SANDIA REPORT SAND81-2527 • Unlimited Release • UC-13
Printed January 1982

MC3644 Detonator Development Status Report for the Period Ending October 30, 1981

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Prepared by
Sandia National Laboratories
Albuquerque, New Mexico 87185 and Livermore, California 94550
for the United States Department of Energy
under Contract DE-AC04-76DP00789

SF2900Q(8-81)

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Printed in the United States of America
Available from
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161

NTIS price codes
Printed copy: A03
Microfiche copy: A01

SAND81-2527
Unlimited Release
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Distribution
Category UC-13

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Abstract

The MC3644 detonator is being developed as a replacement for the MC3132 flying plate detonator in the parachute deployment system of the B83 weapon. The MC3644 is a CP, deflagration-to-detonation transition device. Two models are being developed: an interim design using the MC3423 ignitor and a new production version with a one-piece ignitor/header assembly. Features of both designs are described. Results of development tests involving the interim design are presented. No-fire sensitivity test and proof-test results with the WR version are also included. The development program is on schedule.

Acknowledgments

The author thanks M. L. Lieberman and F. J. Villa, (2515); J. E. Kennedy, J. G. Harlan, and R. J. Burnett (2513); and A. C. Schwarz (2515); all of Sandia National Laboratories; W. R. Henderson and E. E. Tibbitts of Mound Facility; R. DeCoursey of Unidynamics/Phoenix, Inc; and G. Seavy of VELER, Inc for their technical input and support during MC3644 development and in the preparation of this report.

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Summary

Development of the MC3644 Interim Detonator (ID) at Unidynamics/Phoenix, Inc (UPI) is complete. Fifty detonators were shipped to Sandia National Laboratories, Albuquerque (SNLA) for use in the B83 Parachute Deployment System (PDS) development. Of the 50, 6 were successfully tested at the system level; 34 additional MC3644 IDs were tested at UPI. One detonator failed to detonate. The investigation into the cause of the failure has not been completed; however, it appears that a defective header may have caused the failure. Of the 34 detonators tested at UPI, 15 were tested after being subjected to a combined series of mechanical and thermal environments. There were no failures in this group of units.

Functional proof testing of the War Reserve (WR) final design MC3644 was successfully completed at UPI. Ten WR MC3644s and six trainers were shipped to SNLA. No-fire sensitivity tests verified that the 1.0-A requirement is met.

The action items related to the MC3644 development program are described at the end of this report.

MC3644 Detonator Development Status Report for the Period Ending October 30, 1981

Introduction

The MC3644 detonator (part number 318493) is being developed for use in the Parachute Deployment System (PDS) of the B83 weapon. The axial detonator output will side-initiate 10-grains/ft hexanitrostilbene aluminum-sheath mild detonating fuze (HNS-IIA ALMDF).[1] The force generated by the detonating HNS-IIA ALMDF ejects the deployment cover assembly that, in turn, deploys the B83 parachute. Two MC3644s will be used in each weapon. A typical detonator/mild detonating fuse (MDF) assembly is illustrated in Figure 1. The MC3644 development activities are being conducted at Sandia National Laboratories, Albuquerque (SNLA) and at UPI under Contract 61-3840

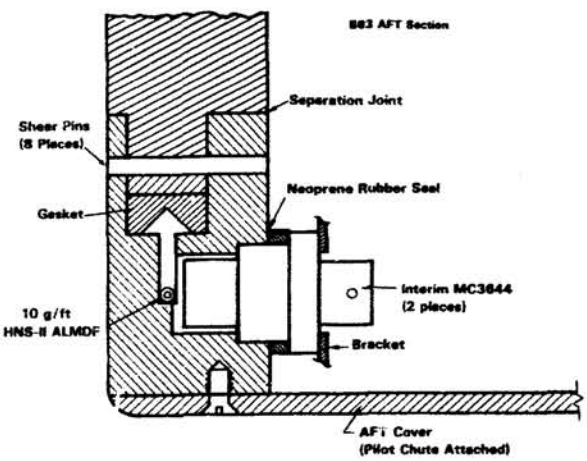

Figure 1. Typical MC3644/HNS-IIA ALMDF Assembly

The MC3644 is a deflagration-to-detonation transition (DDT) detonator using the explosive 2-(5-cyanotetrazolato) pentaamminecobalt (III) perchlorate, which is designated CP. The synthesis,[2] explosive properties,[3] thermal capabilities,[4] ignition, and electrostatic sensitivity characteristics have been reported in relation to the development of other DDT components. A list of these components is provided in Appendix A. A list of reports and resources are included in Reference 4.

Two versions of the MC3644 are being developed in parallel activities. The development testing of an interim design (Figures 2 and 3) was completed at UPI. This version will be used in parachute development testing until the war reserve (WR) version becomes available. The interim design consists of three subassemblies. The output subassembly, which is common to both versions, includes the DDT and output charges. The 6.2-mm-long DDT column consists of 0.072 g of CP pressed in four equal increments to a density of 1.5 Mg/m^3. Two increments of CP (0.037 g total) are pressed to a density of 1.75 Mg/m^3 in the output pellet. The output pellet length is 2.54 mm. The ignitor used in the interim MC3644 is in production at UPI for the MC3423 detonator.[5] The proven functional characteristics of this ignitor meet the requirements of the B83 program. The ignitor is laser-welded into the output subassembly. The electrical header is used to adapt the ignitor pigtail leads to the SA2052 connector on the system electrical cable. The pins in the electrical header are hollow and act as the receptacle for the ignitor leads. The leads are soldered to the header pins. Four laser welds are required to complete the assembly.

The WR version (Figure 4) is discussed later in this report. A list of drawings defining the MC3644 WR is included in Appendix B. The design requirements are included in Appendix C.

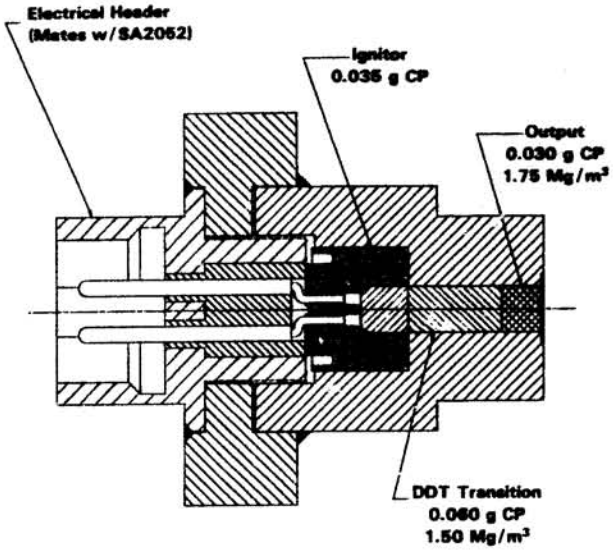

Figure 2. Cutaway of MC3644 ID

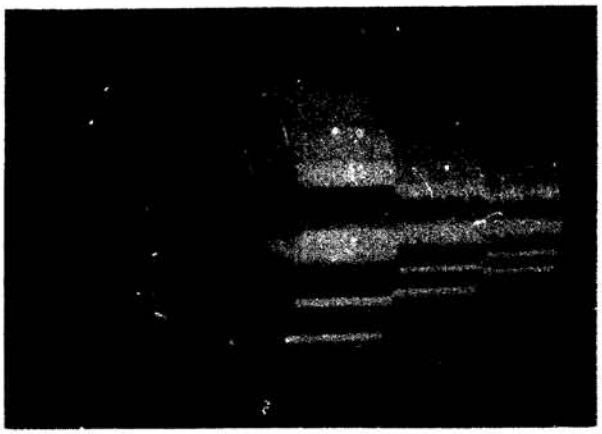

Figure 3. MC3644 ID

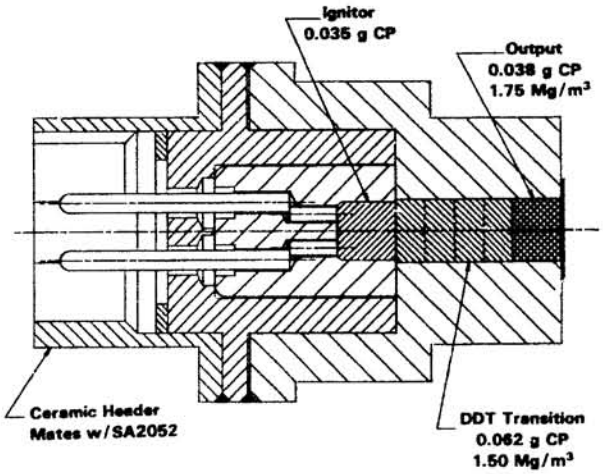

Figure 4. MC3644 WR Detonator

MC3644 ID Functional Characteristics

The ignition and safety characteristics of the MC3644 ID were demonstrated in the development of the MC3423 detonator.[5-7] The combined ignitor and output characteristics were tested as part of the MC3644 ID development effort.

Ignition Characteristics

The MC3644 ID ignitor (MC3423) has a single 0.051-mm-diameter Tophet A bridgewire resistance welded to 1.02-mm-diameter Kovar pins. The pin spacing is 1.40 mm. The wire is looped to achieve sufficient length for a 1.0-ohm bridgewire. Two 18-mg increments of CP are pressed onto the wire at a density of 1.75 Mg/m³ at 276 MPa.

The all-fire and no-fire characteristics for this design were determined by forty-unit Bruceton sensitivity tests run at –54°C and ambient temperature, respectively.[8] The resulting reliability statements are summarized below.

All-Fire at –54°C

Fifty-percent threshold: 2.21 A with a standard deviation of 0.038 A.

Ninety-five-percent confidence statement: 999 in 1000 will fire at 2.41 A.

No-Fire at Ambient Temperature

Fifty-percent threshold: 1.46 A with a standard deviation of 0.064 A.

Ninety-five-percent confidence statement: only 1 in 1000 will fire at 1.14 A.

Electrostatic Discharge Sensitivity (ESD)

ESD protection for the MC3644 ID is achieved through the use of a 0.25-mm-wide spark gap between the electrical leads and the case of the ignitor. Development ESD test results for the MC3423 have been reported.[7] Over 200 loaded ignitors were tested without a firing to the 20-kV 600-pf 500-ohm requirement.

Feasibility Test Results

The feasibility of using a CP-DDT detonator to initiate the HNS-IIA ALMDF in the B83 application was demonstrated at UPI in a series of test firings at –55°C, ambient, and 130°C. Ten MC3644 IDs were fabricated and assembled with HNS-IIA ALMDF into

test fixtures designed to simulate the B83 hardware configuration (Figure 5). The design includes a 1.3-mm air gap between the detonator and the HNS-IIA ALMDF. Three assemblies were conditioned at each of the three temperatures for a minimum of 2 h. One detonator has not been tested.

The electrothermal response (ETR) data for the group of detonators are summarized in Table 1. Test fire results at each temperature are given in Table 2. The test current was 5.0 A from a constant current source.

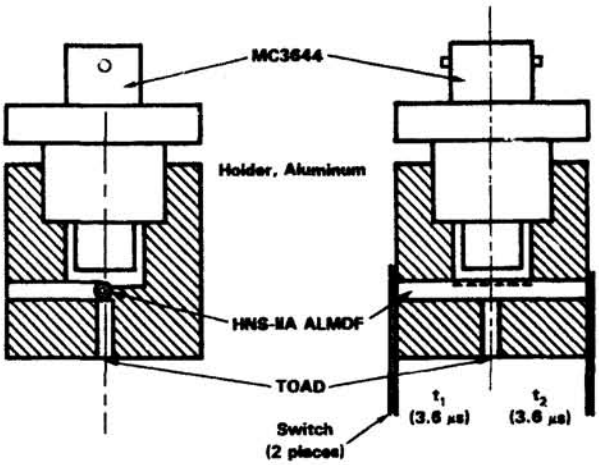

Figure 5. Test Fixture Assembly

The ignition time (t_i) shown in Table 2 was calculated from bridgewire current and voltage with the use of the Calculator Controlled Data System (CCDS)[9] UA1538 at UPI. The calculation is based on a bridgewire thermal model which responds to a drop in voltage which typically occurs at ignition of the explosive pressed on the bridgewire.

In this group of tests, the apparent ignition time is longer than the detonator function time. Two possible explanations are that the incorrect program was used or that the model is not sensitive enough to the sudden changes in bridgewire resistance which typically occur at ignition of the explosive. This numerical anomaly is being investigated.

Table 1. ETR Data Summary of MC3644 ID Feasibility Tests

	Bare Bridgewire	Loaded Ignitor	Final Assembly
Average (μW/°C)	690.4	15340	15040
Standard deviation (μW/°C)	21.8	989	1909
Range (μW/°C)	67	3444	5821
Number tested	10	10	10

Table 2. MC3644 ID Feasibility Test-Fire Results

Shot	Temp. (°C)	Serial No.	Ignition Time (t_i) (μs)	Bridgewire Open (μs)	Function Time (μs)	t_1* (μs)	t_2* (μs)	Gamma** (μW/K)
1	Ambient	19	–	–	621	6.8	7.6	15000
2	Ambient	16	660	700	641	7.2	7.2	16000
3	Ambient	11	640	680	627	7.0	7.1	16000
4	–55	10	750	780	731	7.2	7.2	17000
5	–55	12	730	770	711	7.1	7.1	16000
6†	–55	14	730	770	702	–	–	10000
7	130	13	550	580	529	7.2	7.1	15000
8	130	11	550	590	526	7.2	7.2	15000
9	130	15	550	600	527	7.2	8.5	13000

*Transit time in HNS-IIA ALMDF
**Gamma after temperature conditioning
†No MDF detonation

The times t_1 and t_2 are the elapsed time from shock arrival at the time-of-arrival detector (TOAD) (Figure 5) to the arrival of the detonation wave at the end of the HNS-IIA ALMDF. This was the first attempt to measure detonation transit time in the HNS-IIA ALMDF after impact of the detonator closure disc. The program goal is to initiate a length of HNS-IIA ALMDF with each MC3644 tested. Once the technique is developed, the times t_1 and t_2 should give an indication of how uniformly the detonation is developing in the side-initiated HNS-IIA ALMDF.

The transit time has been calculated using a velocity of detonation for HNS-IIA ALMDF of 6.5 km/s and a shock velocity in aluminum of 6.0 km/s. For the purpose of this calculation, it was assumed that detonation occurred immediately inside the aluminum sheath, i.e., zero run distance to detonation, and that it occurred either on the detonator axis or at the edge of the closure disc. The calculated transit time, is 7.11 to 7.52 μs, depending on the origin of detonation, and taking into account the transit time from point of detonation to the TOAD.

With the exception of Shot 6, the HNS-IIA ALMDF detonated in each shot. An aluminum witness block was used to determine if the HNS-IIA ALMDF detonated. Additional evaluation of this technique will be required before a specification can be established and before the 8.5-μs time in Shot 9 should be considered a problem.

It has been determined that the CP in detonator 14 (Shot 6) failed to grow to detonation. The investigation into this failure is discussed later in this report.

MC3644 ID System Vibration Test

Two deployment covers with two MC3644 IDs each were subjected at room temperature to a simulated sled-track random-vibration environment. The sled-track environment is an overtest for the system, but it was used because some parachute testing is done on the sled track. Subsequent to vibration, the deployment covers were assembled to a static test stand and fired. The deployment velocity of each cover was measured. The fire-pulse current was applied to only one detonator in each test. In test 1, the second detonator was sympathetically initiated by the HNS-IIA ALMDF. The second detonator in test 2 (unit 61, Shot 3, Table 2) was removed from the cover and tested in a separate fixture. A short length of HNS-IIA ALMDF was initiated successfully, but an instrumentation problem erased the data.

ETR measurements were made on each detonator before and after vibration. The data are given in Table 3. Units 28 and 56 were subjected to two cycles of vibration. Deployment test results are shown in Table 4. The range in gamma is larger than one would expect and is probably due to differences in the unit assembly procedures.

MC3644 ID Proof Test Results

Fifteen MC3644 IDs were assembled and subjected to the combined environments of thermal shock, mechanical shock, and vibration (Appendix C) as outlined in PS318493 Issue A. The units were subjected to the mechanical shock and vibration environments at room temperature. The units were fired in the fixtures shown in Figure 5. The effect of the environments on the CP/bridgewire interface as determined by ETR testing is summarized in Table 5. The destructive test data are summarized in Table 6. The raw test data are included in Appendix D. The times t_1 and t_2 in Table 6 are the elapsed times from TOAD output to switch closure at each end of the HNS-IIA ALMDF (Figure 5). With one exception, the data in channel 2 (t_2) average 17 ns longer. This characteristic has persisted since the start of the program. The cause remains to be determined. The HNS-IIA ALMDF has fired satisfactorily in 29 MC3644 ID tests at UPI.

A summary of ETR data at each assembly step is included in Table 7. ETR measurements were made of two small group of detonators (serial nos. 70–79 and 90–107) to determine if the final assembly weld of the connector and the soldering of the connector pins affected the unit quality. The limited data indicate there is no effect.

Table 3. Electrothermal Response Data for MC3644 ID System Random Vibration Tests

	Gamma (μW/°C)			
Serial No.	Ignitor Only	After Weld	After Shipping	After Vibration
18	14,000	16,000	15,000	15,000
28	13,000	13,000	14,000	12,000
56	10,000	10,000	10,000	10,000
61	9,000	9,000	9,000	9,000
Average	12,000	12,000	12,000	12,000
Standard Deviation	3,000	3,000	3,000	2,000

Table 4. Static Deployment Test Results

Shot	Unit	Bridgewire Resistance at Ignition (ohms)	Ignition Time (μs)	BW Open (μs)	Ignition Energy (mJ)	First Motion* (μs)	Cover Velocity (m/s)
1	56	1.07	600	640	13.6	860/810	23.8
2	18	1.03	640	700	15.9	980/860	21.3
3	61	ND	ND	ND			

*First motion is the elapsed time from the leading edge of the fire pulse to the time the shear pins retaining the cover began to shear. The times recorded were monitored 180° apart, adjacent to the detonator mounting holes. The early time was recorded adjacent to the fired detonator.

Table 5. MC3644 ID Combined Environment Test Series Electrothermal Response Data

	Before Environment	After Thermal Shock	After Mechanical Shock	After Vibration
Number of units	15	15	15	15
Gamma*(μW/°C)				
Average	17000	16000	15000	15000
Standard Deviation	3000	2000	3000	3000
Minimum	10000	12000	9000	9000
Maximum	22000	20000	19000	19000
Bridgewire Resistance (ohm)				
Average	1.004	1.092	1.053	1.051
Standard Deviation	0.024	0.04	0.023	0.021
Minimum	0.971	1.035	1.011	1.008
Maximum	1.048	1.204	1.113	1.091
Theta (°C)				
Average	29.9	35.0	36.9	36.7
Standard Deviation	7.8	5.9	8.6	8.6
Minimum	22.2	26.4	27.3	26.8
Maximum	49.8	47.0	58.5	59.3

*Values are rounded off to be consistent with an expected error of approximately 800 in standard deviation.

Table 6. Summary of MC3644 Proof Test Data After Combined Environments

Number of Units	Test Temperature	t_i (μs)	E_i (mJ)	t_b (μs)	t_f (μs)	R_i (ohm)	t_1 (μs)	t_2 (μs)
5	Ambient							
	Average	628	15.8	752	624	1.15	6.84	7.01
	Standard Dev.	50	0.76	82	46	0.05	0.07	0.07
5	−55°C							
	Average	760	19.9	1404	757	1.19	6.82	7.11
	Standard Dev.	87	2.2	646	86	0.02	0.07	0.03
5	132°C							
	Average	522	14.2	900	525	1.22	7.00	7.06
	Standard Dev.	35	1.17	403	40	0.03	0.23	0.12
5	Ambient Control							
	Average	588	15.2	882	584	1.17	6.91	7.12
	Standard Dev.	8.4	0.21	205	15.2	0.02	0.07	0.05

Notes:

t_i = Ignition time
E_i = Ignition energy
t_b = Bridgewire break time
t_f = Function time: leading edge of pulse to TOAD output
R_i = Bridgewire resistance at ignition
t_1 and t_2 = Transit times in HNS-IIA ALMDF

Table 7. Summary of MC3644 ID Electrothermal Response Data

Item Tested	Group Serial Number	R_0 (ohm)	Theta (°C)	Gamma (μW/°C)
Bare Bridgewire	10-38			
Mean		1.040	95.9	680
Minimum		0.971	85.5	590
Maximum		1.089	109.0	760
Standard Dev.		0.038	6.5	40
Number Tested		29	29	29
Bare Bridgewire	39-98			
Mean		0.954	97.6	620
Minimum		0.864	73.0	530
Maximum		1.052	125.6	800
Standard Dev.		0.045	9.1	60
Number Tested		60	60	60
Bare Bridgewire	99-137			
Mean		0.994	97.6	660
Minimum		0.926	77.0	530
Maximum		1.027	121.2	810
Standard Dev.		0.025	11.0	70
Number Tested		39	39	39
Loaded Ignitor	10-38			
Mean		1.011	23.9	15300
Minimum		0.939	20.6	13300
Maximum		1.064	27.7	16900
Standard Dev.		0.038	1.6	1100
Number Tested		29	29	29
Loaded Ignitor	25-37			
Mean		1.022	26.0	14200
Minimum		0.965	23.9	12700
Maximum		1.075	28.2	15900
Standard Dev.		0.033	1.7	1100
Number Tested		12	12	12
Loaded Ignitor	30-98			
Mean		0.951	26.6	13500
Minimum		0.860	17.7	6400
Maximum		1.024	52.0	19000
Standard Dev.		0.043	7.7	3000
Number Tested		62	62	62
Loaded Ignitor	99-137			
Mean		0.997	25.0	16000
Minimum		0.951	15.3	7000
Maximum		1.026	54.8	23000
Standard Dev.		0.020	9.4	4000
Number Tested		39	39	39
Explosive Subassembly	10-19			
Mean		1.016	32.5	15000
Minimum		0.957	28.9	10000
Maximum		1.073	46.5	17000
Standard Dev.		0.044	5.3	2000
Number Tested		10	10	10
Explosive Subassembly	20-79			
Mean		1.009	36.3	14000
Minimum		0.911	25.7	8000
Maximum		1.083	59.8	18000
Standard Dev.		0.056	9.6	3000
Number Tested		13	13	13

Table 7. (cont)

Item Tested	Group Serial Number	R_0 (ohm)	Theta (°C)	Gamma (μW/°C)
Explosive Subassembly	10-133			
Mean		0.987	33.3	15400
Minimum		0.857	21.7	6500
Maximum		1.078	71.9	21900
Standard Dev.		0.040	9.8	3400
Number Tested		77	77	77
Detonator Subassembly	70-79			
Mean		1.058	32.8	16000
Minimum		0.927	27.5	14500
Maximum		1.113	37.4	18600
Standard Dev.		0.060	3.4	1400
Number Tested		8	8	8
Detonator Subassembly	99-107			
Mean		1.046	40.8	14000
Minimum		1.010	29.1	7000
Maximum		1.074	73.0	18000
Standard Dev.		0.027	16.3	4000
Number Tested		9	9	9

When tested at room temperature after exposure to combined environments unit 108 exhibited a high bridgewire resistance after thermal shock (Table 8).

Table 8. Bridgewire Resistance History of Unit 108

Assembly Stage	Date Recorded	Resistance (ohms)
Bare Wire	5/5/81	0.997
Ignitor	6/8/81	0.996
Explosive Subassembly	6/11/81	1.005
After Thermal Shock	7/27/81	1.204
After Mechanical Shock	7/30/81	1.058
After Vibration	8/3/81	1.059

The resistance readings will normally increase at the explosive subassembly stage due to the increased lead length required to attach the connector. The resistance after thermal shock is higher than expected and may reflect a damaged bridgewire or a poor bridgewire weld. The unit had a comparatively short ignition time compared to units in the ambient group, which might suggest a "hot spot" in the wire due to

damage. The open time for this unit agrees with the other units in the group. The weld process should be reviewed.

Detonator Output Studies

The MC3644 has a 1-mm standoff from the HNS-IIA ALMDF in the next assembly. The purpose of the gap is twofold:

1. It prevents any low-level preshock which originates in the DDT column and travels through the steel body ahead of the detonation from entering the HNS-IIA ALMDF, compressing the HNS-IIA ALMDF core and thereby decreasing its sensitivity. Computer modeling by J. Harlan has shown that preshock exists and that it will arrive in the HNS-IIA ALMDF ahead of the main detonation wave. The preshock amplitude is approximately 0.5 to 0.8 GPa. The exact effect of preshock on the HNS-IIA ALMDF detonation sensitivity is not understood. The approach is to isolate the detonator to prevent preshock.
2. The 10-grain/ft HNS-IIA ALMDF is large enough in terms of explosive diameter to be side-initiated through its aluminum sheath. However, the sheath is not strong enough to support forces imposed by the detonator in contact with it for 20 yr. Tolerances in the assembly would not allow a zero-standoff zero-contact assembly.

Therefore, the assembly was designed to hold the detonator 1.0 mm above the HNS-IIA ALMDF and to use the detonator steel closure disc as a flying plate to initiate detonation in the HNS-IIA ALMDF. The pressure threshold for HNS-IIA ALMDF[9] and for other explosives,[10] is dependent on particle size, pulse width, density and geometry. For a 35-ns pulse width, coarse powder requires a higher shock pressure at a given density and geometry than does fine powder.

HNS-IIA ALMDF begins as a coarse (<0.5 m^2/g) powder; however, it undergoes somewhat severe mechanical deformation during manufacture which causes the particles to break. Particle-sized measurements by R. Jungst[11] indicates an order of magnitude size reduction. The effect of this size reduction on sensitivity, particularly in HNS-IIA ALMDF where geometry would be a significant parameter, is not known. The available data indicate that the pressure threshold for pelletized HNS-IIA ALMDF at 1.60 Mg/m^3 density and a 35-ns pulse width is 8.6 GPa,[11] and that this would appear to be the worst case. To achieve 8.6 GPa in the HNS-IIA ALMDF, the steel closure disc would be required to have a minimum velocity of 1.8 km/s, assuming planar impact. In the present MC3644 design, the closure disc is 0.127 mm thick. The pressure pulse width into the HNS-IIA ALMDF in the MDF as calculated by a computer model[9] using CSQ[12] is less than 30 ns.

To determine the MC3644 disc velocity at 1.0-mm displacement, a number of output subassemblies were fabricated without ignitors. Ignitors were in limited supply; therefore in Shots 1, 2, and 3 (Table 9) an RP87 exploding bridgewire detonator was used to initiate the DDT column in the output subassembly to full detonation (Figure 6). VISAR (Velocity Interferometer System for Any Reflector) techniques were used to determine the instantaneous disc velocity. The output charge parameters and the results are shown in Table 9. The DDT column and output charge are the same diameter. Typical VISAR data illustrating velocity and displacement histories for discs 0.13 mm and 0.25 mm thick are shown in Figure 7.

The results for Shot 4 (Table 9) represent the average for three shots in which MC3644s of the WR version were tested for disc velocity. The discs were 0.13 mm thick. The velocity of 2.93 km/s compares with that obtained in Shot 2. It does not appear that RP87 affected the disc velocity in Shot 2. The VISAR velocity and displacement histories for Shot 4 are shown in Figure 8.

The Gurney equation for calculating the velocity of a metal plate in an open-face sandwich geometry[13] was used to obtain an estimate of the closure disc velocity. A Gurney characteristic velocity ($\sqrt{2E}$) of 2.41 km/s[14] was used for the CP output charge which has a density of 1.75 Mg/m^3. The calculated velocities for 0.13 mm and 0.25 mm closure discs were 2.84 km/s and 2.19 km/s, respectively. In this calculation, the mass of explosive included both the output charge and the DDT column. When only the mass of the output charge was considered, the calculated velocities were 33% lower; this indicates that the DDT column makes a significant contribution to the disc velocity. A comparison of the disc velocities of Shots 1 and 2 suggests that the output charge should be as long as possible.

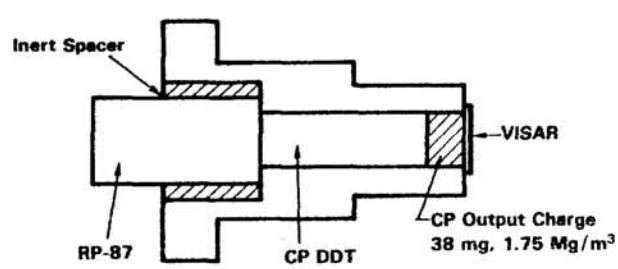

Figure 6. Assembly for Closure-Disc Velocity Measurement

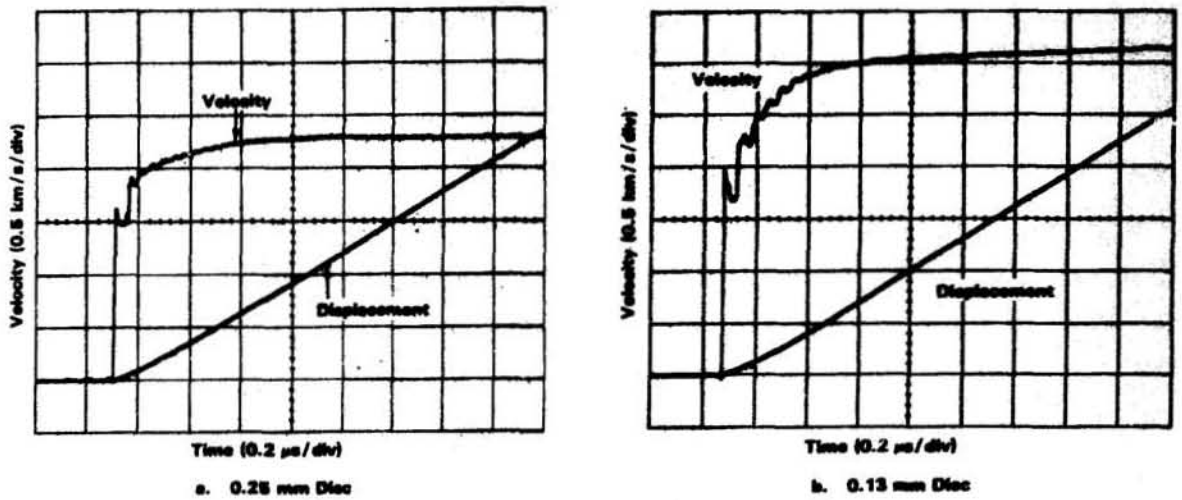

Figure 7. Typical Closure-Disc Velocity and Displacement Histories

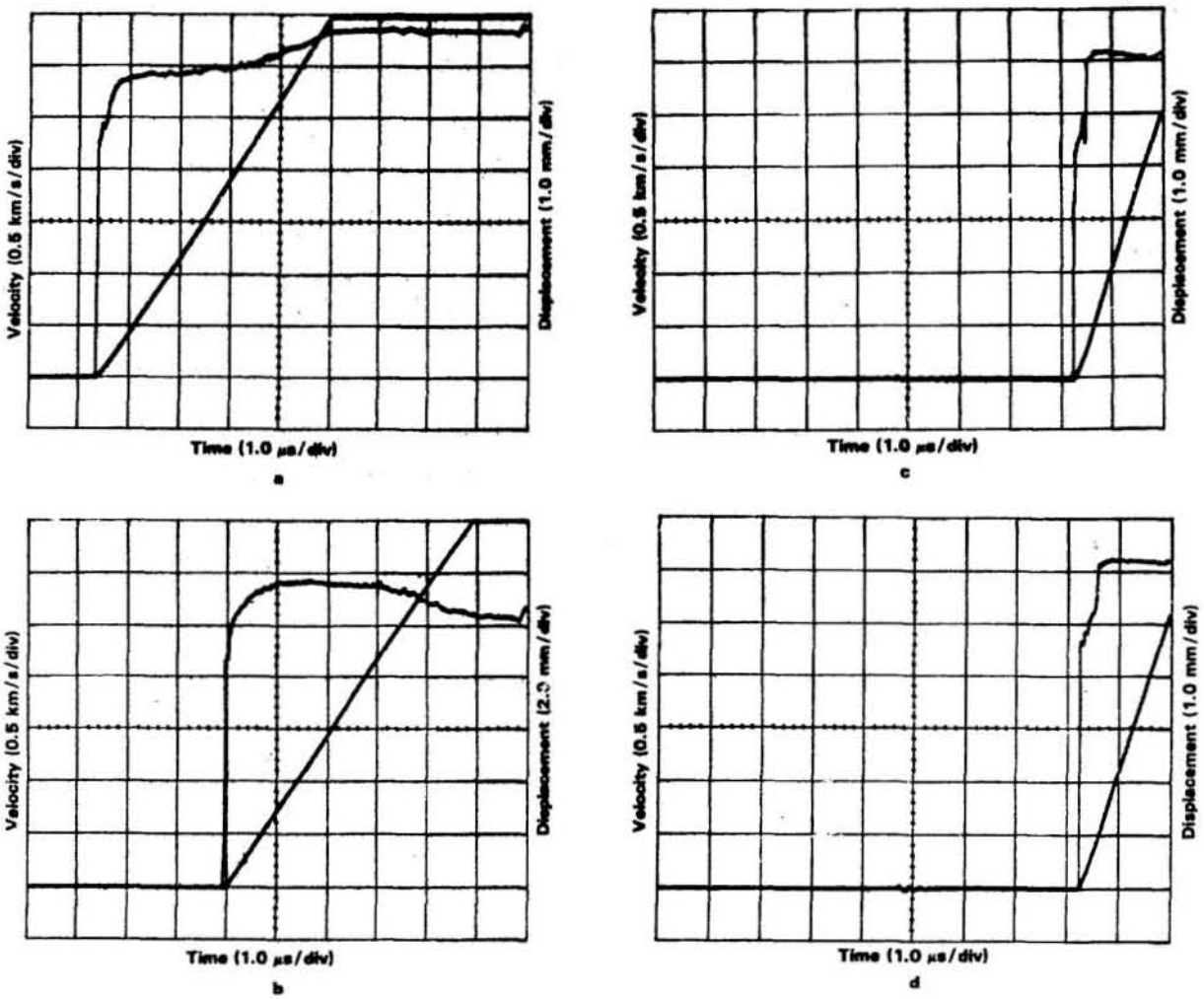

Figure 8. Closure-Disc Velocity and Displacement Histories for MC3644 WR Detonator With 0.13-mm-Thick Disc

Table 9. Output Charge Parameters and Closure Disc Velocity Data at Room Temperature (Velocity at 1.0-mm Displacement)

Shot	Unit	Diameter (mm)	Charge Length (mm)	Charge Weight (mg)	DDT Length (mm)	Disc Velocity (km/s)	Disc Thickness (mm)
1	42	3.30	1.27	19	7.24	2.75	0.13
2	57	3.30	2.54	38	5.97	2.90	0.13
3	52,54	3.30	2.54	38	9.10	2.05	0.25
4	15,13,10	3.30	2.54	38	9.10	2.93	0.13

The VISAR records for Shot 4 (Figure 8) indicate that the closure discs did not accelerate as uniformly as did those in Shots 1, 2, and 3 (Figure 7). The scale factors are the same in both cases. The reason for this difference is not understood. The intensity, contrast, and data traces from the VISAR records do not indicate experiment setup, disc surface preparation, or computational problems.

The effects of output charge length, DDT column length and density, and closure disc thickness should be investigated further. Increasing the disc thickness from 0.127 to 0.254 mm would double the pressure pulse width and would be beneficial if the disc velocity remained greater than 2.0 km/s. The calculated[11] pressure pulse driven into the HNS-IIA ALMDF by a 0.127-mm-thick disc at a velocity of 2.2 km/s is approximately 15.0 GPa.

Flash radiography should be used to determine the shape and mechanical integrity of the closure disc.

Failure Investigation

During feasibility testing at –34°C, one MC3644 ID (Unit 14) failed to initiate the HNS-IIA ALMDF. It had been agreed that functional-rejected ignitor headers from the MC3423 development could be used for feasibility tests. Some of these functional rejects had hairline cracks in the ceramic substrate. Postmortem of the detonator by UPI showed that the DDT column did not grow to detonation. A comparison of the output body inside diameters of the failed unit and a successful unit is illustrated in Figure 9.

Further investigation revealed that the ETR gamma value for the ignitor in the failed unit decreased from 16,000 μW/°C after loading to 10,000 μW/°C after the ignitor assembly was welded into the output body subassembly. This change in gamma is indicative of a decoupling of the CP and bridgewire. During the ignitor assembly, a compressive force of 489 Newtons is applied between the ignitor and output body to insure contact of the ignitor output and DDT column input surfaces. In addition to the change in gamma, several ignitors which had been loaded with the feasibility units, but not used, were found to have a contaminant on the CP. This contaminant was a silicon grease which was used to seal the covers of desiccated containers. How these units became contaminated with this grease is not known.

Table 10 summarizes a series of 16 test firings conducted in an effort to duplicate the failure. Various possible failure mechanisms were incorporated into the units. These included

- Cracked headers
- Contaminants such as water, silicon grease, and isopropyl alcohol in the CP
- Excess free volume
- Output bodies without closure disc

Except for the contaminants, these failure mechanisms were intended to show that a sudden decrease in pressure at the ignitor/DDT column interface may have been the cause of the failure. All of these units were fired successfully. The excess free volume test in which a small hole is drilled into the side of the ignitor has not been performed.

It is still felt that a cracked header was the cause of the failure. The 10,000 μW/°C gamma, per se, is not sufficient to cause the failure. CP detonators with gammas as low as 3000 have fired. However, if the decrease in gamma was caused by a cracked header which failed structurally at assembly, it is possible that complete failure occurred shortly after ignition—dropping the pressure behind the burn front and extinguishing the reaction. The isopropyl alcohol contaminant caused the CP to swell and made the units totally unusable. The cause of this failure should be determined to aid in future header designs intended for use in DDT devices.

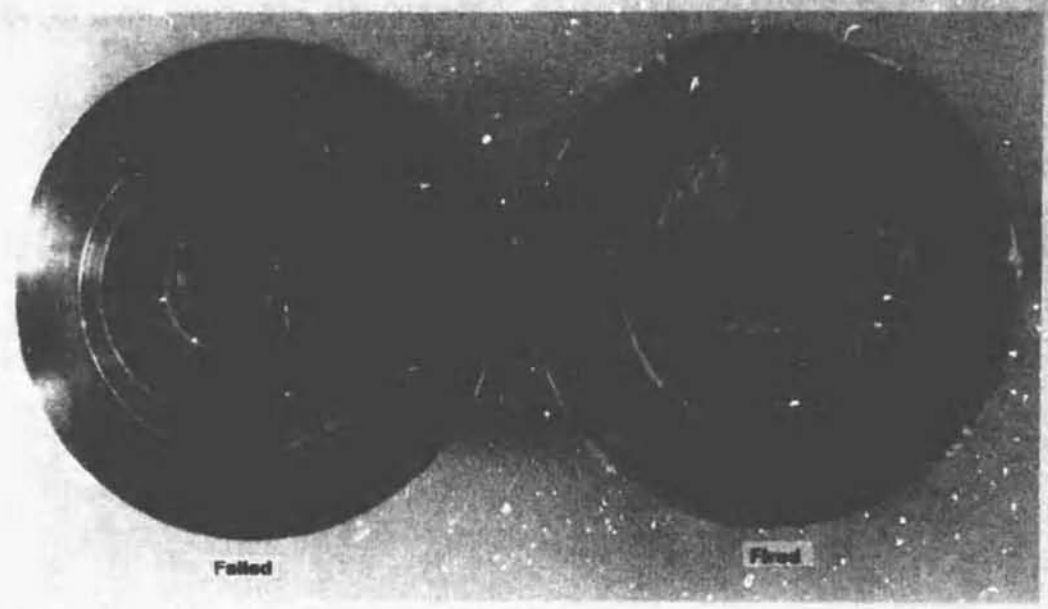

Figure 9. Comparison of Fired and Failed MC3644 ID Detonators

Table 10. MC3644 ID Failure Analysis Test Data

Test	Serial	Gamma (μW/°C)	Bridgewire Resistance (ohm)	Function Time (μs)	Bridgewire Break (μs)	Comments
			Cracked Headers			
1	77	15500	0.95	840	740	Tested at –55°C.
2	78	18600	1.16	823	720	Fired high order as
3	79	17400	0.990	728	730	determined by x-
			Grease Contaminant			ray and visual ex-
1	76	14500	1.019	570	600	amination of DDT
2	75	15300	1.048	600	650	column metal ex-
			Water Contaminant			pansion.
3	72	14900	0.968	650	700	
4	70	15800	0.979	660	700	
5	71	15900	1.079	—	600	
			No Closure Disc			
1	85	14000*	1.00	656	660	
2	86	7700	1.08	479	480	
3	87	14200	1.05	623	620	
			10 Cycles Thermal Shock: –55°C to 132°C.			
1	22	15300	1.128**	670	980	Tested at –65°C
2	23	15000	1.087	670	1010	Fired HNS-IIA
3	21	16200	1.124	650	12490	ALMDF.
4	24	13200	1.135	640	670	
5	20	16200	1.108	650	850	

*Ignitor stage
**Includes cable resistance

MC3644 WR Detonator

The major difference between the interim and WR or final design MC3644 is the header (Figure 4). The number of pieces has been reduced from three to two, the number of assembly bonding steps from four welds plus one solder connection to three welds (not including the bridgewire weld). The ignitor and electrical leads are in one part. The electrical connector is machined separately to reduce the cost of broaching the inside grooves. This also should reduce the cost of the brazed header.

Header and Ignitor Design and Development Status

The ceramic header is being manufactured by VELER, Inc, Santa Clara, California, on Contract 61-6817. The header and electrical shells are fabricated from Kovar. The ceramic is supplied by Mound Laboratory in the bisque state. Comments made by VELER indicate that the Diamonite ceramic produces a better header than other ceramics because the chromium in the Diamonite ceramic gives better metallizing adhesion. The Mound bisque is isostatically pressed, and as a result the shrinkage is less and more uniform. The fact that VELER can machine the bisque is an advantage in that they have better control over the parts. Equally important, the lead times for procuring ceramic parts for metallizing is considerably less—6 to 8 wk from the bisque stage as compared to 15 to 20 wk from other sources.

The fabrication process involves core-drilling blanks from the bisque stock. At the present time, the percentage of waste is high; it would be reduced if the bisque bar diameter were increased to 38.1 mm.

Six headers were subjected to a 276 MPa (40k psi) loading test. Subsequently, the headers were cleaned and sectioned; no cracks were found and no significant voids were found in the braze joints.

UPI has completed bridgewire, connector assembly, and header-to-output body weld studies and loading studies on the new header.

The CP explosive is loaded into the header in two parts of 17.5 mg each. The first part is loaded at 276 MPa (40k psi) and the second at 69 MPa (10k psi).

Forty ignitors were assembled for subsequent testing and delivery to SNLA. The ETR data recorded at three stages of assembly are summarized in Table 11. The gamma values are 29% higher than for the interim units in Table 1. Six trainers and ten MC3644 WR detonators have been shipped to SNLA for use in FTU system test series.

Table 11. Electrothermal Response Test Results on Development Lot A of MC3644 WR Detonator

Parameter	Bare Bridge	Ignitor	Final
Bridge Resistance (ohms)			
Average	0.991	1.003	1.006
Minimum	0.911	0.938	0.942
Maximum	1.060	1.062	1.066
Standard Deviation	0.044	0.037	0.037
Number Tested	39	31	31
Gamma (μW/°C)			
Average	860	21,000	21,500
Minimum	710	15,600	15,800
Maximum	1160	25,100	25,700
Standard Deviation	90	2,500	2,500
Number Tested	39	31	31

Ignitor No-Fire Sensitivity

The size, geometry, and materials, including the bridgewire design,* are patterned after the MC3423 Detonator for which ignition and no-fire sensitivities have been demonstrated and reported. Since the no-fire sensitivity is very crucial in the MC3644 application, a 10-unit Langlie sensitivity test was completed to verify that no change in sensitivity has occurred. ASENT computer program analysis shows that a 95% confidence level, 1 unit in 1000 would be expected to fire at 1.28 A. The 50% threshold was 1.46 A with a standard deviation of 0.228 A. The results show that no significant changes have occurred and that the no-fire requirement of 1.0 A can be met easily. A probability plot of the no-fire test results is included in Figure 10.

Functional Proof Test

Nine WR design detonators were assembled and subjected to 10 consecutive cycles of thermal shock from -54°C to 132°C. The units were held at each temperature for 2 h. ETR and electrostatic susceptibility tests were completed before temperature conditioning. ETR tests also were done following temperature conditioning. The nine units were assembled into a fixture with HNS-IIA ALMDF and test fired at -54°C, room temperature, and 100°C—three units at each temperature, respectively.

*Alumina ceramic charge holder 3.05 mm deep x 3.05 mm diameter; 0.051 mm diameter Tophet A bridgewire

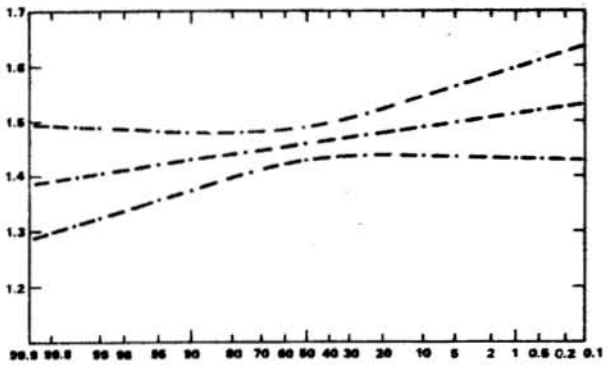

Figure 10. No-Fire Probability Curves for MC3644

The prethermal and postthermal shock ETR data for the nine units is summarized in Table 12. As a result of temperature conditioning, the average value for gamma decreased 23%; there was a corresponding increase of 40% in the standard deviation. The range in gamma values increased from 9.000 to 12,900. It is not clear that this change was due to the temperature conditioning. The nine units were run through the ETR test twice after thermal conditioning. The first time the average gamma was greater than 30,000, which is not realistic. The average in Table 12 is the result of the second run, which was done 24 h later. The raw ETR data is being reviewed by UPI for possible test procedure problems.

Table 12. Prethermal and Postthermal Shock for Electrothermal Response Data for MC3644 WR Functional Proof Test

Parameter	Average	Standard Dev.	Minimum	Maximum
		Bridge Resistance (ohm)		
Prethermal Shock	1.012	0.042	0.977	1.057
Postthermal Shock	1.013	0.043	0.950	1.064
% Change	0	0	–2.7	+0.06
		Gamma (μW/°C)		
Prethermal Shock	22000	3000	16000	25000
Postthermal Shock	17000	4000	12000	25000
% Change	–23	+40.7	–21.9	+1.96

The gamma for MC3644 ID units decreased 8.4% after thermal shock (Table 5) and 14.3% after mechanical shock and vibration.

The destructive test fire data are given in Table 13. The data met all requirements for the MC3644.

Table 13. MC3644 WR Proof Test Data (After Thermal shock –55°C to 132°C, 10 cycles)

Temperature (°C)	Number Tested	R_i (ohms)	E_i (mJ)	t_f (μs)	t_{bo} (μs)	t_1 (μs)	t_2 (μs)
Amb	3	1.16*	15.7	603	1150	6.91	7.11
		0.02	1.7	5	210	0.26	0.35
–55°C	3	1.10	18.4	777	1150	6.88	7.04
		0.13	2.8	67	46	0.07	0.04
100°C	3	1.10	13.5	540	1030	6.93	7.06
		0.02	0.4	1	120	0.05	0.02

Note:
R_i = Bridgewire resistance at ignitor
E_i = Ignition energy
t_f = Function time
t_{bo} = Bridgewire open time
t_1, t_2 = HNS-IIA ALMDF transit time

*Number above each line is the average and number below line is standard deviation.

There is some interest in studying the relationship of gammas as measured in the ETR test and the dynamic functional characteristics. Figures 11 and 12 illustrate the relationship of function time and gamma for the MC3644 ID combined environment group and the MC3644 WR proof test group. About the only conclusion one can draw from these few data is that, although there is a trend toward longer times with higher gammas, there are also unexplainable anomalies. Function time is used in this comparison because ignition time, which might give different results, is not being calculated correctly by the CCDS: it is calculated to be longer than the function time. In an earlier component (MC3095) in which titanium subhydride potassium perchlorate was loaded on the bridgewire and ceramic header, there was no correlation between gamma and ignition time.

This is not to suggest that ETR nondestruct testing is not of value, because it is. Bad welds, decoupled powder, powder and wires, and contamination of the

powder can be detected. The ETR data cannot be used to predict which units will have long or short function times, however.

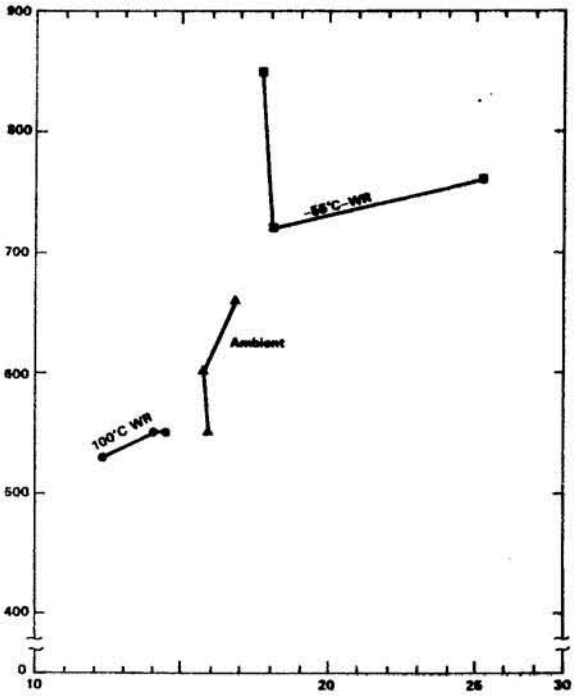

Figure 11. MC3644 ID Function Time as a Function of Gamma

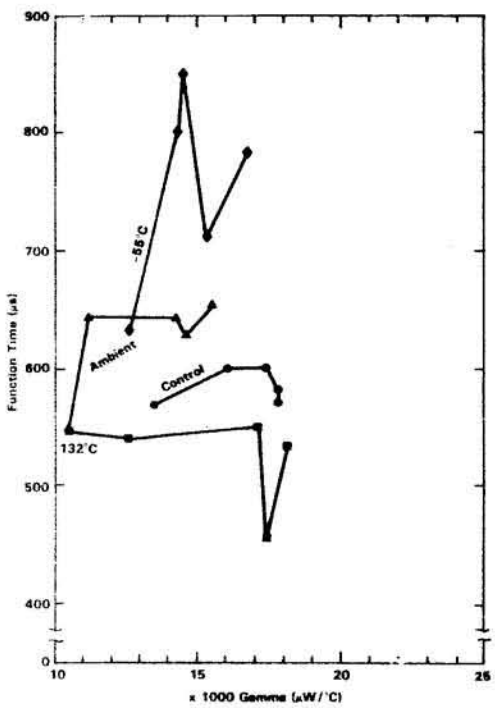

Figure 12. MC3644 WR Function Time as a Function of Gamma

MC3644 Design Verification Plan

Design verification testing at UPI will include the following:

- Fabrication of 158 units
- ETR and ESD nondestruct testing
- Ship 30 to SNLA

Perform the following destructive tests:

- 20 units Langely no-fire
- 63 units all-fire regression analysis
- Subject 45 units to combined environments per PS318493 and D-test 15 each at room temperature, –55°C, and 100°C, respectively

Most of the hardware for this series of tests is on hand.

Deliveries and Schedules

Deliveries

Delivery of units to meet system test needs is on schedule. Fifty MC3644 IDs were received from UPI. Ten additional MC3644 IDs have been ordered. The MC3644 ID has been designated for use in the Bomb Test Unit (BTU) and Parachute Development Unit (PDU).

Ten MC3644 WR detonators were received along with six trainers. These units have been designated for use in the FTU test program only.

Schedules

The development and Phase II production activities at UPI are defined by PERT Network ND 318493. A summary of these activity peg points is shown in Figure 13. The development program is on schedule.

Action Items

The development program at UPI is presently on schedule; however, the following items will require timely attention to maintain the schedule for first production unit delivery in March 1983.

- An Advance Engineering Release (AER) for the detonator should be issued as soon as UPI has assembled the design verification lot. An AER for the header has been issued.
- The drawings should be transferred to Mound
- The velocities of the 0.13- and 0.25-mm closure discs must be determined. The closure disc

thickness should be changed to 0.25 mm, provided the velocity is high enough.

- The effects of DDT column length and density and output column length on disc velocity should be evaluated.
- The calculation of ignition time by CCDS is not correct. The ignition model needs to be reviewed.
- The ETR test procedure should be evaluated. The gamma values obtained for a given unit at different times are varying over unrealistic ranges.
- The cause for the failure (discussed earlier) should be determined.
- Test fixtures and instrumentation need to be defined and procured for production lot acceptance testing of the MC3644 at UPI.
- The bridgewire welding process at UPI should be reviewed to eliminate possible bridgewire damage.

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[5]*Development Test Report on the MC3423*, UPI DTR-128, Contract 13-3148, (Phoenix: Unidynamics/Phoenix, Inc, 23 June 1980).

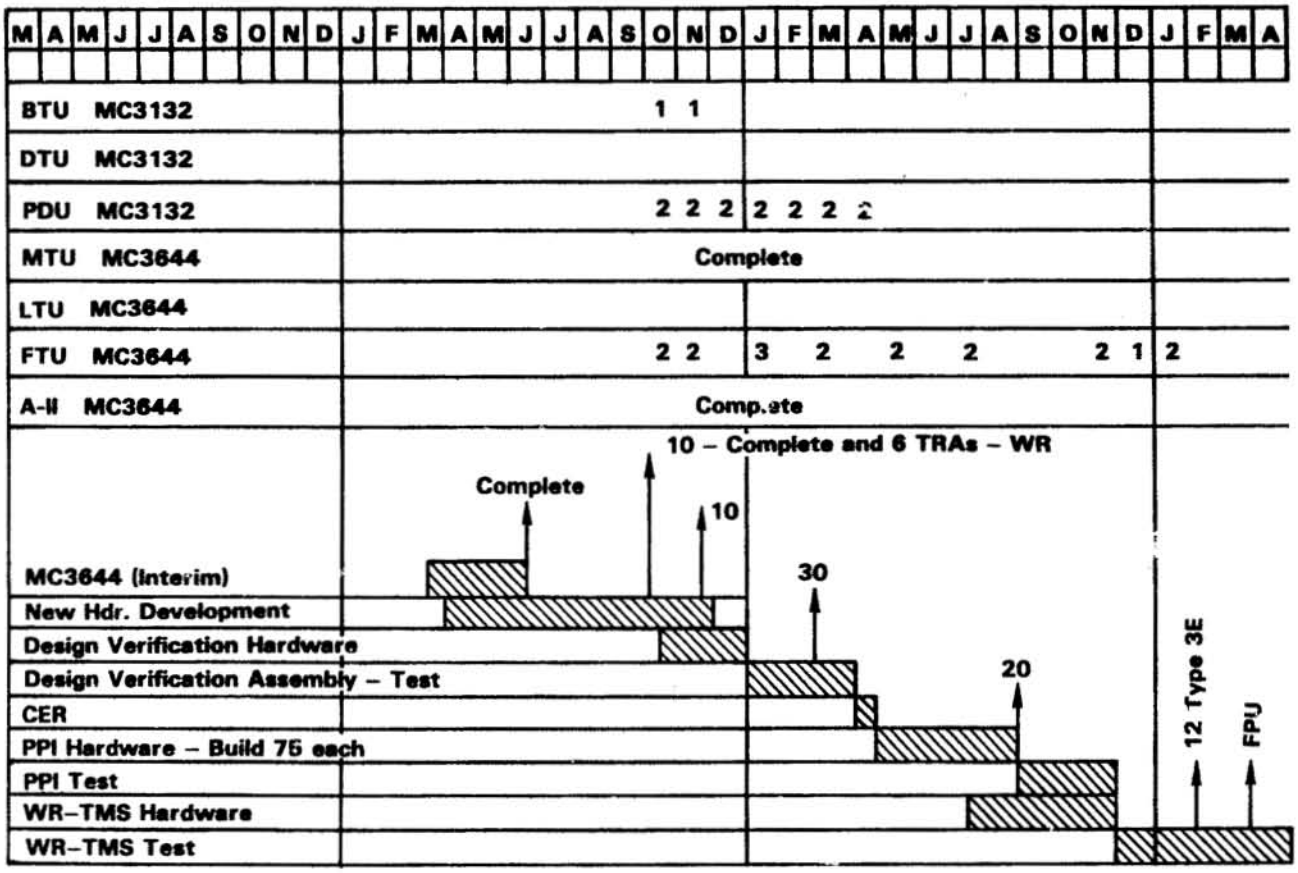

Figure 13. MC3644 WR Development and Phase IV Production Schedules

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APPENDIX A

DDT Detonators in Production

Detonator	Weapon
MC3196A	B61-3, -4; W85
MC3423	W80
MC3533	Development completed; cancelled
MC3608	W79
MC3614	W84

APPENDIX B

Hardware and Assembly Drawings for War Reserve MC3644

No.	Title	Dwg No.
I	MC3644	318493
IA	MC3644 TRA	318494
II	Detonator Assembly	346212
III	Output Assembly	346211
IV	Body Assembly	346210
	Body Output	346209
	Disc	345364
V	Ignitor	346234
VI	Header Assembly, Bridged	346208
	Bridge	345354
VII	Header Assembly	346207
	Connector Shell	346206
VIII	Header	346109
	Shell	346107
	Insert, Ceramic	346104
	Insert, Metallized	346105
	Pin, Aft	346102
	Pin, Foward	346103
	Insert, Assembly	346106

APPENDIX C

MC3644 Design Requirements

All-Fire Current	5.0 A at –55°C
Current Duration	7.5 ms
No-Fire	1.0 A, 5 min at room temperature
Electrostatic Discharge Capability	20 kV, 600 pF, 500 ohms
Pin to Case Isolation	> 100 MΩ at 500 Vdc
Temperature	–55° to 100°C
Thermal Cycle	10 Cycles, –55° to 100°C
Mechanical Shock	390.0 m/s², 1.5 to 2.0 ms, 1/2 sine
Vibration	Sinusoidal, 98 m/s², 26 to 2000 Hz, 7.6 mm double amplitude

Initiate 10 grain per foot HNS-IIA ALMDF.

APPENDIX D

MC3644 ID D-Test After Combined Environments*

Test	Serial	Firing Temperature	TOAD Function Time (μs)	TOAD to Foil SW 1 (μs)	TOAD to Foil SW 2 (μs)	Calculated Ignition Time (μs)	Bridge Open (μs)	Ignition Energy (mJ)	Resistance at Ignition (ohms)	MDF Time t_1 (μs)	MDF Time t_2 (μs)
1	100	Ambient	657.6	7.1	7.1	660	880	15.9	1.08	6.81	7.10
2	107	Ambient	645.1	7.1	7.0	650	700	16.4	1.15	6.86	6.95
3	108	Ambient	544.4	7.1	7.1	540	700	14.6	1.21	6.87	6.94
4	109	Ambient	644.1	7.1	7.1	650	790	15.7	1.11	6.74	6.99
5	110	Ambient	628.8	7.2	7.1	640	690	16.5	1.19	6.92	7.05
		Mean	624.0			628	752	15.8	1.15	6.84	7.01
		Std. Dev.	46			50	82	0.76	.05	.07	.07
6	111	−55°C	785.1	7.1	7.2	790	1960	20.3	1.18	6.81	7.14
7	112	−55°C	633.0	7.1	7.2	630	990	16.9	1.21	6.88	7.06
8	113	−55°C	802.1	7.2	7.1	810	2300	20.5	1.16	6.75	7.11
9	114	−55°C	852.9	7.1	7.1	850	1090	22.9	1.21	6.89	7.11
10	115	−55°C	713.5	7.1	7.2	720	780	19.1	1.19	6.75	7.14
		Mean	757.5			760	1404	19.9	1.19	6.82	7.11
		Std. Dev.	86			87	646	2.2	.02	.07	.03
11	116	+132°C	550.8	7.2	7.1	540	660	14.6	1.21	6.93	7.02
12	118	+132°C	534.5	6.9	7.0	530	580	14.0	1.19	6.70	6.89
13	119	+132°C	455.8	7.2	7.2	460	600	12.3	1.22	7.32	7.18
14	120	+132°C	547.3	7.1	7.1	540	1450	15.4	1.28	6.96	7.15
15	121	+132°C	539.9	7.2	7.1	540	1210	14.7	1.22	7.01	7.08
		Mean	525			522	900	14.2	1.22	7.00	7.06
		Std. Dev.	40			35	403	1.17	.03	.23	.12

*Firing current 4.85 A, 7.0 ms pulse

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