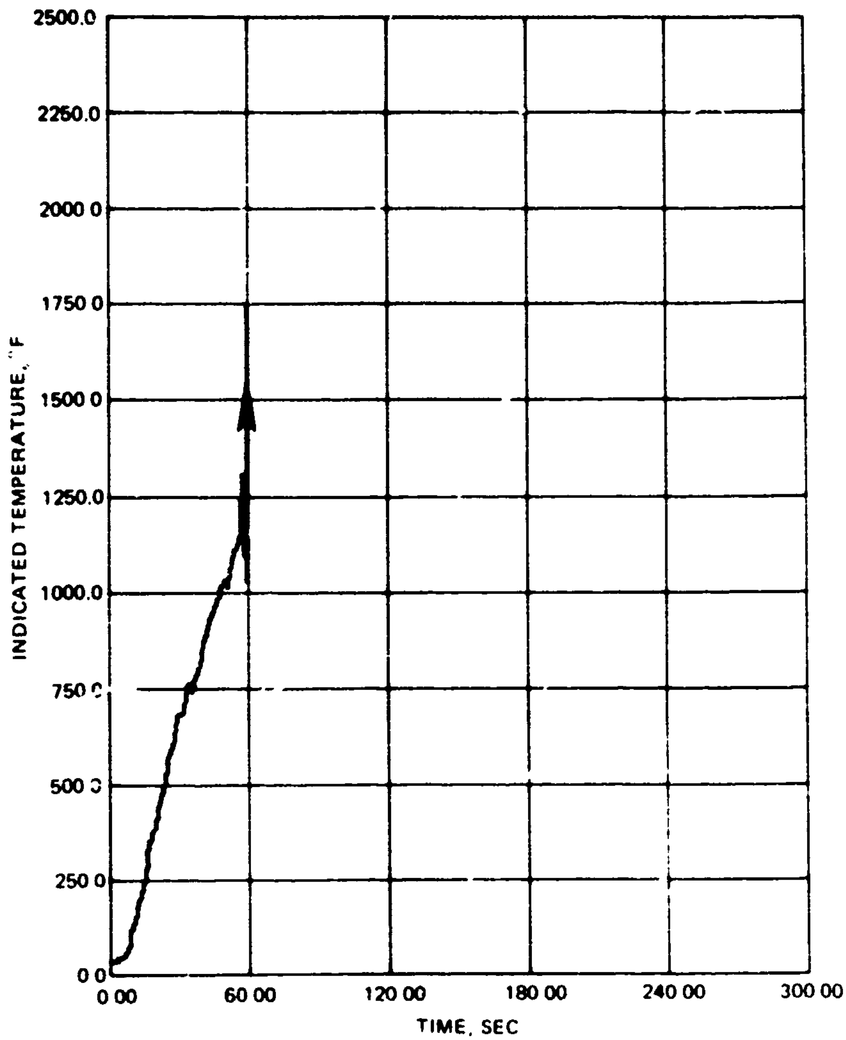

FIGURE C-42a. Heat-Flux Surface Thermocouple, SH-12A

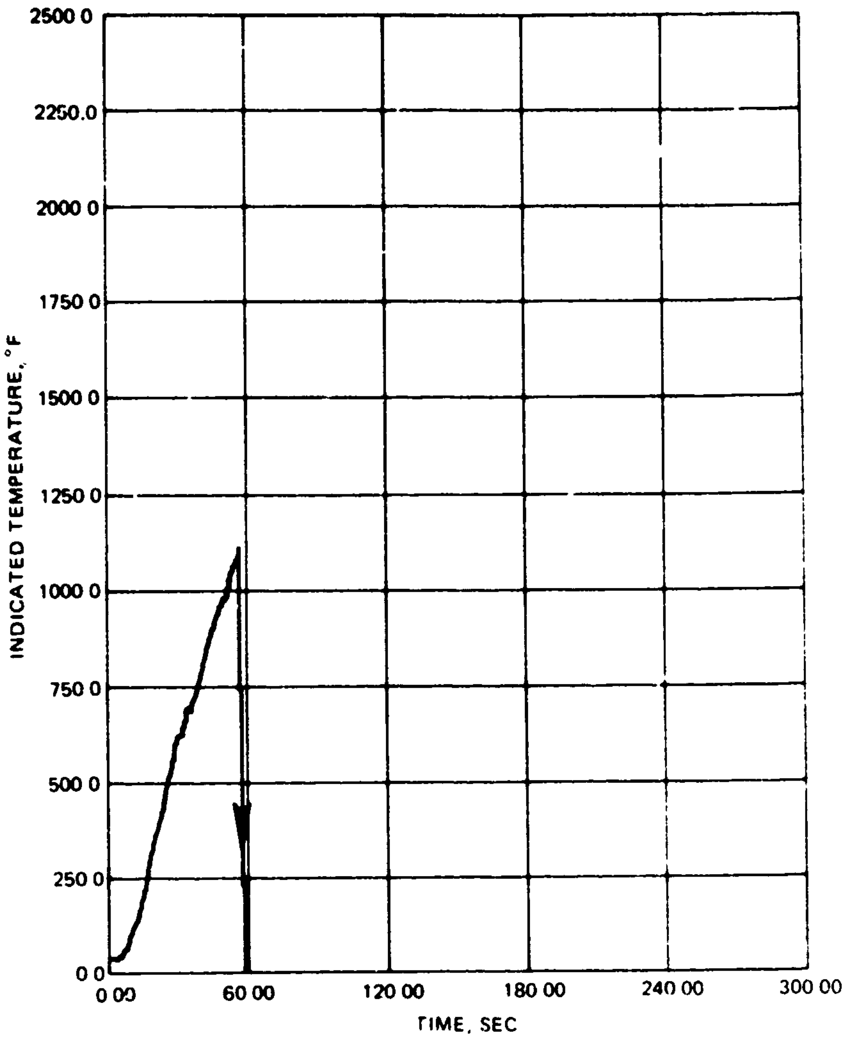

FIGURE C-42b. Heat-Flux Thin Disk Thermocouple, SH-12A

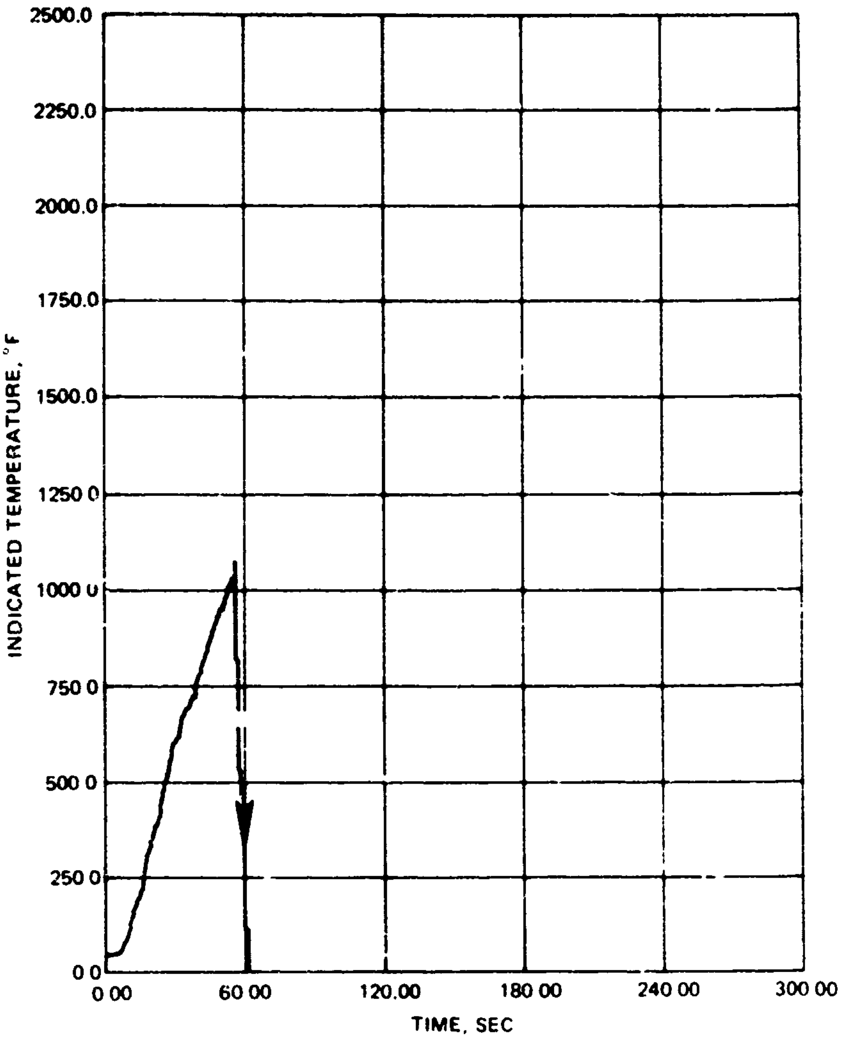

FIGURE C-42c. Heat-Flux Thick Disk Thermocouple. SH-12A.

FIGURE C43. SHRIKE SH-13A Test Configuration.

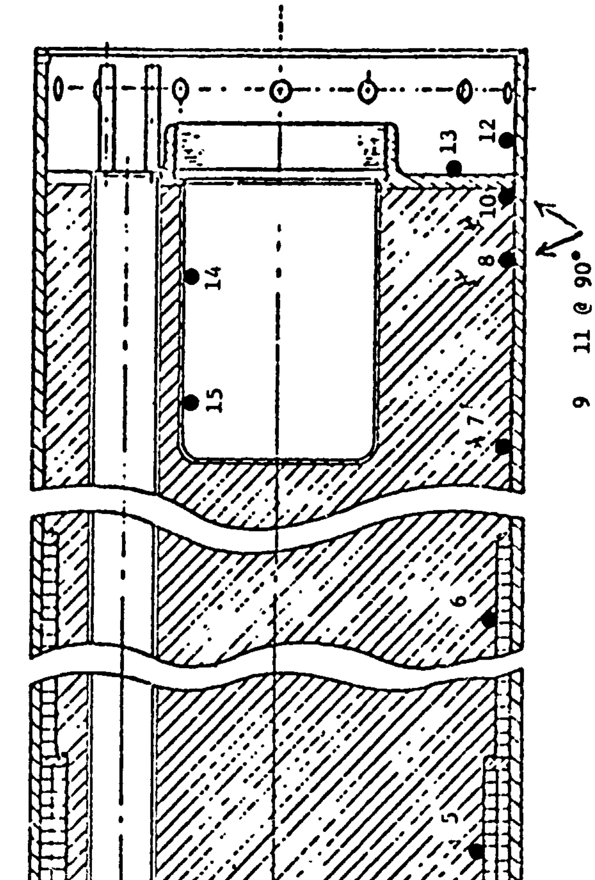

FIGURE C-44. Mk 68 Mod 0 Warhead Thermocouple Locations.

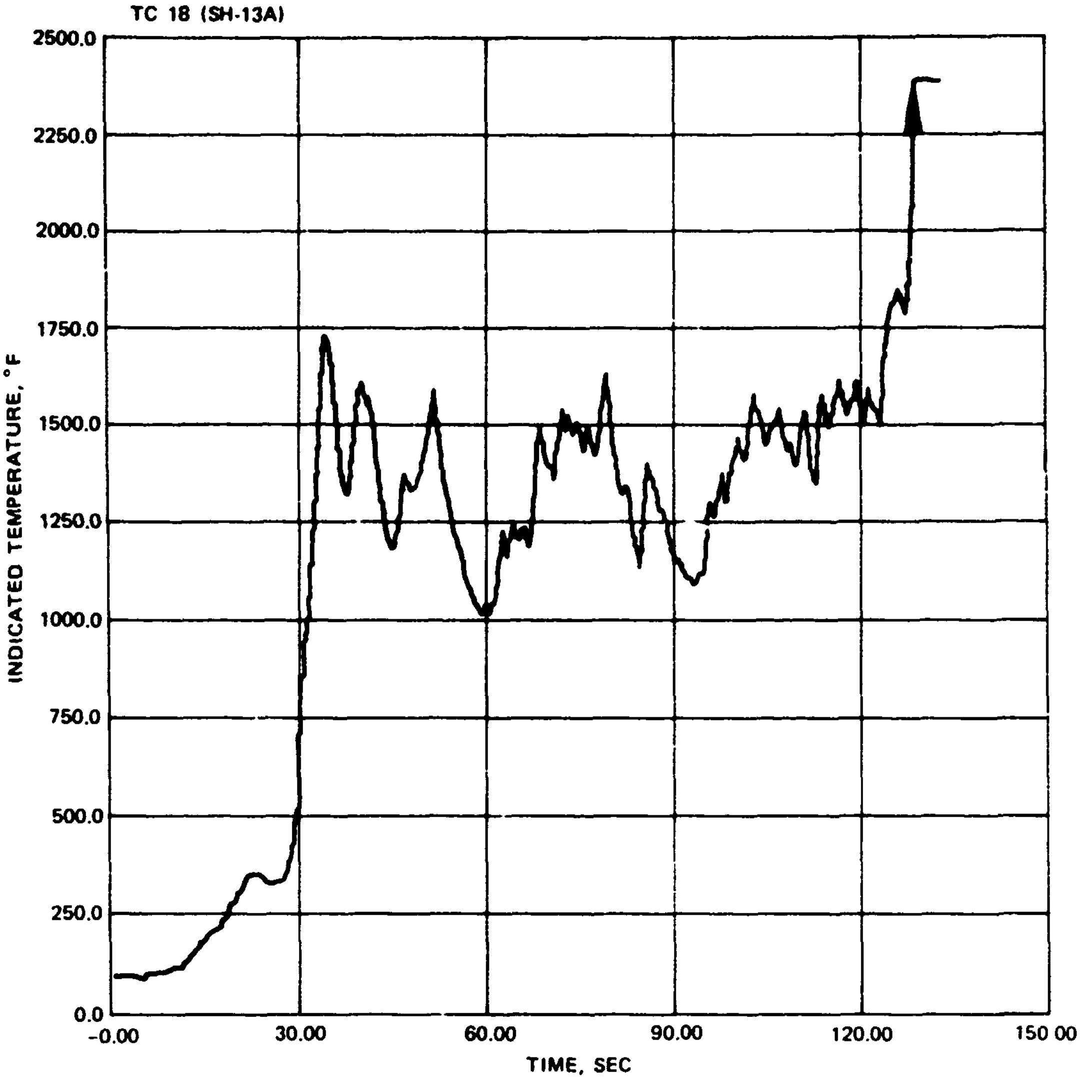

FIGURE C-45a. TC 18, Forward Flame Temperature, SH-13A

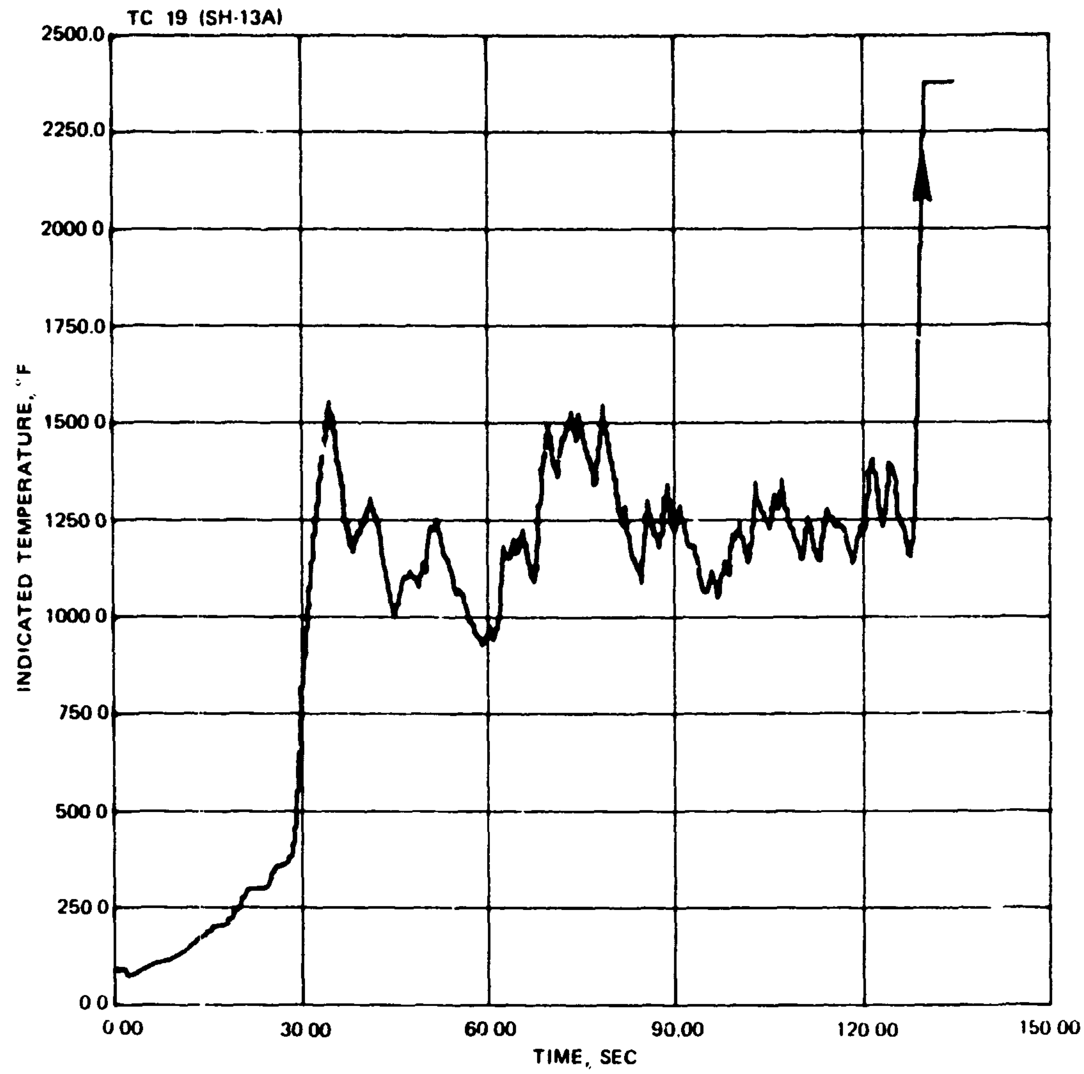

FIGURE C-45b TC 19, Port Flame Temperature, SH-13A

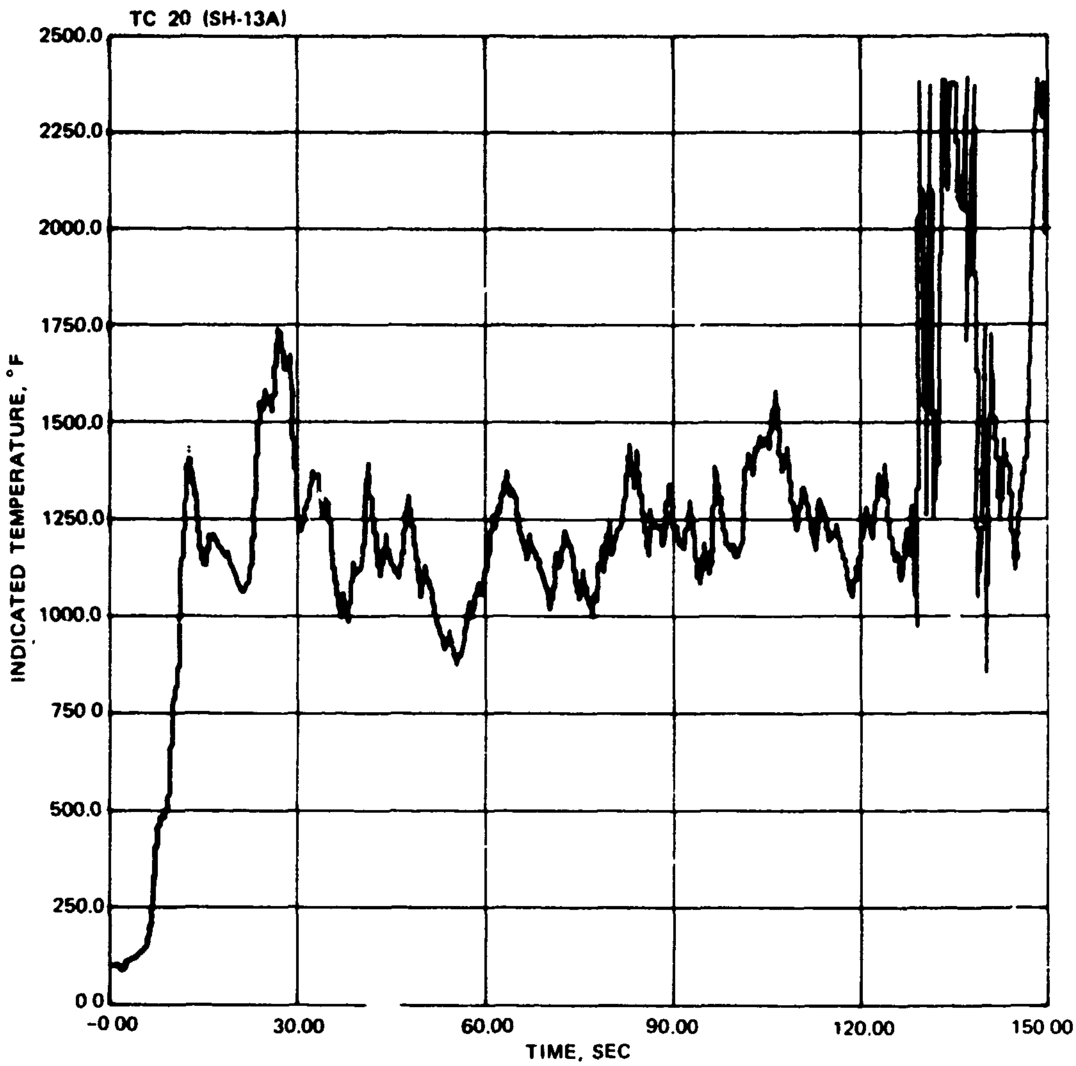

FIGURE C-45c. TC 20, Aft Flame Temperature, SH-13A.

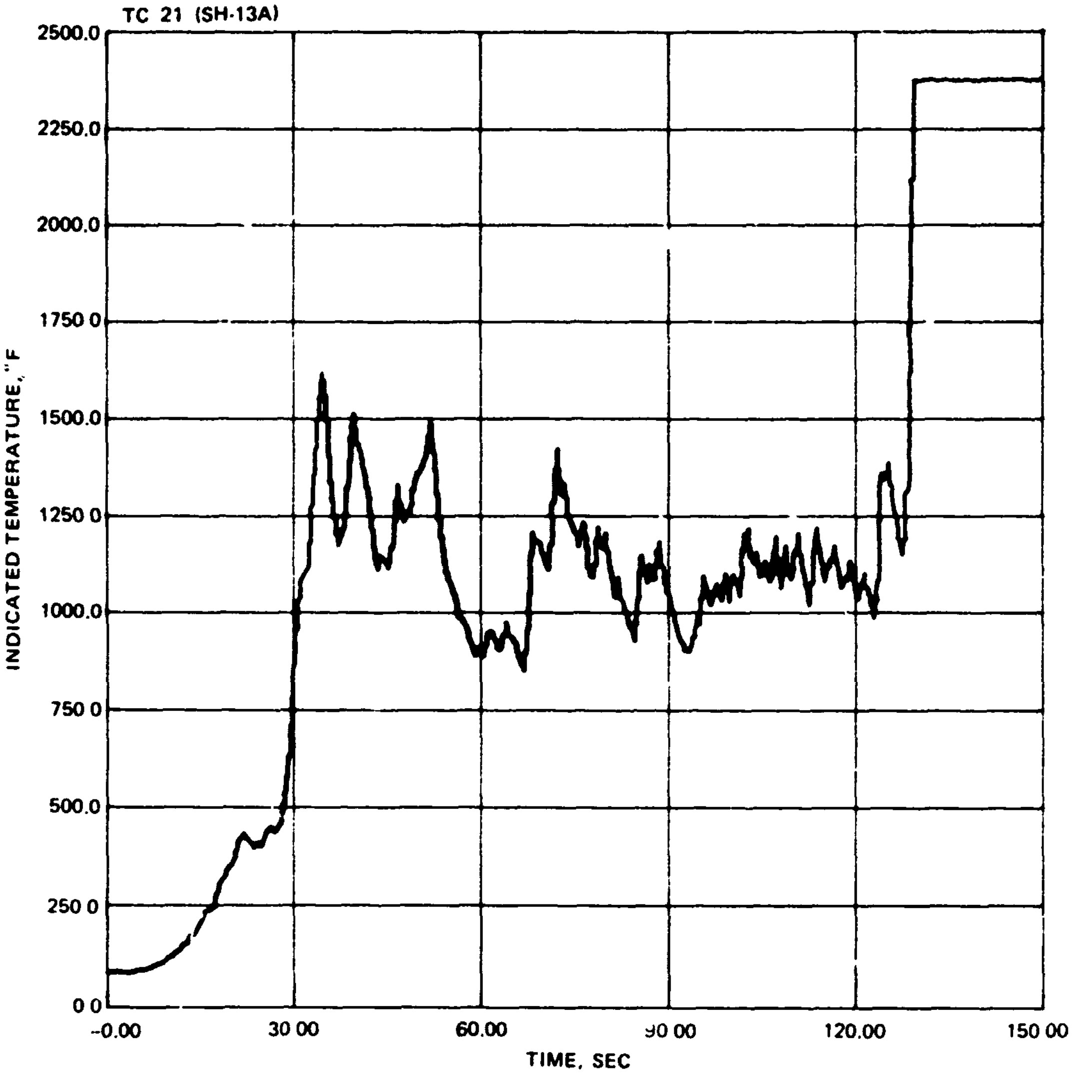

FIGURE C-45d TC 21, Starboard Flame Temperature, SH-13A

FIGURE C-46. SHRIKE SH-13A Post Test Configuration.

FIGURE C-47. Shrapnel Penetration of Wind Screen, SH-13A.

FIGURE C-48. Motor and Over Debris, SH-13A.

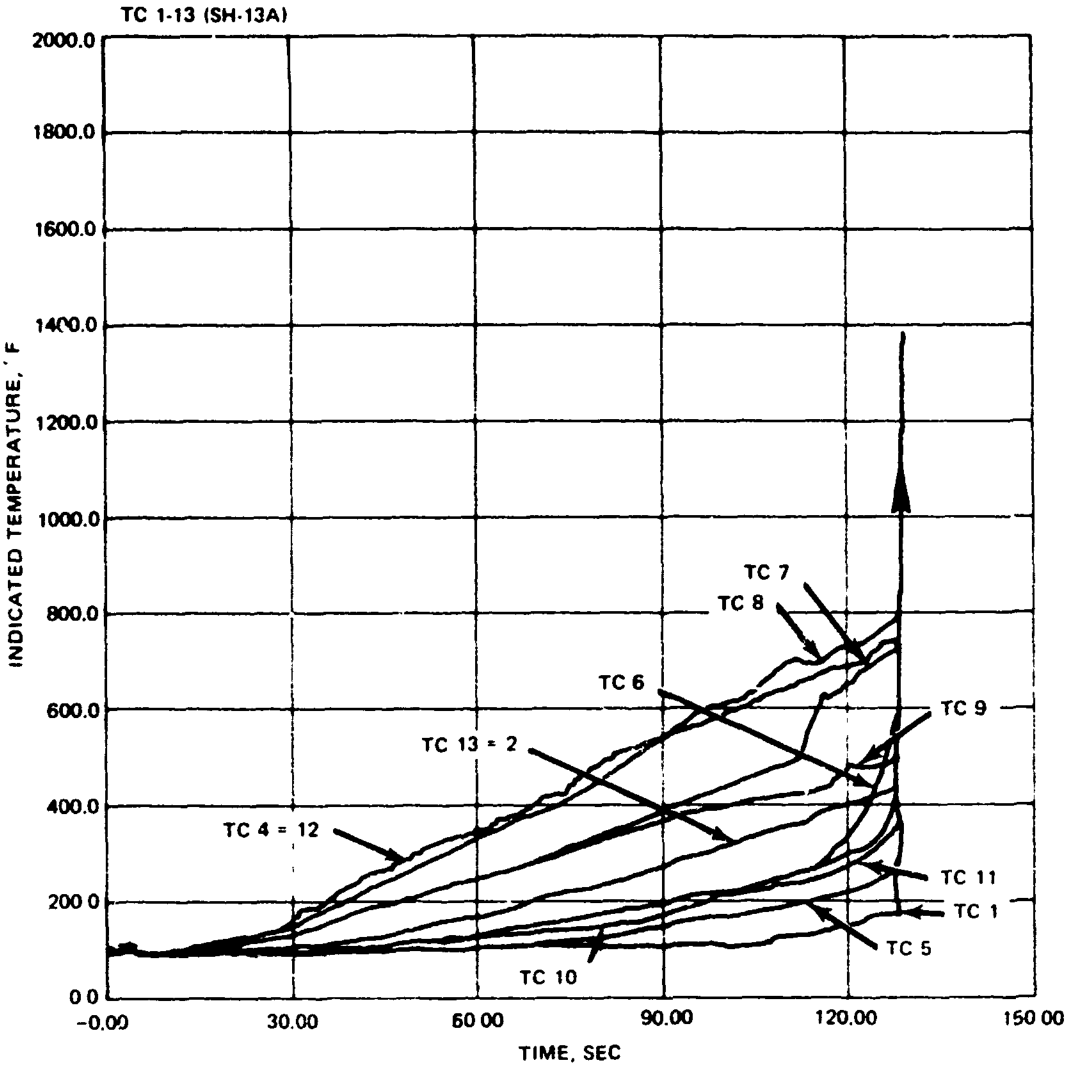

FIGURE C-49 TC 1-13 Response, SH-13A

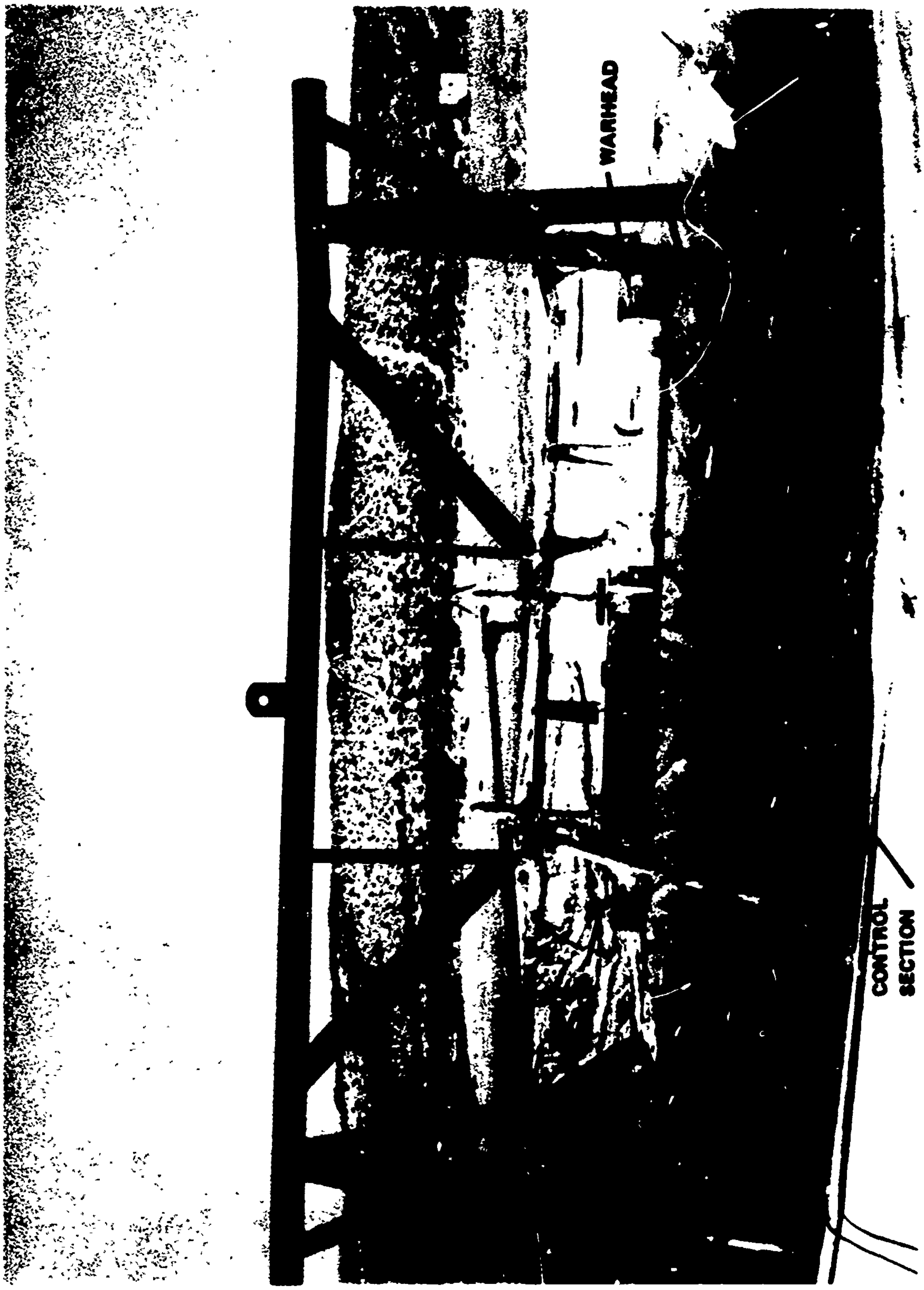

FIGURE C-50. SHRIKE SH-14A Test Configuration.

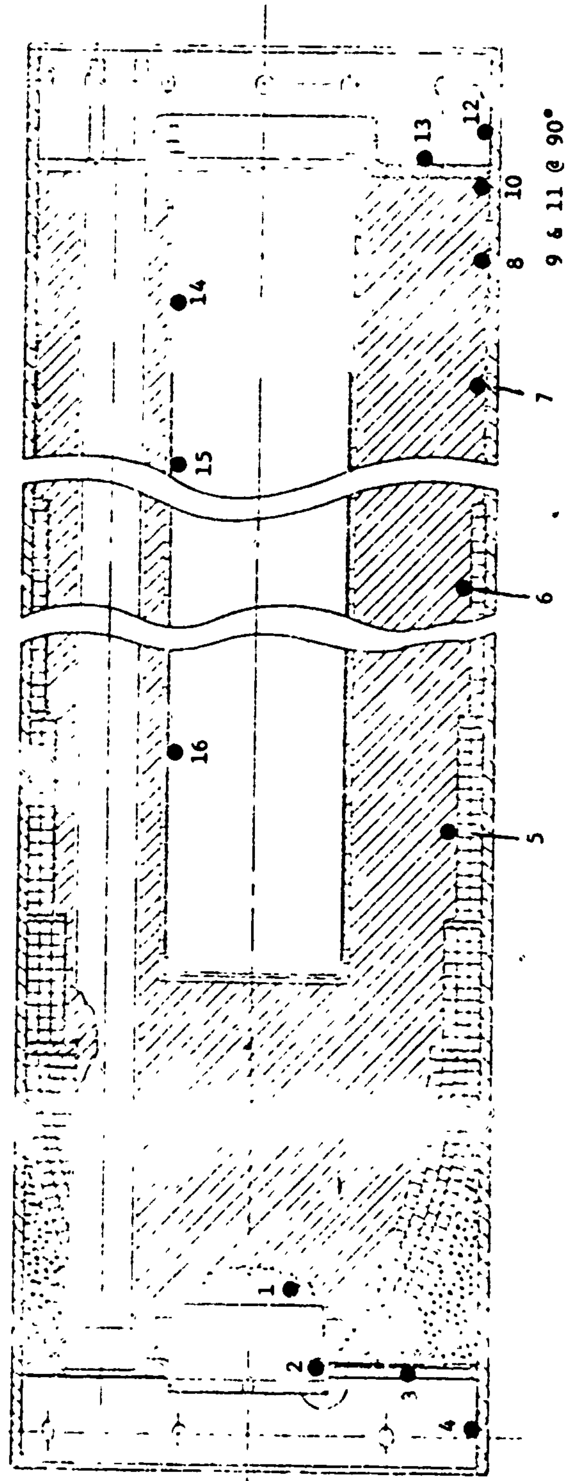

FIGURE C-51. Mk 80 Mod 0 Warhead Thermocouple Locations.

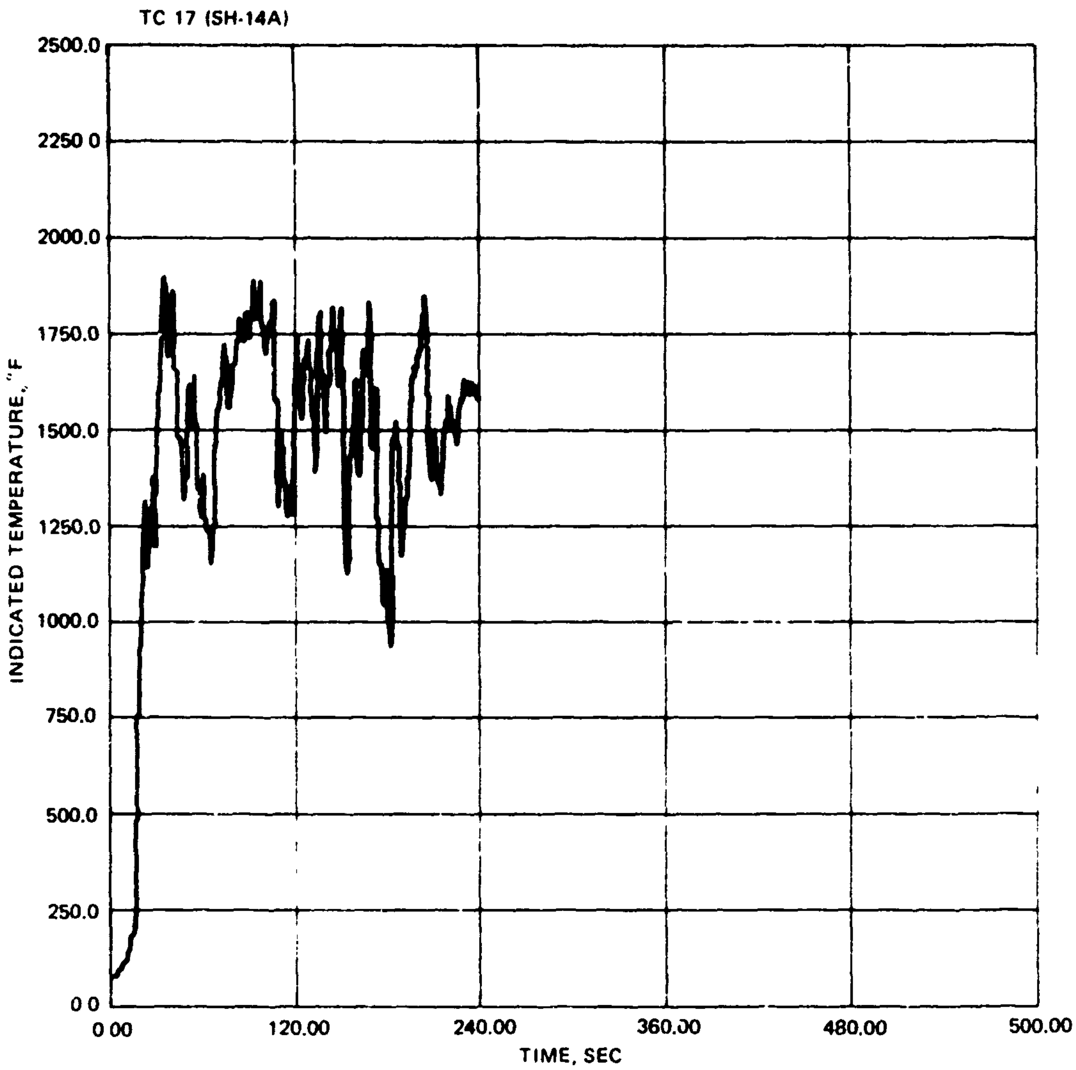

FIGURE C-52a. TC 17, Forward Flame Temperature, SH-14A

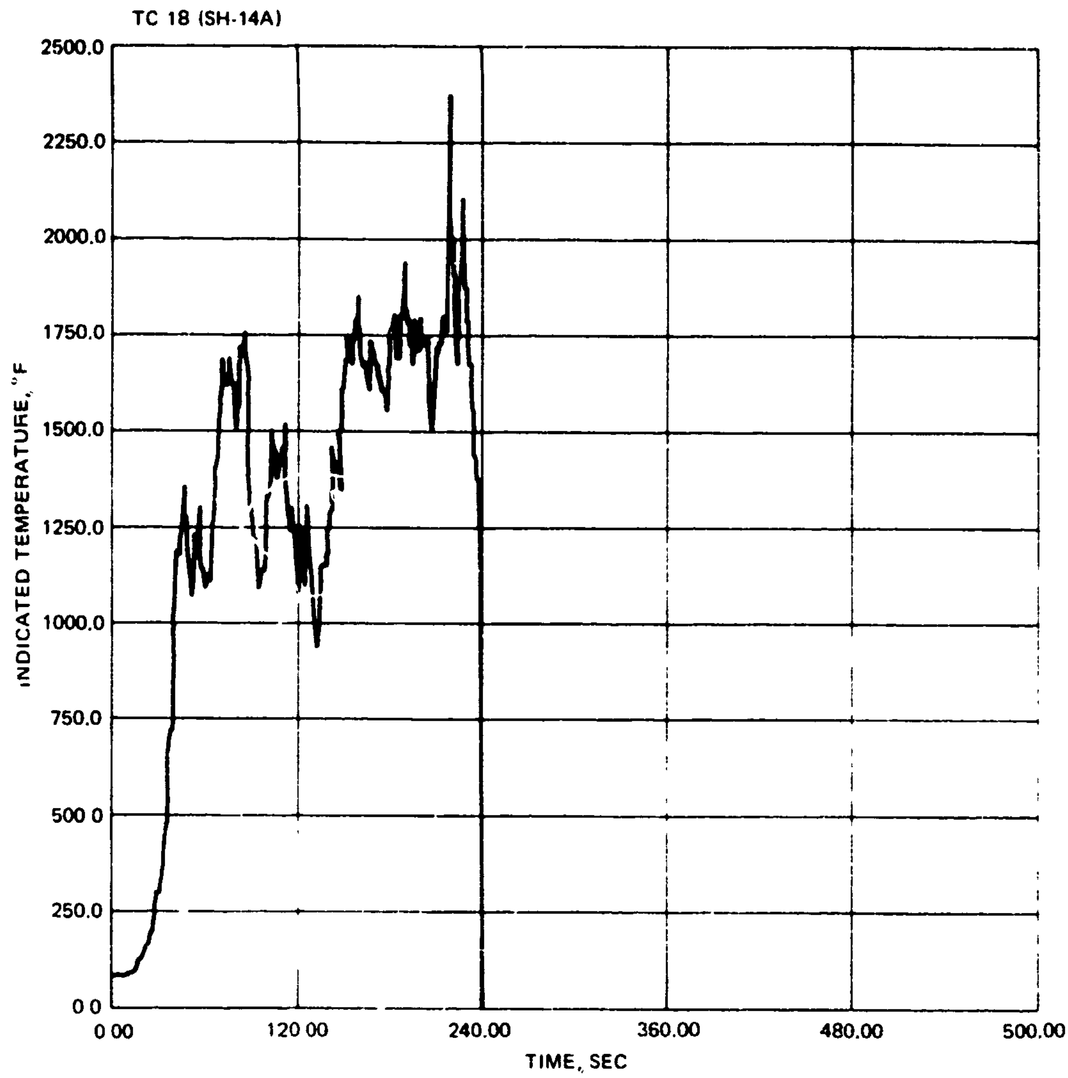

FIGURE C-52b. TC 18, Starboard Flame Temperature, SH-14A.

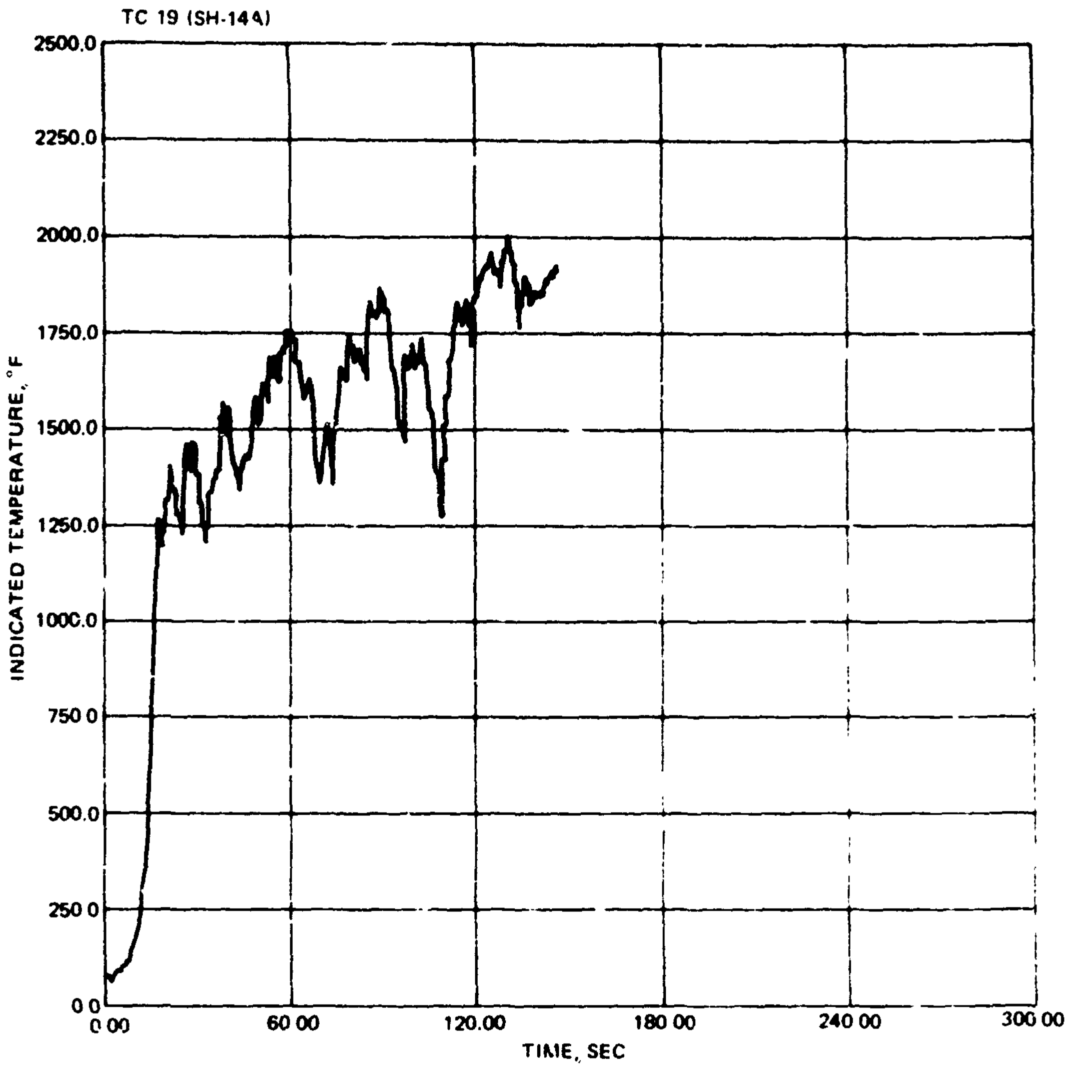

FIGURE C-52c. TC 19, Aft Frame Temperature, SH-14A.

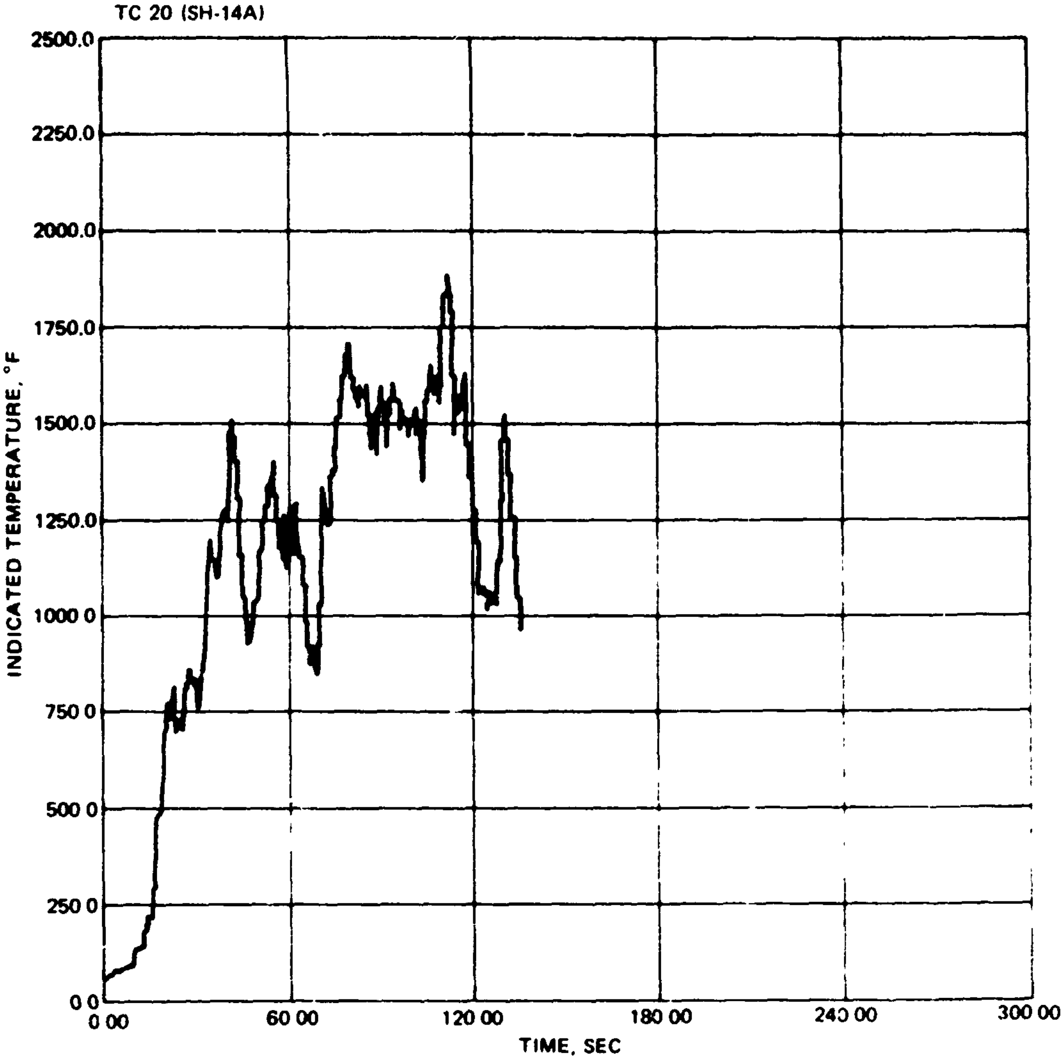

FIGURE C-52d. TC 20, Port Flame Temperature, SH-14A

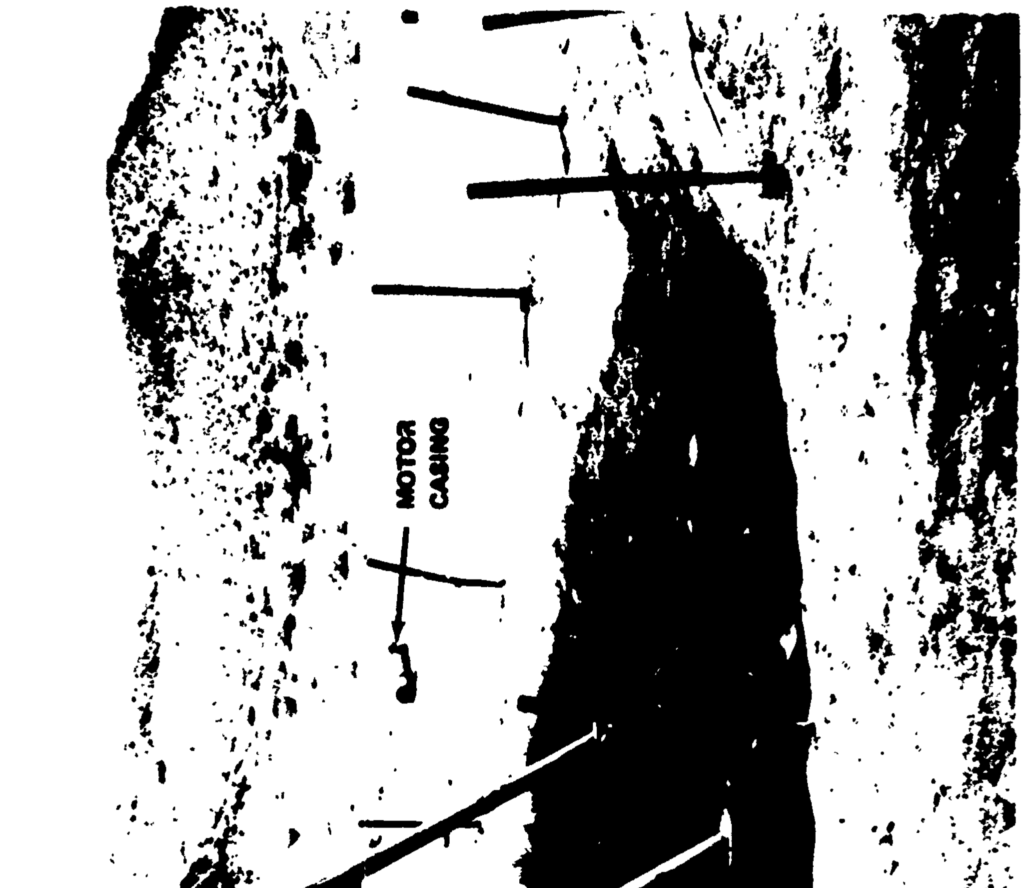

FIGURE C-53. SHRIKE SH-14A Post Test Configuration.

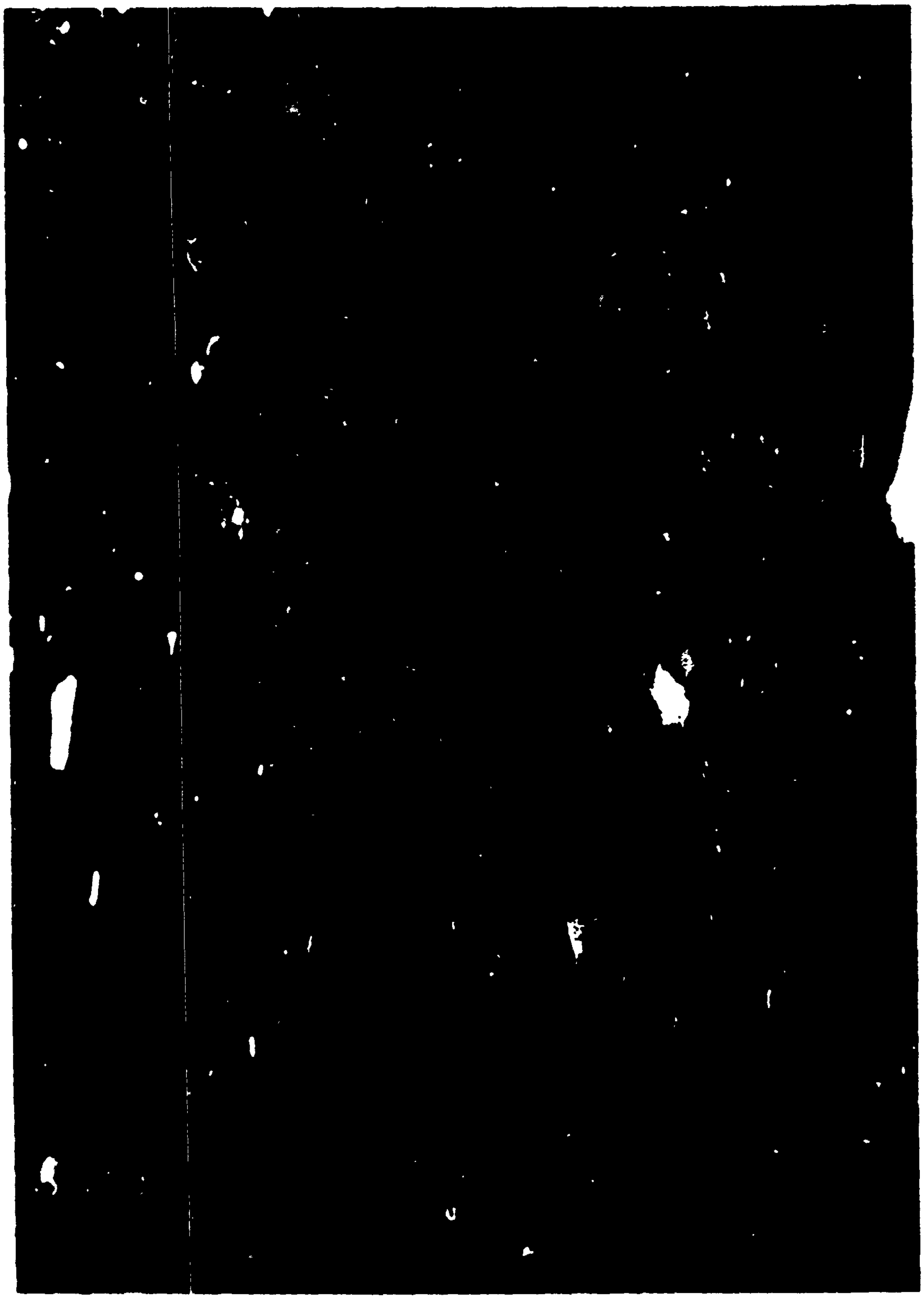

FIGURE C-54. Scatter of Warhead Cubes, SH-14A.

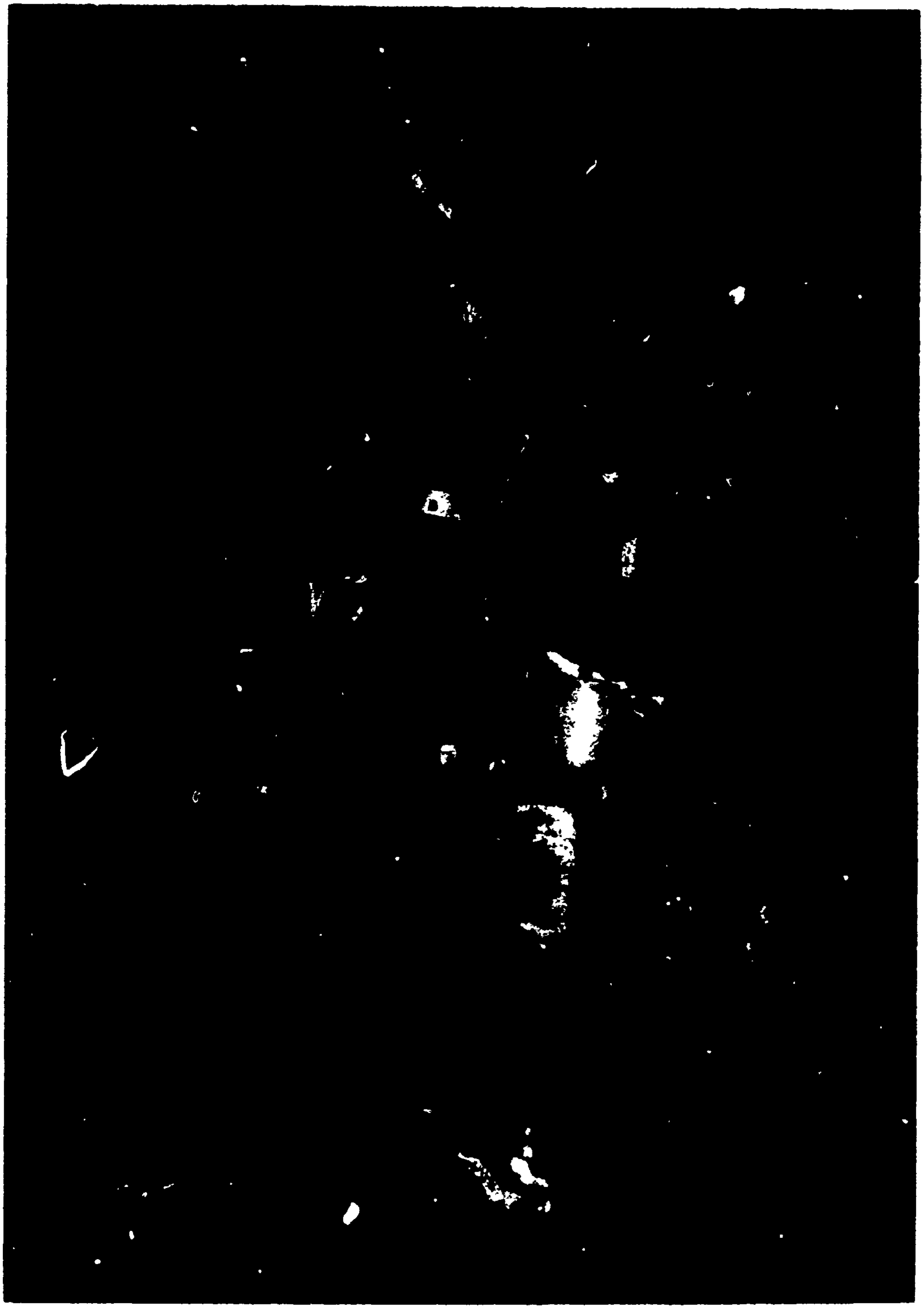

FIGURE C-55. Samples of Shrapnel, SH-14A.

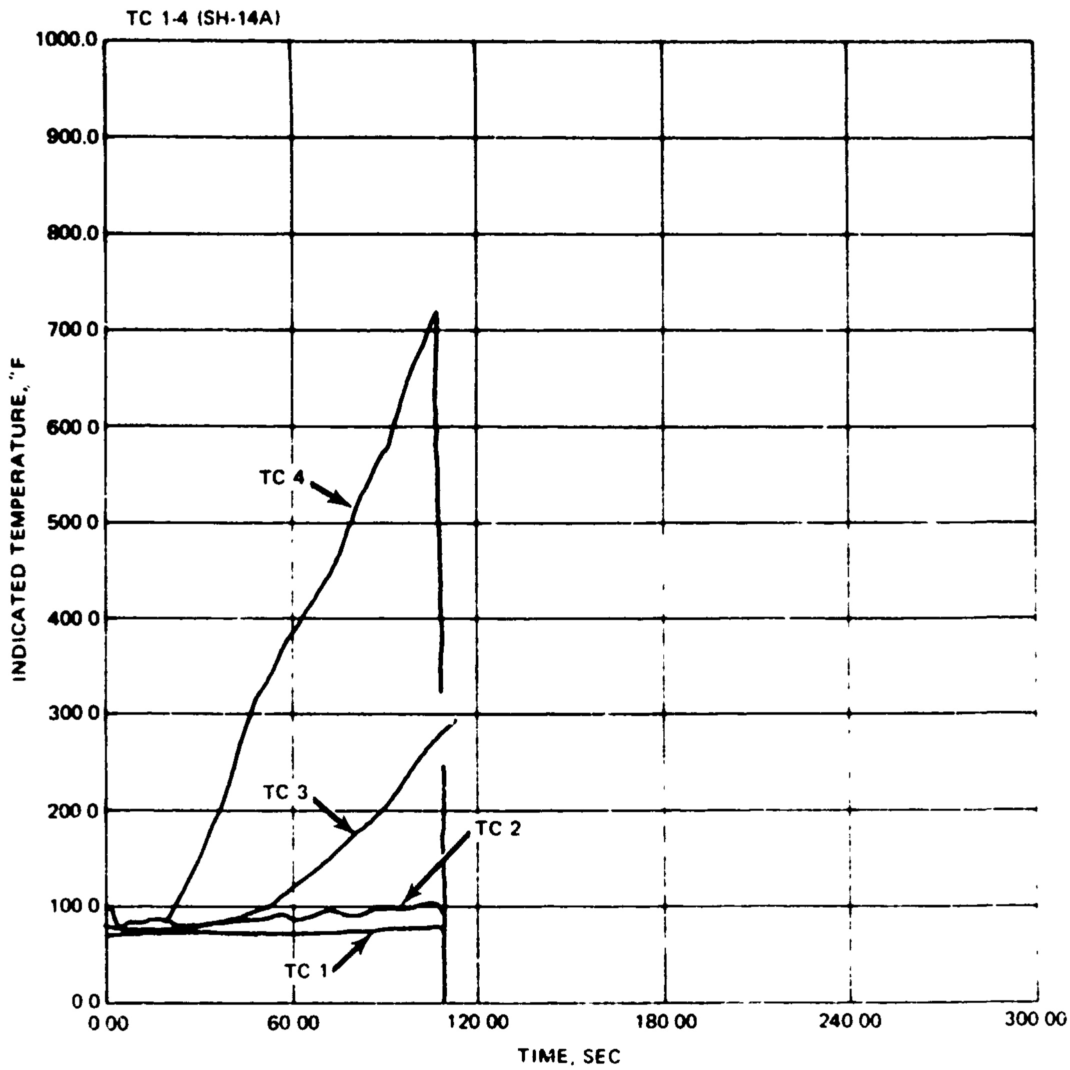

FIGURE C-56. TC 1-4 Response, SH-14A

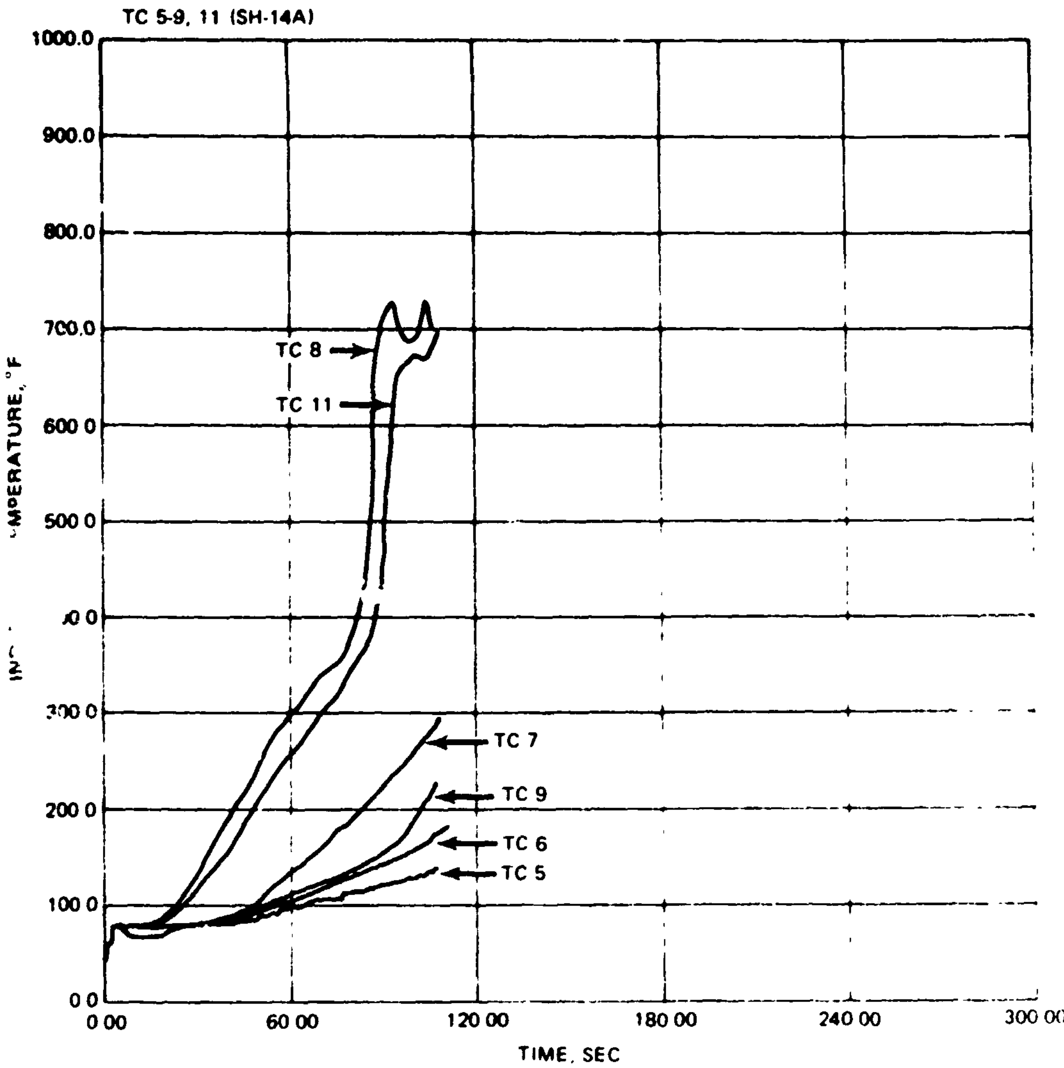

FIGURE C-57. TC 5-11 Response, SH-14A.

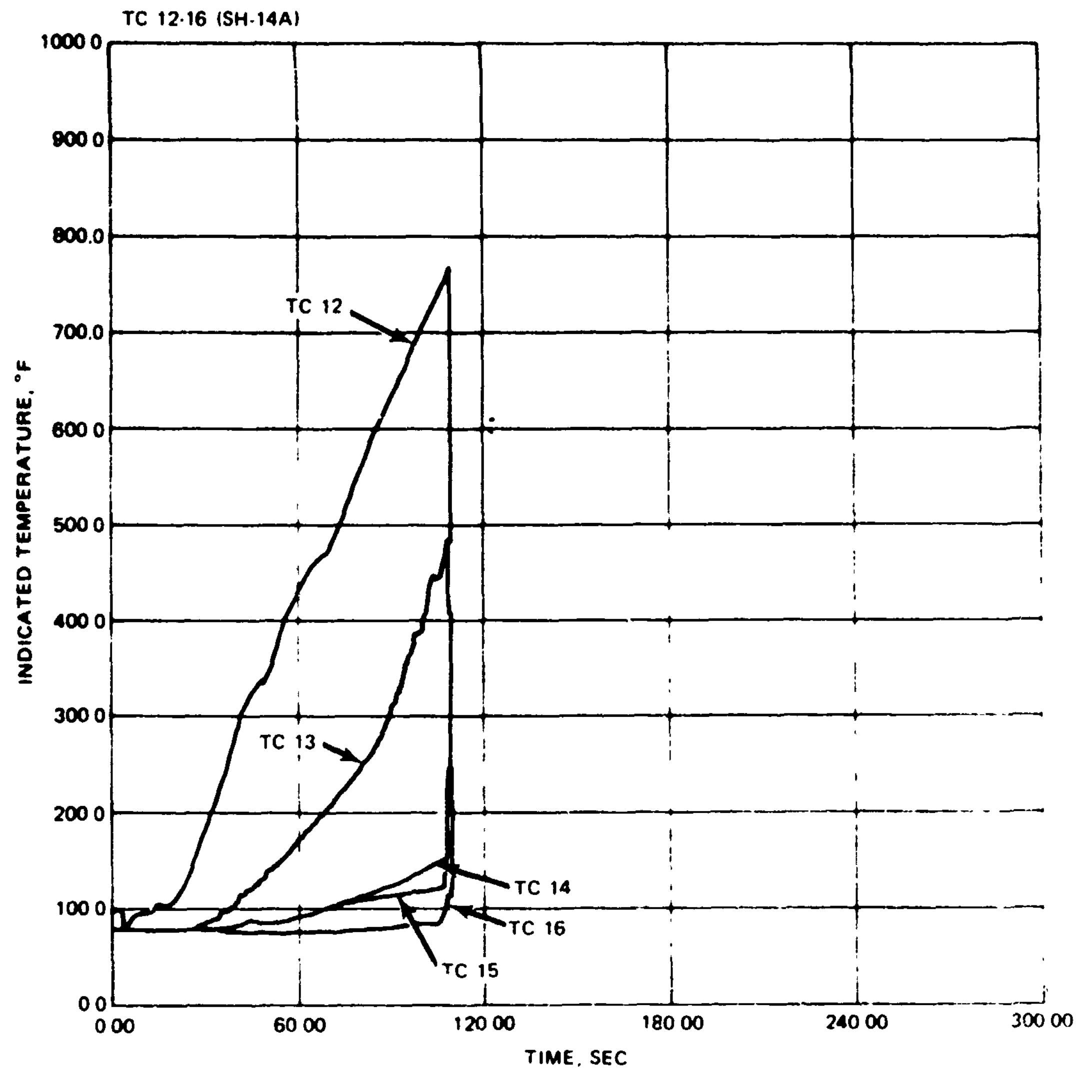

FIGURE C-58 TC 12-16 Response, SH-14A

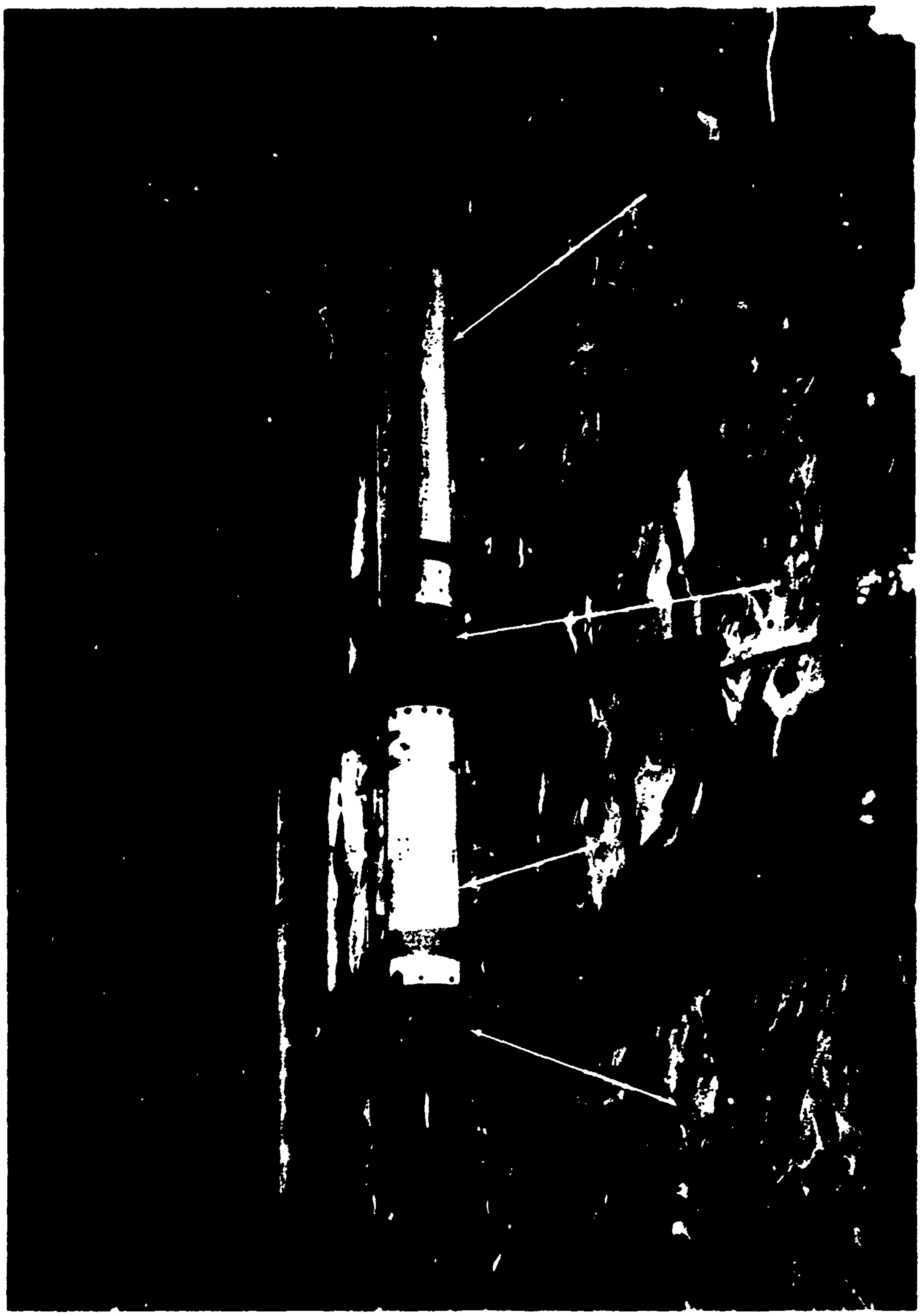

FIGURE C-59. SHRIKE SH-16A Test Configuration.

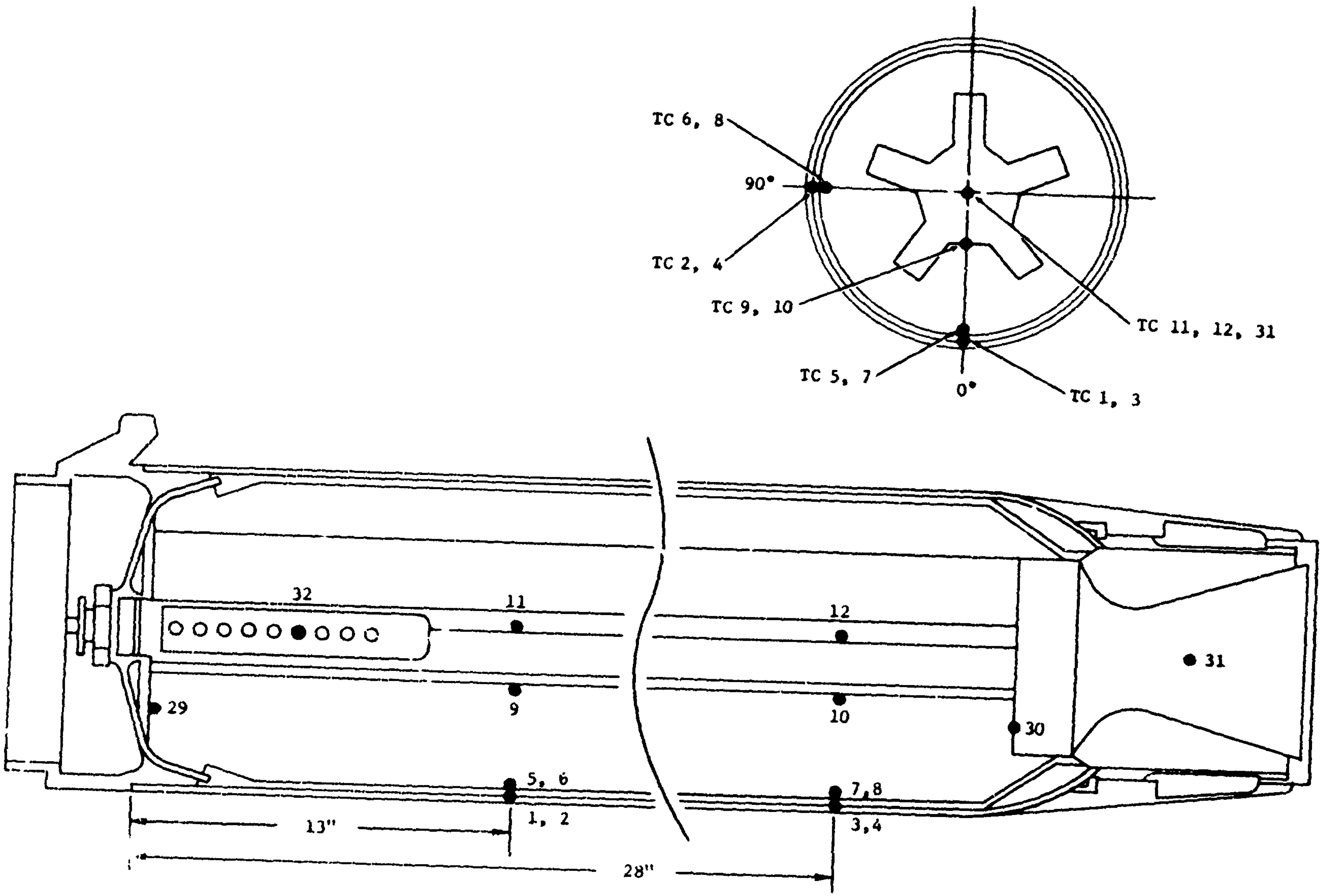

FIGURE C-40. MK 36 Mod 7 Motor Thermocouple Locations

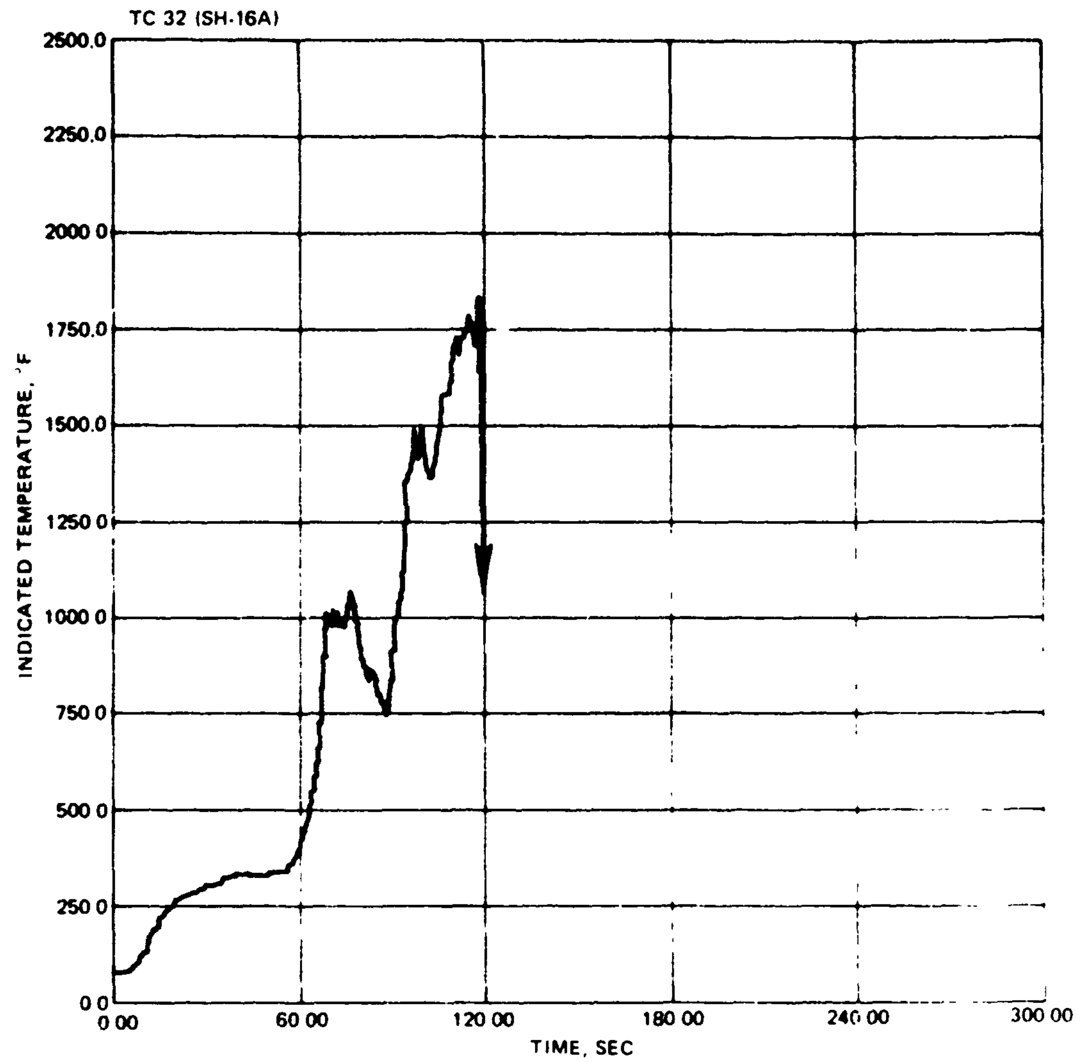

FIGURE C-61a. TC 32, Forward Flame Temperature, SH-16A

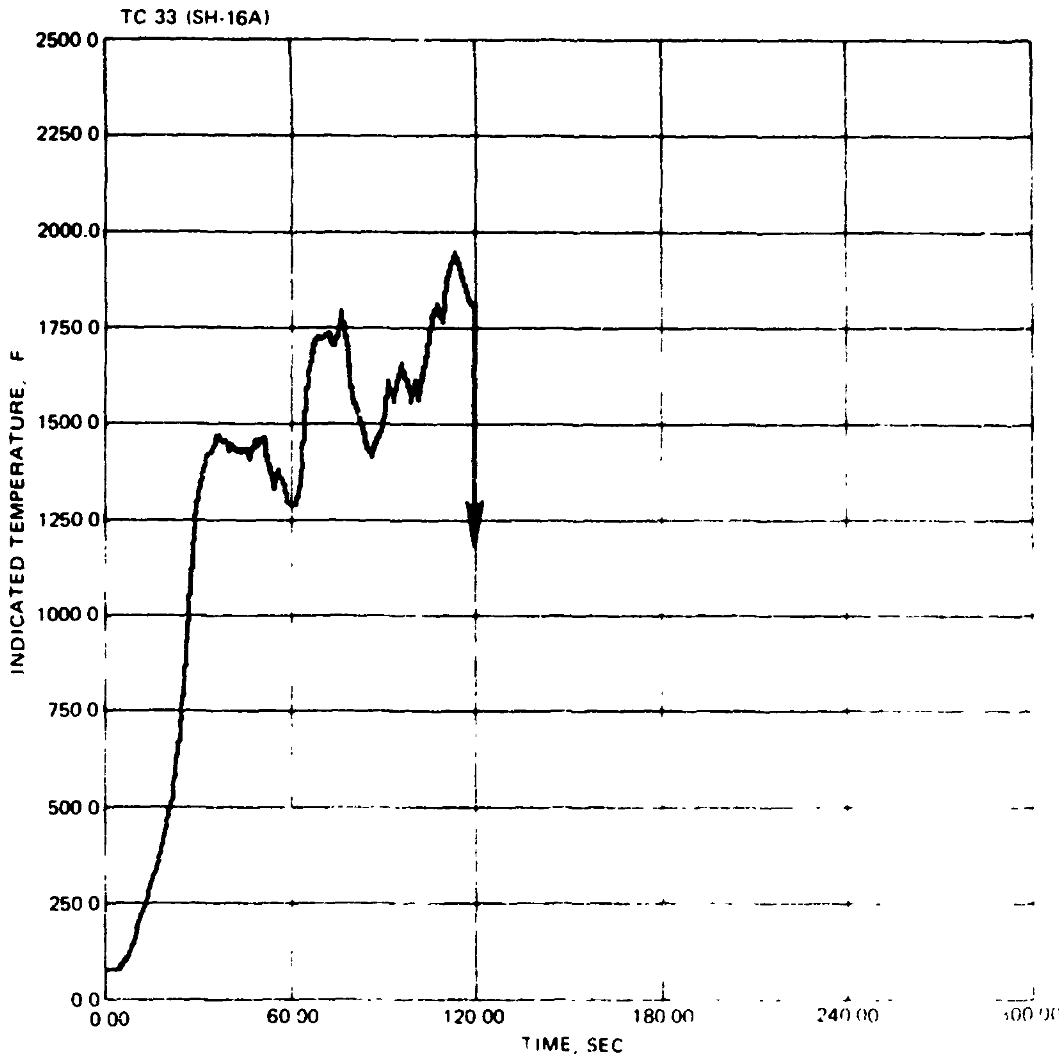

FIGURE C-61b. TC 33, Starboard Flame Temperature SH-16A

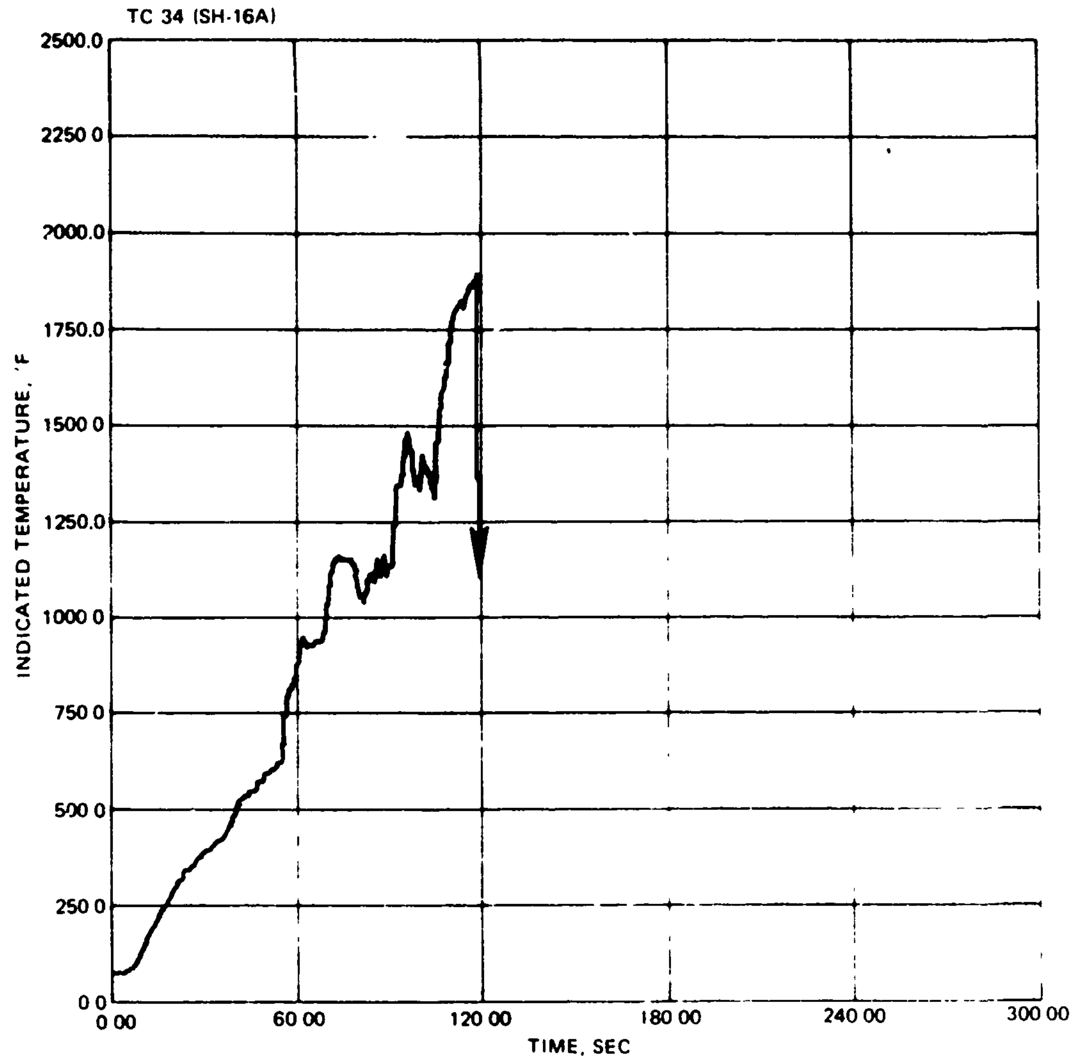

FIGURE C-61c. TC 34, Aft Flame Temperature, SH-16A

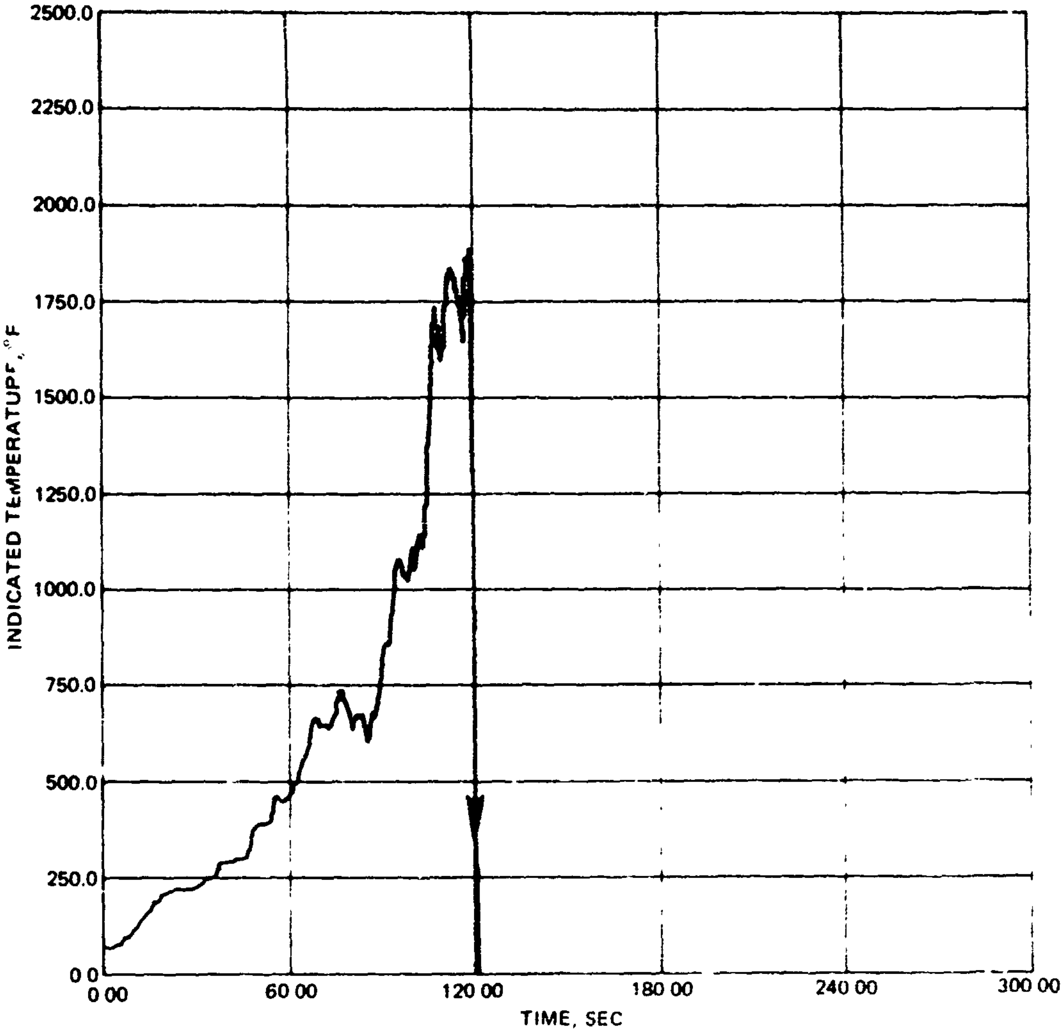

FIGURE C-61d. TC 35, Port Flame Temperature, SH-16A

FIGURE C-62. SHRIKE SH-16A Post Test Configuration.

FIGURE C-63. View of Embedded Guidance Section, SH-16A.

FIGURE C-64. Damage to Exterior Submarine Net, SH-16A.

FIGURE C-65. Control Section Remains SH-16A

FIGURE C-66. Aft End of Motor, SH-16A.

FIGURE C-67. Collected Pieces of Explosive and Propellant, SH 16A

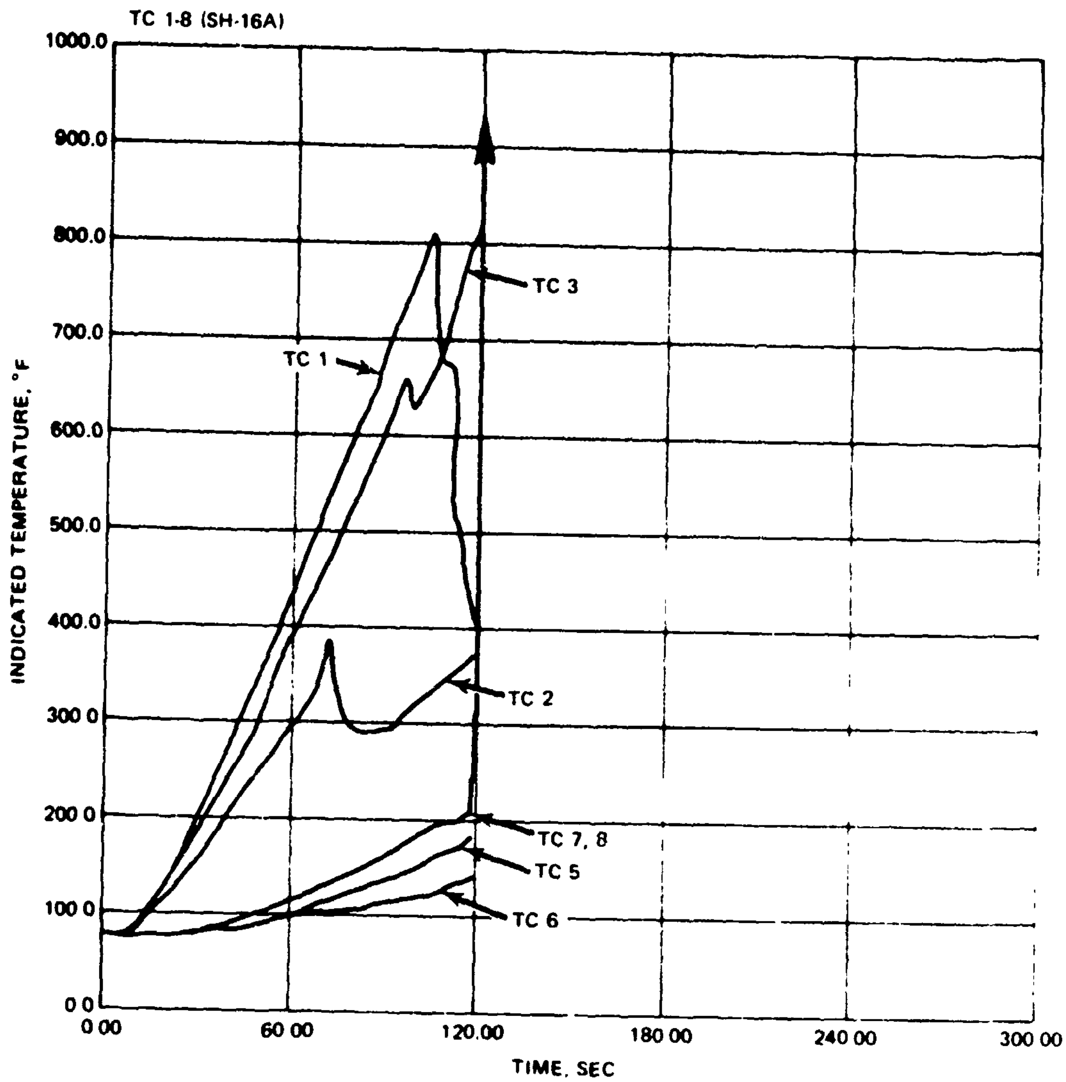

FIGURE C-68. TC 1-8 Response, SH-16A

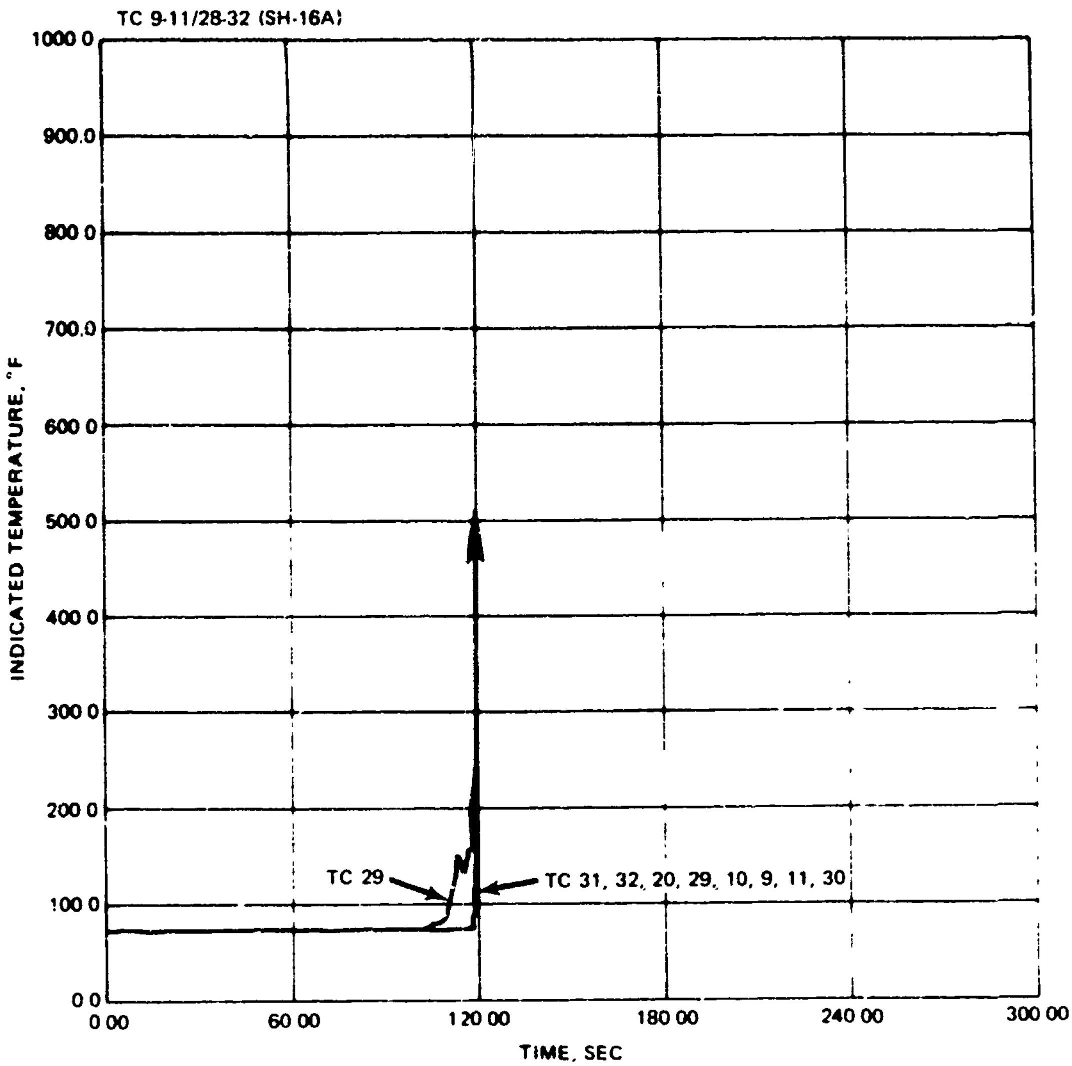

FIGURE C-69. TC 9-11/28-32 Response, SH-16A

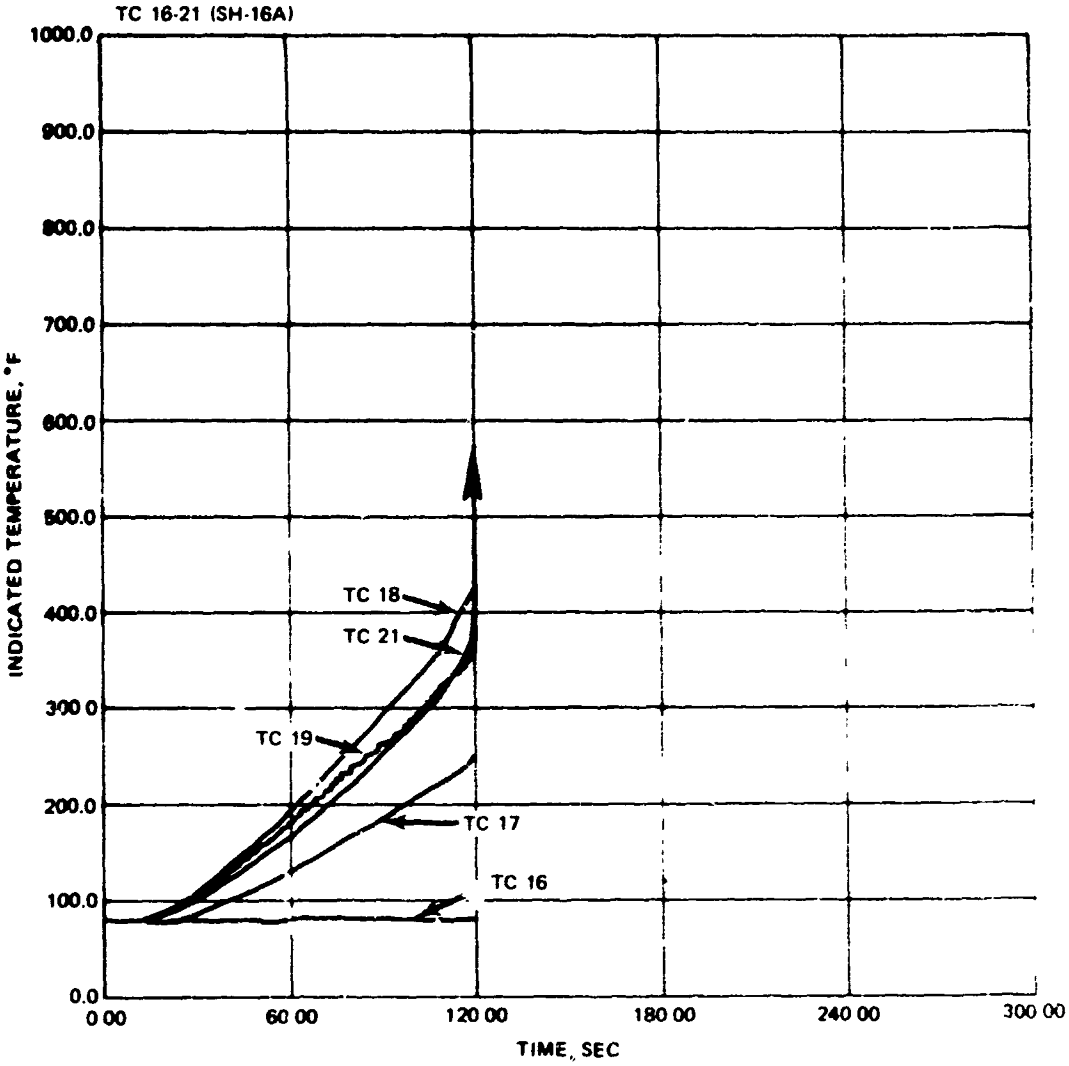

FIGURE C-70. TC 16-21 Response, SH-16A

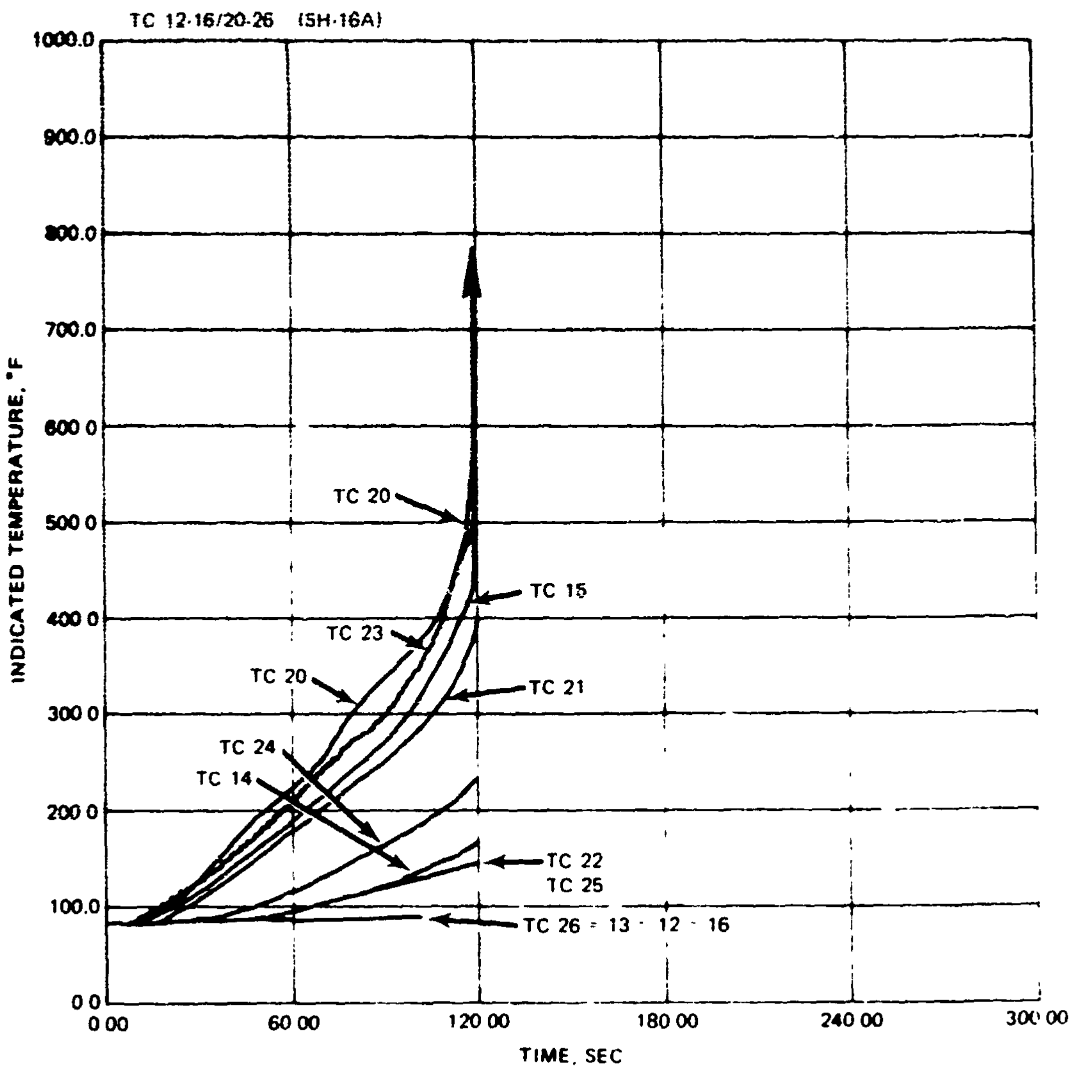

FIGURE C-71 TC 12-16/20-26 Response, SH-16A

Appendix D

SPARROW MISSILE
DETAILED TEST DESCRIPTION

LIST OF FIGURES

SPARROW MISSILE
DETAILED TEST DESCRIPTION

Each of the five SPARROW baseline cookoff tests is described separately. The format for all reports is the same: General Results, Detailed Description of the Test Item, Thermocouple Locations, Characterization of the Fire, and Graphs of Uncorrected Transient Thermocouple Data. The components used to configure the various test items have already been listed in Table 2 of the body of the report. Although an attempt was made to use complete production hardware (Appendix B) wherever feasible, in many instances secondary hardware was either simulated or not used at all. The meteorological conditions varied from test to test, and are shown in Table D-1. The test set-ups are shown in Figures D-1, D-12, D-14, D-20, and D-27, which also show the heavily insulated lead-wires and flame thermocouples. Test SP-14A was done in the 24-ft-square caged pit at Skytop. The others were done in the 24-ft octagonal pit at CT 4.

The primary hardware, i.e., motors and warheads, was modified in that thermocouples were embedded during test item assembly. Thermocouples (24-28 gauge) were used to minimize breakage during handling and processing. Care was taken to minimize intrinsic thermocouple installation errors. Unfortunately the size of the thermocouples precluded quantitative analysis because of the well known uncertainties associated with transient-temperature and lead errors which are large because of the good thermal insulative properties of propellants, explosives and liners. Therefore the interpretation of the thermocouple data obtained in these tests was only qualitative.

The data from each test are given here as received by the recorder. Data acquisition was terminated if the temperatures exceeded the scale (usually 1000°F), or if obvious discontinuities occurred. It is important to note that the recorded temperature is that of the thermocouple bead, which can conceivably move during the test. Heat entering the leads from a different area and other circumstances can also warm the bead. A discontinuity can occur anywhere along the leads as a result of mechanical fracture or of burn-through caused by explosive/propellant burning. Electrical arcing across the frayed leads can also lead to spurious EMF readings.

TABLE D-1. SPARROW Test Meteorology.

Test no	Temp. °F	Humidity (Rel %)	Wind
SP-312	70	Near 0	Calm, slight from W
SP-7B	41	Near 0	2-3 knots S
SP-13A	86	Near 0	2 knots W
SP-13B	53	None	Slight, from SW
SP-14A	100	None	5 knots W

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No attempt was made to separate data as valid or invalid. Such a judgment would be purely subjective. For example, it was observed by separate test that fractured thermocouple leads will arc in a fire, and give an EMF which could erroneously be attributed to some other bead located elsewhere. Another example is the apparent exothermic behavior observed at steel case/organic liner interfaces. If the liner is properly cured it could be argued that endothermic behavior should first occur there. On the other hand, exotherm liner behavior could certainly explain the apparently premature ignition of explosive/propellants. Thermocouple data (if quantitatively correct) taken between liner and explosive/propellant suggest that auto-ignition temperatures are generally not reached prior to deflagration or explosion. Therefore, until future laboratory tests examine such phenomena, abnormally high heating of a thermocouple bead is called "apparent exothermic behavior" in these test descriptions.

Other pertinent data are times to unusually loud sounds, and light flashes recorded on audio/video tape. Post-test observations are also given. Noise intensity cannot be directly correlated to quantitative hazard or explosion analysis. Also, post-test observations by different investigators were generally not in exact agreement. Hence only those observations which are in agreement are listed. Some information was lost in that it was difficult to reconstruct from only post-test photographs possible alternative events which conceivably could explain some of the responses indicated by the transducers.

SUMMARY OF SP-3A TEST

Results

All four flame thermocouples reached or exceeded an indicated temperature of 1000°F by 42 sec. By 70 sec the motor-case/liner region exhibited apparent exothermic behavior. Similarly by 120 sec materials in the region between the warhead rods and the potting material also showed apparent exothermic reaction. Hot gas produced in the warhead vented out the aft seal at 130 sec and escaped through the umbilical hole at the aft hangar, weakening it. By 180 sec venting through the thermocouple holes drilled in the forward warhead bulkhead was evident. At 216 sec the aft hangar gave way, and the motor end of the ordnance dropped into the pit. By 320 sec the magnesium in the forward portion of the warhead was burning. The warhead safe/arm device was ejected at 360 sec, suggesting that the magnesium liner was also burning in the aft section of the warhead The Mk 38 Mod 0 warhead deflagrated.

Test Item Description

The item (Figure D-1) consists of an inert motor (Mk 38 Mod 4) with case-bonded liner, an inert warhead, and an incomplete control section. The motor chamber was filled with crystal-white stucco sand (30 mesh) Ten 24-gauge chromel-alumel thermocouples (1-10) were located as shown in Figure D-2. The leads were routed through the sand, the nozzle seal, and out to the A-frame

The inert warhead was a Mk 38 Mod 0 casing, with an empty Mk 35 Mod 1 safe/arm housing bolted in place, and a wooden billet in the explosive cavity. Thirteen 24-gauge chromel-alumel thermocouples (11-23) were located as shown in Figure D-3. The leads were routed forward along grooves longitudinally machined in the magnesium liner, and out through holes drilled in the casing fillet, and exited through the control section to the A-frame.

SP-3A Fire

A thermocouple was placed at the centerline plane six inches from the test item at the forward (TC 24), starboard (TC 25), aft (TC 26), and port (TC 27) regions. The uncorrected thermocouple outputs of flame temperatures are seen in Figures D-4a, b, c, and d. The fire was abnormally cool between 180 and 210 sec, particularly on the port and starboard sides.

Post-Fire Commentary

The control section was consumed except for the steel ball joint. The test item dropped from the aft hangar into the pit at 216 sec, as indicated by the breaking of the thermocouples in the motor interior at that time. The underside of the test item seen in Figure D-5, shows a gap between the warhead fairing and the forward bulkhead. The safe/arm device was also ejected.

Thermocouples 11, 13, 16, 19, and 21 were located on the warhead rods. Both TC 11 and 16 malfunctioned. The responses of TC 13, 19 and 21 are shown in Figure D-6. As expected, TC 19 was hotter than either TC 13 or TC 21. By 493 sec it was apparent from thermocouple failure and video-tape record, that the magnesium liner was burning. Magnesium melts at about 1200°F, boils near 2000°F, and hence probably ignites near that temperature. TC 19, which is not at the hottest location, indicated a maximum temperature before failure of some 1500°F. It is probable that the fuel-flame heat, together with exothermic heat, created by decomposition products of the potting material, ignited the magnesium liner by 493 sec. Evidence that the potting material and/or other materials such as cavity paint, are producing exothermic reaction is given by TC 12, 14, 20 and 22, as shown in Figures D-7 and D-8. TC 12 and TC 20, located at the inner bottom of the magnesium liner, both exhibit apparent exothermic behavior before 120 sec. Similarly, at a later time, TC 14 and 22 exhibit the same response. Their indicated rates of heating are greater than those of the thermocouples bonded to the steel rods (Figure D-6). The indicated temperatures seem to be too low for auto-ignition of the magnesium.

Warhead venting can be inferred from the outputs of TC 15, 17, 18, and 23 (Figure D-9). TC 23 suggests that venting out the aft potting material seal occurs by 130 sec, and that the magnesium flames vent by 493 sec. TC 18 suggests that the warhead safe/arm device had ejected before 360 sec TC 15 and 17 indicate that venting through the forward bulkhead thermocouple holes was well established by 180 sec. It appears likely that the magnesium was burning in the forward portion of the liner by 320 sec, since TC 15 exhibited extraordinarily high temperatures.

It would appear that the warhead vents through the rear seal into the motor safe/arm cavity and out the lower keyhole and/or umbilical hole under the rear launch hangar. If the warhead safe/arm device were expelled then venting would also occur through the warhead cavity into the control section. Another possible vent source was at the point where the thermocouples exit out the front end of the warhead at the weld bead. Finally if the edge welds had failed, then venting would have occurred between the rods and the outer steel-fairing

Rocket motor thermocouples 1-4 were welded to the inner side of the case (Figure D-10) and showed high initial heating rates up to about 70 sec. Then a significant temperature reversal occurred which may be attributed to liner degradation at temperatures above 700°F. This behavior is ascribed to apparent exothermic reaction in the steel-case/liner region. Further evidence of exothermic reaction in this area before 70 sec is indicated by some of the thermocouples placed on the sand side of the liner (Figure D-11). Thermocouples 6-8 responses indicate apparent exothermic behavior at temperatures above 400°F, beginning at about 160 sec. The motor thermocouple data are discontinuous after 216 sec, indicating that the motor dropped into the fire at that time.

SUMMARY OF SP-7B TEST

Results

All data were lost, including the first 30 sec of video-tape. At 490 sec a continuous jetting sound was attributed to venting of the magnesium and explosive gases through the aft warhead seal. The violent jetting at 845 sec, with burning particles being thrown about, was believed to be the warhead steel fairing being removed. The violent fireball reaction at 1200 sec was apparently the result of an over-pressurization caused by explosion of the safe/arm device The Mk 38 Mod 0 warhead deflagrated.

Test Item Description

The item (Figure D-12) consisted of a modified live Mk 38 Mod 0 warhead with a Mk 35 Mod 0 safe/arm device, and a Mk 38 Mod 1 booster, attached to an empty motor case. A cylindrical thick-walled fixture was attached to the warhead for additional support.

SP-7B Fire

All data were lost

Post-Fire Commentary

The test item was still suspended from the A-frame at the end of the test (Figure D-13) It was apparent that the burning explosive and magnesium vented through the forward end of the warhead, and was also apparent at the aft seal of the warhead, since the forward motor enclosure had burned almost completely away. The warhead rods, as a result of explosion of the safe/arm device, expanded. Audio-visual recording showed a sound at 357 sec. At 490 sec a continuous jetting sound began Comparing this with the second event of test SP-3A, it is probable that the explosive had ignited. The jetting sound was attributed to the magnesium and explosive gases venting through the aft warhead seal into the empty motor chamber. At 845 sec burning particles were noticed in the fuel fire, which could well have been from the thin steel warhead fairing being ejected. At 1200 sec a loud violent reaction occurred with a large fireball. This event would account for the expanded rod configuration shown in Figure D-13 and was probably caused by explosion of the safe/arm device, which possibly did not eject, because there was adequate venting through the empty motor case. It was obvious that the burning explosive and magnesium vented through the aft end of the warhead seal, since the forward motor enclosure had burned almost completely away.

SUMMARY OF SP-13A TEST

Results

All four thermocouples reached or exceeded an indicated flame temperature of 1000°F by 51 sec. Apparent exothermic reactions were indicated by 145 sec for the thermocouples attached to the warhead rods, and particularly the thermocouple (coated with potting material) attached to the magnesium liner. Venting through the aft warhead seal began at 100 sec. Venting through the warhead safe/arm cavity was indicated by 220 sec, by both thermocouple response and a roaring sound. The Mk 38 Mod 0 warhead deflagrated. The fire was poor because of the relatively high wind velocity with the A-frame visible from time to time.

Test Item Description

The item consisted of a live warhead, an empty motor casing, and an incomplete control section (Figure D-14). The warhead did not contain a safe/arm device. Thirteen 24-gauge chromel-alumel thermocouples (11-23) were located as shown in Figure D-3. The thermocouple leads were routed as described in SP-3A, and through the umbilical hole in the control section to the A-frame.

SP-13A Fire

Thermocouples were placed at the centerline plane, six inches from the test item at the forward (TC 24), starboard (TC 25), aft (TC 26), and port (TC 27) regions. The uncorrected thermocouple output of flame temperatures shown in Figures D-15a, b, c, and d, together with that from the video tape, reflected occasional wind gusts. At 295 sec the forward section of the item dropped into the pit (Figure D-16) fracturing the flame temperature thermocouple leads. The fire was abnormally cool between 175 and 193 sec, particularly on the forward and port sides. A similar occurrence was reported for SP-3A.

Post-Fire Commentary

As with SP-3A, the control section was consumed except for the steel ball joint. A loud report was heard at 220 sec. The test item dropped from the forward sling into the pit at 295 sec, as indicated by the breaking of most of the thermocouples.

Thermocouples 11, 13, 16, 19 and 21 were located on the warhead rods (Figure D-3). Their responses are shown in Figure D-17. All became inoperative after 295 sec, when the forward section of the test item fell into the pit. Thermocouples 13 and 16 exhibited peculiar behavior from about 190 sec, and failure of these may have occurred prior to the loud report heard at 220 sec. Again, as expected, TC 19 and TC 11 were hotter than TC 13 and TC 21. The loss of all thermocouples at 295 sec precluded further comparison with SP-3A.

Apparent exothermic reaction is given by TC 12, 14, 20 and 22 (Figure D-18). The reactions are not so spectacular as those for SP-3A. This difference may be tentatively attributed to the use of a wood billet in SP-3A as opposed to an explosive in SP-13A. Hence the reverse spikes may be ascribed to exothermic reactions. These thermocouples also were fractured at 295 sec.

The outputs of TC 15, 17, 18 and 23 are given in Figure D-19. TC 23 does not give a strong indication of venting out the aft potting material seal, although it was non-linearly increasing in magnitude up to 295 sec. On the other hand, TC 18 shows that venting through the safe/arm tube began at about 220 sec, which may account for the loud report at that time.

SUMMARY OF SP-13B TEST

Results

All four flame thermocouples reached or exceeded an indicated flame temperature of 1000°F by 52 sec. Apparent exothermic behavior in the warhead was evidenced by 96 sec. Venting of product gas through the aft warhead seal was probable by 102 sec. The magnesium spool was ignited and vented through both the forward and aft ends of the warhead by 195 sec.

Test Item Description

The item, Figure D-20, consisted of an inert warhead, attached to an empty motor casing. A live SIDEWINDER motor was located four feet away.

The inert warhead was a Mk 38 Mod 0 casing without the safe/arm housing, and with a wooden billet in the explosive cavity. The forward and aft circumferential ends were trimmed back a half-inch so that there was a one-eighth-inch spacing between the wood and the rods, which was filled with additional potting material.

Thirteen 24-gauge chromel-alumel thermocouples (11-23) were located as shown in Figure D-3. The leads were routed forward along the longitudinally machined magnesium liner grooves, out through holes drilled in the casing fillet, and exited through the control section to the A-frame.

SP-13B Fire

Chromel-alumel thermocouples were placed at the centerline plane six inches from the test item at the forward (TC 24), starboard (TC 25), and port (TC 26) regions. The uncorrected thermocouple

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outputs of flame temperatures are shown in Figures D-21a, b, and c. The fire was abnormally cool at the starboard and port sides, between 82 and 95 sec.

Post-Fire Commentary

The test item is shown in Figures D-22 and D-23. Venting of gases between the motor warhead and motor casing from the magnesium liner is evident in both these figures. Venting of these gases through the upper circumference of the control section can also be seen.

The outputs of the thermocouples attached to the steel rods are given in Figure D-24. There are apparent exotherms for TC 13 at 96 sec, for TC 19 and TC 11 at 152 sec, and TC 16 at 465 sec. TC 19 failed at 535 sec.

The outputs of thermocouples 12, 14, 20 and 22 are shown in Figure D-25. These were attached to the inner cone of the magnesium liner. Pronounced apparent exothermic behavior is evident at 163 sec, 275 sec, and also at about 540 sec.

Outputs of TC 15, 18, and 23 are given in Figure D-26. Venting at the aft of the warhead is suggested by the exotherm at 102 sec for TC 23. Venting through the forward thermocouple fillet holes is indicated at 150 sec by TC 15. Venting through the safe/arm cavity is suggested by TC 18 to have occurred by 195 sec, and then again at a higher rate at 490 sec. The magnesium was completely consumed during the test. Further evidence of internal burning with gases exiting through the simulated guidance section and the motor/warhead interface was the deposit of a very fine white ash around the exit regions.

SUMMARY OF SP-14A TEST

Results

All four flame thermocouples reached or exceeded an indicated flame temperature of 1000°F by 16 sec. By 30 sec the motor fiberglass liner and/or standoff legs reacted exothermically to produce internal heat in addition to that produced by the external fuel fire. By 134 sec the warhead also exhibited apparent exothermic behavior to produce internal heat The Mk 38 Mod 0 rocket motor exploded at 62 sec, followed by continuous propellant burning to 100 sec. The Mk 38 Mod 0 warhead deflagrated and vented through the aft seal by 84 sec. At 482 sec a noise was heard At 495 sec a loud noise with light flash was ascribed to explosion of the safe/arm device.

Test Item Description

The item (Figure D-27) consisted of an incomplete control section, a live warhead, and a live motor. The motor was a Mk 38 Mod 0 with a solid-propellant grain of a standoff design. Twenty-three 29-gauge chromel-alumel thermocouples (1-10 and 24-36) were located as shown in Figure D-28. The thermocouple leads were routed through the nozzle to the A-frame

The live warhead was a Mk 38 Mod 0, containing a Mk 35 Mod 1 safe/arm device Thirteen

24-gauge chromel-alumel thermocouples (11-23) were located as shown in Figure D-29. The leads exited through the umbilical hole in the control section to the A-frame.

SP-14A Fire

Thermocouples were placed at the centerline plane some six inches from the test item, at the forward (TC 37), starboard (TC 38), aft (TC 39), and port (TC 40) regions. The uncorrected outputs of flame temperatures are shown in Figures D-30a, b, c, and d. The fire was abnormally cool on the aft and port sides, between 62 and 70 sec.

Post-Fire Commentary

Items remaining after the test are shown in Figures D-31–D-34. The warhead casing was still attached to the A-frame (Figure D-31). On the ground in front of the warhead is the spherical control mechanism, and to the right the fiberglass grain-support tube.

In the lower righthand corner of Figure D-32 is seen the boattail section with nozzle attached to a piece of motor casing. To the right of the A-frame is a piece of the motor casing. Figure D-33 shows the safe/arm device lying in front of the spherical control component. There is a significant bulge on the steel warhead fairing. Figure D-34 shows a crease on the outer periphery of the nozzle, possibly caused by impact with the heavy steel windscreens shown in the background of Figure D-32. Screens were both forward and aft of the test item. The A-frame leg is partially buried under dirt, indicating that thrust had moved it. Motor fragments were located as follows: boattail 12 ft at 5.30 o'clock, a piece of the casing 25 ft at 8 o'clock, a piece of casing 10 ft at 2.30 o'clock, and forward dome 10 ft at 7.30 o'clock. These items may have ricocheted to their resting places.

Audio-visual monitoring revealed a small flash and a noise at 61 sec, a large fireball and explosion at 62 sec, followed by continuous propellant burning until 100 sec, a slight noise at 482 sec, and a loud noise with light flash at 495 sec.

Output from thermocouples 1-10 and 24-36 located in the motor are shown in Figures D-35-D-38. All of these dat ended at 62 sec, suggesting that the motor exploded. TC 32-34 (Figure D-38) indicate that the grain bore had not yet ignited at the time the thermocouples were fractured. The same can be said for TC 36 at the igniter (Figure D-37). On the other hand, the airspace behind the nozzle seal began heating at 34 sec. The thermocouple responses from the bottom of the grain are shown in Figure D-35. Thermocouples 1, 7, and 26 are typical of thermocouples in the steel case to glass liner, between the glass liner and air, and between air and propellant respectively. Apparent exothermic behavior of the interface thermocouples 1, 3, 9, 26, 28, and 30 is shown at times between 20 and 60 sec. Thermocouple responses from the side of the grain are shown in Figure D-36. These data are similar to those in Figure D-35, except that apparent exothermic behavior is observed only for the interface thermocouples 10, 12, 27, 29 and 31

Outputs from thermocouples 11-23, located in the warhead, are shown in Figures D-39, -40, and -41. Thermocouple 21 was inoperative. The outputs of TC 12, 14, 20, and 22, located on the magnesium liner, are shown in Figure D-39. Again apparent exothermic behavior is observed for all thermocouples. It is possible that both the magnesium liner and explosive were ignited by 152 sec, since TC 14 was fractured at that time. The data for TC 11, 13, 16, and 19 located on the steel rod/potting material interfaces, are found in Figure D-40. Again apparent exothermic reactions occurred between 134 and 240 sec. The temperatures recorded in this time domain surely would ignite the warhead explosive which in turn would have ignited the magnesium. Significant aft venting of the warhead had already started at 84 sec, as suggested by TC 23 shown in Figure D-41. Evidence that explosive/magnesium gas venting had occurred by 130 sec is given by TC 15, 17 and 18 in Figure D-42. It is possible that the safe/arm device exploded at 495 sec.

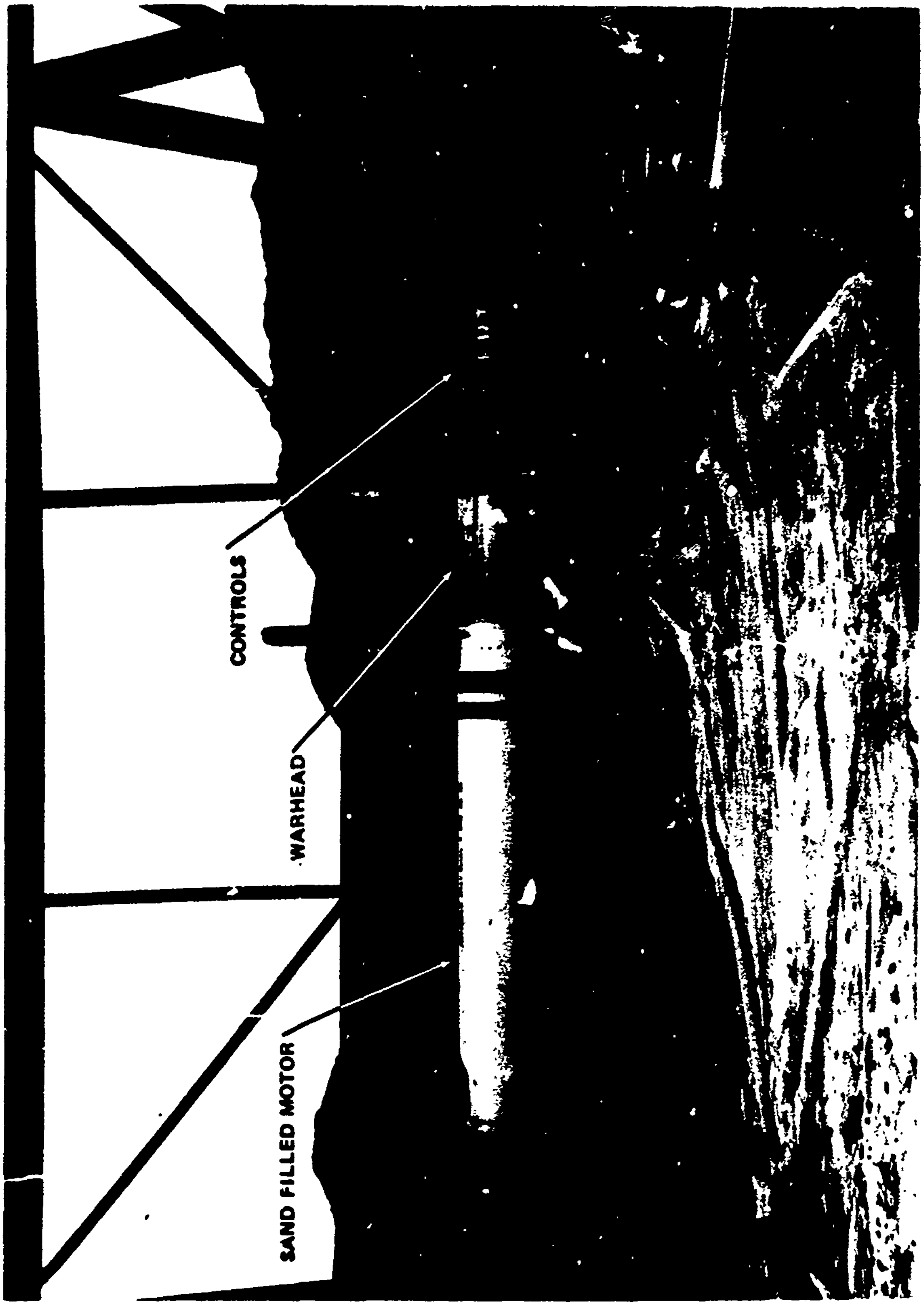

FIGURE D-1 SPARROW SP-3A Test Configuration

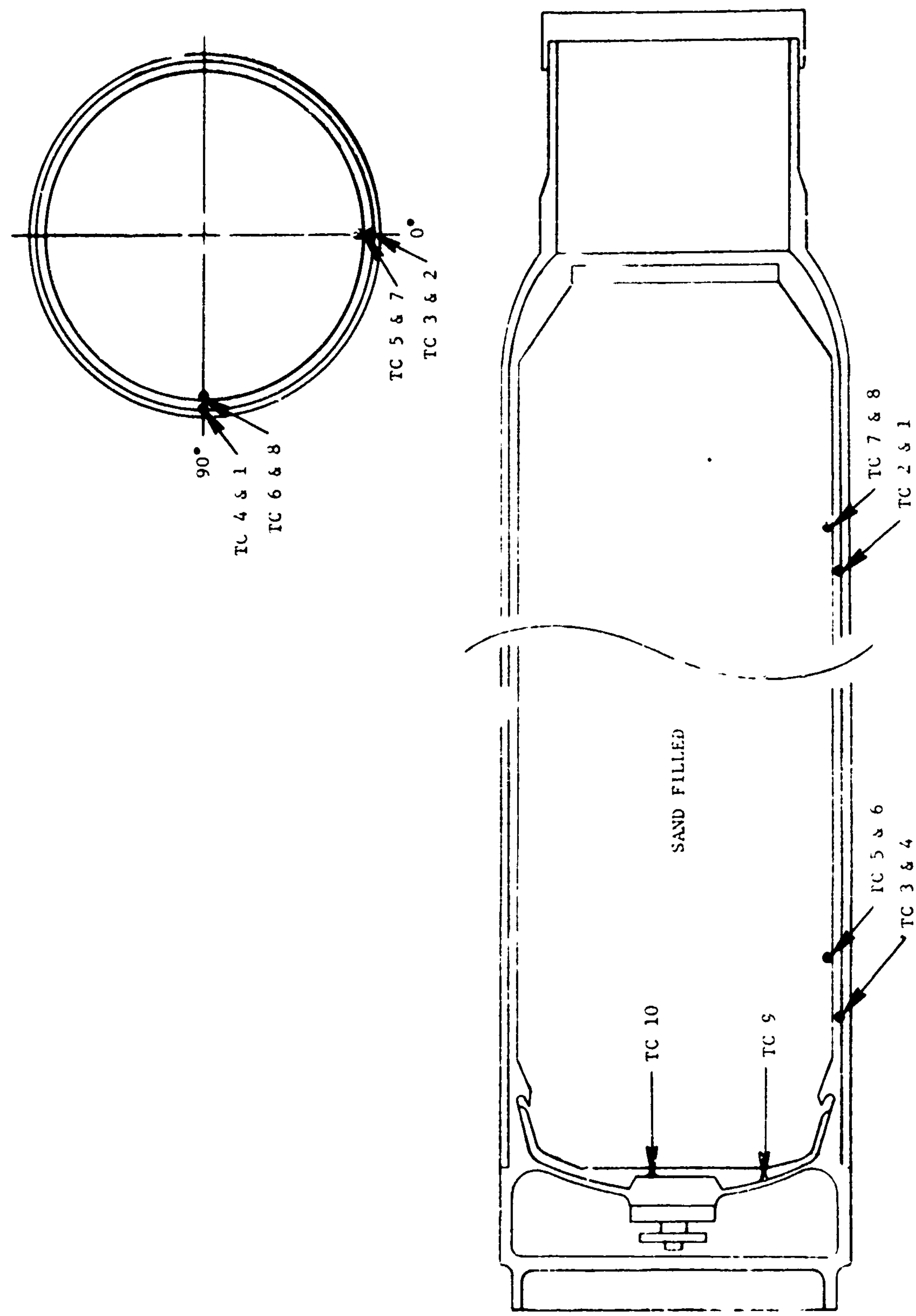

FIGURE D-2. MK 38 Mod 4 Motor Thermocouple Locations

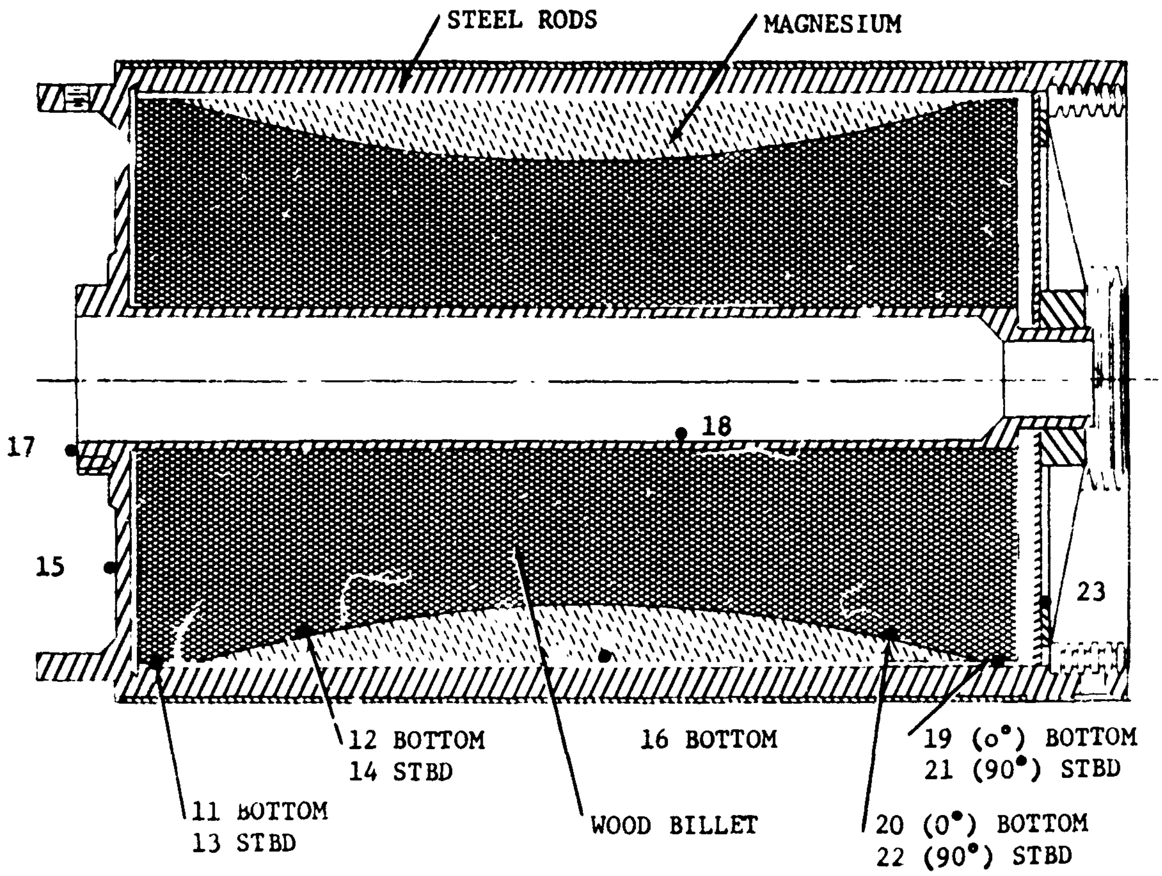

FIGURE D-3. Mk 38 Mod 0 Warhead Thermocouple Locations

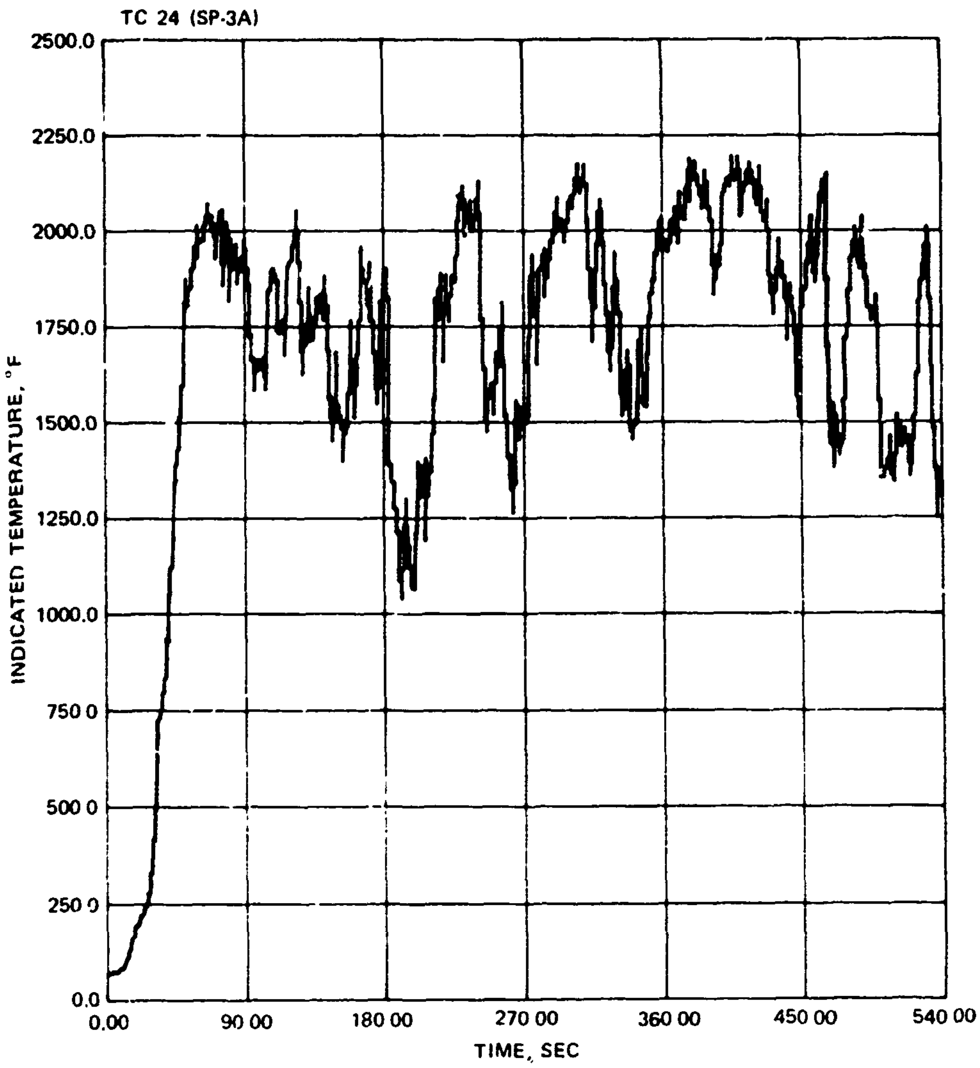

FIGURE D-4a TC 24, Forward Flame Thermocouple, SP 3A

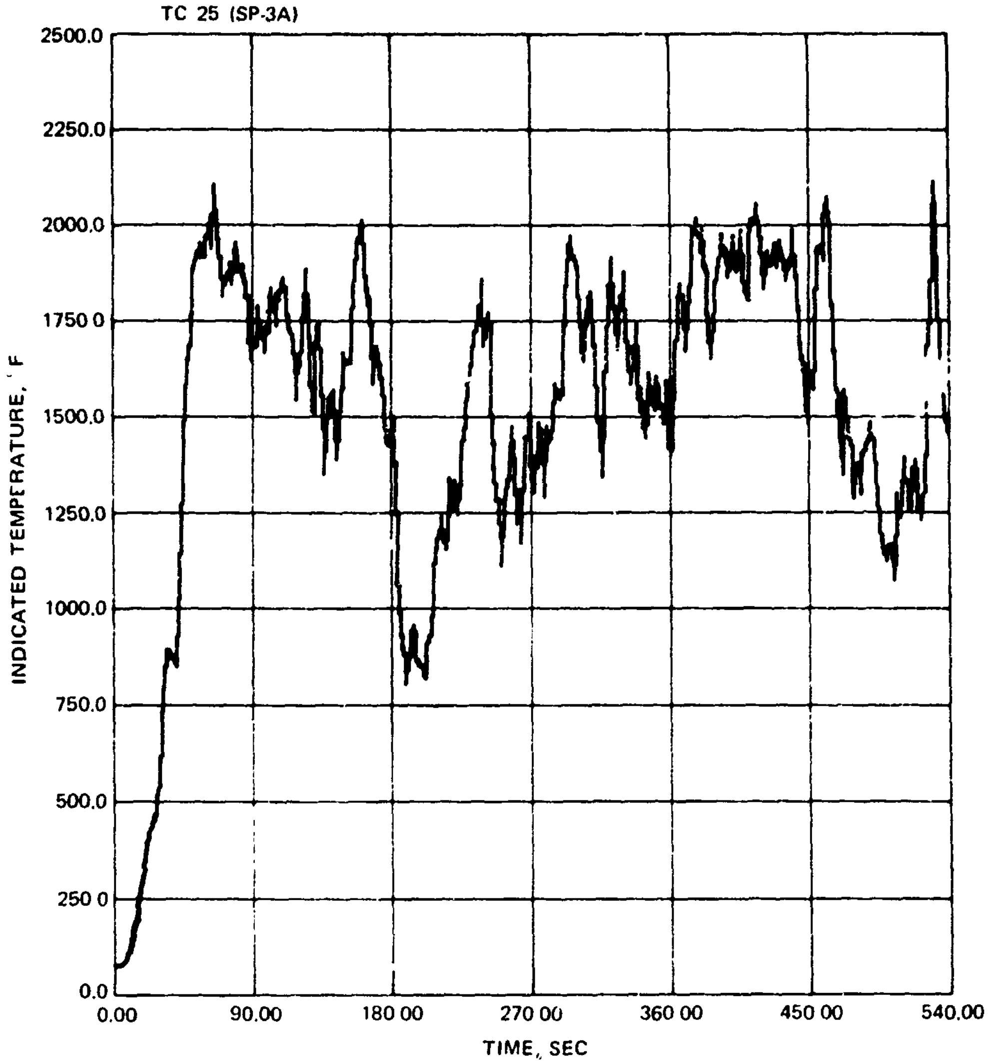

FIGURE D-4b. TC 25, Starboard Flame Thermocouple, SP-3A

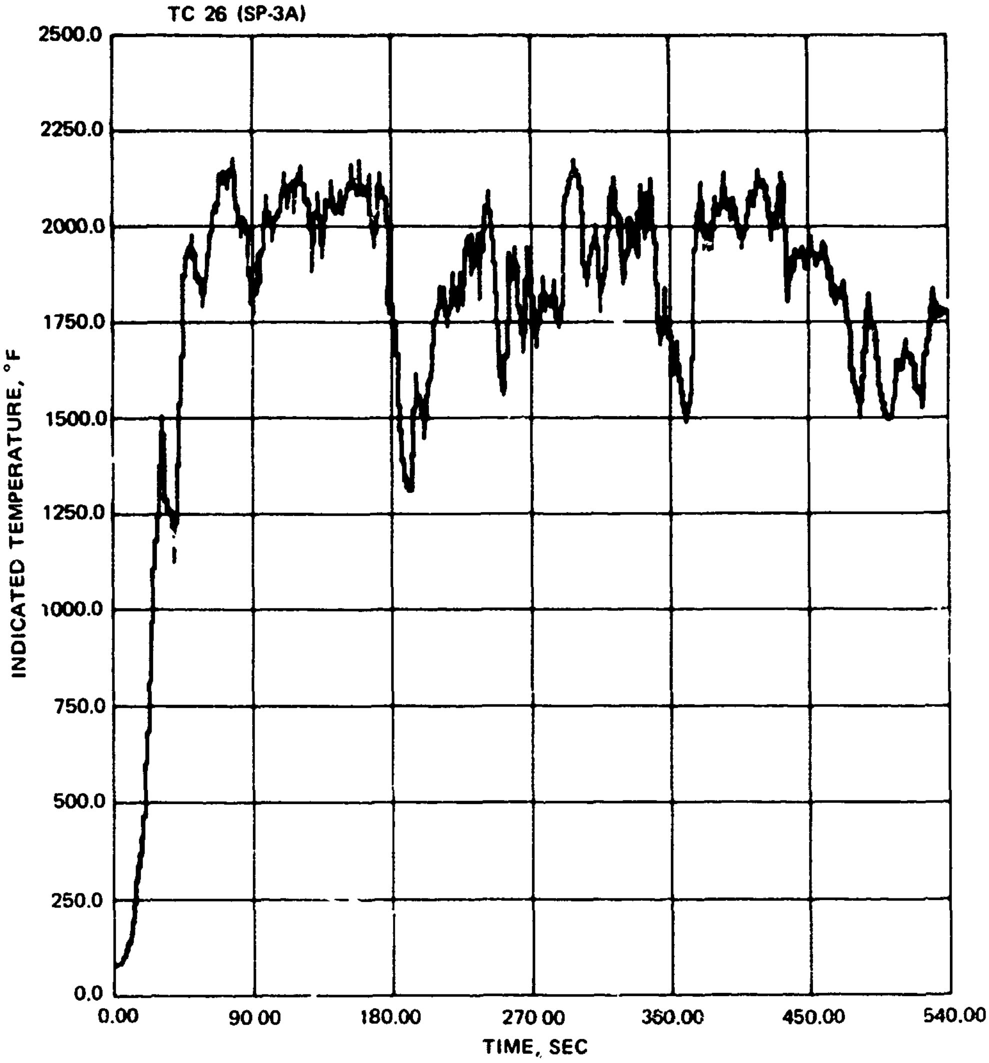

FIGURE D-4c. TC 26, Aft Flame Thermocouple, SP-3A

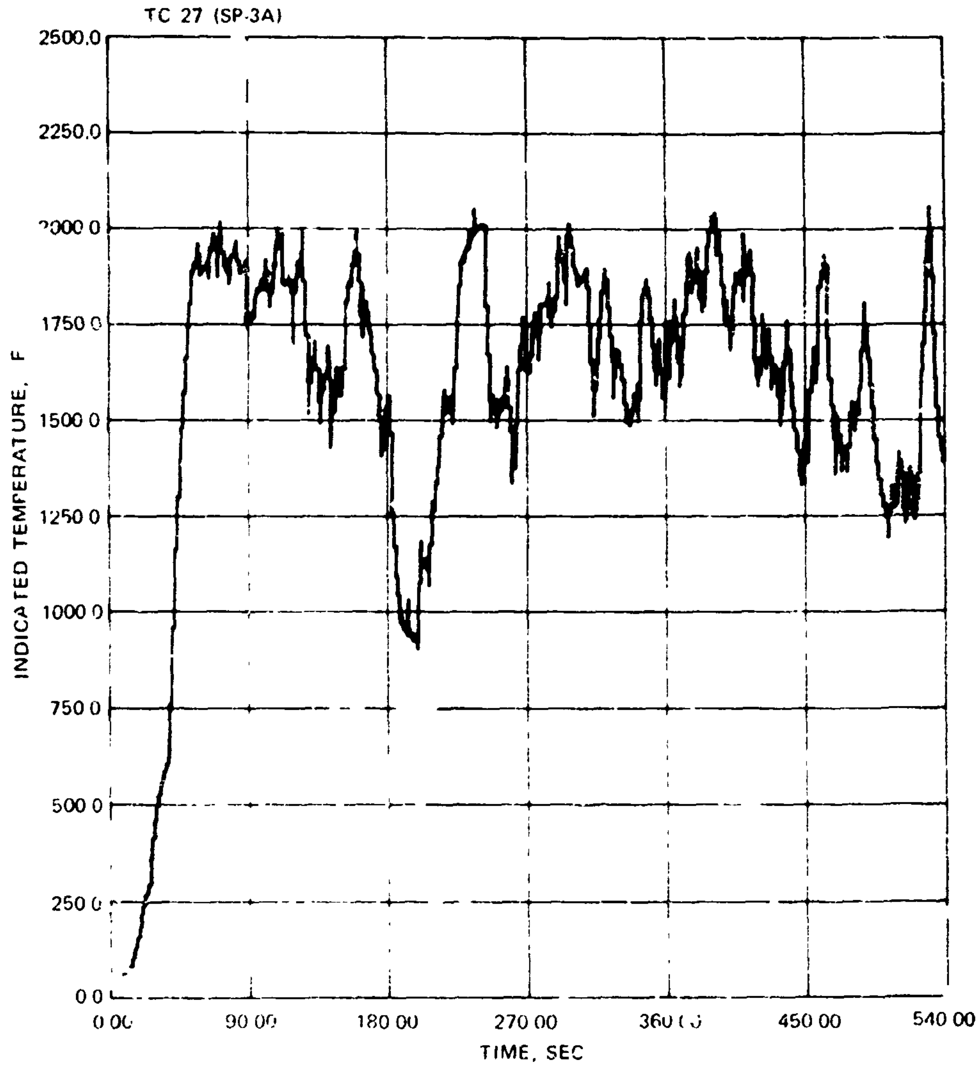

FIGURE D-4d. TC 27 Port Flame Thermocouple, SP-3A

FIGURE D-5. SPARROW SP-3A Post Test Configuration.

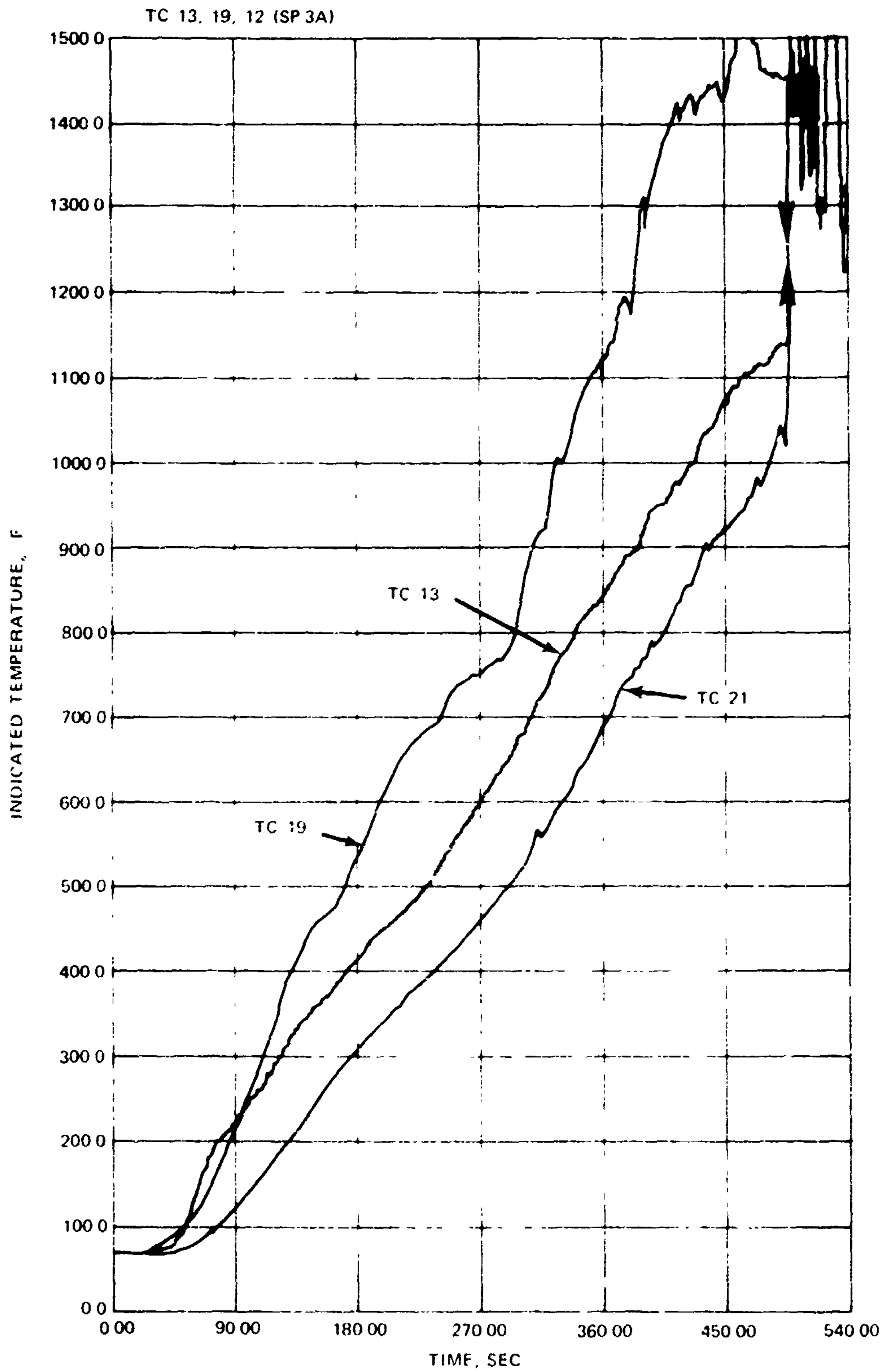

FIGURE D-6. TC 13, 19, 21 Response, SP 3A

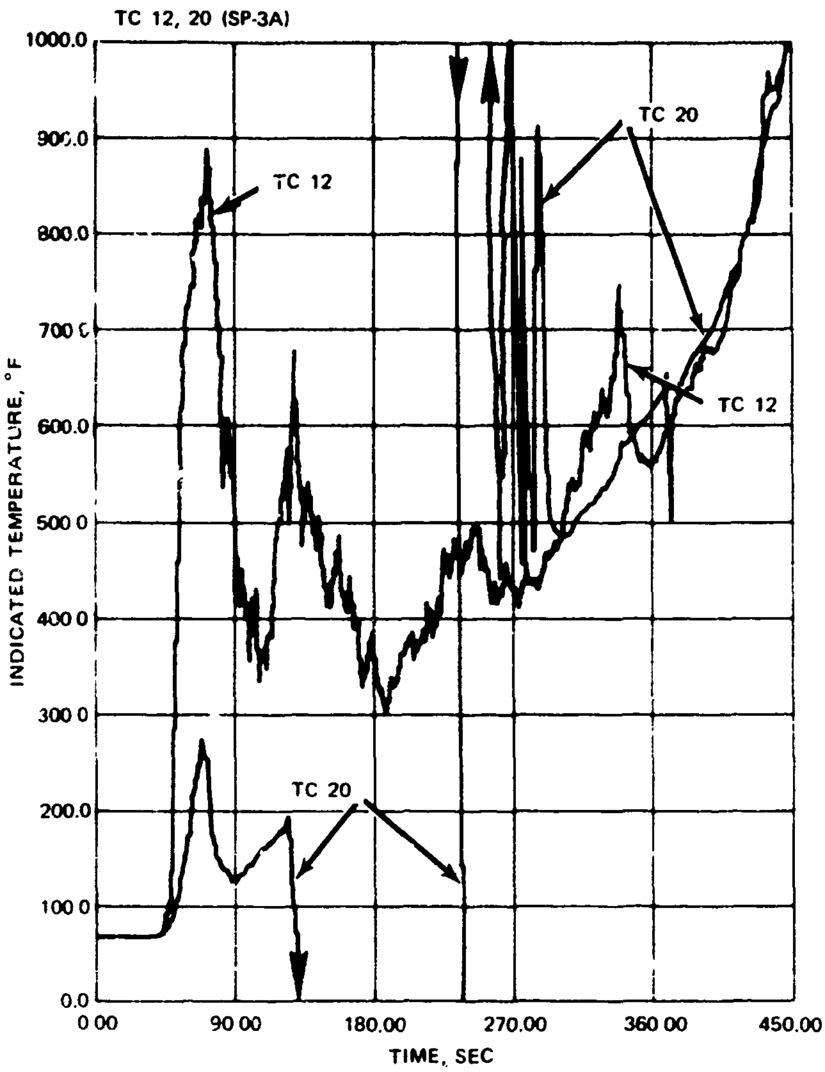

FIGURE D-7. TC 12, 20 Response, SP-3A

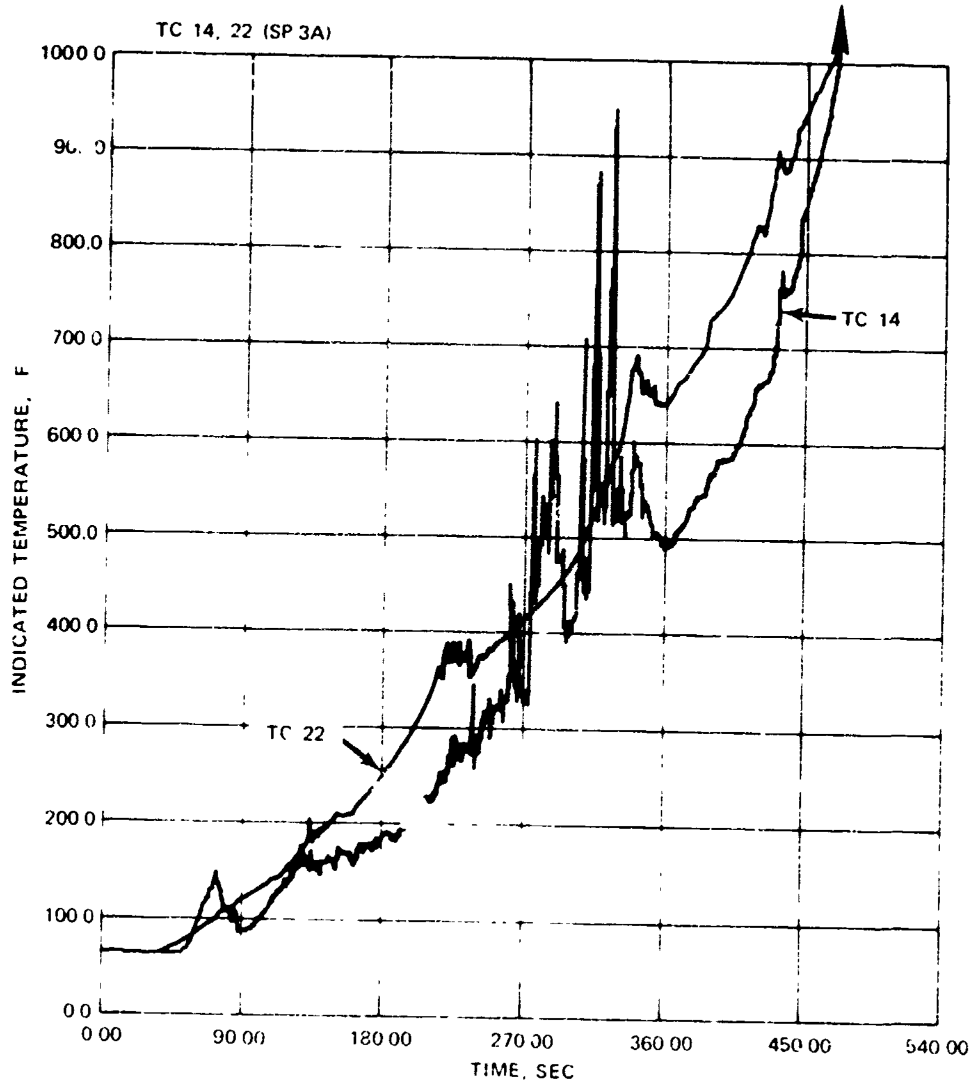

FIGURE D.8. TC 14, 22 Response, SP-3A

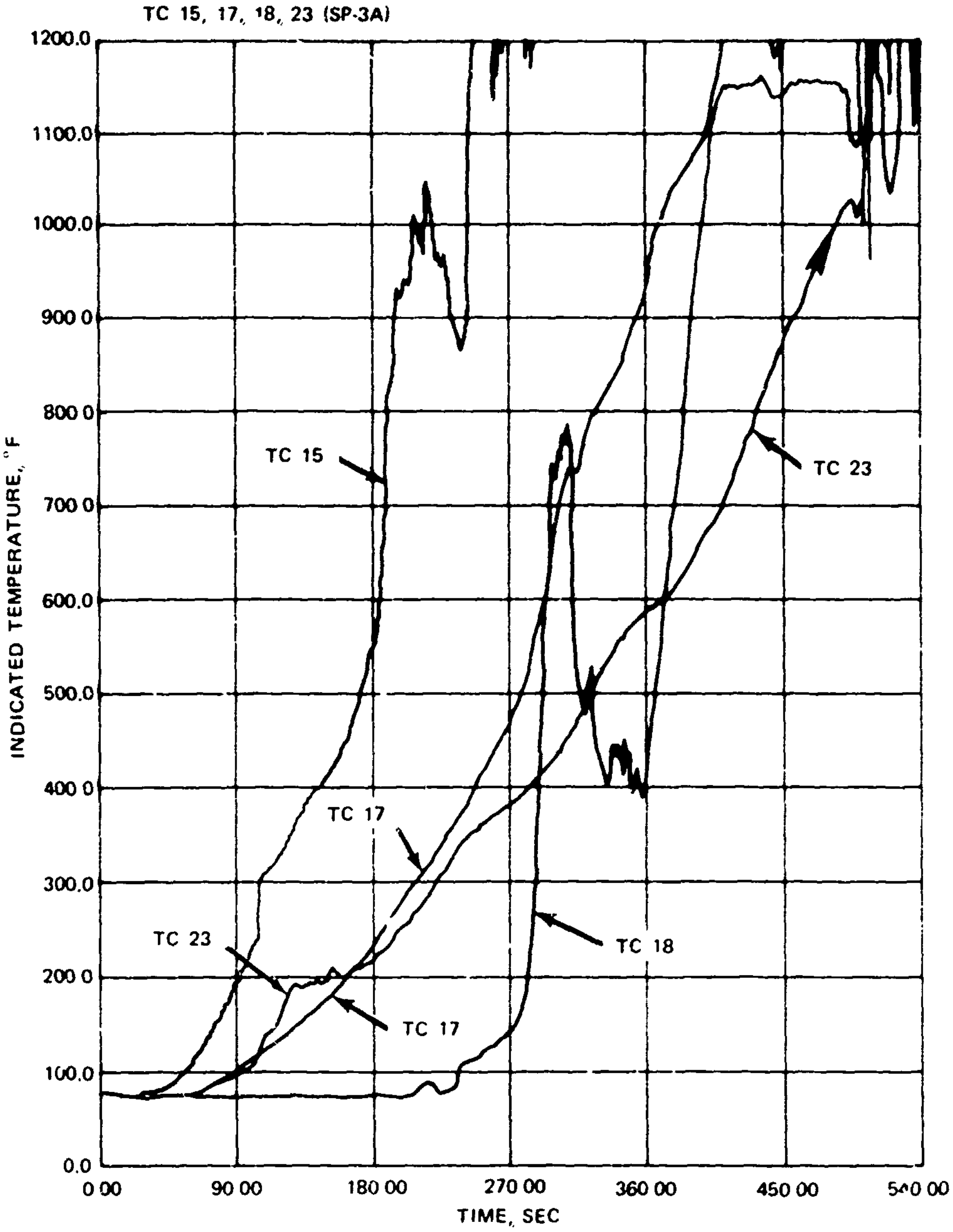

FIGURE D-9. TC 15, 17, 18, 23 Response, SP 3A

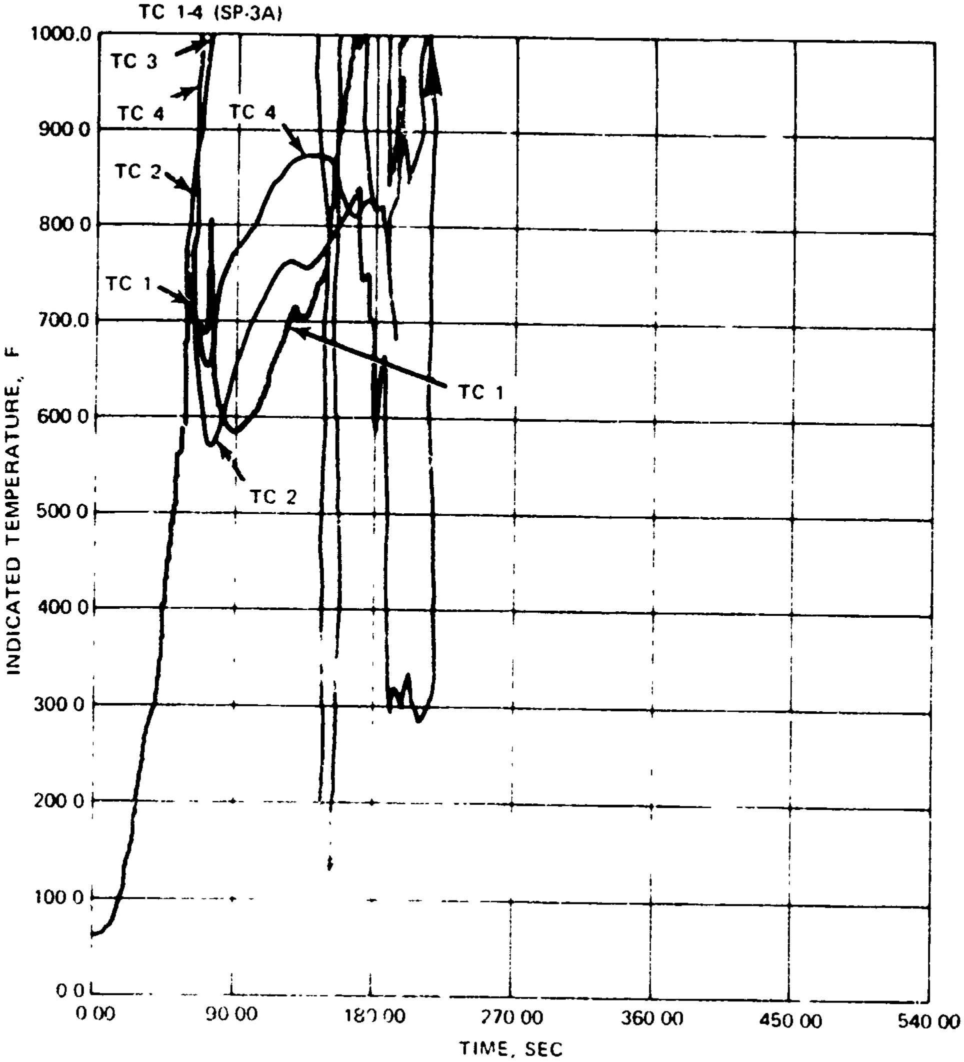

FIGURE D-10. TC 1-4 Response, SP-3A

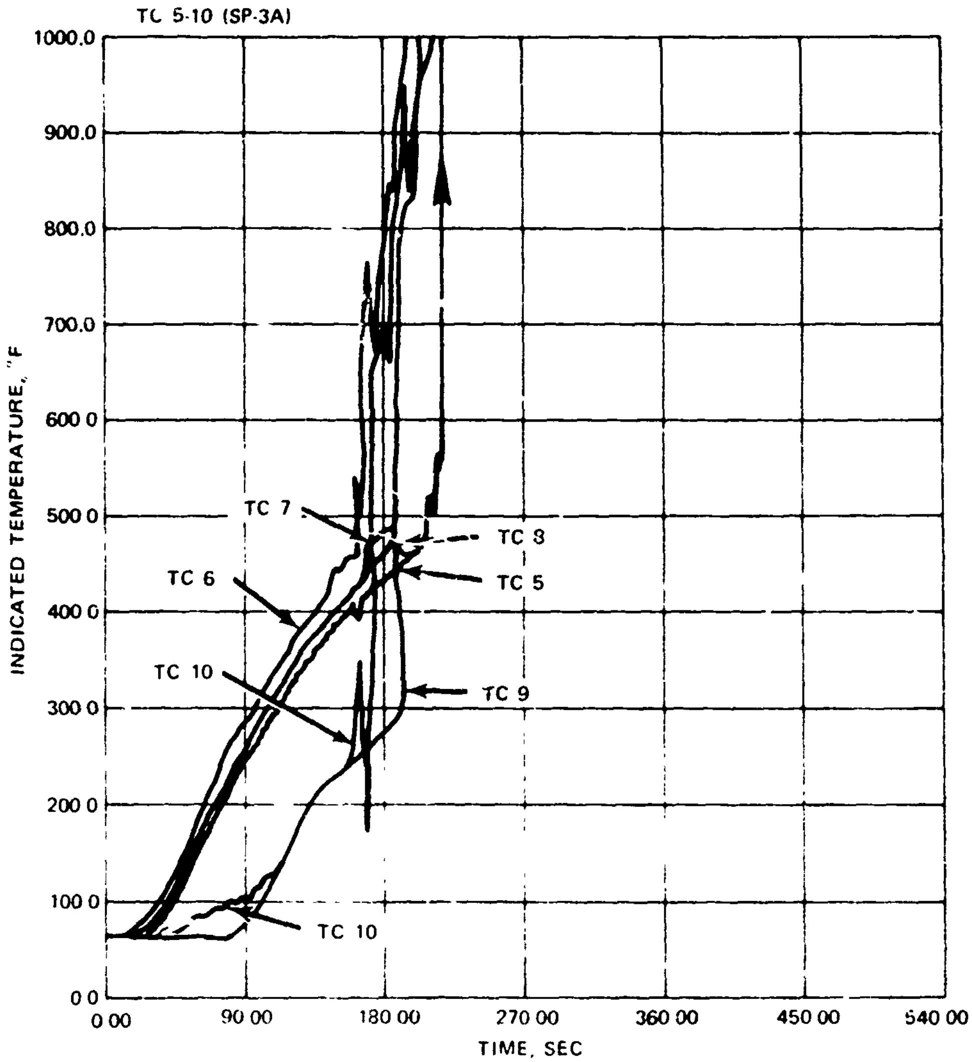

FIGURE D-11. TC 5-10 Response, SP-3A.

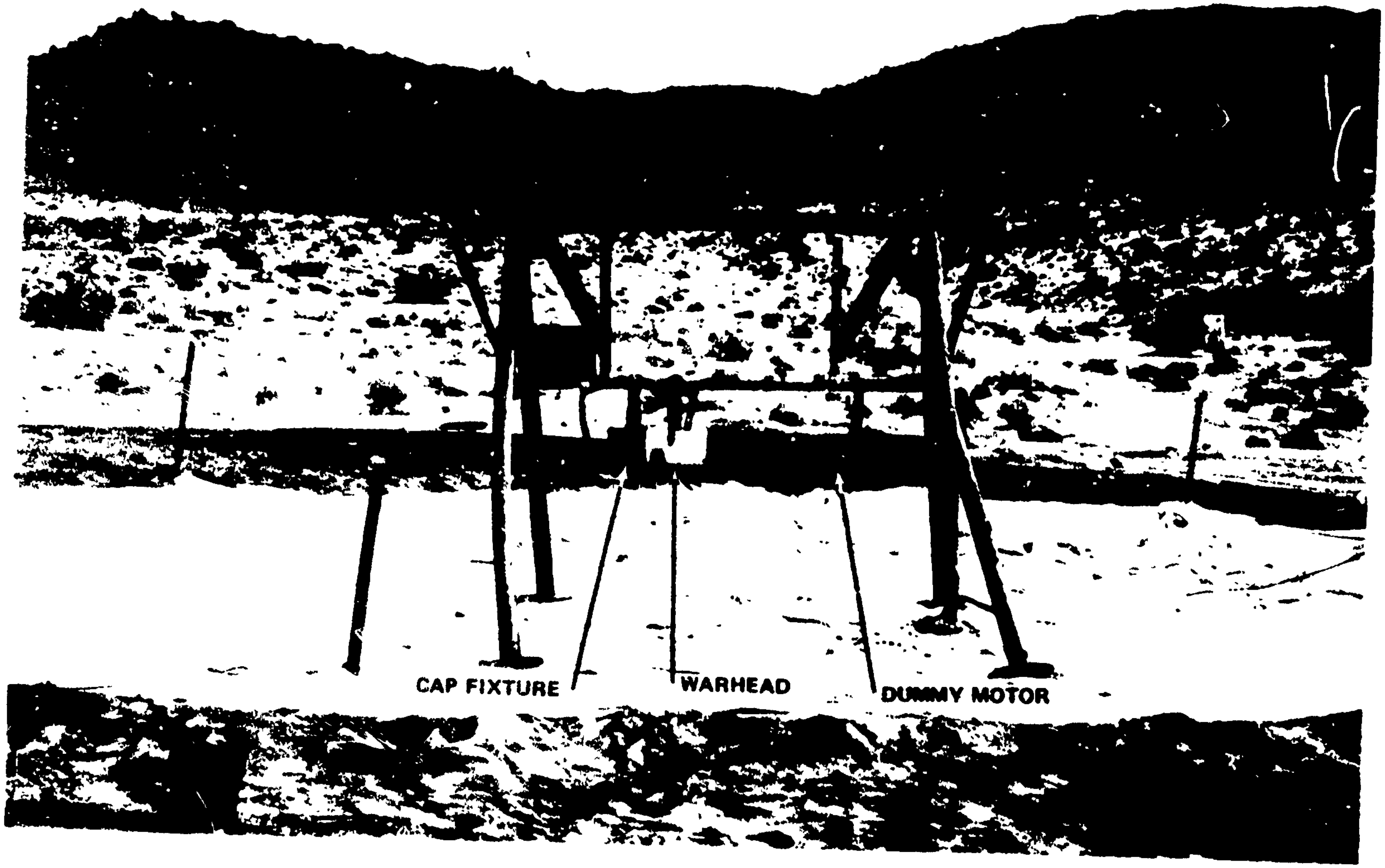

FIGURE D-12. SPARROW SP-7B Test Configuration.

FIGURE D-13. SPARROW SP-7B Post Test Configuration.

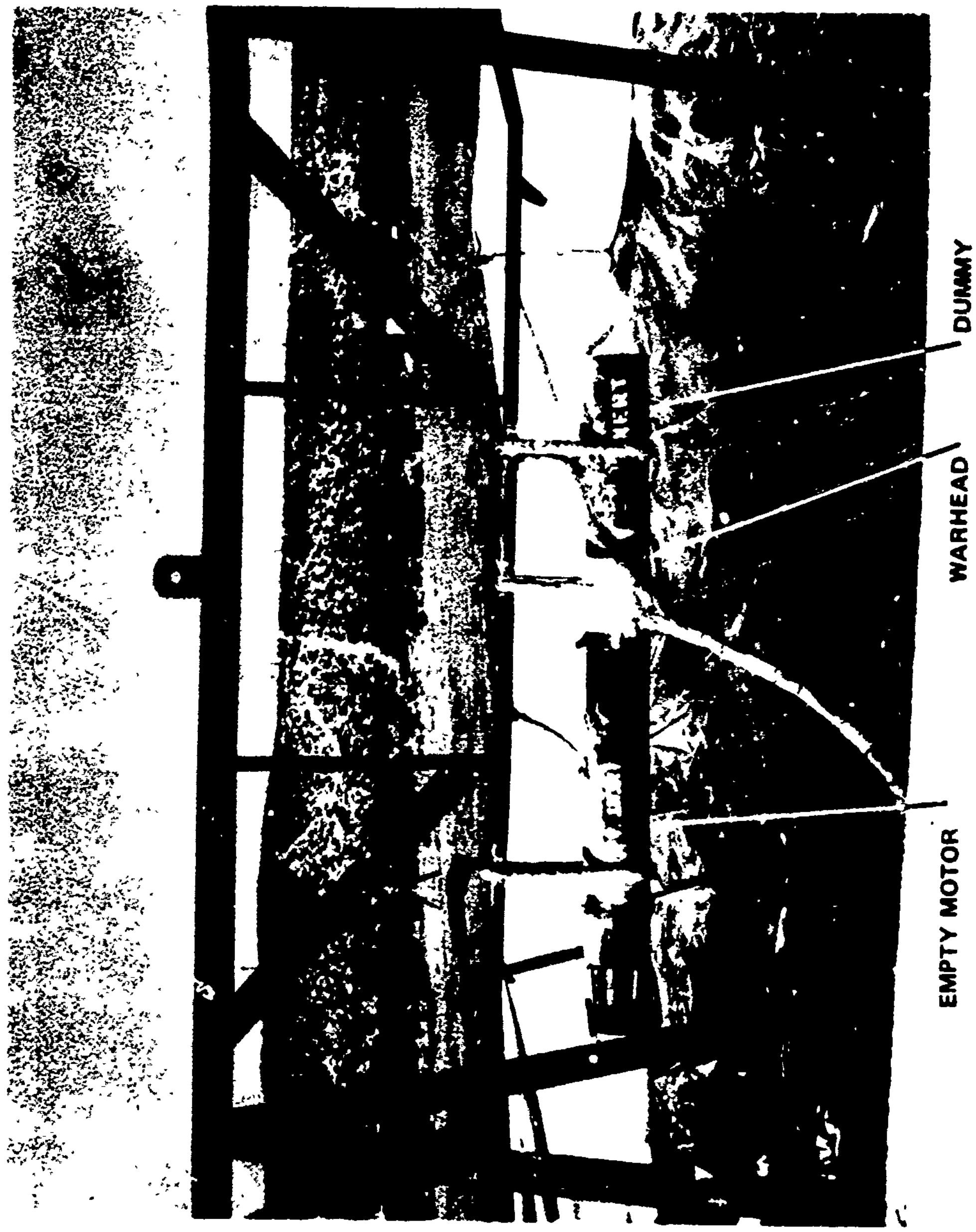

FIGURE D-14. SPARROW SP 13A Test Configuration.

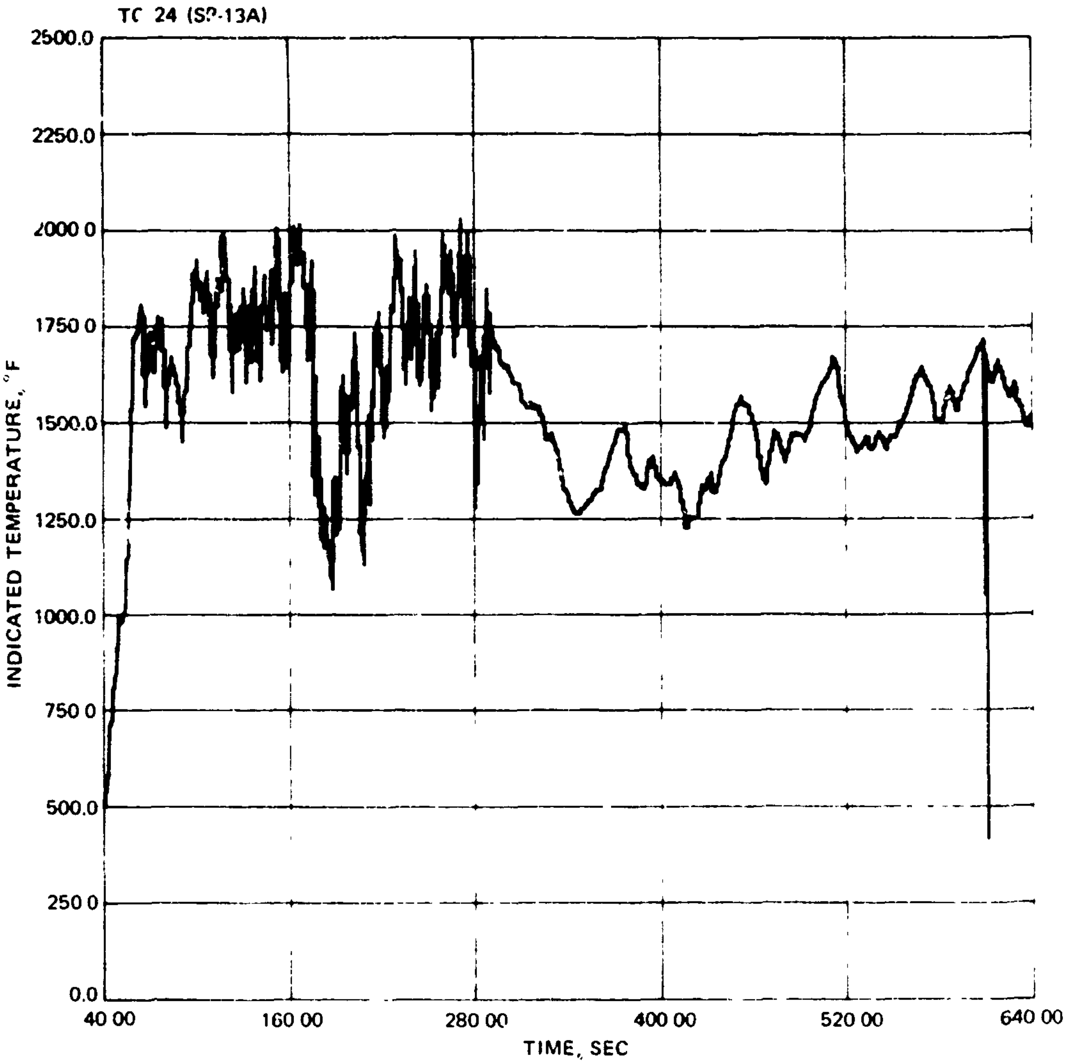

FIGURE D-15a. TC 24, Forward Flame Temperature, SP-13A

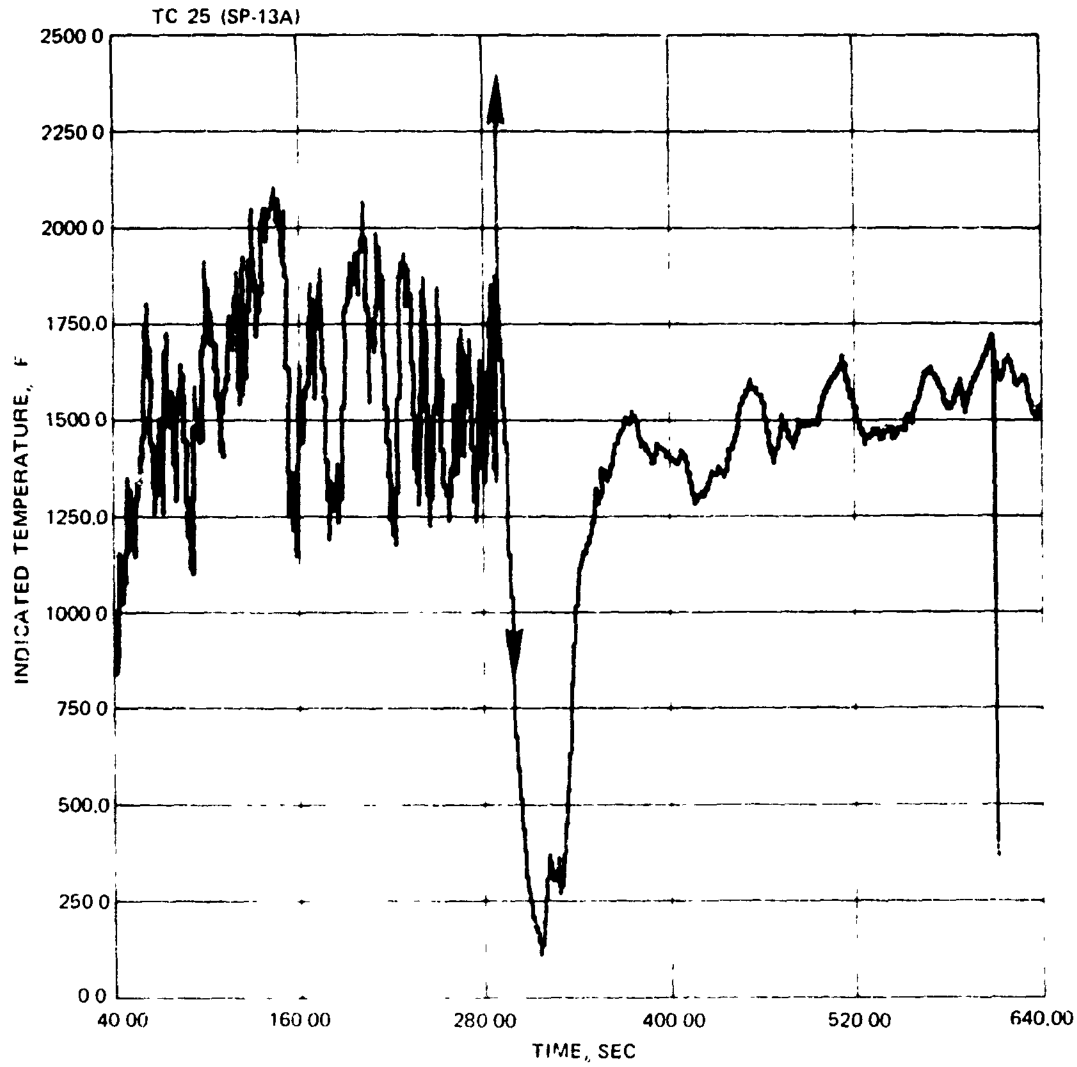

FIGURE D-15b. TC 25 Starboard Flame Temperature, SP-13A

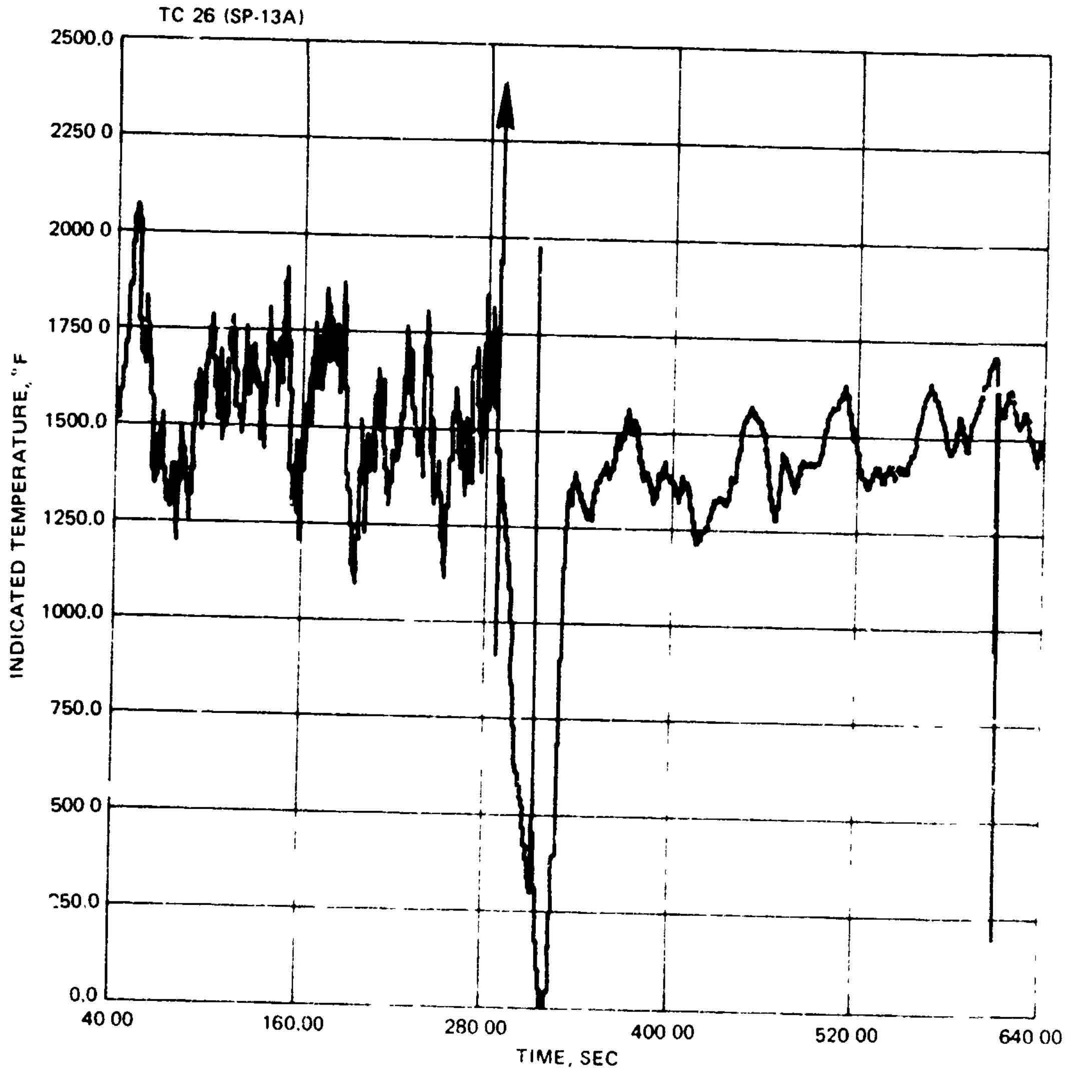

FIGURE D-15c. TC 26 Aft Flame Temperature, SP-13A

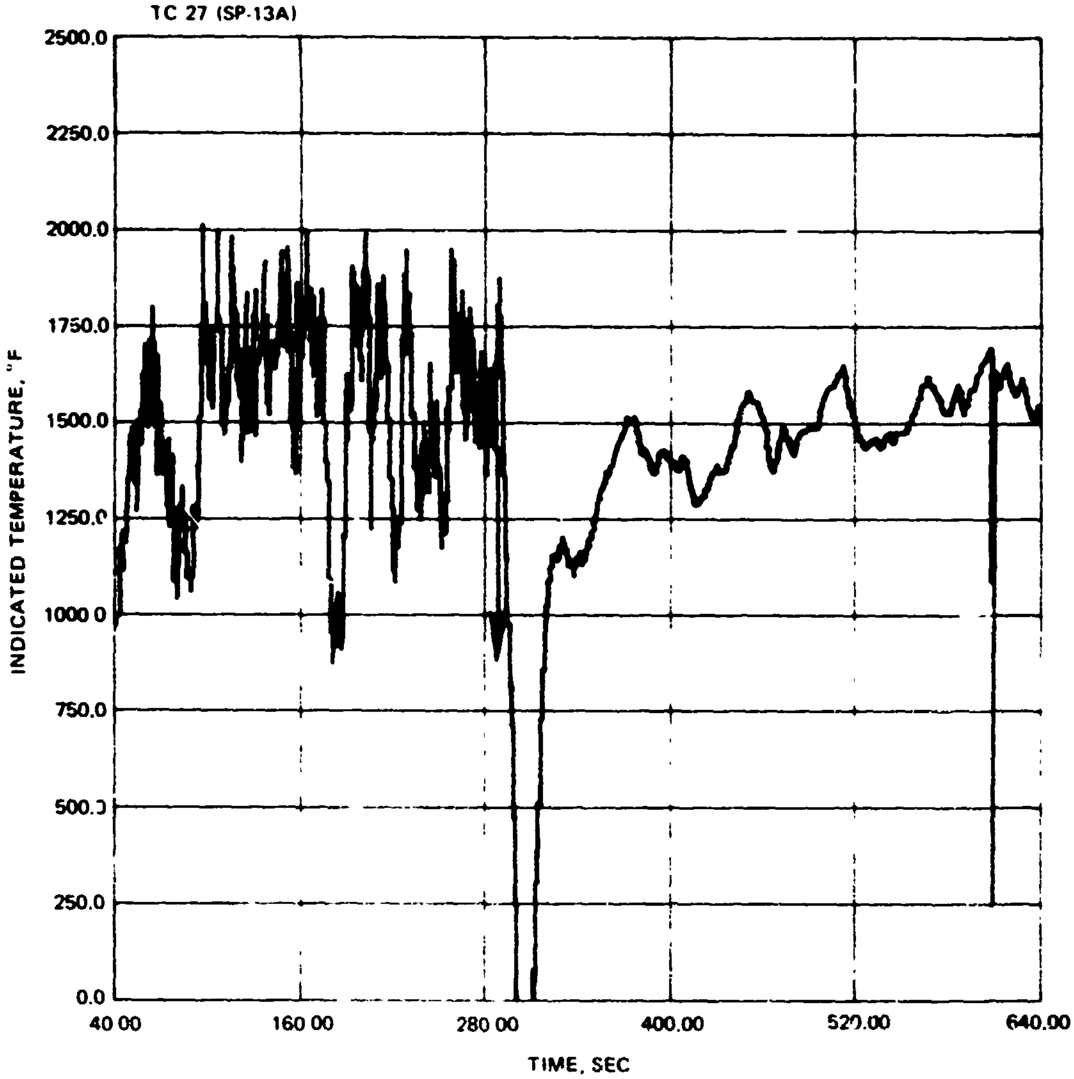

FIGURE D-15d TC 27, Port Flame Temperature, SP-13A

FIGURE D-16. SPARROW SP-13A Post Test Configuration.

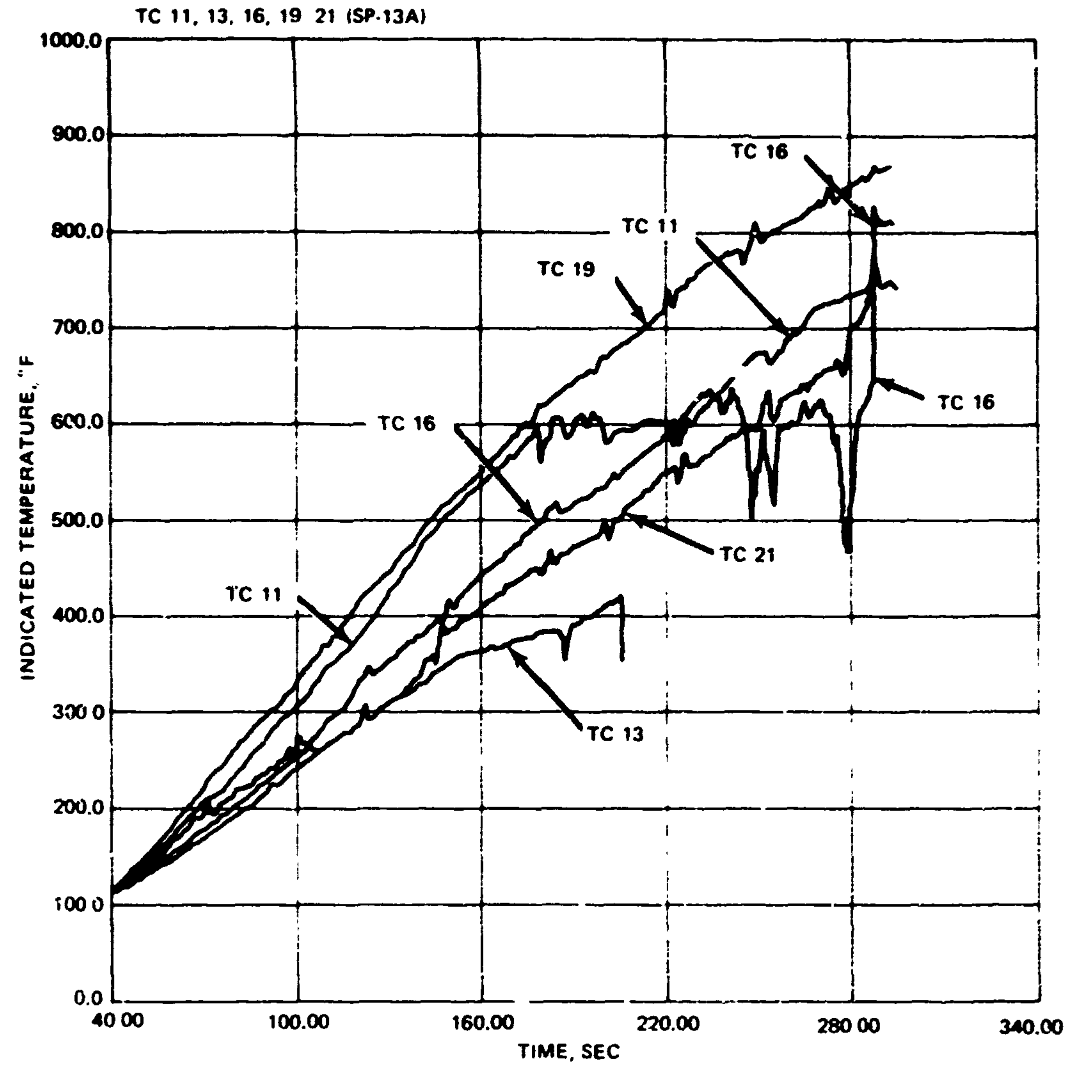

FIGURE D-17. TC 11, 13, 1', 19, 21 Response, SP-13A.

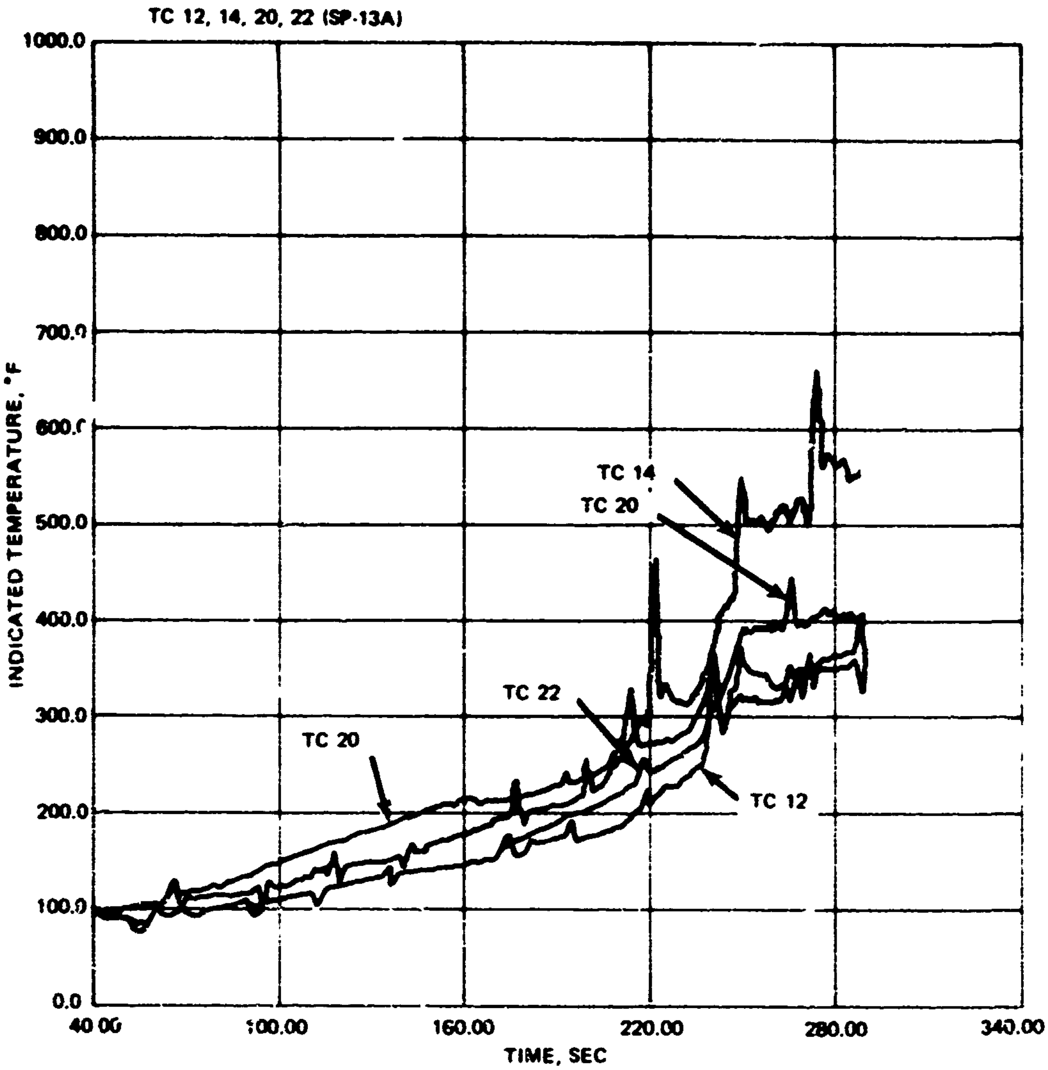

FIGURE D-18. TC 12, 14, 20, 22 Response, SP .3A

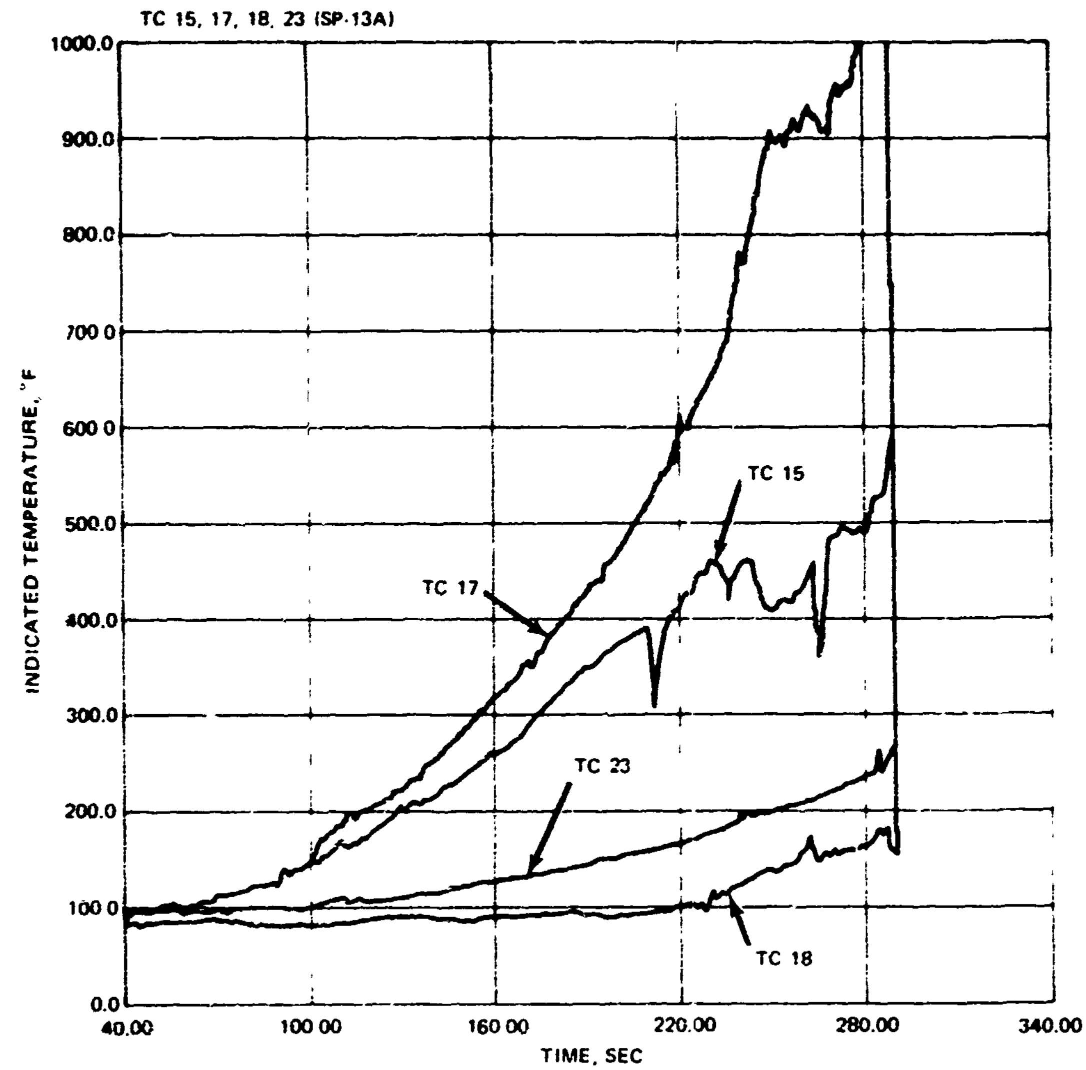

FIGURE D-19. TC 15, 17, 18, 23 Response, SP-13A.

FIGURE D-20. SPARROW SP-13B Test Configuration.

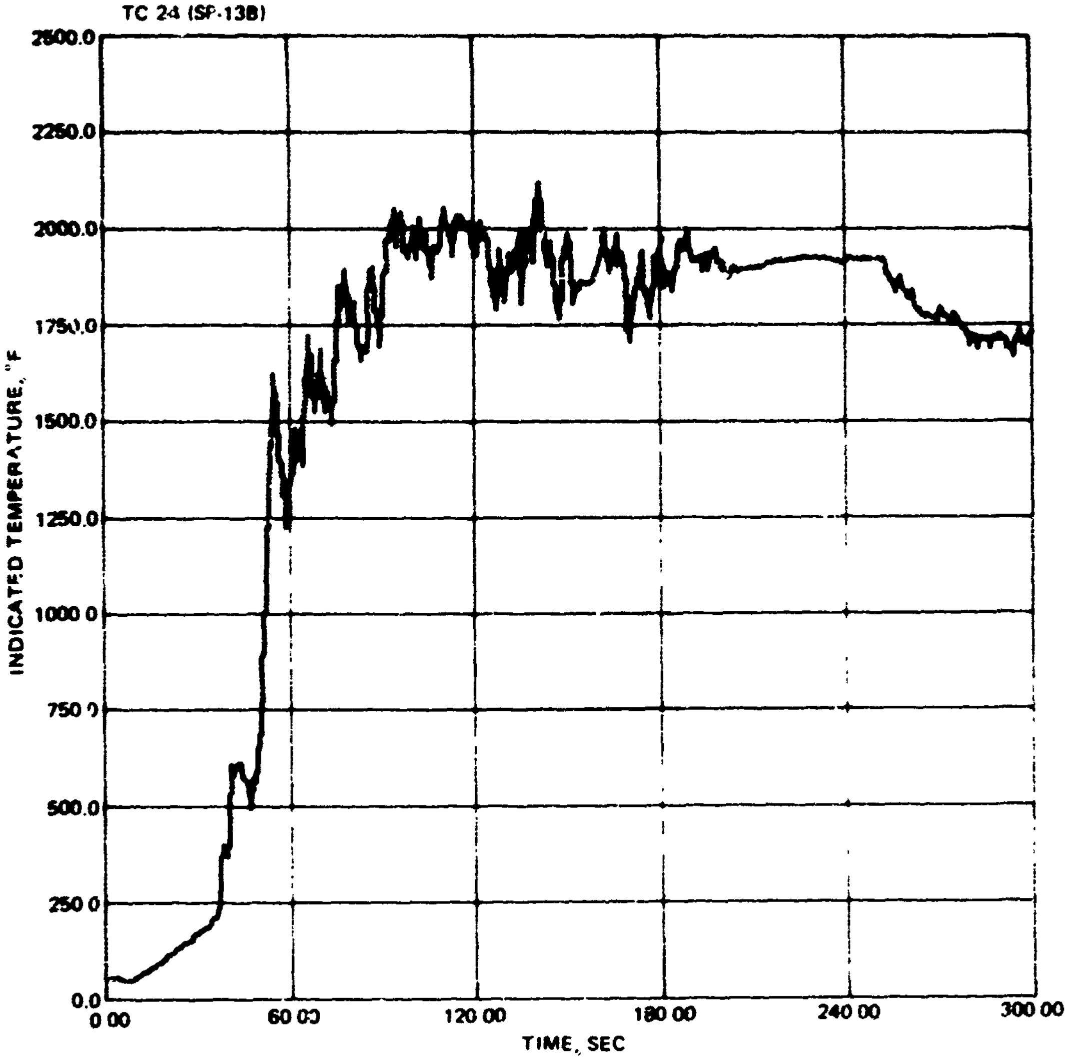

FIGURE D-21a. TC 24. Forward Flame Temperature, SP-13B.

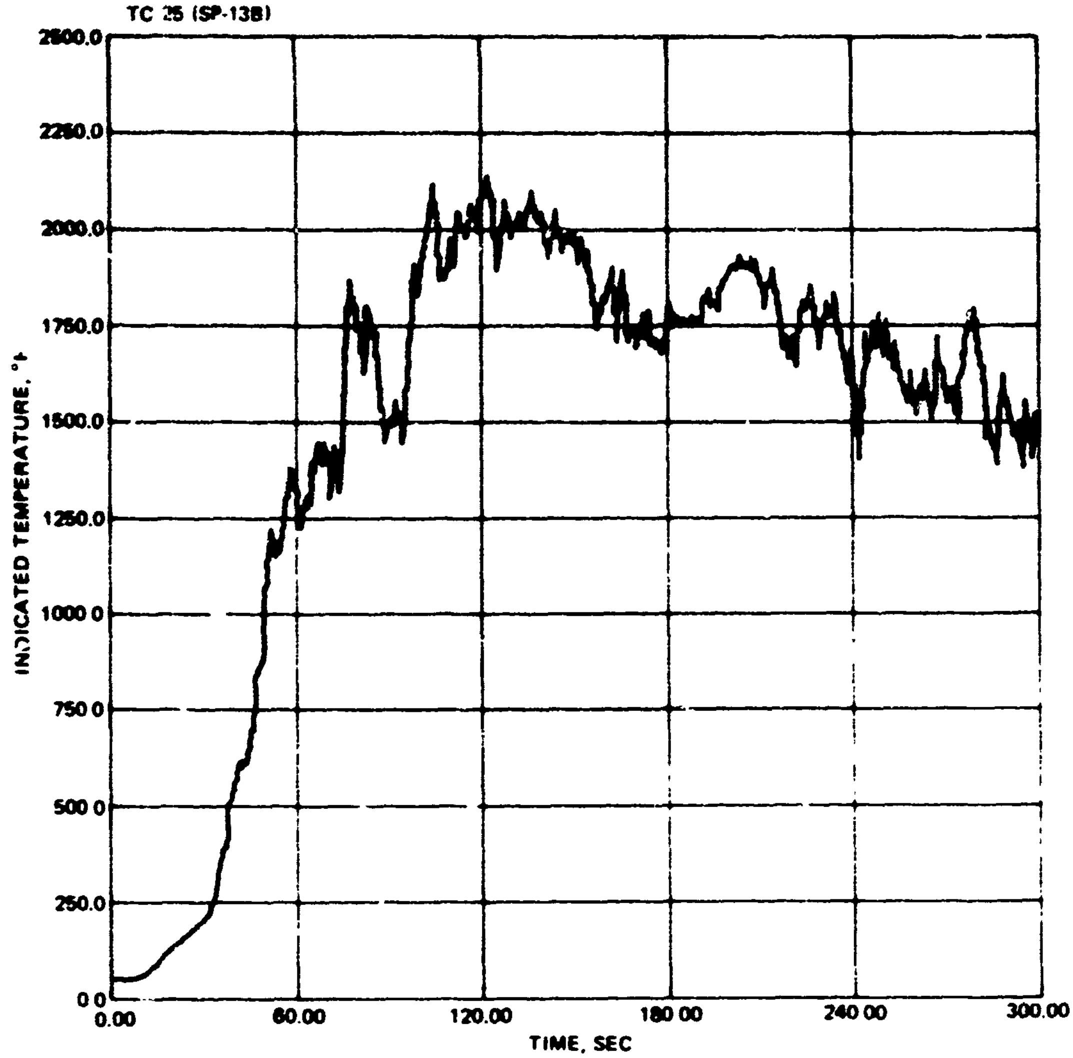

FIGURE D-21b. TC 25, Starboard Flame Temperature, SP-13B.

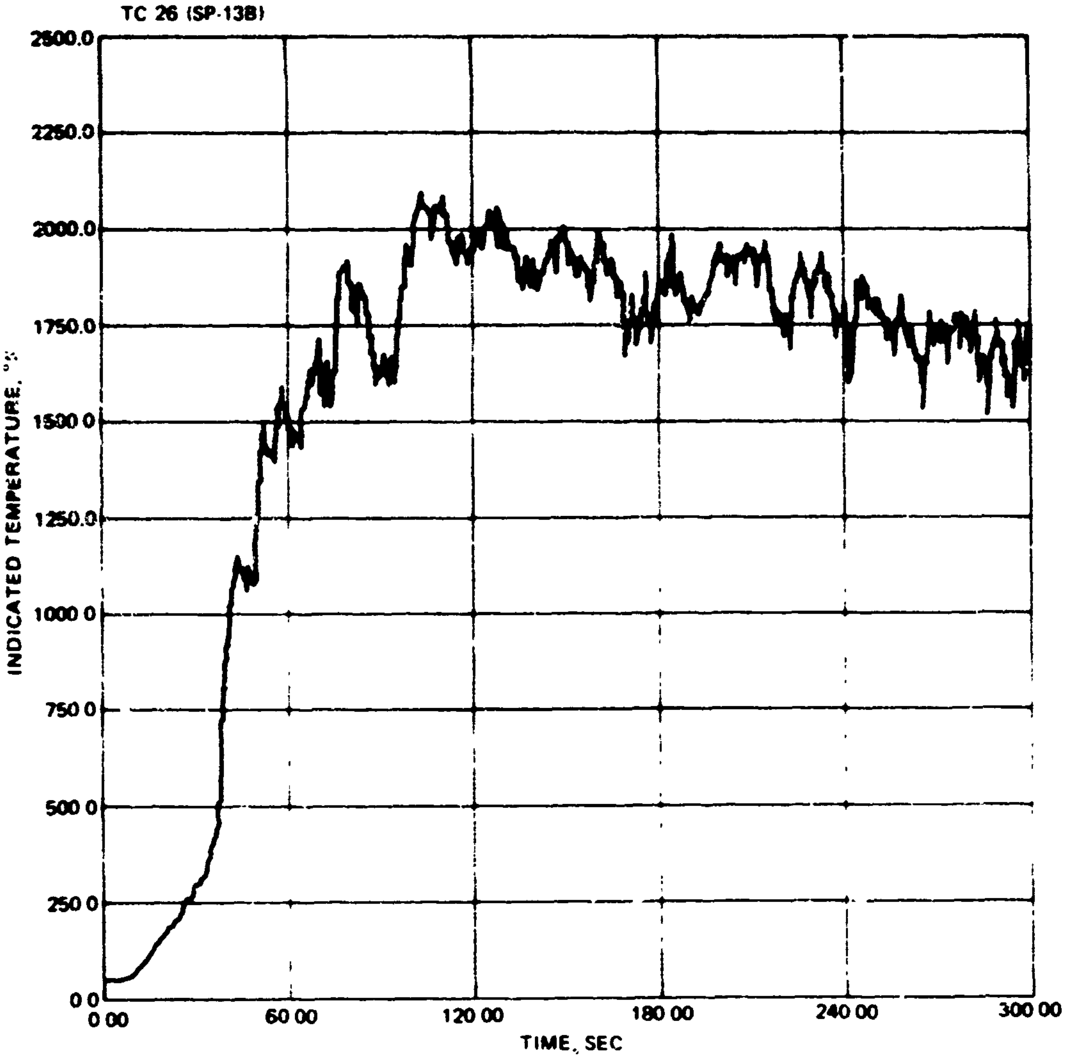

FIGURE D-21c. TC 26, Port Flame Temperature, SP-13B.

FIGURE D-22. SPARROW SP-13B Post Test Configuration, 1.

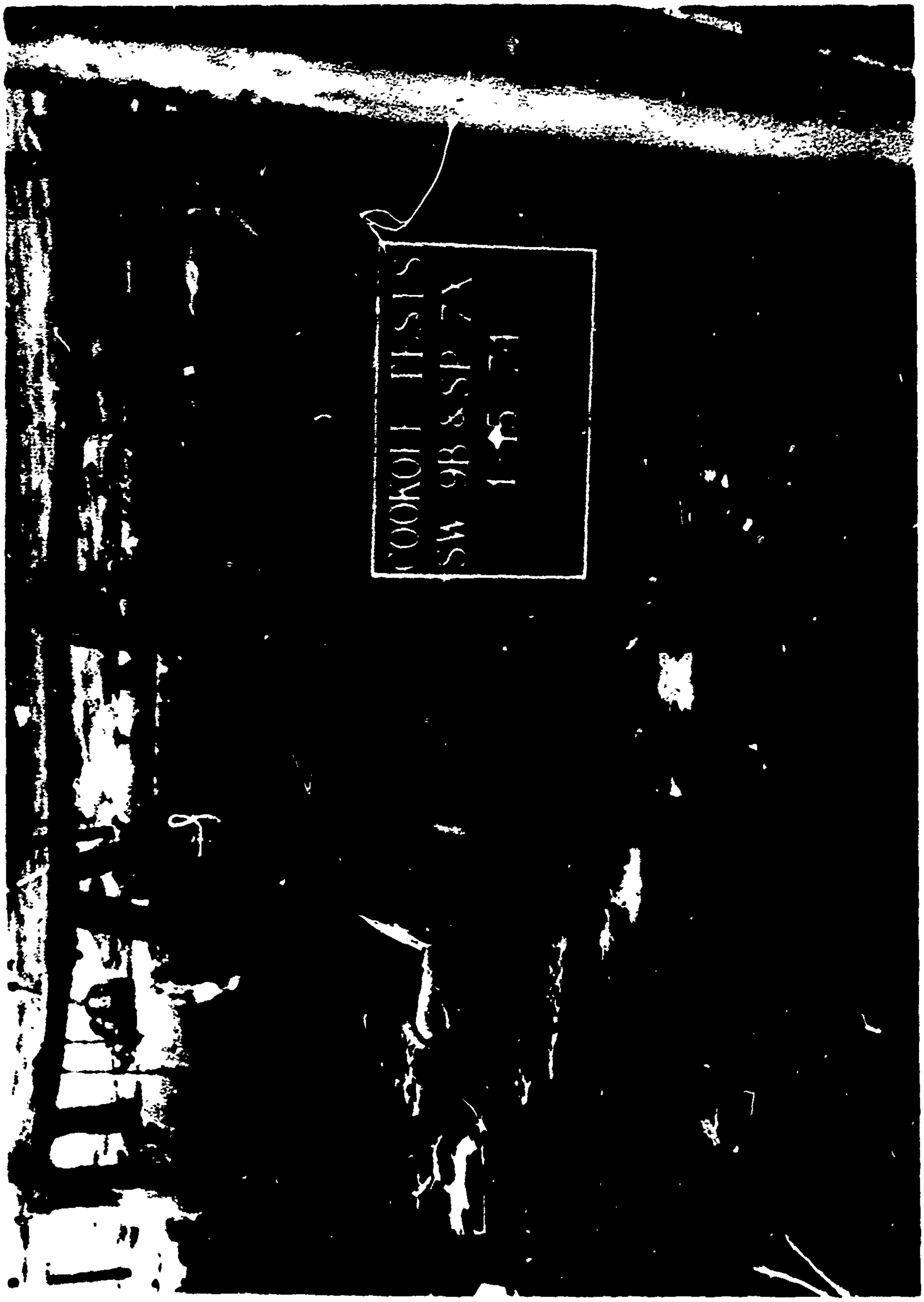

FIGURE D-23. SPARROW SP-13B Post Test Configuration, II.

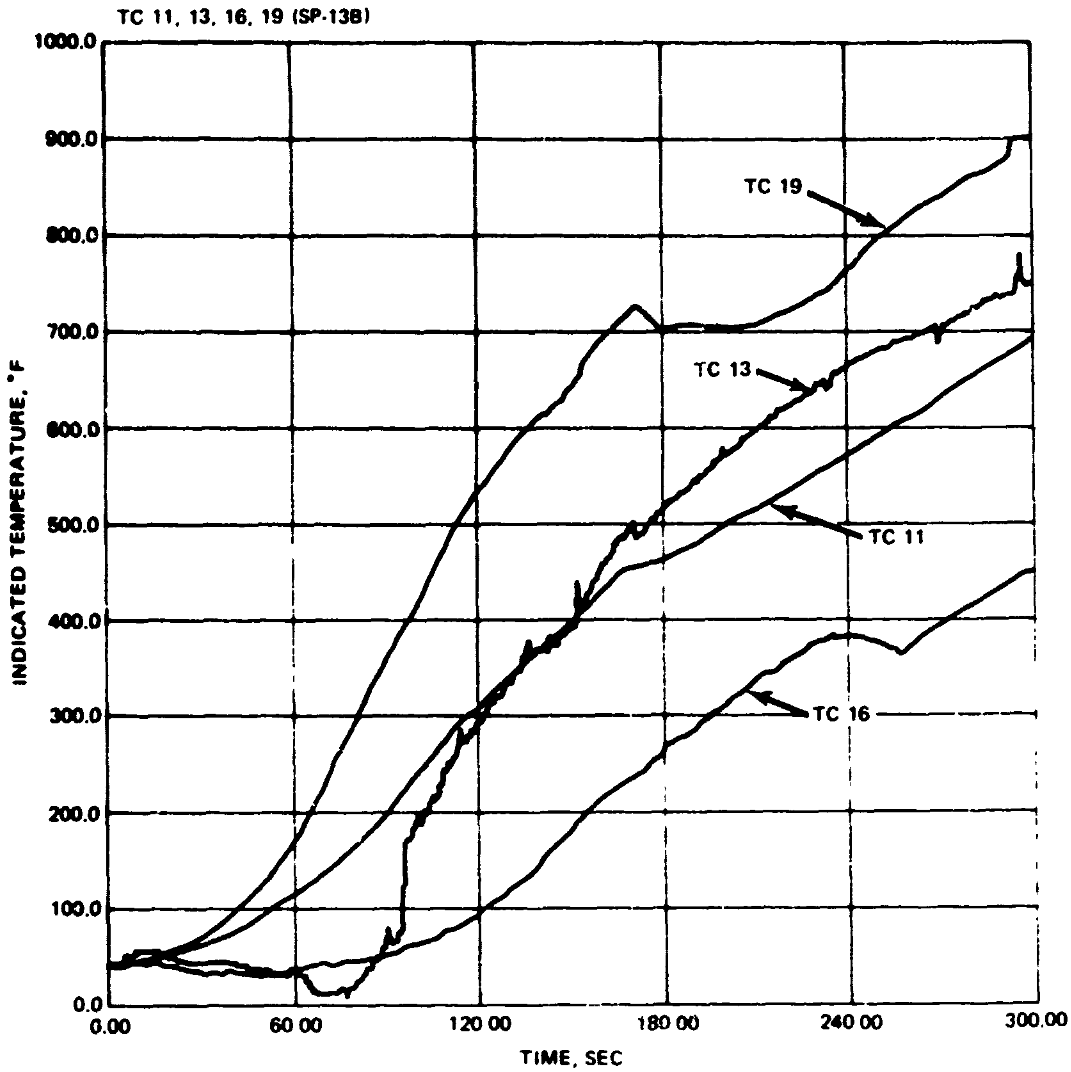

FIGURE D-24. TC 11, 13, 16, 19 Response, SP-13B.

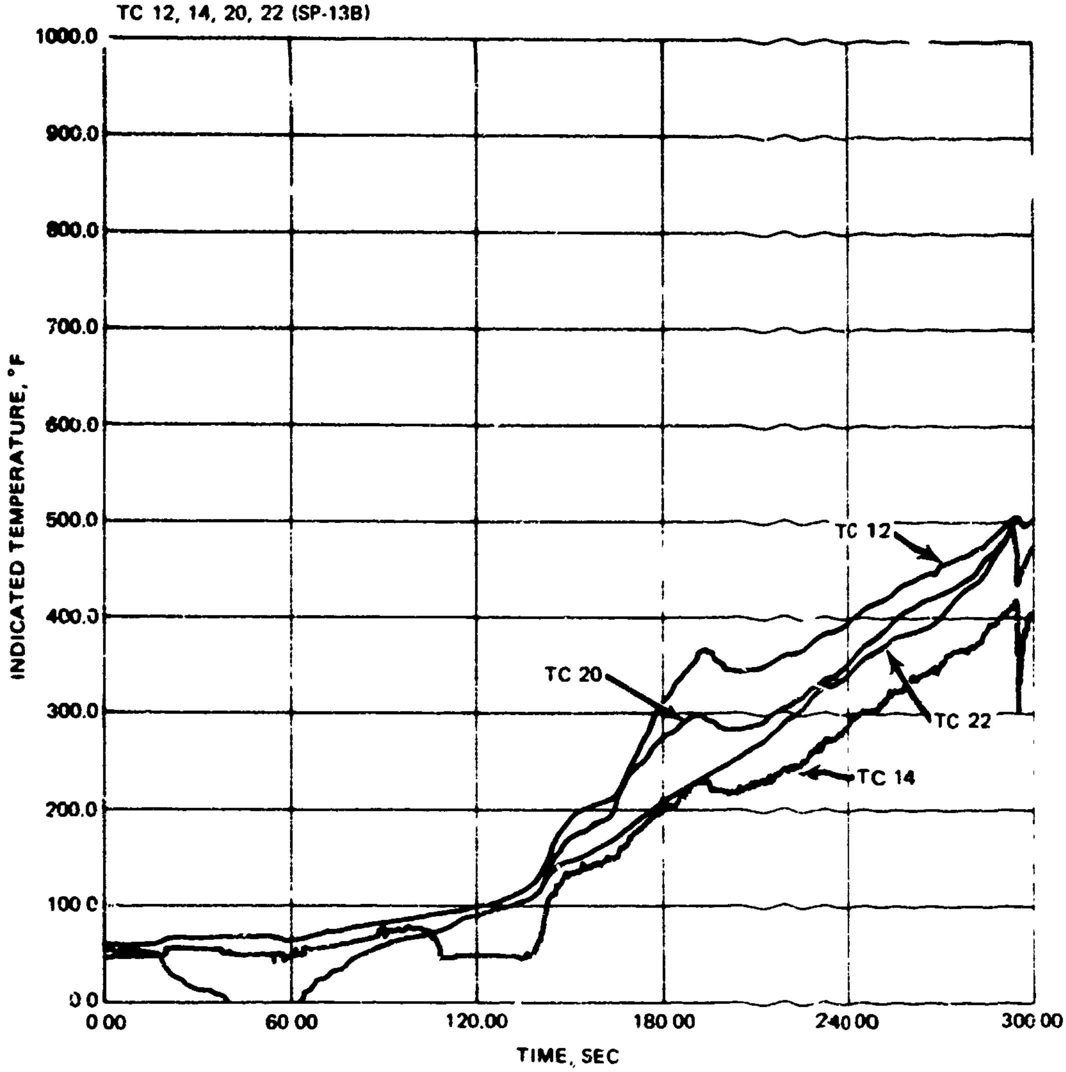

FIGURE D-25. TC 12, 14, 20, 22 Response, SP-13B.

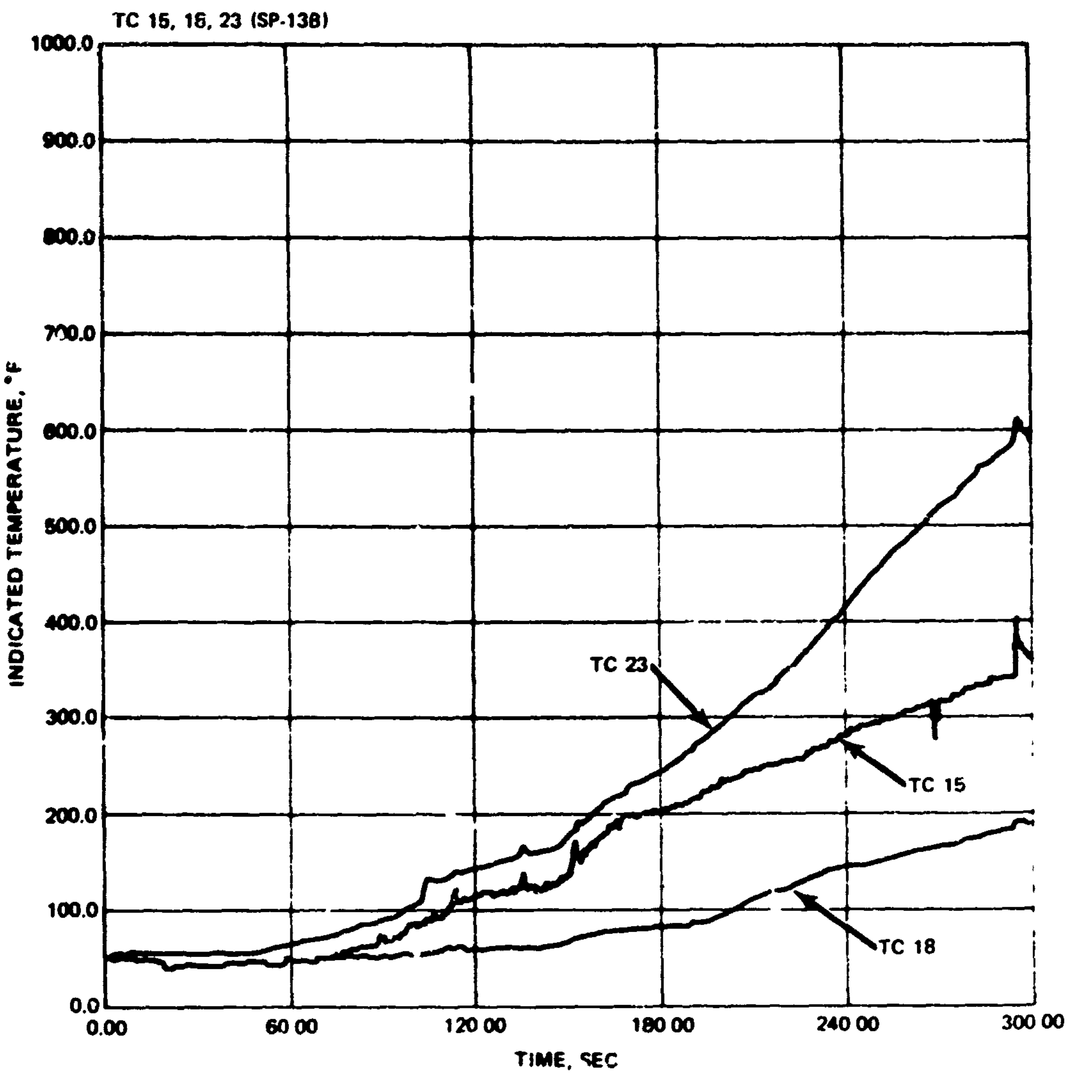

FIGURE D-26. TC 15, 18, 23 Response, SP-13B.

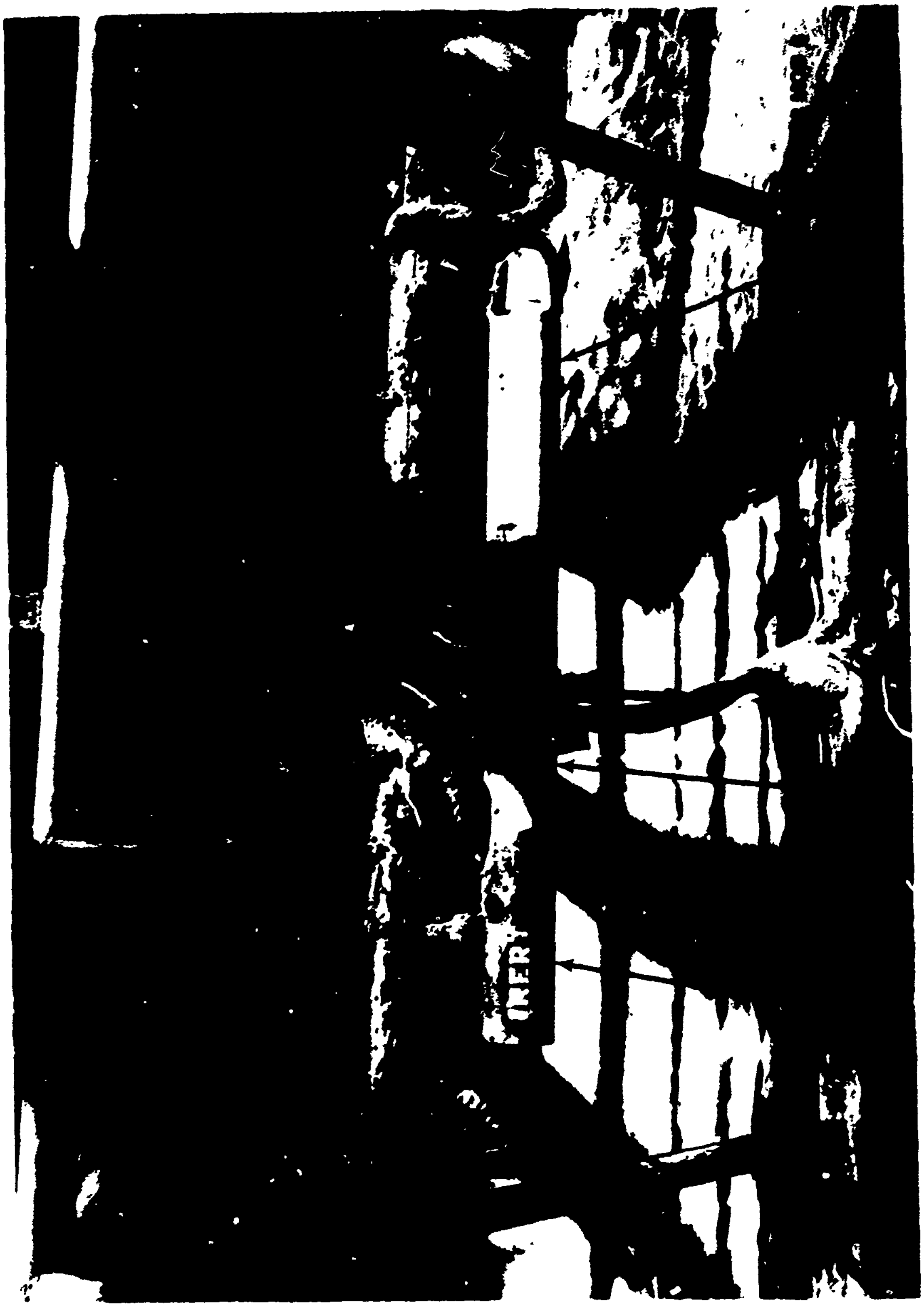

FIGURE D-27. SPARROW SP-14A Test Configuration.

MOTOR CASE/LINER INTERFACE: TC-1, 2, 3, 4, 5 & 6
CASE LINER INNER SURFACE: TC-7, 8, 9, 10, 11 & 12
GRAIN OUTER SURFACE: TC-26, 29, 28, 29, 30 & 31
GRAIN INNER SURFACE: TC-32, 33 & 34
WEATHERSEAL: TC-35
IGNITER BASKET: TC-36

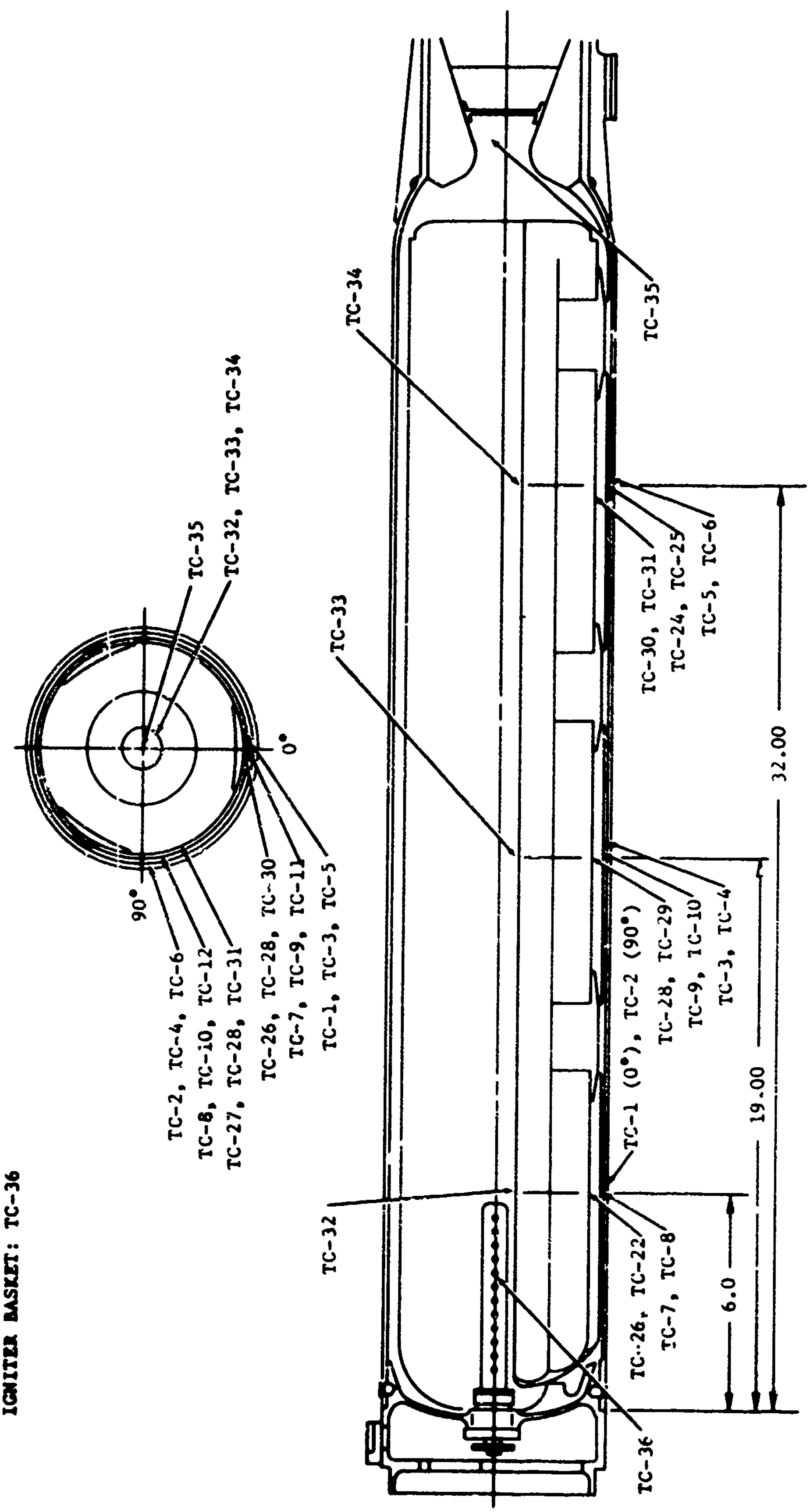

FIGURE D-28. Mk 38 Mod 0 Motor Thermocouple Locations.

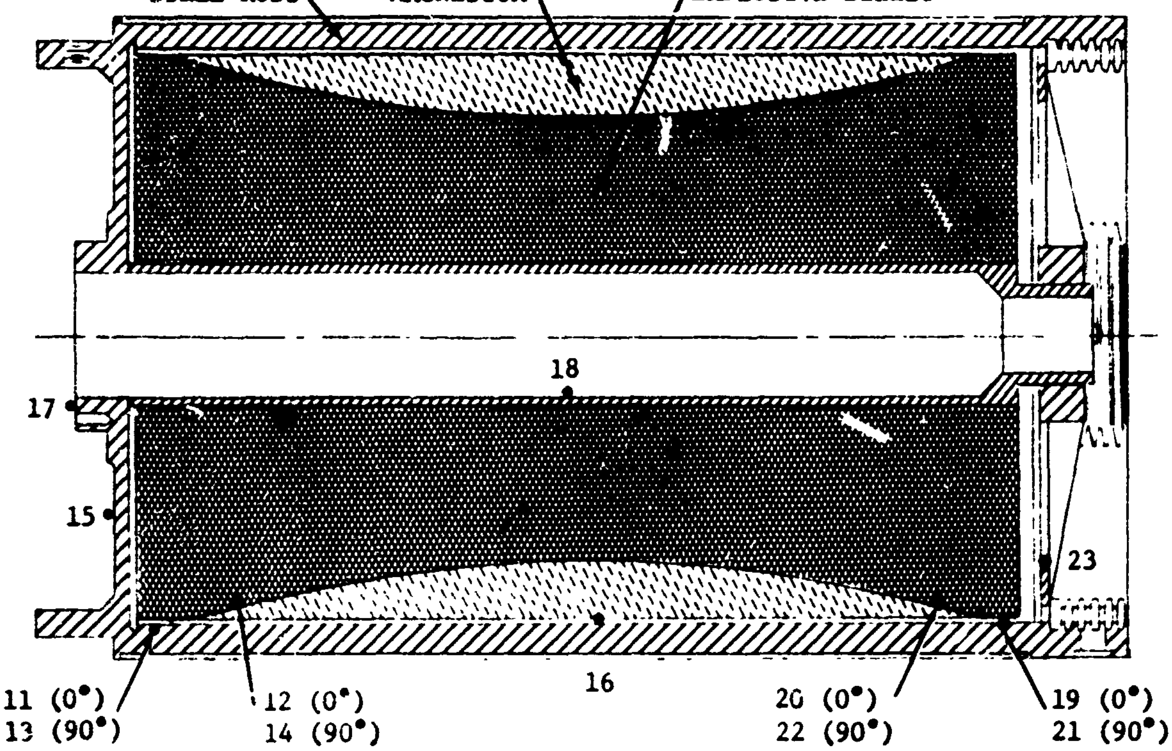

FIGURE D-29. Mk 38 Mod 0 Warhead Thermocouple Locations.

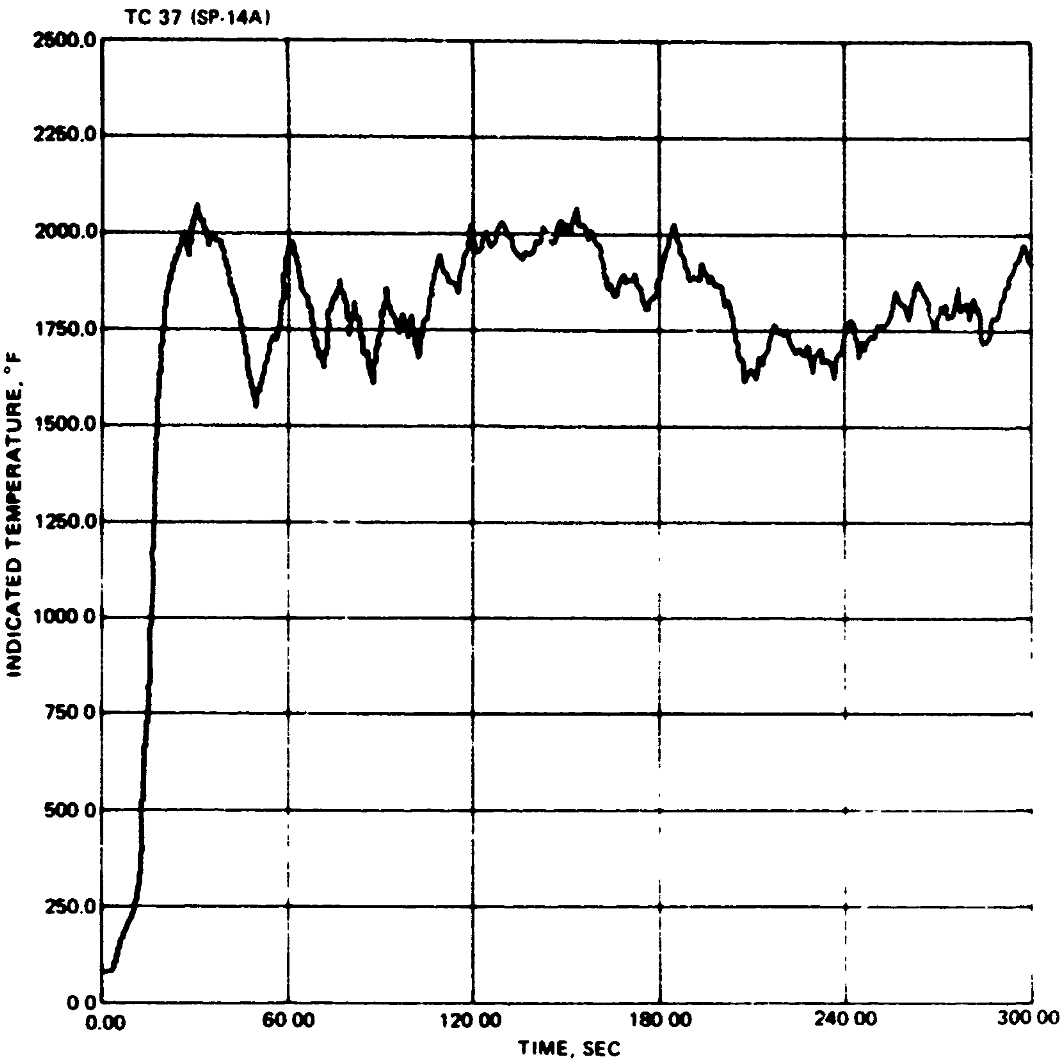

FIGURE D-30a. TC 37, Forward Flame Thermocouple, SP-14A

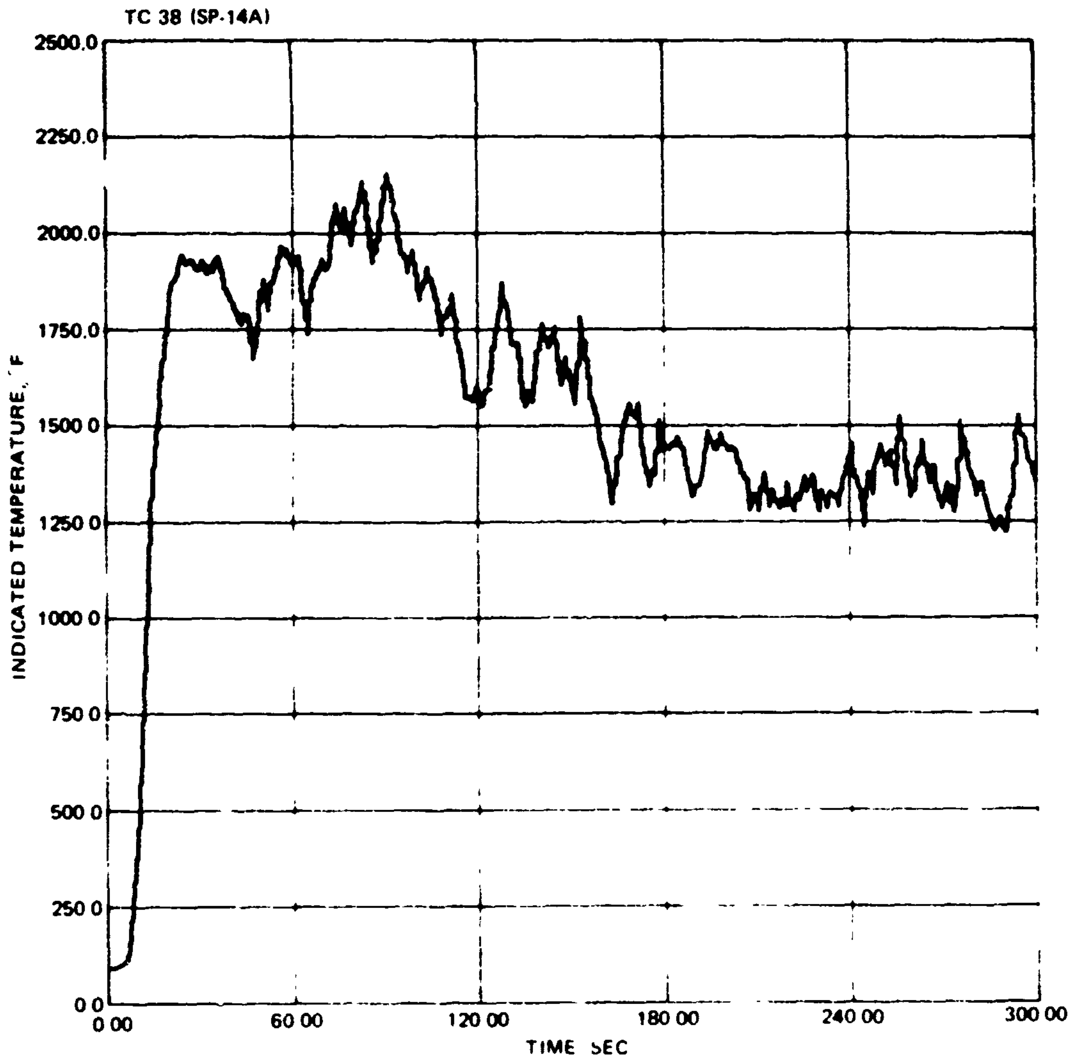

FIGURE D-30b TC 38, Starboard Flame Thermocouple, SP-14A

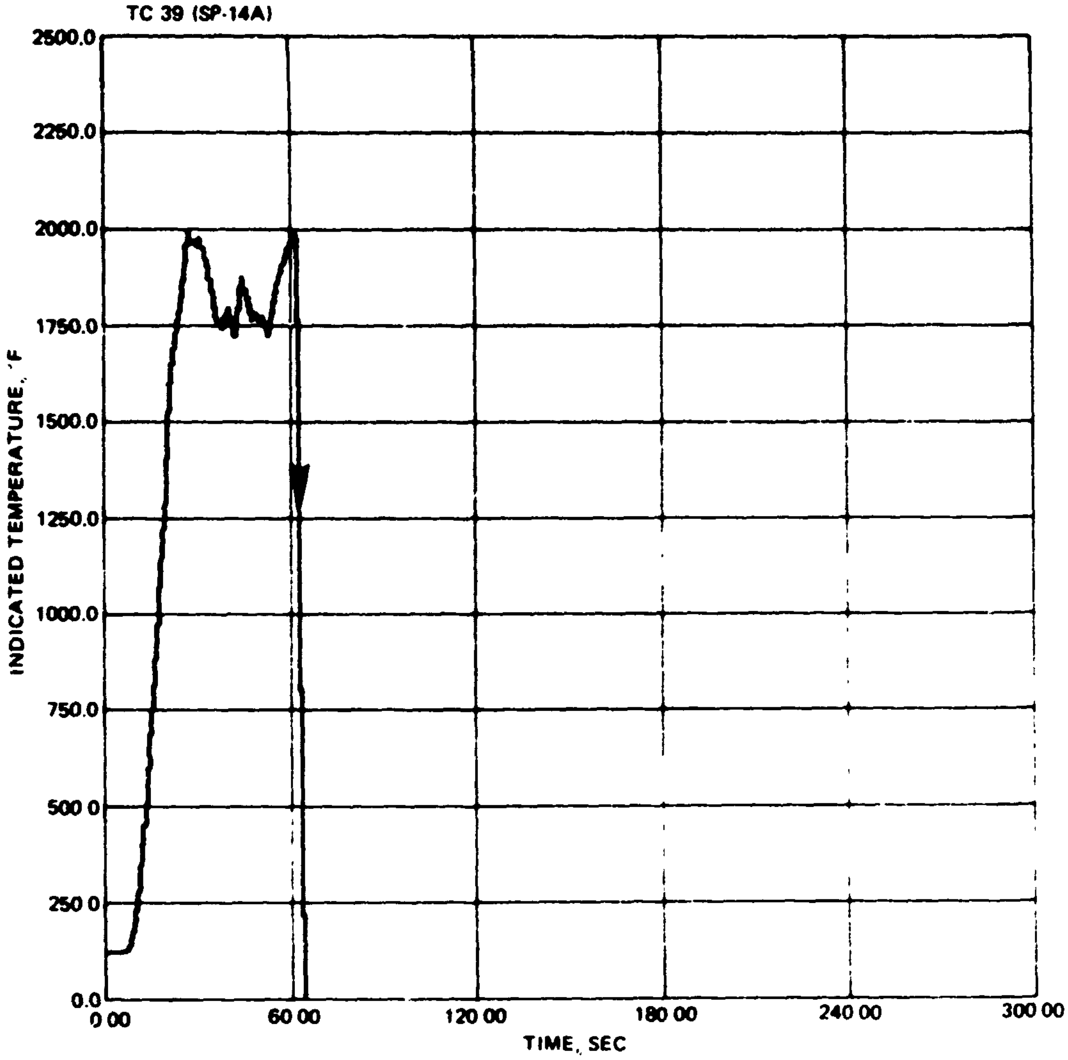

FIGURE D-30c. TC 39, Aft Flame Thermocouple, SP-14A

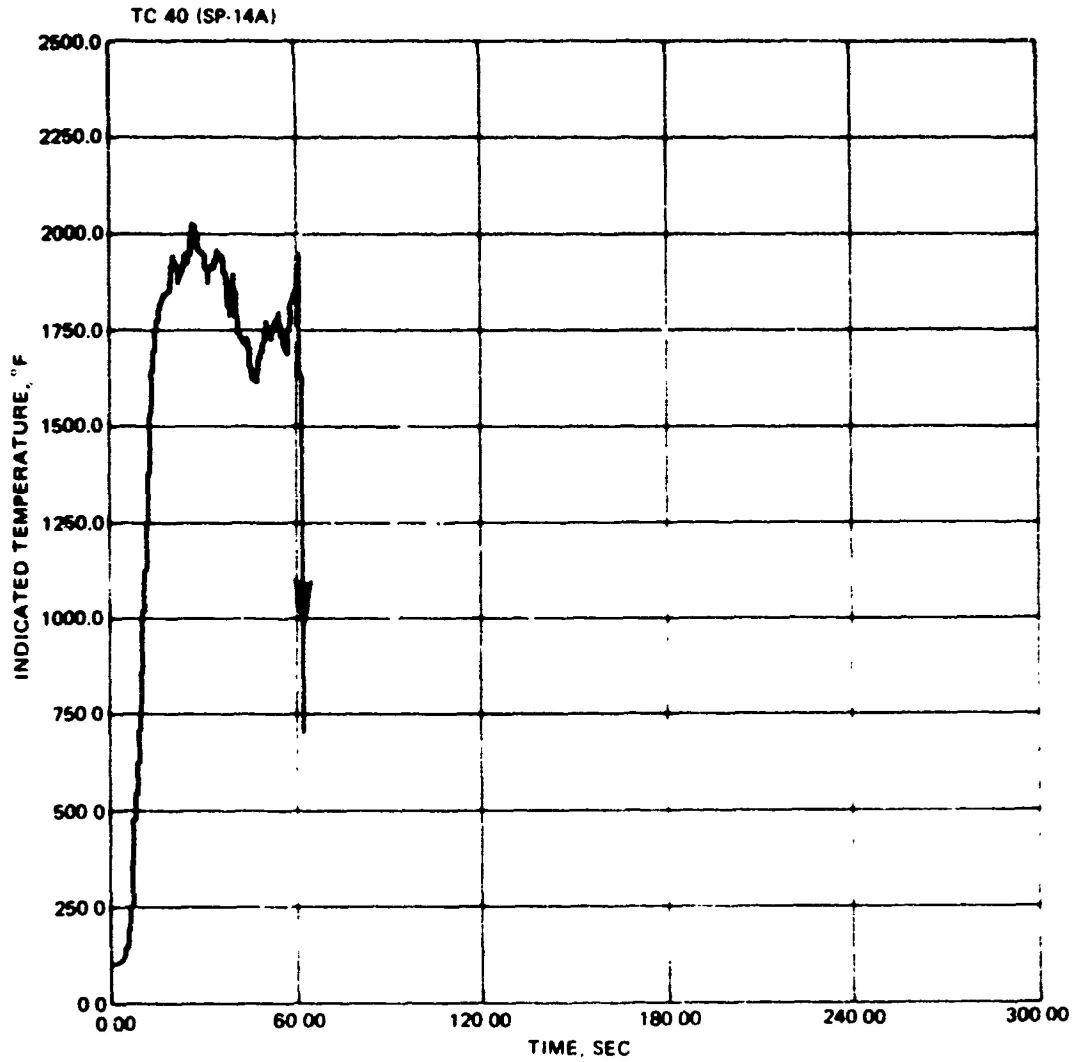

FIGURE D-30d. TC 40, Port Flame Thermocouple, SP-14A.

FIGURE D-31. SPARROW SP-14A Post Test Configuration, I.

FIGURE D-32. SPARROW SP-14A Post Test Configuration, II.

FIGURE D-33. SPARROW SP-14A Post Test Configuration, III.

FIGURE D-34. SPARROW Motor Nozzle.

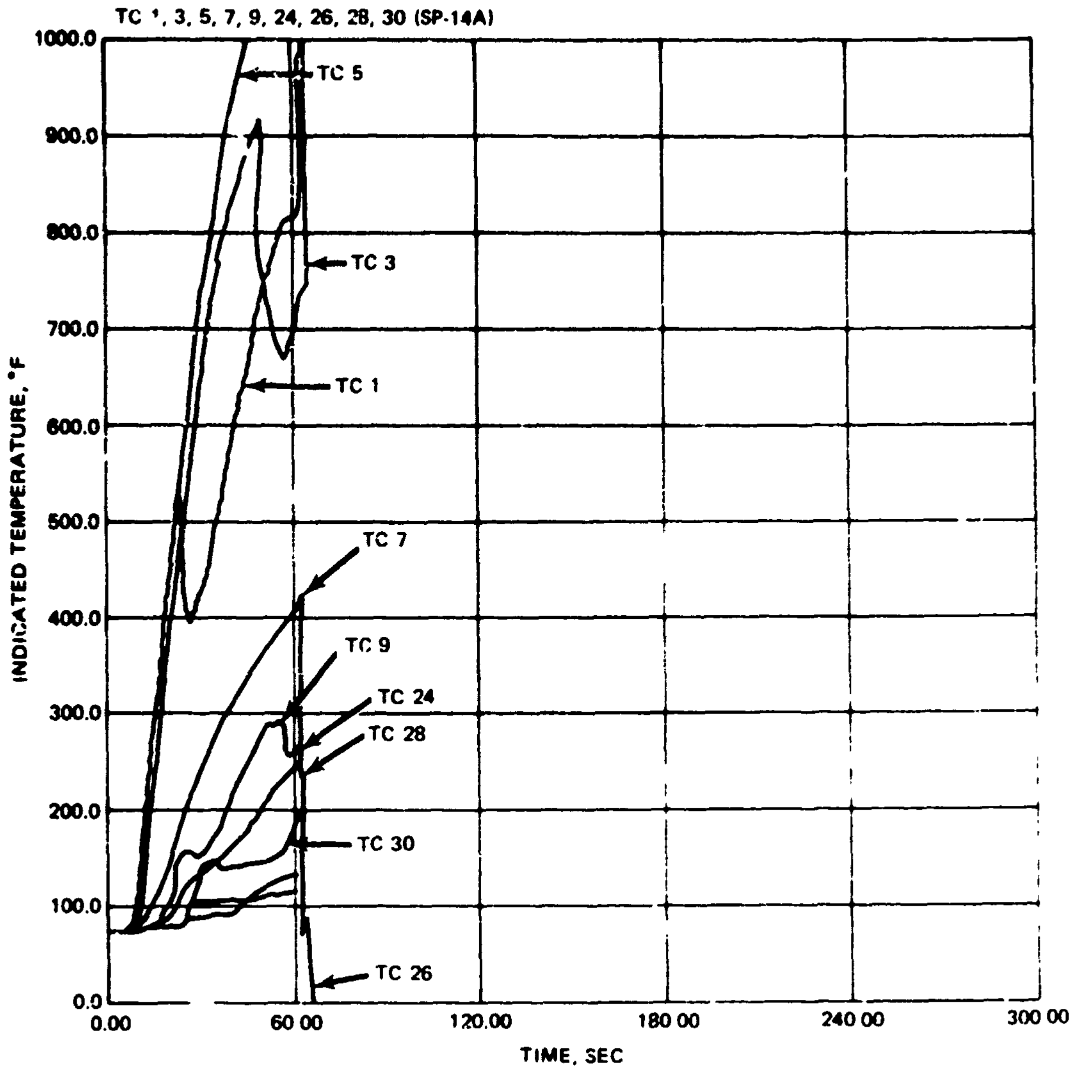

FIGURE D-35. TC 1, 3, 5, 7, 9, 24, 26, 28, 30 Response, SP-14A.

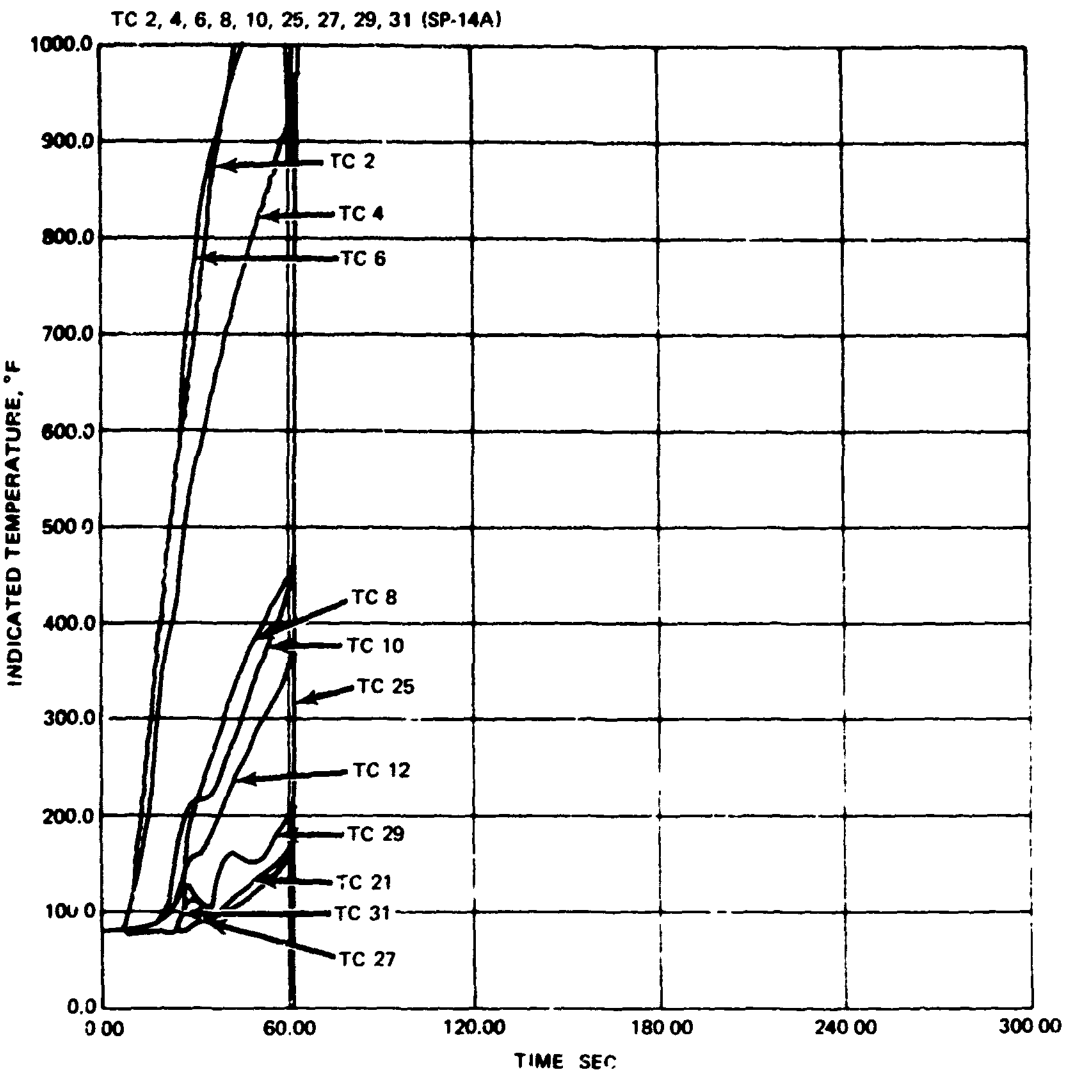

FIGURE D-36. TC 2, 4, 6, 8, 10, 25, 27, 29, 31 Response, SP-14A.

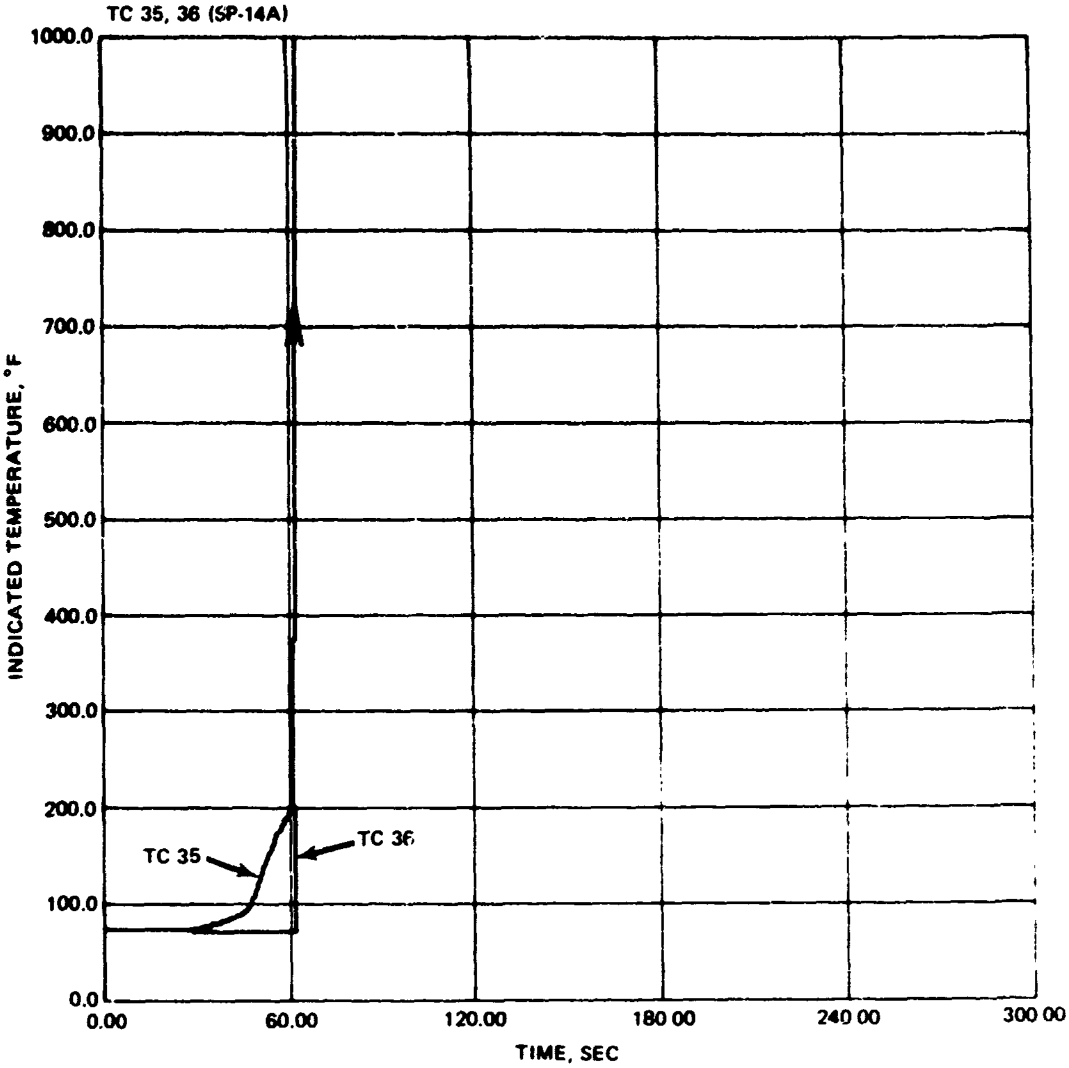

FIGURE D-37. TC 35, 36 Response, SP-14A.

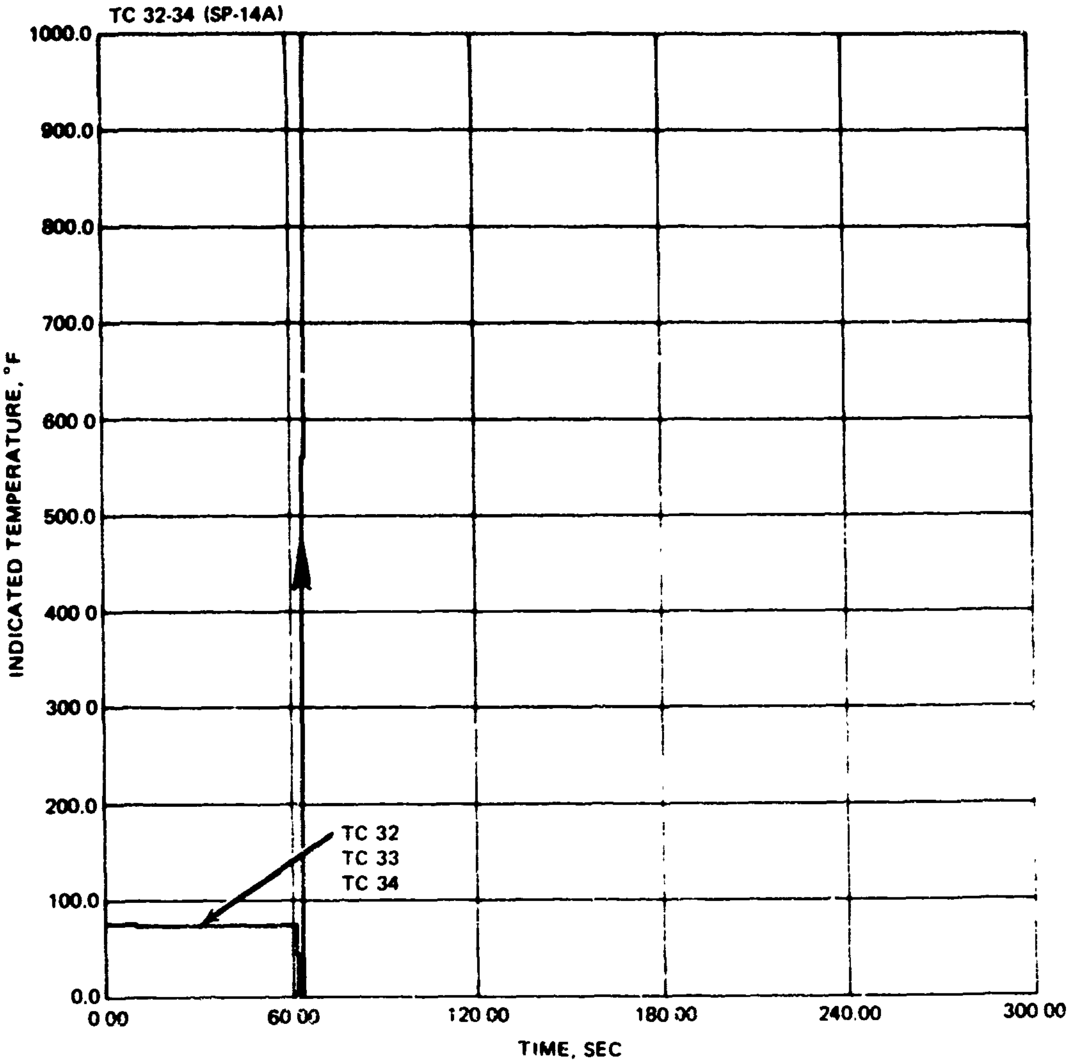

FIGURE D-38. TC 32-34 Response, SP-14A.

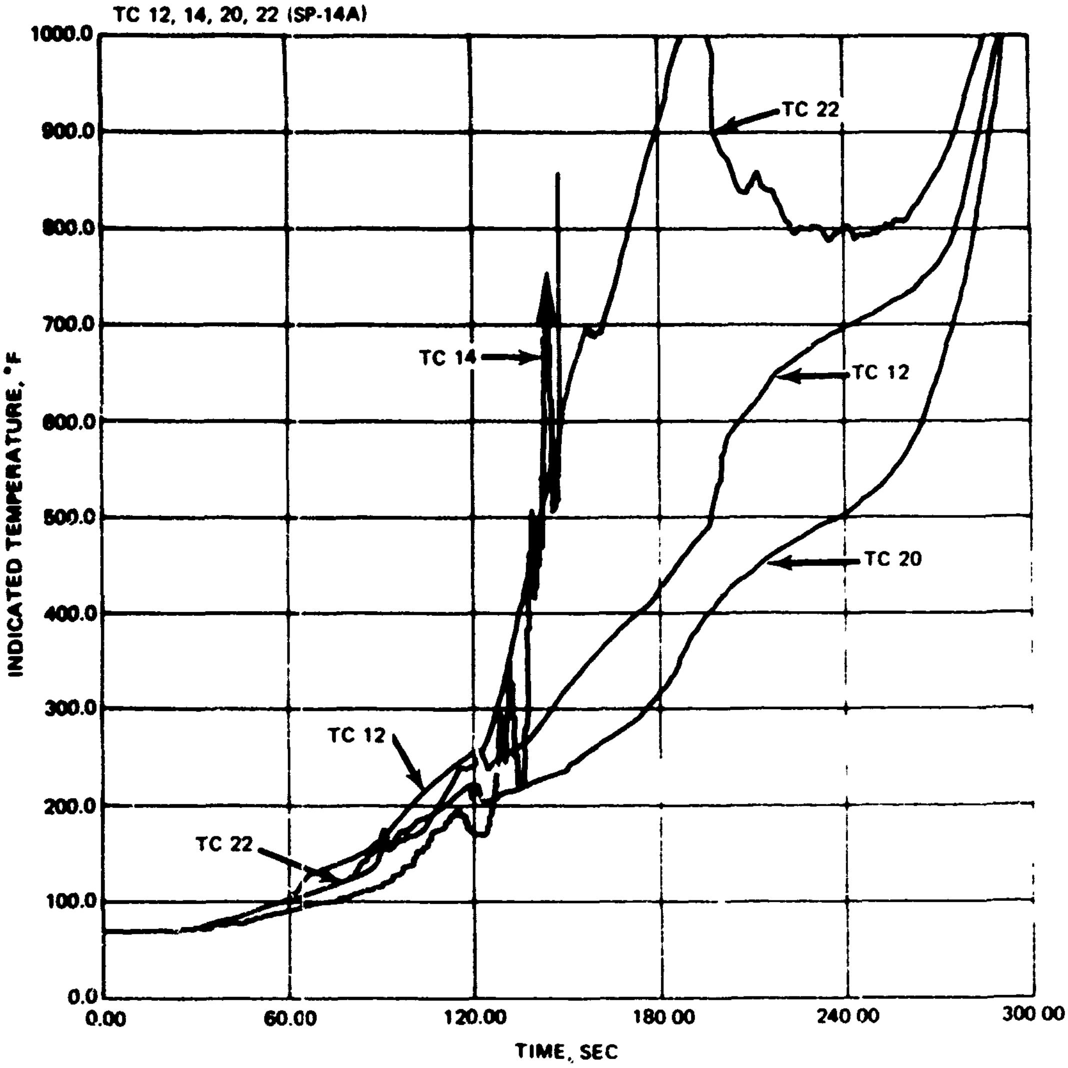

FIGURE D-39. TC 12, 14, 20, 22 Response, SP-14A.

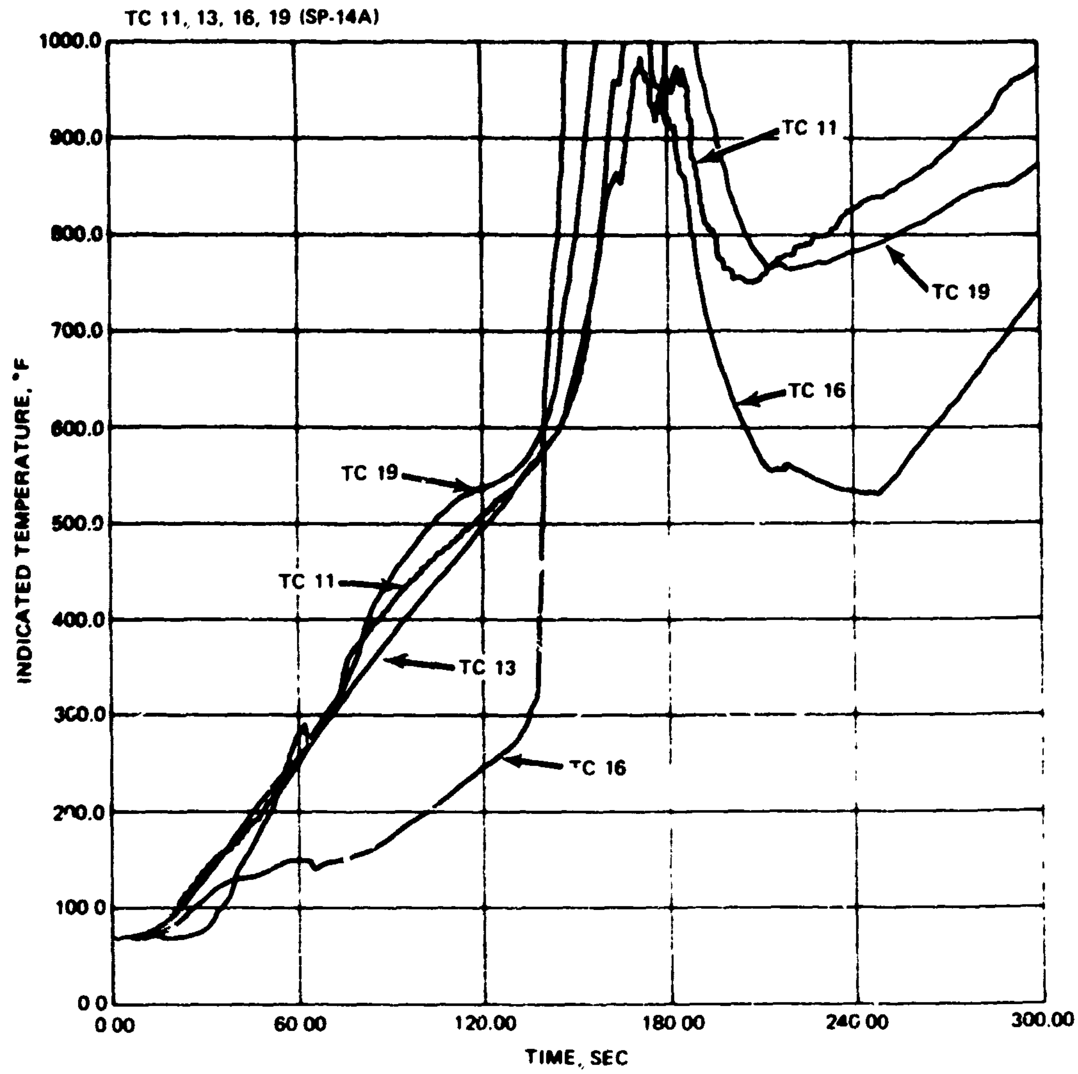

FIGURE D-40. TC 11, 13, 16, 19 Response, SP-14A

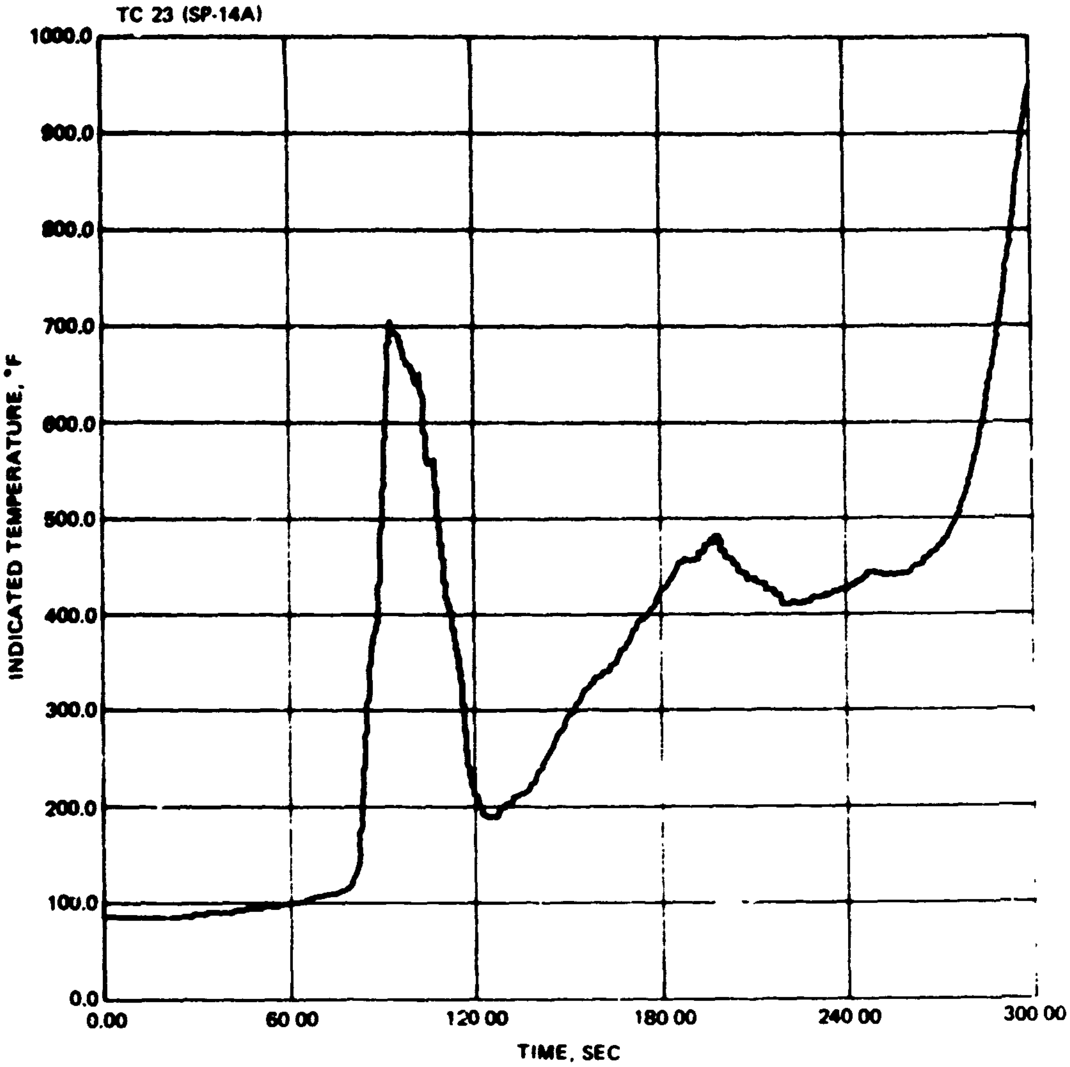

FIGURE D-41. TC 15, 17, 18 Response, SP-14A.

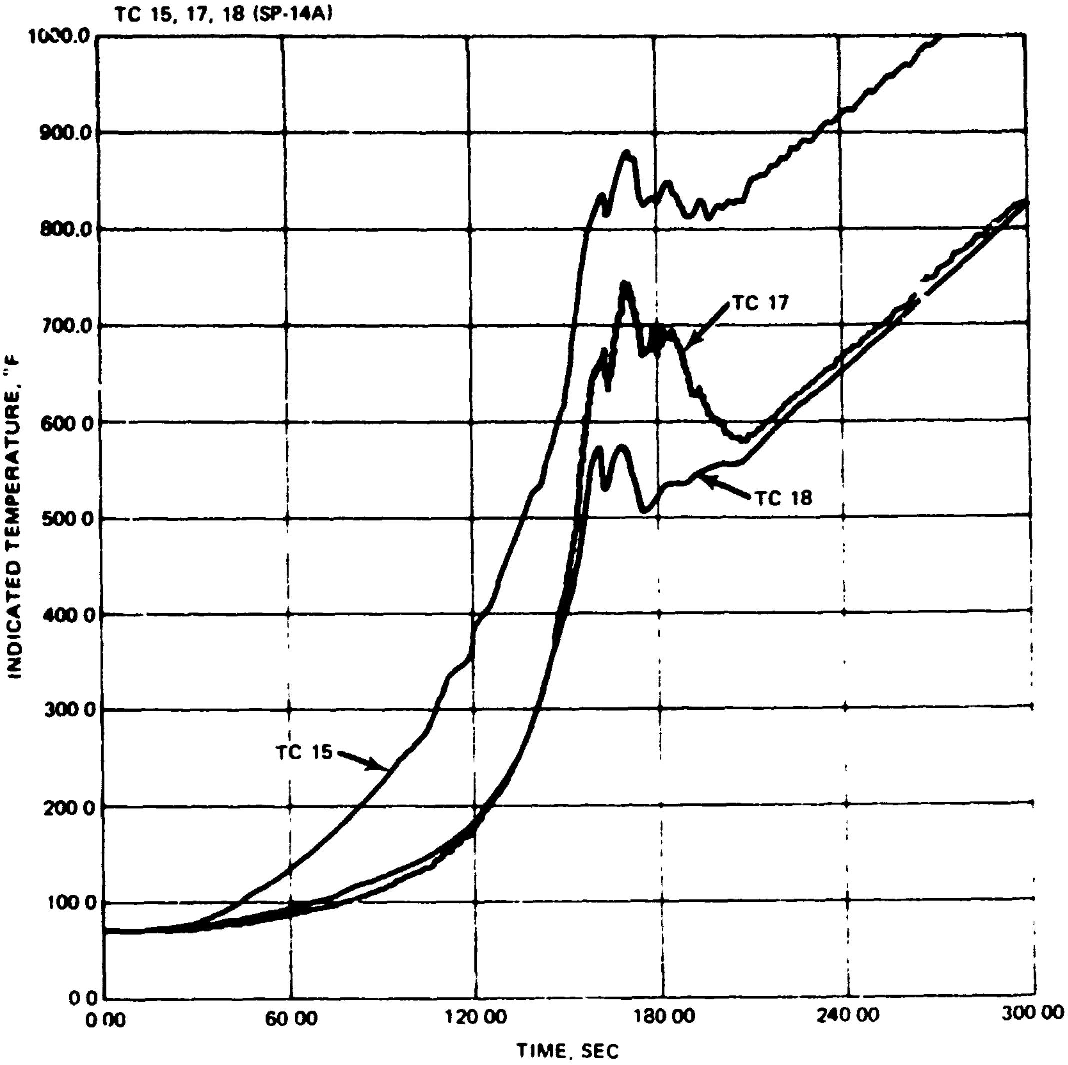

FIGURE D-42. TC 23 Response, SP-14A.