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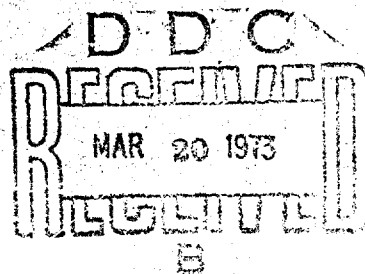
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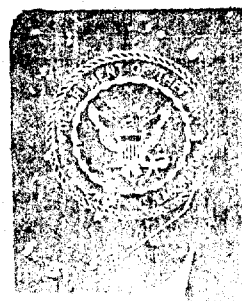
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December 1972

BOMB SURVIVABILITY IN FIRE PROGRAM

C. P. Hontgas



NAVAL WEAPONS LABORATORY
DAHLGREN, VIRGINIA



NAVAL WEAPONS LABORATORY

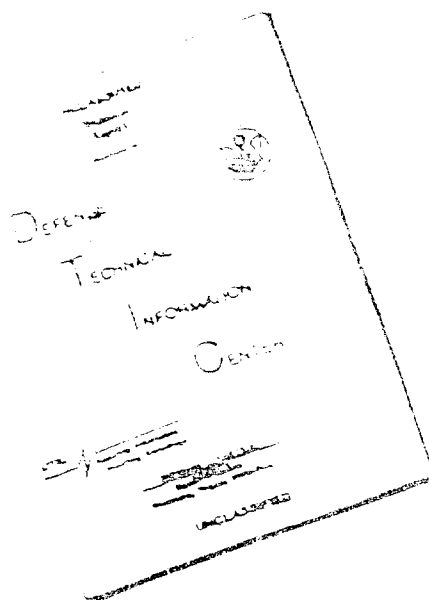
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by

C. P. Hontgas

Test and Evaluation Department

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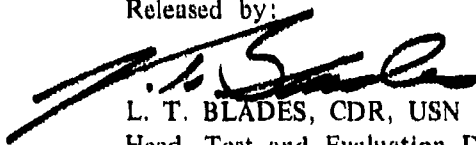
ACKNOWLEDGEMENT

We wish to acknowledge the drafting of this program and the early research performed by Messrs. J. A. Sizemore and B. R. Johnson. We also wish to thank Messrs. J. A. Canfield, J. A. Copley and L. H. Russell for their research in fuel fires and computer heat transfer studies which assisted greatly in several of the program's supporting tasks.

FOREWORD

The work presented herein was accomplished under AIRTASKS NOS. A05-532-015/291-1/W4703-02 and A05-532-011/291-4/00000, representing the joint efforts of NWL, Dahlgren, NWC, China Lake and NWS, Yorktown. The report has been reviewed by H. P. Caster, Head, Project Engineering Division, and F. W. Kasdorf, Assistant Head, Test and Evaluation Department.

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ABSTRACT

The bomb survivability in fire program was initiated to determine the hazards that exist when bombs are exposed in a carrier flight deck fire (fast cook-off) and to investigate methods of minimizing or eliminating these hazards.

All M117, AN-M65 and MARK 80 series bombs employed in the program were exposed in a JP-5 jet fuel fire environment that simulated a flight deck conflagration.

The severity of reaction, time to reaction and, when pertinent, internal time-temperature information were obtained. Also determined from the program were: (1) relationship of bomb size, explosive load and fuze configuration to cook-off time and severity of reaction, (2) influence of aircraft structure on bomb cook-off time and severity of reaction, (3) likelihood of bomb cook-off after abbreviated heating periods, (4) adequacy of water and aqueous film forming foam (light-water) as cooling measures for preventing bomb cook-off, and (5) effect of elevated temperatures on bombs subjected to accidental ejection from parked aircraft or other accidental drops on board ship.

The results of supporting tasks investigating quick fire starting, wind effects, internal thermocouple design, inert filler, water and light-water rates apparatus design, ejection cartridge cook-off, evaluation of fire retardant paints and computer studies and analysis are also presented.

CONTENTS

	Page
ACKNOWLEDGEMENT	i
FOREWORD	ii
ABSTRACT	iii
I. INTRODUCTION	1
II. OBJECTIVES	2
III. GENERAL TEST CONFIGURATIONS AND PROCEDURES	4
IV. INSTRUMENTATION	9
V. SPECIFIC CONFIGURATIONS, PROCEDURES AND RESULTS	12
A. Phase 1 -- H-6 TNT and TRITONAL Loads	12
B. Phase 1A -- Comp-B Loads	12
C. Phase 2 -- Bomb Characteristics	14
D. Phase 2A -- Effect Contiguous Heat Sources	16
E. Phase 2B -- Influence of Aircraft Structures	19
F. Phase 3 -- Abbreviated Heat Input (Inert Bombs)	22
G. Phase 3A -- Cooling Measures	22
H. Phase 4 -- (Abbreviated Heat Input -- HE Loaded Bombs)	35
I. Phase 5 -- Impact Tests of Heated Bombs	38
VI. CONCLUSIONS	42
VII. RECOMMENDATIONS	48
VIII. SUPPORTING TASK OBJECTIVES	49
REFERENCES	50
APPENDICES	
A. Fast Cook-Off Test Specification for MARK 80 Series LD Bombs	
B. Phase 1 and 1A Test Data Sheets and Photographs	
C. Phase 2, 2A and 2B Test Data Sheets, Tables and Photographs	
D. Phase 3 and 3A Test Data Sheets, Tables and Graphs	
E. Phase 4 Test Data Sheets and Tables	
F. Phase 5 Test Data Sheets and Photographs	
G. Supporting Tasks Results and Conclusions	
H. Distribution	

I. INTRODUCTION

The USS FORRESTAL conflagration exposed a deficiency in the knowledge of hazards associated with the reactions of general purpose bombs in a flame enveloping environment. In order to determine these hazards so that effective means of minimizing or eliminating them can be developed, the Naval Weapons Laboratory, Dahlgren was assigned by References 1 and 2 the task of managing and conducting simulated carrier flight deck fire (fast cook-off) research on ordnance.

Research was conducted relative to explosive load, fuzing configuration, bomb size, heat flux effect and aircraft structure influence on cook-off. In order that tests would be truly representative of a flight deck conflagration, supporting tasks were conducted to investigate quick fire starting, wind effects, internal thermocouple design, inert filler, water and light-water rates apparatus design, ejection cartridge cook-off, evaluation of fire retardant paints and computer studies and analysis.

Due to its complexity the Bomb Survivability in Fire Program was divided into several phases of investigation, specifically:

- Phase 1 Fast Cook-off of selected bombs involved in the USS FORRESTAL conflagration.
- Phase 1A Hazards of Comp-B explosive loaded bombs when reacting.
- Phase 2 Bomb size, fuzing configurations and explosive load relationships to cook-off.
- Phase 2A Cook-off of bombs when positioned just above the deck.
- Phase 2B Aircraft structure influence on cook-off time and severity of reaction.
- Phase 3 Likelihood of bomb cook-off after abbreviated heating periods using inert bombs.
- Phase 3A Water and light-water cooling measures for preventing bomb cook-off while bomb is exposed in flames.
- Phase 4 Verification of Phase 3 results using explosive loaded bombs.
- Phase 5 Additional hazards due to impact of bombs at elevated temperatures.

II. OBJECTIVES

The prime objective of the Bomb Survivability in Fire Program was to determine the fast cook-off characteristics of bombs exposed in a flame environment under conditions representative of a CVA flight deck conflagration that might occur during launch and recovery operations. Equally important objectives of a general nature were to: (a) Determine the relative cook-off characteristics of Comp-B, H-6 and TRITONAL explosives in different bombs and bomb configurations, (b) Provide data to assist in establishing fire fighting procedures where bombs are involved, and (c) Provide data useful in the design of future weapons. The program was divided into several phases whose specific objectives were as follows:

- Phase 1 To provide early information on fast cook-off time and severity of reaction of selected bombs involved in the USS FORRESTAL fire.
- Phase 1A To confirm the high-order (detonation) reactions that occurred during Phase 1 with Comp-B explosive loaded bombs.
- Phase 2 Determine the relationship of bomb size, explosive load and fuzing configuration to cook-off time and severity of reaction. Bombs positioned horizontally approximately 3.5 feet above the fire surface to simulate their position when racked to an aircraft wing.
- Phase 2A Determine cook-off time and severity of reaction of a bomb positioned just above the deck.
- Phase 2B To determine what influence, if any, the presence of aircraft structures have on cook-off time and severity of reaction.
- Phase 3 Determine by the use of inert bombs the internal temperature rise rates and air cooling rates of bombs.
- Phase 3A Determine if pre-heated bombs could be cooled while engulfed in flames.
- Phase 4 Verify, that the internal temperature rise rates and cooling rates of Phase 3 are characteristic of explosive loaded bombs.

Phase 5 Determine if any additional hazards exist if a live pre-heated bomb is forcibly ejected onto a steel deck.

III. TEST CONFIGURATIONS AND GENERAL PROCEDURES

Basically, fast cook-off tests were conducted by suspending a bomb, or bombs, over a jet fuel fire then recording time to and degree of reaction. The environment duplicated was representative of a worst case condition for bombs exposed in a CVA flight deck fire. However simple this procedure may appear, much preparation was required before tests could be conducted.

The ground area to be used as the test site was cleared and leveled. An earthen retaining wall, approximately one-foot high and one-foot thick, was built to the desired length and width. This retaining wall constituted the test pan boundary. The pan was then lined with polyethylene to retain a few inches of water, which provided a level surface to float the JP-5 jet fuel used as the energy source for all fires. Enough fuel was floated on the water base to insure flame engulfment and reaction of the bomb(s) under test. Bombs were suspended horizontally by their lugs from a frame structure constructed of heavy pipe secured to I-beams and positioned in the center of the test pan. Figure 1 is an example of a bomb positioned for testing in a cook-off pan. The bomb's height above the fuel surface was determined by the information required from the test. Thirty gallons of gasoline were poured over the JP-5 fuel surface for quick spreading of the fire. Instrumentation was then checked out and all personnel were called into shelter. A count down was begun and at time zero the fire was started by remotely detonating four thermite grenades, placed one in each corner of the test pan. Also at this time, all temperature recording and timing devices were started. The test was visually observed for complete flame engulfment and time to reaction of the bomb being tested. Observations were made through a periscope and on a closed circuit TV receiver located in the shelter. A mirror was also positioned outside the shelter for viewing from the shelter doorway.

Initially many tests had to be postponed because of excessive wind (4 knots or above) at the test site. In order to overcome this difficulty, a pit 8 feet deep and 35 feet square was constructed as shown in Figure 2. A chimney effect, to feed air to the fire, was achieved by the placement of large feeder pipes on each side of the pit. Successful fast cook-off tests were conducted using the pit in winds up to 20 knots.

Most cook-off tests conducted were done in either the pit or pan. The exceptions were the bomb cooling tests of Phases 3, 3A and 4. In these cooling tests, control of the flame environment was critical, therefore a slant test pan was constructed whereby the fire could be removed when desired. This was accomplished by designing the slant pan with a 10-degree sloping bottom and a remotely controlled drop gate at the lowest end (Figure 3). Water was then added to the



FIGURE 1

A MARK 82 Bomb Positioned in a Cook-Off Pan Prior to Testing



FIGURE 2

A MARK 82 Bomb Positioned in a Cook-Off Pit



FIGURE 3

The Slant Pan Used in Cook-Off Tests of Phase 3, 3A and 4 of the Survivability Program.
Notice the Opening at the Far End of the Pan Where the Drop Gate Is Normally Positioned.

slant pan until a level surface approximately 24 X 24 feet was obtained. JP-5 jet fuel was then floated on the surface. The bomb under test was suspended horizontally above the fuel surface and the fire ignited as previously described. When the bomb reached the desired internal temperature, or a specific amount of time had elapsed, the gate was dropped, immediately releasing the water and burning fuel into a reservoir some distance from the test site.

The need to standardize some of the basic fast cook-off test configurations and define the flame environment so that all agencies conducting such tests could correlate data was recognized. On 20 May 1969, a bomb fast cook-off meeting was held at NWL and attended by all interested agencies of the Navy, Army and Air Force. A preliminary document was drafted and agreed upon for fast cook-off test specifications for MARK 80 series LD bombs. A revised version of the document and the accepted NAVORD definitions for the various cook-off reactions are presented in Appendix A.

IV. INSTRUMENTATION

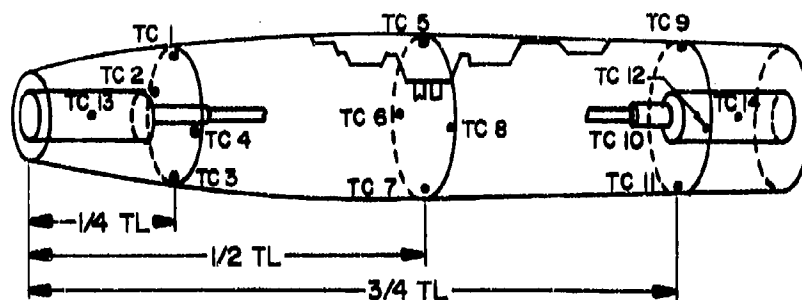
Instrumentation consisted of motion picture and still camera coverage for documentation, pressure measurements to help determine severity of reaction, and temperature measurements of the flame environment at the bomb. When necessary, thermocouples were placed inside the bomb between the body and hot-melt (interface) to determine (1) the origin of reaction, (2) temperature rise rate during heating, and (3) interface temperature at the time of reaction. In some cases, thermocouples were placed in the center of the explosive load and on the nose and tail fuze wells to study the temperature profile in these areas.

Two motion picture cameras were positioned (behind fragment shelters) 90° apart and upwind of the test area. When the cook-off pit was employed, the motion picture cameras were elevated to a height of approximately 30 feet on portable stands. Black and white stills were made before and after each test.

Piezoelectric lollipop pressure gauges were positioned 50 feet from the bomb under test at four different locations to measure the pressure wave.

When thermocouples were placed inside the bomb, its interior surface was thoroughly cleaned with a reliable solvent that removed all substances such as grease, rust, hot-melts, or any foreign substance that might have an adverse effect in securing the thermocouple to the bombs interface.

Iron-constantan thermocouples, manufactured by NWL, were used to measure both external and internal temperatures because of their accuracy at the more critical lower temperatures. The iron-constantan wire used was Type J, AWG #24 asbestos and fiber glass coated, manufactured by Leeds and Northrup Company. The two conductors were thoroughly cleaned, twisted, and then arc-welded, forming a bead junction. The external thermocouples were placed in a horizontal plane coincident with the center line of the bomb being tested. The lead were protected (bead junction only exposed to the flame environment) by encasing them in asbestos tape and then covering them with Duc-seal (a pliable asbestos base compound). Four external thermocouples were used, one at each end and one at each side, six inches from the bomb. Thermocouples that were placed internally (Figure 4) were positioned at 90 degree intervals around the nose, center and tail section, and secured in place by welding, cementing or with small strips of Scotch Brand Aluminum tape. The bomb's internal conduit system was removed and the connector (top center of the bomb) was used as the exit point for the thermocouple wires. This exit point was then sealed with an epoxy and asbestos sealant creating a high pressure and flame proof closure.



THERMOCOUPLES ARE LOCATED BETWEEN THE HOT MELT AND METAL CASE
 TL-TOTAL LENGTH OF BOMB

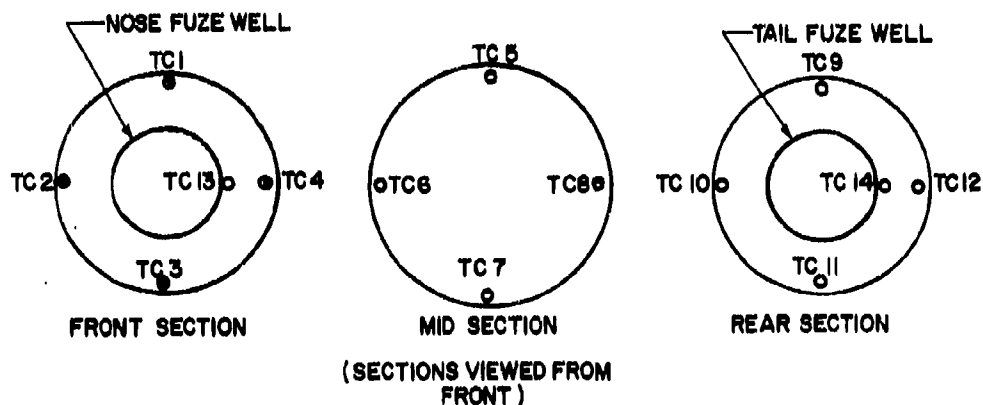


FIGURE 4

Location of Iron Constantan Thermocouples in Bombs Tested
 in the Bomb Survivability in Fire Program

At the test site, with the bomb properly positioned, both external and internal thermocouple leads were made into a bundle and thermally protected by covering them with 3-inch asbestos pipe covering and a wrapping of aluminum tape. The leads were brought overhead or underground into a small junction box located next to the pan or pit and connected to an iron-constantan extension cable of AWG #20 wire. The extension wire was run underground to a field control box where a constant temperature electric oven was used to generate the 150°F used as a reference for all temperature measurements. The temperature signal was then transmitted on copper wire to the instrument van some 750 feet away where calibrations were made and data recorded. A high sensitive linegraph, self-developing photographic paper manufactured by Kodak Company was used to record the signals from a Model 133 electromagnetic oscillograph manufactured by Consolidated Electrodynamic Corporation. The oscillograph employed a Type 315 galvanometer with a natural frequency response of 100 hertz. Sixty-cycle frequency filters were placed in the circuit to reduce extraneous readings.

At the bomb shelter, a timing recorder, that started simultaneously with the ignition of the thermite grenades, was used to accurately determine time to reaction.

V. SPECIFIC CONFIGURATIONS PROCEDURES AND RESULTS

A. Phase 1 - H-6, TNT and TRITONAL Loads

Six tests were conducted with a representative sample of the different bombs that were on board the USS FORRESTAL at the time of the conflagration. The explosive loads selected did not include Comp-B, later determined to have been on board during the fire. Consequently, Comp-B loaded bombs were tested under Phase 1A. All bombs had live nose fuze/booster combinations, and live tail fuzes installed. A brief summary of the tests is presented in Table 1 with a more detailed accounting and photographs appearing in Appendix B.

In all the above tests, the flame temperatures were below the average of 1650°F experienced in subsequent fires. In none of the tests did the nose fuze/boosters or tail fuzes react before the bombs. In Tests P1-1 thru P1-4, all reactions were much the same in that the bombs, when deflagrating, broke into several large pieces with burning and nonburning pieces of unreacted explosive being scattered about the test site. Minor shock waves were created and damage to the witness panels was minimal. In Test P1-5, the bomb was loaded with TNT and reacted higher order (explosion) than the H-6 loaded bombs. The highest order reaction (partial detonation) was experienced in Test P1-6 with a TRITONAL loaded bomb. A significant factor in this test was that the TRITONAL bomb had no cavity hot-melt. It is strongly suspected that the absence of cavity hot-melt contributed to the higher order reaction, since subsequent TRITONAL loaded bombs with hot-melt that were tested, generally deflagrated.

B. Phase 1A - Comp-B Loads

In Phase 1A, only Comp-B loaded bombs were tested to complete that portion of the survivability program dealing with the USS FORRESTAL investigation. All bombs tested were equipped with live nose fuzes and in some cases live boosters. No live-tail fuzes were employed. Table 2 is a brief summary of Phase 1A tests with a more detailed accounting and photographs in Appendix B.

Upon detonating, the AN-M65 and M117 bombs reacted in or very near their design mode. Fragments were scattered over several thousand yards of the test area. The severity of the blast resulted in the formation of large earth craters which necessitated rebuilding of the test site for each test.

The two MARK 81 bombs exploded and tossed large pieces of the bomb body up to 150 feet from the point of reaction. Unreacted explosive, some burning, was scattered about the area.

TABLE 1

BOMB COOK-OFF
PHASE 1 TEST SUMMARY

Test No.	Bomb	Explosive Load	Fuzing Nose	Booster	Tail	Time to Bomb Reaction (min:sec)	Reaction ¹	Fuze/Booster Reaction (min:sec)	Reaction ¹
P1-1	M117	H-6	M904E2	T45E7	M990E1	2:25	Deflagration	--	--
P1-2	MARK 81	H-6	M904E2	T45E7	M990E1	3:00	Deflagration	7:00	Deflagration
P1-3	MARK 82	H-6	M904E2	T45E7	M990E1	4:00	Deflagration	7:15	Partial Detonation
P1-4	MARK 83	H-6	M904E2	T45E7	M990E1	2:55	Deflagration	8:15	Detonation
P1-5	AN-M65	TNT	M904E2	T45E7	Plug	4:05	Explosion	--	--
P1-6 ²	M117	TRITONAL	M904E2	T45E7	Plug	2:55	Detonation	--	--

¹ These reactions, as defined in Appendix A, were originally listed only as high or low order.² Bomb did not contain cavity hot-melt, possibly accounting for the partial detonation.

TABLE 2
BOMB COOK-OFF
PHASE 1A TEST SUMMARY

Test No.	Bomb	Fuzing		Tail	Time to Reaction (min:sec)	Reaction ¹
		Noze	Booster			
P1A-1	AN-M65	M904E2	None	Plug	1:25	Detonation
P1A-2	AN-M65	M904E2	None	Plug	2:10	Detonation
P1A-3	MARK 81	M904E2	T45E7	None	2:15	Explosion
P1A-4	MARK 81	M904E2	T45E7	None	1:55	Explosion
P1A-5	M117	M904E2	T45E7	None	2:00	Detonation
P1A-6	M117	M904E2	T45E7	None	2:14	Detonation

¹ Reactions, as defined in Appendix A were originally listed only as high or low order.

C. Phase 2 - Bomb Characteristics

Phase 2 served as that part of the program in which most of the bomb basic cook-off characteristics were determined. A total of 44 tests were conducted with M117 and MARK's 81, 82, 83 and 84 bombs. These bombs are representative of the ones found on board aircraft carriers and their approximate specifications are listed as follows:

Bomb	Minimum Wall Thickness (inches)	Empty Weight (lbs)	Explosive (lbs)	Approx. Bomb Surface Area (in ²)
MARK 81	0.312	160	100	1310
MARK 82	0.400	313	192	1870
MARK 83	0.475	514	445	4260
MARK 84	0.562	1000	946	6800
M117	----	390	360	4200

The M904E2 nose and M990E1 tail fuzes, and T45E7 adapter boosters were employed in this phase of testing. Bomb fuze configurations were varied as can be seen from Table 3. In addition, thick and thin walled M1 fuze extenders were cooked off.

In Tests P2-1 through P2-25, the bombs were internally instrumented as shown in Figure 4, lined with approximately 1/8" of cavity hot-melt (the nominal amount), then filled with either the Navy H-6 or Air Force TRITONAL explosive load. By instrumenting the bombs, all of the basic cook-off data, heating rates and temperatures at reaction were obtained. It was also possible to study some of the dynamic conditions and occurrences within a bomb during the heating cycle up to time of reaction.

In Tests P2-26 through P2-44, all bombs were lined with approximately 1/8" of cavity hot-melt and then filled with Filler-E, an inert compound developed for the Army with heat transfer characteristics similar to those of H-6 explosive. Detailed information on Filler-E may be found in Reference 3. In this series of tests, fuze and booster cook-off characteristics were investigated. A summary of all tests conducted in Phase 2 may be found in Table 3. Detailed test data with photographs are presented in Appendix C.

In Tests P2-1 through P2-25, H-6 and TRITONAL explosive loaded bombs were exposed in a cook-off environment and the following results obtained. No high order (detonation or partial detonation) reactions occurred. When the bombs reacted, burning and unburned explosive was tossed over the test site and the bombs broke into several large pieces.

- (a) All the explosive bombs, with one exception, deflagrated; Test No. P2-11, loaded with H-6, which exploded.
- (b) In every case, the bombs reacted before the fuzes; however, when fuze reactions did occur (after bombs reacted) some were high order.
- (c) A comparison of time-to-reaction vs explosive load of the same type bombs shows that both H-6 and TRITONAL explosive loaded bombs react in the same time frame, whereas, Comp-B loaded bombs (as seen from Table 2) react at a higher order and in a shorter time.
- (d) The average interface temperature at the time of reaction for H-6 loaded bombs was 557°F and for TRITONAL loaded bombs the average temperature was 537°F.

- (e) The maximum interface temperature rise rate for various types of bombs was: M117 - 3.7°F/sec., MARK 81 - 3.7°F/sec., MARK 82 - 4.3°F/sec., MARK 83 - 3.9°F/sec. and MARK 84 - 3.5°F/sec. The overall average temperature rise rate for all bombs was 3.8°F/sec.

The average cook-off times for the various bombs, disregarding the explosive load, was:

M 117	3 minutes 23 seconds
MARK 81	3 minutes 7 seconds
MARK 82	3 minutes 9 seconds
MARK 83	3 minutes 0 seconds
MARK 84	4 minutes 4 seconds

Tests P2-26 through P2-44 using inert bombs and live fuzes and boosters, yielded the following results:

- (a) For the worst case, live M904E2 nose fuze/T45E7 booster combinations reacted in a longer cook-off time (6 minutes 10 seconds) and a higher order reaction (detonation) than the M904E2 nose fuze in combination with an adapter plug (3 minutes 48 seconds; deflagration).
- (b) The live T45E7 booster with an inert fuze resulted in a deflagration in 7 minutes 38 seconds.
- (c) Minimum time to cook-off for the M990E1 tail fuzes was 22 minutes when conical tail fins were installed; without the conical tail fins the minimum time to cook-off was 16 minutes 54 seconds.
- (d) M-1 fuze extenders tested were Comp-B explosive loaded and divided into two categories, that is, thin and thick walled. The thin walled extenders deflagrated in a minimum time of 2 minutes 15 seconds, whereas the thick walled extenders detonated or exploded in a minimum time of 2 minutes 25 seconds.

D. Phase 2A - Effect of Contiguous Heat Source

Four tests were conducted in Phase 2A. The M117 and MARK 84 bombs selected for these tests were positioned 9 to 12 inches above the fuel surface as

TABLE 3
BOMB COOK-OFF
PHASE 2 TEST SUMMARY

Test No.	Bomb	Explosive Load	Fuzing Nose	Booster	Tail	Time to Reaction (min:sec)	Internal Temp Rise Rate °F/sec	Max. Temp At Reaction °F	Reaction ¹
P2-1	M117	H-6	Plug	None	None	3:35	3.4	565	Deflagration
P2-2	M117	H-6	Plug	None	M990E1	3:20	3.9	495	Deflagration
P2-3	M117	H-6	M904E2	T45E7	M990E1	3:35	(2)	--	Deflagration
P2-4	M117	TRITONAL	Plug	None	None	2:55	(3)	--	Deflagration
P2-5	M117	TRITONAL	Plug	None	M990E1	3:27	3.3	525	Deflagration
P2-6	M117	TRITONAL	M904E2	T45E7	M990E1	4:10	4.0	655	Deflagration
P2-7	MARK 81	H-6	M904E2	T45E7	None	3:20	3.9	475	Deflagration
P2-8	MARK 81	H-6	M904E2	T45E7	M990E1	3:20	3.8	505	Deflagration
P2-9	MARK 81	TRITONAL	M904E2	T45E7	None	2:55	3.5	540	Deflagration
P2-10	MARK 81	TRITONAL	M904E2	T45E7	M990E1	2:55	(4)	--	Deflagration
P2-11	MARK 82	H-6	Plug	None	None	3:06	(5)	--	Explosion
P2-12	MARK 82	H-6	M904E2	T45E7	None	3:00	(6)	--	Deflagration
P2-13	MARK 82	H-6	M904E2	T45E7	M990E1	3:42	3.8	615	Deflagration
P2-14	MARK 82	TRITONAL	M904E2	T45E7	None	2:56	5.3	588	Deflagration
P2-15	MARK 82	TRITONAL	M904E2	T45E7	M990E1	3:05	4.0	439	Deflagration
P2-16	MARK 83	H-6	M904E2	T45E7	None	3:13	2.3	430	Deflagration
P2-17	MARK 83	H-6	M904E2	T45E7	M990E1	2:32	5.2	580	Deflagration
P2-18	MARK 83	TRITONAL	M904E2	T45E7	None	3:19	4.2	458	Deflagration
P2-19	MARK 83	TRITONAL	M904E2	T45E7	M990E1	2:56	3.9	415	Deflagration
P2-20	MARK 84	H-6	Plug	None	Plug	3:31	4.1	675	Deflagration
P2-21	MARK 84	H-6	M904E1	T45E7	M990E1	3:02	4.6	510	Deflagration
P2-22	MARK 84	H-6	M904E2	T45E7	Plug	5:02	3.5	720	Deflagration
P2-23	MARK 84	TRITONAL	M904E2	T45E7	M990E1	4:57	2.2	540	Deflagration
P2-24	MARK 84	TRITONAL	M904E2	T45E7	Plug	3:31	3.2	650	Deflagration
P2-25	MARK 84	TRITONAL	Plug	None	Plug	4:24	3.5	560	Deflagration
P2-26	MARK 81	Inert	M904E2	T45E7	M990E1	9:00 ⁷	--	--	Detonation of nose fuze/adaptor booster
P2-27	MARK 81	Inert	M904E2	T45E7	Plug	6:10 ⁷	--	--	Deflagration of nose fuze
P2-28	MARK 82	Inert	M904E2	Inert	Plug	4:27	--	--	Deflagration of nose fuze
P2-29	MARK 82	Inert	M904E2	Inert	Plug	3:48	--	--	Deflagration of nose fuze
P2-30	MARK 82	Inert	M904E2	Inert	Plug	4:00	--	--	Deflagration of nose fuze

TABLE 3 (Continued)

Test No.	Bomb	Explosive Load	Fuzing	Tail	Time to Reaction (min:sec)	Internal Temp Rise Rate °F/sec	Max. Temp At Reaction °F	Reaction ¹
P2-31	MARK 82	Inert	Inert	Plug	7:38	--	--	Deflagration of adapter booster
P2-32	MARK 82	Inert	Inert	Plug	8:09	--	--	Deflagration of adapter booster
P2-33	MARK 82	Inert	Inert	Plug	8:04	--	--	Deflagration of adapter booster
P2-34	MARK 82	Inert	Plug	M990E1	22:00 ⁸	--	--	Deflagration of tail fuze (fins installed)
P2-35	MARK 82	Inert	Plug	M990E1	32:20 ⁹	--	--	Deflagration of tail fuze (fins installed)
P2-36	MARK 82	Inert	Plug	M990E1	33:35 ⁹	--	--	Deflagration of tail fuze (fins installed)
P2-37	MARK 82	Inert	None	M990E1	16:54	--	--	All three fuzes deflagrated (no fins installed)
					19:30			
					23:15			
P2-38 ¹⁰	MARK 81	Inert	Inert	T45E7	7:02	--	--	Deflagration of fuze extender
P2-39 ¹⁰	MARK 81	Inert	M904E2	T45E7	2:15	--	--	Deflagration of fuze extender
P2-40 ¹¹	MARK 81	Inert	M904E2	T45E7	3:00 ¹¹	--	--	Deflagration of fuze extender
P2-41 ¹¹	MARK 81	Inert	M904E2	T45E7	3:30	--	--	Detonation (believed to be fuze extender)
P2-42 ¹¹	MARK 82	Inert	M904E2	T45E7	3:38	--	--	Detonation (believed to be fuze extender)
P2-43 ¹¹	MARK 82	Inert	M904E2	T45E7	4:25	--	--	Explosion (believed to be fuze extender)
P2-44 ¹¹	MARK 81	Inert	M904E2	T45E7	2:25	--	--	Detonation (believed to be fuze extender)

¹ Bomb reactions as defined in NAVGRD OP5, Volume 1, Part 1, Third Revision and Repeated in Appendix A of this report.² Thermocouple instrumentation failure at 106 seconds.³ Thermocouple instrumentation failure at beginning of test.⁴ Instrumentation recorder failure at 160 seconds.⁵ No internal temperature data taken.⁶ Thermocouple instrumentation failure at 150 seconds.⁷ Fire out approximately 5 minutes after start of test.⁸ Fire out approximately 11.5 minutes after start of test.⁹ Fire out approximately 15 minutes after start of test.¹⁰ Test conducted with 36-inch THIN walled M-1 Comp-B loaded fuze extender.¹¹ Approximate time to reaction.¹² Test conducted with 36-inch THICK walled M-1 Comp-B loaded fuze extender.¹³ Nose fuze, fuze extender and adapte booster installed in tail section of bomb do to nose fuze wall damage.¹⁴ Test conducted with 18-inch THICK walled M-1 Comp-B loaded fuze extender.

shown in Figure 5. The bombs had M904E2 nose fuzes and T45E4 adapter boosters but no tail fuzes installed. Table 4 is a brief summary of Phase 2A test results, with details and photographs appearing in Appendix C.

TABLE 4

**BOMB COOK-OFF
PHASE 2A TEST SUMMARY**

Test No.	Bomb	Explosive Load	Fuzing			Inches Above Fuel	Time to Reaction (min:sec)	Reaction
			Nose	Booster	Tail			
P2A-1	M117	TRITONAL	M904E2	T45E4	None	9	5:25	Deflagration
P2A-2	M117	H-6	M904E2	T45E4	None	9	3:00	Deflagration
P2A-3	MARK 84	TRITONAL	M904E2	T45E4	Plug	12	3:37	Explosion
P2A-4	MARK 84	H-6	M904E2	T45E4	Plug	12	3:23	Deflagration

E. Phase 2B - Influence of Aircraft Structures

To study the influence of aircraft structures on cook-off time and severity of reaction, it was decided to conduct tests on bombs in close proximity to an aircraft wing. The wing structure was selected because the majority of aircraft carry their bomb load under the wing. Figure 6 shows a typical test set-up used in this phase of testing. Of the eight tests conducted, six were without fuzes attached to the bombs and two with fuzing. A summary of Phase 2B results is presented in Table 5, post test photographs and detailed results are presented in Appendix C.

TABLE 5

**BOMB COOK-OFF
PHASE 2B TEST SUMMARY**

Test No.	Bomb	Explosive Load	Fuzing			Time to Reaction (min:sec)	Reaction
			Nose	Booster	Tail		
P2B-1	MARK 81	H-6	Plug	None	Plug	2:06	Explosion
P2B-2	MARK 81	H-6	Plug	None	Plug	1:50	Explosion
P2B-3	MARK 81	H-6	Plug	None	Plug	2:04	Explosion
P2B-4	MARK 82	H-6	Plug	None	Plug	2:12	Explosion
P2B-5	MARK 82	H-6	Plug	None	Plug	2:04	Explosion
P2B-6	MARK 82	H-6	Plug	None	Plug	2:12	Explosion
P2B-7	MARK 84	H-6	M904E2	T45E4	M990E1	3:38	Partial Detonation
P2B-8	MARK 84	TRITONAL	M904E2	T45E4	M990E1	3:30	Deflagration



FIGURE 5

A M117 Bomb Positioned 9 Inches Above the Fuel Surface for Fast Cook-Off Testing
in the Phase 2A Portion of the Bomb Survivability Program



FIGURE 6

An Aircraft Wing Positioned Over the Test Stand Simulating a Racked to
Aircraft Configuration for Fast Cook-Off Tests Conducted in
Phase 2B of the Bomb Survivability Program

The first reaction occurring during each of this series of tests was the burning of the aircraft wings. This was followed closely by the bombs reacting. The unfuzed MARK 81 and 82 bombs exploded, whereas one of the fuzed MARK 84 bombs partially detonated and the other deflagrated. Large portions of the burning and unreacted explosive loads were found in all tests where explosion or deflagration occurred. In test P2B-7, the partial detonation scattered fragments several thousand feet from the test site. The average time to bomb reaction was:

MARK 81	2 minutes 0 seconds
MARK 82	2 minutes 09 seconds
MARK 84	3 minutes 34 seconds

F. Phase 3 -- Abbreviated Heat Input (Inert Bombs)

Unfuzed, inert Filler-E loaded MARK 81 bombs were used in all Phase 3 tests. The bombs were suspended 3 feet 4 inches at their lowest point above the fuel surface. All tests were conducted in the slant pan so that control of the flame environment could be maintained. All bombs were instrumented as shown in Figure 4 and lined with the normal (1/8-inch) thickness of hot-melt before inert loading. The internal temperature rise rate was recorded and after a pre-determined time the flames were removed and the air cooling rate recorded. A brief summary of Phase 3 results are presented in Table 6, the more detailed time-temperature data are presented in Appendix D.

The average internal temperature rise rate for MARK 81 bombs was calculated from the above data to be 4.0°F/sec and the average air cooling rate was 0.47°F/sec.

G. Phase 3A -- Cooling Measures

The MARK 81 and 82 bombs employed in Phase 3A testing were instrumented as shown in Figure 4. The bombs were lined with the normal (1/8-inch) thickness of hot-melt before being inert loaded with Filler-E. The bombs were then suspended 3-1/2 feet at their centerline above the fuel surface. The slant pan was used in the tests in order that control of the flame environment could be maintained.

Since the NBC (nuclear, bacteriological, and chemical) washdown system exists on CVA's (Figure 7), the question of its effectiveness when used as a fire fighting and/or ordnance cooling device during a conflagration was raised. The first bomb cooling tests were conducted using water (salt and fresh) at an application rate of 0.03 gal/ft²/min which simulated the flow rate of the NBC washdown

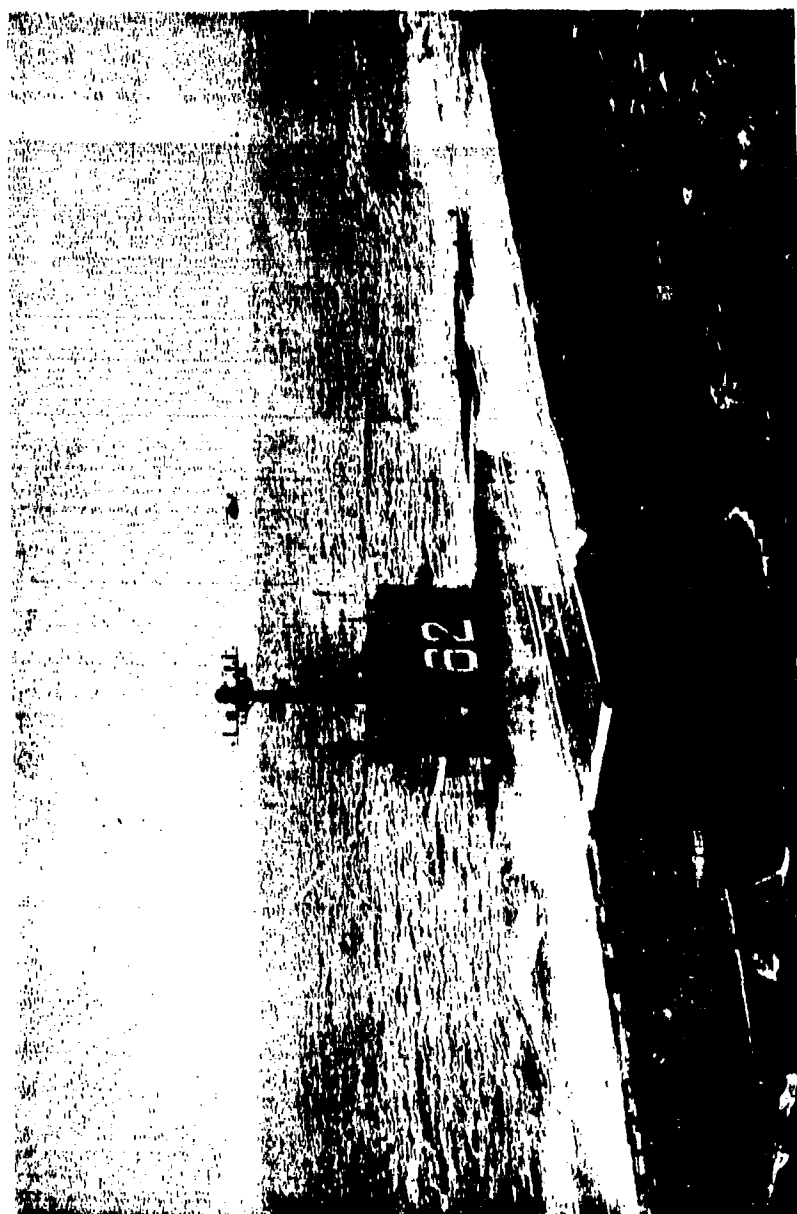


FIGURE 7

A View of CVA 62 With Her NBC Washdown System Activated

TABLE 6

BOMB COOK-OFF
PHASE 3 TEST SUMMARY

Test No.	Wind Velocity (Knots)	Bomb ¹	Temp. Rise Rate °F/sec	Fire Burned (min:sec)	Ave. Flame Temp (°F)	Time to (min:sec) Temp °F Reached in Bomb	Air Cooling Rate °F/sec
P3-1 ²	3.5	MARK 81	2.3	1:30	> 800	3:00 271	0.17
P3-2	0.1	MARK 81	3.6	2:20	1590	2:50 506	0.5
P3-3 ²	3.5	MARK 81	2.1	2:15	> 900	2:40 269	0.27
P3-4	0	MARK 81	5.2	1:30	1720	2:00 489	0.39
P3-5	0.1	MARK 81	3.9	1:35	1370	2:50 436	0.6
P3-6	2.4	MARK 81	3.3	1:45	1360	2:15 261	0.4

¹ All bombs were loaded with Filler-E, an inert material whose thermal characteristics closely resembles those of H-6 and TRITONAL Explosive.

² Tests consider invalid due to low flame temperature.

system. Tests were also conducted with a water application rate 0.48 gal/ft²/min in a deliberate over test. Water application rates were determined under a no-fire condition, therefore the rates do not reflect the amount of water reaching the bombs when they were engulfed in flames. A view of the system employed is shown in Figure 8. The two sprinklers were located one on either side of the bomb and were positioned approximately 12 feet away and 4 feet above the bomb. Thirty degree injection type "full jet" nozzles manufactured by Spraying System Company dispensing a full cone spray pattern were employed. The spray pressure could be varied in order to obtain the desired application rate. A summary of the four tests conducted are presented in Table 7, the more detailed time-temperature data are presented in Appendix D.

TABLE 7
WATER SPRINKLER TESTS SUMMARY
PHASE 3A

Test No.	Application Rate (gal/ft ² /min)	Internal Temp. Rise Rate System Inactive (°F/sec)	System On After Time-0 (min:sec)	Internal Temp. Rise Rate System Active (°F/sec)	System Off After Time-0 (min:sec)	Max. Temp. in Bomb °F
P3A-1	0.03	5.0	1:00	5.0	3:00	735
P3A-2	0.03	5.5	0:52	5.5	3:04	773
P3A-3	0.48	1.7	1:00	1.7	2:00	239
P3A-4	0.48	3.4	1:00	3.4	3:00	352

A comparison of bomb temperature rise rates during the times the sprinkler system was passive and then active, does not show any cooling effect on the bombs. However, decrease in flame temperature of approximately 20% was recorded after the sprinkler system was activated. Water was observed impinging onto the bomb after flame build-up.

Evaluation of the NBC washdown system was continued by employing 3/4-inch Grennell S-110-438 flush deck nozzles that are used on carrier NBC washdown systems. The philosophy of test design was one of positioning the bombs in an optimum cooling configuration so that in the event tests were unsuccessful no further tests would be needed. In the first test series, a flush deck nozzle was positioned directly under the bombs as shown in Figure 9. In this configuration the center water plume of the nozzle was impinged directly on the bottom of the

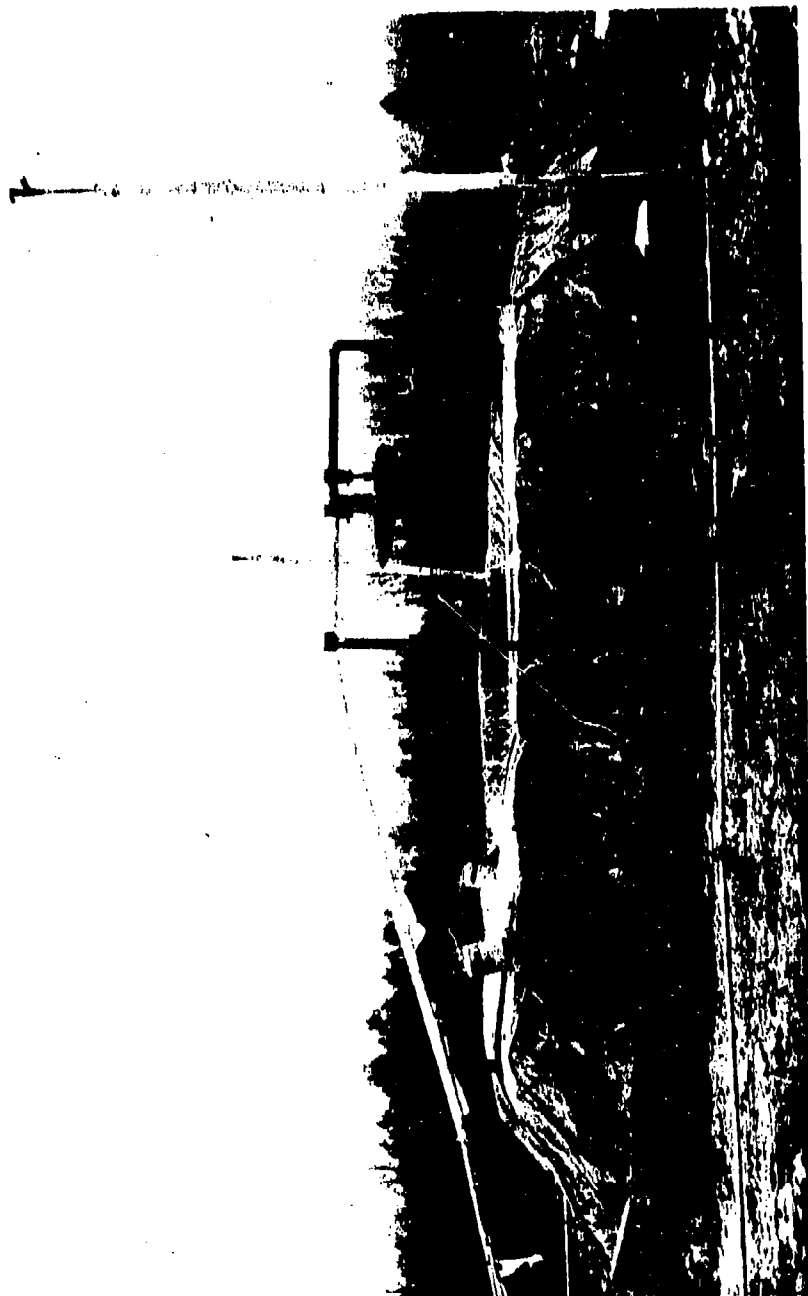


FIGURE 8

Spray Cooling Tests Using Two Spray Nozzles Positioned On Either Side
of an Instrumented MARK 81 Bomb



FIGURE 9

**A Single Flush Deck Nozzle Positioned Directly Under a MARK 81 Inert Instrumental Bomb.
Notice the Center Plume of the Nozzle Impinging Directly Onto the Bomb**

bomb. In the remaining tests, nozzles were positioned on either side, 10 feet away and perpendicular to the bomb as shown in Figure 10. These tests were designed to simulate ordnance ideally positioned between two nozzles with the side spray of each impinging on either side of the bomb. The pumping system used in all NBC washdown system evaluation tests is shown in Figure 11. A 1000 gallon water storage tank was positioned on the back of a flat bed truck. Water was pumped from the tank by a "Hale" pump capable of delivering 350 gpm. From the pump, a 2-1/2-inch fire hose was coupled to a 1-1/2-inch water pipe that connected to the sprinklers. A water pressure of 60 gpm was used in the single nozzle configuration and 75 gpm in the two nozzle configuration. These pressures were maintained at the nozzles by regulating a hand valve in the system. A summary of the result of three tests conducted are listed in Table 8 and the more detailed data are presented in Appendix D.

TABLE 8
FLUSH DECK NBC WASHDOWN SYSTEM
WATER COOLING TESTS SUMMARY
PHASE 3A

Test No.	No. of Nozzles	Pressure In System (PSI)	Internal Temp. Rise Rate System Inactive (°F/sec)	System On (min:sec)	Internal Temp. Rise Rate System Active (°F/sec)	Fire Removed (min:sec)	Cooling Rate System On System On (°F/sec)
P3A-5	1	60	3.5	1.00	1.5	5:00	0.6-0.8
P3A-6	2	75	2.1	0.56	1.8	1:51	1.0
P3A-7	2	75	1.6	0.54	1.6	1:28	0.2

An examination of the data shows very little difference in the bomb internal temperature rise rate before or after the NBC system was activated. Some improvement was noted in cooling the bombs after the fire was out as compared with the air cooling rate in Phase 3, Table 6.

Three water cooling tests with fire fighting personnel were conducted. Fire fighters, positioned from 50 to 70 feet from the bomb, applied water over the outside surface of the bomb from a 1-1/2-inch hand held fire hose, Figure 12. Personnel were positioned at various angles (from 10° to 50°) to the bomb's nose or tail section to help determine the effective angles of water application.



FIGURE 10

Inert Bomb Ideally Positioned Between Two Flush Deck Nozzles During Fast Cook-Off Testing
in the Phase 3B Portion of the Bomb Survivability Program



FIGURE 11

Pumping System Employed in Conducting the NBC Washdown System Evaluation Tests of Phase 3A



FIGURE 12

Fire Fighting Personnel Applying Water to a Bomb at an Angle of 45°
to the Tail During Bomb Cooling Tests of Phase 3A

A standard hose nozzle producing a fairly tight stream of water was directed onto the bomb in such a manner as to have the water completely cover its outside surface. Water application rates were varied from 60 to 90 gpm. A summary of results of the three tests conducted are listed in Table 9 and the more detailed data are presented in Appendix D.

TABLE 9

SUMMARY OF WATER COOLING TESTS EMPLOYING FIREMAN

Test No.	Water Delivery Rate (GPM)	Angle of Application	Internal Temp. Rise Rate No Water (°F/sec)	Time of Water Application (min:sec)	Bomb Max. Internal Temp (°F)	Internal Cooling Rate Water On (°F/sec)	Stabilizing Temp (°F)	Time Fire Out (min:sec)
P3A-8	60	10°-15° Tail	4.6	1:40	330	5.0	110	6:00
P3A-9	60	45°-50° Tail	3.4	1:10	260	2.6	110	7:25
P3A-10	95	30°-35° Nose	3.4	1:30	415	2.5	110	6:00

Water applied at rates of from 60-95 gpm and at angles of from 10° to 50° to the nose or tail section of the bomb cooled the bombs while they were engulfed in flames. In all tests where water was properly and continually applied, internal bomb temperatures stabilized at 110°F. (250°F is considered critical for these tests.)

The same series of cooling tests as previously discussed were conducted using foaming "light-water" chemical mixed with fresh or salt water. "Light-water" concentrate FC-194, manufactured by the 3M Company, is a product based on the chemical action of fluorochemical wetting agents. Its action stems from its ability to make water float on flammable fuels which are lighter than water. In all the following tests, the "light-water" used consisted of a 6% solution mixed with fresh or salt water. Three sprinkler tests were conducted. A summary of results is presented in Table 10, the more detailed time-temperature data are presented in Appendix D.

TABLE 10
"LIGHT-WATER" SPRINKLER TESTS SUMMARY
PHASE 3A

Test No.	Application Rate (gal/ft ² /min)	Internal Temp. Rise Rate System Inactive (°F/sec)	System On After Time 0 (min:sec)	Internal Temp. Rise Rate System Active (°F/sec)	System Off After Time 0 (min:sec)	Max. Temp. In Bomb °F
P3A-11	0.03	1.7	3:15 ¹	1.7	6:40	508
P3A-12	0.03	3.2	1:31	3.2	3:00	680
P3A-13	0.03	3.5	1:12	3.5	3:00	710

¹ Flame build up time was 2 minutes.

No change in the bomb's internal temperature rise rate was noted when the sprinklers were on or off. The application of such a small quantity of "light-water" had no measurable effect on extinguishing the test fire.

Three "light-water" cooling tests were conducted with a single flush deck nozzle (Grennell S-110-438) positioned directly under the bomb. A summary of results is presented in Table 11 and the more detailed time-temperature data are presented in Appendix D.

A small decrease in the temperature rise rate was noted in the bombs tested, however, cooling of the bombs did not take place. It was noted that the test fires were effectively extinguished by the application of "light-water".

The final six "light-water" cooling tests in Phase 3A were conducted with fire fighting personnel (see Figure 13). The procedures employed were the same as those used in tests P3A-8 thru P3A-10 inclusive. The first three tests were done with a "light-water" application rate of 60 gpm and the final three delivering



FIGURE 13

Fire Fighting Personnel Applying "Light-Water" on a Bomb at an Angle of 10°
to the Nose During Phase 3 Fast Cook-Off Tests

TABLE 11

**FLUSH DECK NBC WASHDOWN SYSTEM "LIGHT-WATER" COOLING TEST
PHASE 3A**

Test No.	Pressure In System (PSI)	Internal Temp. Rise Rate System Inactive (°F/sec)	System On (min:sec)	Internal Temp. Rise Rate System Active (°F/sec)	Fire Out (min:sec)	Cooling Rate Fire Out System On (°F/sec)
P3A-14	75	3.5	1:10	1.5	2:25	0.5
P3A-15	60	2.3	1:40	1.1	2:35	0.7
P3A-16	60	3.5	1:12	2.7	2:00	0.7

95 gpm. A summary of results is presented in Table 12, the more detailed time-temperature data are presented in Appendix D.

No appreciable decrease in temperature rise rate in the bombs was noted while "light-water" was applied over the bomb's surface with the ordnance engulfed in flames. No attempt was made to extinguish the fires but because to the "light-water" falling off the bomb into the test pit the fire was out in 2 to 4 minutes. No stabilization of temperature in the bomb was noted after the fire was out and "light-water" was being applied.

H. Phase 4 -- Abbreviated Heat Input -- HE Loaded Bombs

All ordnance used in the nine tests conducted were MARK 81 bombs. Some of the bombs were fuze (see Appendix E) in order to gather additional data on fuze effects. A brief summary of test results are presented in Table 13 and the more detailed time-temperature data are presented in Appendix E.

The average internal temperature rise rate for explosive loaded MARK 81 bombs, calculated from the data presented in Table 13, was 4.4°F/sec and the average air cooling rate was 0.41°F/sec. The bomb used in Test P4-3 did not react and was reused three days later in Test P4-4. In Test P4-3, the highest average temperature at 1 minute 40 seconds into the test was 336°F and in Test P4-4 the average temperature at reaction was only 278°F.

TABLE 12

**SUMMARY OF LIGHT-WATER COOLING TESTS EMPLOYING FIREMEN
PHASE 3A**

Test No.	Bomb	Angle of Application	Internal Temp		Time of Light-Water Application (min:sec)	Internal Temp. Rise Rate		Fire Out (min:sec)	Internal Temp. Cooling Rate Fire Out (°F/sec)
			No	Rise Rate No Light-water (°F/sec)		Light-Water Applied (°F/sec)			
P3A-17	MARK 81	45°-50°Nose		3.2	1:35	3.0	3:50	2.8	
P3A-18	MARK 81	35°-40°Nose		2.2	1:20	2.2	3:55	1.0	
P3A-19	MARK 81	45°Tail		3.2	1:38	3.0	2:42	0.8	
P3A-20	MARK 82	15°Nose		3.2	1:08	3.0	2:08	0.6	
P3A-21	MARK 82	40°Nose		3.6	1:20	2.0	3:45	1.4	
P3A-22	MARK 82	45°Nose		4.7	1:10	4.3	2:05	2.5	

TABLE 13
BOMB COOK-OFF TEST SUMMARY
PHASE 4

Test No.	Explosive Load	Fire Removed (min:sec)	Bomb Reaction	Time to Reaction (min:sec)	Bomb Internal Heating Rate (°F/sec)	Bomb Internal Cooling Rate (°F/sec)	Average Internal Temp at Reaction (°F)	Max. Temp. at Reaction (°F)
P4-1	TRITONAL	1:50	Deflagration	1:56	4.7	---	516	544
P4-2	TRITONAL	1:30	None	---	5.5	0.5	---	---
P4-3	H-6	1:28	None	---	4.6	0.2	---	---
P4-4 ¹	H-6	No	Deflagration	2:08	2.6	---	278	305
P4-5	H-6	No	Deflagration	2:15	5.3	---	565	628
P4-6	H-6	No	Deflagration	2:15	4.7	---	565	580
P4-7	H-6	1:30	None	---	4.7	0.45	---	---
P4-8	H-6	No	Deflagration	2:40	2.8	---	335	369
P4-9 ²	H-6	1:22	Deflagration	2:00	4.9	0.5 ³	425	445

¹ Same bomb flat was used in Test No. P4-3 (re-heated).

² An excellent example of an exothermic reaction.

³ Temperature continued to increase, in the area of thermocouple No. 7, to reaction. The remainder of the bomb cooled at this given rate.

The best example of an exothermic reaction was observed in Test P4-9. In this test, after the fire was removed, all but one of the thermocouples showed the bomb to be cooling at a rate of 0.5°F/sec. The exception was thermocouple No. 7 which continued to show a temperature increase in the bomb until it deflagrated 38 seconds after the fire was removed.

I. Phase 5 -- Impact Tests of Heated Bombs

In the hot drop tests of Phase 5 the bombs were suspended by a 1/2-inch steel cable 6 feet above the fuel surface (Figures 14 and 15). Two inches below the fuel surface was a one-inch steel plate 8 X 8 feet square that simulated a carrier deck. After the bomb was pre-heated it was remotely released by means of a cartridge activated cable cutting guillotine (Figure 16) and allowed to strike the steel plate, thereby simulating a pre-heated bomb being forcibly ejected onto a steel deck due to ejection cartridge cook-off. Additional tests were conducted on live ejection cartridges installed in triple ejection racks (TER) with mixed live and inert MARK 81 bomb loads. In Tests P5-1 through P5-4, the bombs were pre-heated for approximately 2 minutes (interface temperature about 250°F) and then dropped. In no case, did a bomb react on impact. Reaction did occur after impact and ranged from 2-1/2 to 5 minutes. In Tests P5-5 and P5-6, the aluminum TER racks melted at approximately 2 minutes releasing the bomb load. The cartridges were heard to deflagrate intermittently starting at 2 minutes 47 seconds after start of the test. The detailed data and post test photographs are presented in Appendix F.



FIGURE 14

An Overall View of the Arrangement for Phase 5 Cook-Off Testing



FIGURE 15

A Close View of a Suspended MARK 81 Bomb as Positioned Prior to "Hot Drop" Tests conducted in Phase 5 of the Cook-Off Program

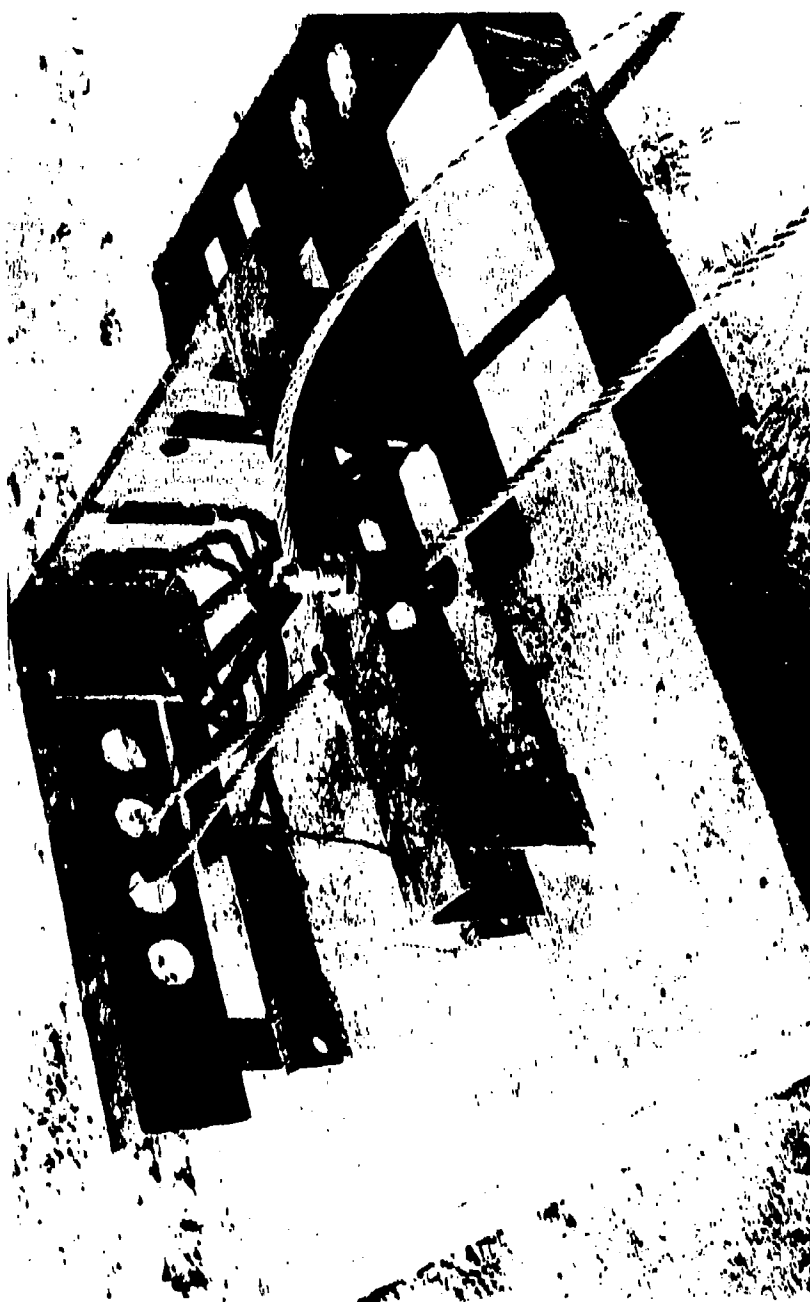


FIGURE 16

A Close-Up View of the Cable Cutter and Anchor Platform Employed
in Phase 5 Cook-Off Tests

VI. CONCLUSIONS

A. General

Bombs exposed in a flight deck conflagration present a serious hazard to personnel, equipment and aircraft when reacting. The hazards result primarily from bomb case fragments that can be scattered over a large portion of the flight deck, also unreacted, burning explosive that can kindle new fires over the deck.

A study of data from Phases 2, 3, and 4 shows that a fairly even temperature distribution exists over the inside surface of bombs exposed in a fast cook-off environment.

The likelihood of bomb exothermic cook-off after a short heating period is possible. That is, if a bomb is exposed to extreme heat for less than the 2 or 3 minutes required for cook-off, an exothermic condition could exist in the explosive fill and the bomb continue to reaction.

Fifty-three bomb tests were selected from applicable phases of the program because they closely followed the specifications outlined in Appendix A. The data from these tests are presented on the next page in a summary of reactions and reaction times listed by bomb type and explosive load.

From the condition of the unreacted explosive examined after HE loaded bomb tests in fires, along with data from instrumented live bomb tests, it is concluded that the asphalt hot-melt liner has melted as has a portion of the explosive load and the two (asphalt and melted explosive) have mixed. It was determined, Reference 4, that asphalt and explosive when mixing in a heated condition accelerate the rate of thermal decomposition of the explosive. Therefore, when temperatures exceed 450°F at the bomb interface, gas evolution of the mixture becomes relatively fast, resulting in a shorter cook-off time.

B. Phases 1 and 1A

Time to and severity of cook-off reactions of Comp-B loaded AN-M65 bombs tested at NWL were in agreement with estimates obtained in the USS FORRESTAL conflagration (Reference 5).

Results of tests conducted reveal that the probability of a detonation (high order reaction) of a Comp-B loaded bomb in a relatively short time is extremely high while the probability of achieving a detonation from fast cook-off of an H-6 loaded bomb is unlikely. As a possible reason for Comp-B being more sensitive than

BOMB FAST COOK-OFF SUMMARY

Number Tested	Bomb	Explosive Load	Mean Reaction Time (min:sec)	Shortest Reaction Time (min:sec)	Type of Reaction
13	MARK 81	H-6	2:32	1:50	Explosion and deflagration
3	MARK 81	TRITONAL	2:35	1:56	Explosion and deflagration
2	MARK 81	Comp-B	2:05	1:55	Explosion
9	MARK 82	H-6	3:00	2:04	Explosion and deflagration
2	MARK 82	TRITONAL	3:00	2:56	Deflagration
2 ¹	MARK 82	Minol	3:22	3:18	Deflagration
2 ¹	MARK 82	PBXW-107	3:42	3:38	Deflagration
3	MARK 83	H-6	2:53	2:32	Deflagration
2	MARK 83	TRITONAL	3:07	2:56	Deflagration
5	MARK 84	H-6	3:43	3:02	Deflagration
4	MARK 84	TRITONAL	4:09	3:23	Deflagration
4	M117	H-6	3:22	3:00	Deflagration
4	M117	TRITONAL	3:59	2:55	Deflagration
2	M117	Comp-B	2:07	2:00	Detonation

¹ Tests conducted, but not part of this program, which may be of interest to the reader.

H-6, it is suggested in Reference 6, that the presence of aluminum powder in the explosive may reduce the possibility of a cook-off detonation since H-6 is Comp-B with 20% aluminum powder. Bomb fuzes or boosters did not initiate any of the reactions.

C. Phases 2, 2A and 2B

A slight increase in time to cook-off was noted as bomb size increased. It is felt that bomb wall thickness (larger bomb, thicker wall) and area of bomb exposed to the fire environment may be a contributing factor. The order of reaction for larger bombs (MARK 84) was no greater than that for smaller ones (MARK 81).

Both TRITONAL and H-6 loaded bombs (of the same size) had essentially the same reaction times and the same type of reaction (deflagration or explosion). Comp-B explosive loaded bombs, generally react in a shorter time than TRITONAL or H-6.

All fuze reactions were observed to take place after the bomb's HE load reacted. Some of these fuze reactions were observed to be detonations. While the probability of fuze cook-off triggering a bomb reaction is small, a fuze can react in a short time as evidenced in Test P2-29 where the fuze cooked off in 3 minutes 48 seconds.

The M990E1 tail fuzes do not present a cook-off hazard. Their reactions are low order (deflagration) and occur at about 17 minutes. It is interesting to note, and will prove helpful in the bomb cook-off fix program, that the conical tail fins protect the tail fuze from cook-off by about 6 additional minutes.

On the following page is a summary of the fuze and booster cook-off data from Phase 2 of the program.

Internally instrumenting bombs to acquire temperature data did not alter the bomb's cook-off characteristics.

In a standard fire, as defined in Appendix A, the temperature rise rate in all types of H-6 and TRITONAL loaded bombs average 4.0°F/sec and the bomb interface temperature at time of reaction was between 500°F and 560°F.

Bombs positioned just above the fire surface cook-off within the same time frame and react with the same severity as do bombs positioned 3 to 8 feet above the flame surface.

BOMB FUZE/BOOSTER FAST COOK-OFF SUMMARY

Number Tested	Device Tested	Explosive Load	Inert Bomb	Mean Reaction Time (min:sec)	Shortest Reaction Time (min:sec)	Type Reaction
2	904E2 Nose Fuze T45E7 Booster	Tetryl Tetryl	MK 81	7:35	6:10	Detonation
3	904E2 Nose Fuze	Tetryl	MK 82	4:05	3:48	Deflagration
3	T45E7 Booster	Tetryl	MK 82	7:57	7:38	Deflagration
3 ¹	M990E1 Tail Fuze (Conical fins installed)	Tetryl	MK 82	29:18	22:00	Deflagration
3 ¹	M990E1 Tail Fuze (No conical fins)	Tetryl	MK 82	19:53	16:54	Deflagration
6 ²	M-1 Fuze Extender	Comp-B	MK 81 MK 82	3:12	2:15	Detonation

¹ Test fires were out from 11.5 to 15 minutes after start of tests.

² M-1 extenders which reacted first as reported were installed between live T45E7 adapter boosters and M904E2 nose fuzes.

The presence of an aircraft structure, such as a wing, does influence cook-off time and severity of reaction in that cook-off times are shorter by approximately one minute and severity of reaction is increased, generally, from deflagration to explosion.

D. Phases 3 and 3A

The average internal (interface) temperature rise rate of inert Filler-E bombs when exposed in a standard cook-off environment (Appendix A) was 4.0°F/sec which correlates well with the live explosive loaded bomb temperature data recorded in Phase 2. The average air cooling rate was 0.47°F/sec.

The use of sprinklers placed on either side of a MARK 81 bomb, dispensing 0.03 to 0.48 gal/ft²/min of water or light water onto a bomb engulfed in flames, are not sufficient to cool or appreciably decrease the rate of heat transferred to the bomb. However, in the case where water was used, it was noted that the flame temperature at the bomb was reduced by approximately 30%.

When flush deck nozzles were ideally placed on either side of a MARK 81 bomb and activated so that water or light-water impinged on the bomb, no effective cooling resulted.

In the case where a flush deck nozzle was positioned directly under a MARK 81 bomb so that the center water or light-water plume of the nozzle impinged on a small area of the bomb, cooling took place in the area of impingement but elsewhere on the bomb the internal temperature continued to increase.

It is concluded that bombs engulfed in a JP-5 jet fuel fire cannot be effectively cooled by a sprinkler system (dispensing rates up to 0.48 gal/ft²/min) or the NBC washdown system currently on board carriers, when these systems are dispensing fresh water, salt water or light-water. However, with the NBC washdown system dispensing light-water the fires were quickly extinguished.

For the water cooling tests employing a 1-1/2" hand held fire hose delivering 60 to 95 gpm it is concluded that when water or salt water is applied to the bomb surface at an angle of from 10° to 50° to the nose or tail section, the bomb can be cooled while engulfed in flames. The water or salt water must be applied in such a manner as to continually and completely cover the outside surface of the bomb. In cooling tests employing a 1-1/2" hand held fire hose applying light-water, no adequate cooling of the bomb was experienced, however, the light-water was effective in putting out the fires.

E. Phase 4

The average internal (interface) temperature rise rate of the live explosive loaded bombs tested in a standard cook-off environment Phase 4 was 4.4°F/sec which correlates extremely well with the live explosive loaded bomb data of Phase 2 and the inert Filler-E bomb average heating rate of 4.0°F/sec of Phase 3. The average air cooling rate of 0.41°F/sec in the phase also compares favorably with the 0.47°F/sec air cooling rate of inert bombs of Phase 3. It is therefore shown that the thermal characteristics of the inert compound Filler-E are similar to those of H-6 and TRITONAL explosives when loaded in a bomb and exposed in a flame environment.

F. Phase 5

Pre-heated bombs when forcibly impacted onto a steel deck did not react from the impact. Therefore, it is concluded that no additional hazard exists when a pre-heated bomb is forcibly ejected onto a steel deck.

When triple ejector racks (TER), made primarily of aluminum, were loaded with live ejection cartridges and bombs and cooked off, the TER first melted allowing the bombs to fall. Later, when cartridge cook-off occurred, the reaction was so mild that it did not trigger the ejection mechanism. Consequently, it is felt that very little possibility exists of bombs on a TER rack being forcibly ejected due to cook-off of the ejection cartridges.

VII. RECOMMENDATIONS

It was recommended to and approved (Reference 7) by the Naval Air Systems Command that all Comp-B loaded bombs be removed from carrier operation. In addition, the following recommendations are made:

- (a) That cook-off testing of ordnance be incorporated as part of the standard weapons clearance for carrier use.
- (b) All carrier personnel be made aware of bomb cook-off characteristics and be instructed in procedures for fighting fires where bombs may be present.
- (c) That light-water be used in the carrier NBC washdown system to help control jet fuel fires that might occur.
- (d) Bombs exposed in or near a fire be disposed of quickly because of a possible exothermic reaction and that prior to disposal, water be continually applied over the bomb surface to retard the exotherm.
- (e) In a flight deck fire water be applied to bombs adjacent to the fire to prevent their cooking off.
- (f) That the current fix program as defined in Reference 8 be continued.
- (g) A method for the abatement of smoke produced in cook-off test fires currently being investigated at NWL be continued.

It is suggested that a fire fighting technique be considered whereby teams of firefighters be trained to confront a carrier conflagration by dispensing light-water to control and extinguish the fuel fire and water applied to the bombs to cool them.

VIII. SUPPORTING TASK OBJECTIVES

Owing to a lack of knowledge in some of the areas pertinent to conducting the weapons survivability in fire program a supporting task plan was formulated. The tasks were divided into several categories that are listed as follows:

1. *Quick Fire Starting.* Experiments were conducted to determine a method which provides almost instantaneous ignition across the fuel surface.
2. *Wind Effects.* Temperatures at various heights within the flame environment of still and wind blown JP-5 fires will be studied to determine the effect of wind on flame intensity.
3. *Internal Thermocouple Design.* This involves design of hardware for mounting thermocouples internally and passing the leads via an external connector without defeating the integrity of the bomb case.
4. *Selection of Inert Filler.* A literature search was conducted to find a filler closely matching H-6 and TRITONAL explosive thermal properties (specific heat, conductance, melting point, etc.). The filler was used in bombs to conduct heat transfer characteristic analysis.
5. *Water and Foam Rates - Apparatus Design.* Piping and nozzle layouts were designed to provide spray rates comparable to those of the NBC washdown system.
6. *Evaluation of Fire Retardant Paints.* In order to economically test and evaluate intumescent, subliming or ablating fire retardant paints that might be used to prolong bomb cook-off, a cylindrical (pipe) test was devised.
7. *Computer Studies and Analysis.* A heat transfer computer program was written such that it simulates the cook-off process and can be used to predict cook-off time under a variety of flame enveloping conditions.

The results and conclusions from experiments conducted and literature searches are presented in Appendix G.

REFERENCES

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2. AIRTASK No. A05-532-011/291-4/00000
3. Murray and Denstish, "*Development of Inert Fillers Containing the Glyceride of 12-Hydroxystearic Acid.*" Report No. 34, Explosives Development Section, Jeltman Research and Engineering Laboratories, Picatinny Arsenal, June 1958.
4. Joyner, T. B., "*Thermal Decomposition of Explosives. Effect of Asphalt on the Decomposition of TNT.*" (U) NWC Technical Report TP4709 Part 2, April 1969. (CONFIDENTIAL)
5. USS FORRESTAL 161048Z August 1967
6. Pakulak, Jack M., Jr., "*Progress Report No. 4 Explosives and Propellants.*" (U) NWC Technical Report REG. No. 4532-21, May 1969. (CONFIDENTIAL)
7. NAVAIR 012327Z December 1967
8. Naval Weapons Cook-Off Program Plan of April 1971.

APPENDIX A

STANDARD FAST COOK-OFF TEST SPECIFICATION FOR BOMBS

1.1 FAST COOK-OFF TEST ARRANGEMENT

1.1.1 Test Pit or Test Pan Size -- Minimum test pit or pan size for fast cook-off testing is 24-foot square and maximum size is 35-foot square.

1.1.2 Construction of Test Site -- The test area may be constructed on either a semi-permanent basis with steel plates, or if the test area is expected to be destroyed by the test, it may be constructed from earth and polyethylene. Construction may be in the form of a pit in the ground or a pan on the surface of the ground.

1.1.2.1 Test Pit -- The test pit is embedded in the ground and the walls banked to a height of approximately eight feet. Around the perimeter of the pit, pipes are placed on each side to furnish oxygen to the flame. (As an example, see Figure 1.)

1.1.2.2 Test Pan -- The test pan is constructed on the surface of the ground. The applicable dimensions are obtained and earth is elevated around this perimeter to form a mound of approximately 8 to 12 inches in height. Polyethylene is then placed over the pan and mounded walls. (As an example, see Figure 2.)

1.1.3 Flame Surface -- To ensure a level surface for the flame, water should be used to completely cover the bottom of the pit or pan before the fuel is added.

1.1.4 Fuel Specifications -- Fuel to be used should be JP-5 aircraft fuel when available. JP-4 aircraft fuel as an alternate.

1.1.4.1 Quantity of Fuel -- The quantity of fuel used should be sufficient to cause a reaction of the ordnance being tested, or ensure a fifteen minute fire, whichever is shorter. (For example: 1600 gallons of fuel in the 25 ft sq. test pit or pan and 2000 gallons of fuel in the 35 ft. sq. test pit or pan, will sustain a fire for approximately fifteen minutes.)

1.1.4.2 Fuel Ignition -- To ensure fuel ignition in a minimum time, twenty gallons of gasoline and/or one gallon ether should be added after the fuel is poured. Maximum pit or pan size requires an addition of thirty gallons of gasoline and/or one gallon of ether.

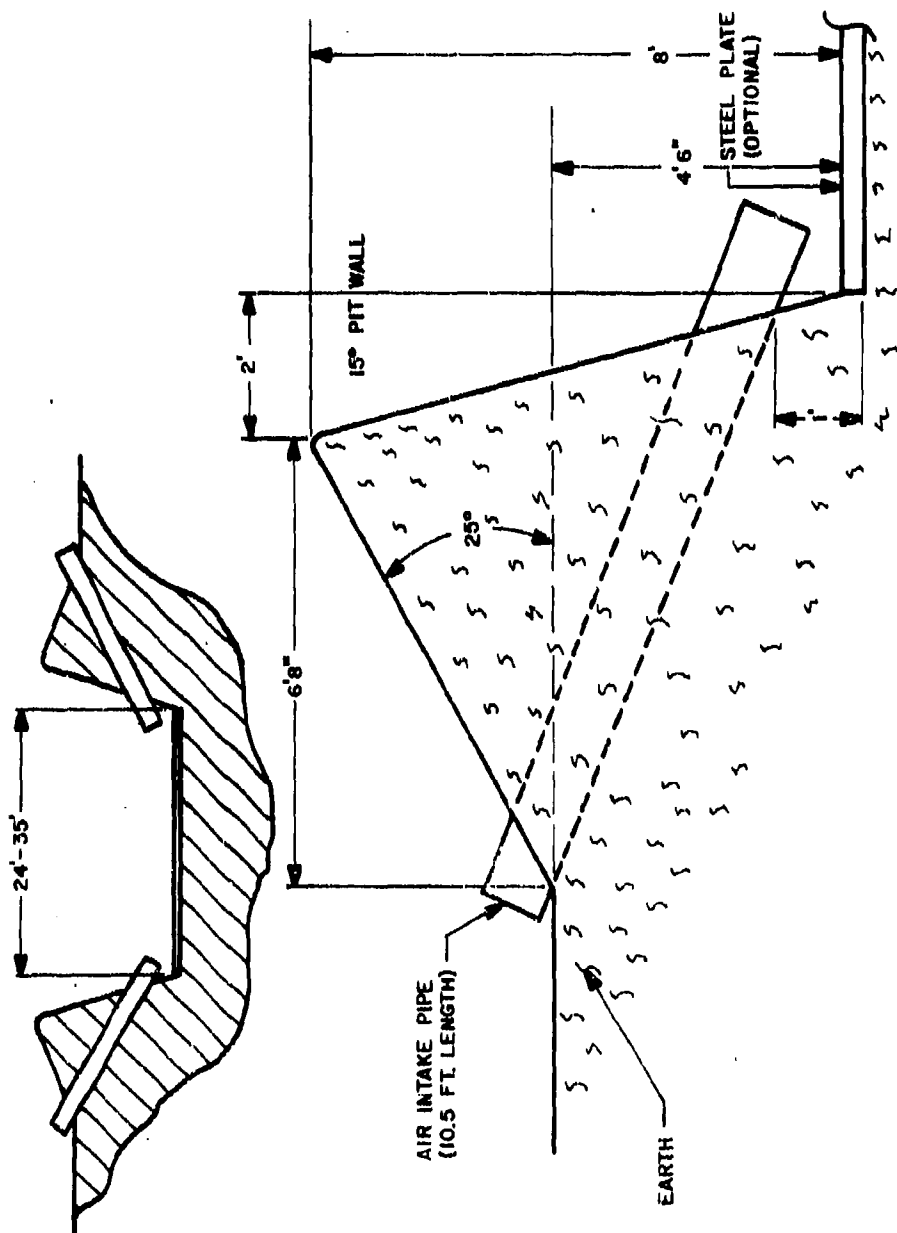


FIGURE A-1

Test Pit

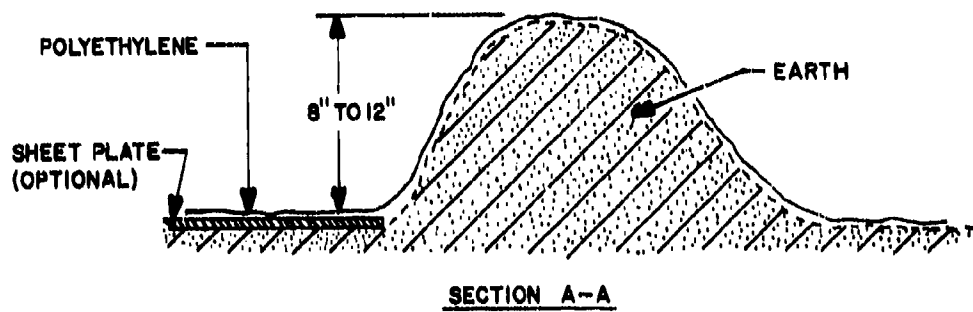
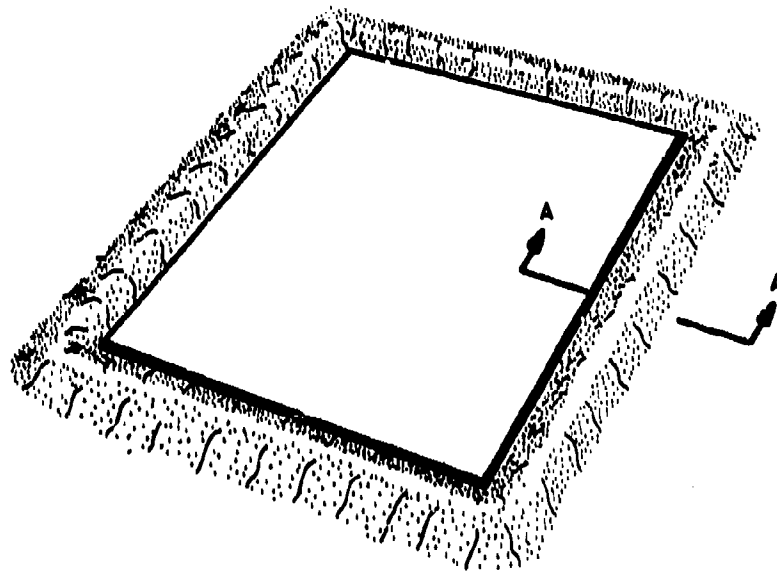


FIGURE A-2

1.1.4.3 Uniformity of Fuel Ignitions – A flame-producing device should be used to initiate the fire. Such devices as thermite grenades with blasting caps, squib or powder bags, etc. may be used. These devices should be located in at least the four corners of the pit or pan to initiate burning over the entire fuel surface as rapidly as possible and should be electrically or remotely ignited from a sheltered area.

1.1.4.4 Flame Buildup – The flame buildup time to 1000°F should not exceed thirty seconds.

1.1.5 Weather Conditions (Test Pit Only) – For a test pit, a wind of 20 knots or less measured within 1000 feet of the test site is acceptable.

1.1.5.1 Weather Conditions (Test Pan Only) – For a test pan, a variable wind of up to 3 knots measured within 1000 feet of the test site is acceptable.

1.1.6 Average Flame Temperature – An average flame temperature of 1650°F or greater at the test item(s) will be considered a good test. This temperature is determined by averaging the flame temperature from the time the flame reaches 1000°F until it drops below 1000°F or until (in the case of live ordnance) there is a reaction from the item(s) being tested.

1.2 TEST ITEM(S) PLACEMENT

1.2.2 Height of Test Item(s) (Live and/or Inert) Above Fuel - The minimum height a test item(s) should be suspended (measured from the item(s) centerline) above the fuel surface is between thirty-six and sixty-six inches.

1.2.2 Suspension of Test Item(s) – The test item(s) should be suspended by the lugs (if applicable) used to attach to the aircraft. The centerline of the item(s) should be parallel to the fuel surface and centered in the test pit or pan.

1.2.2.1 Test Stand – Test support stand should be of such construction as to withstand the fire environment and support the ordnance under test for the duration of the test.

1.2.3 Test Item(s) Configuration – The following configurations are to be used:

- a. All-up round; i.e., including operational fuzes and fin assembly.
- b. Inert fuzes and no fin assembly.
- c. Additional operational configurations as required.

1.3 INSTRUMENTATION

1.3.1 **Thermocouple Locations (External)** — A minimum of four iron-constant or chromel-alumel external thermocouples should be located in a horizontal plane coincidental with the centerline of the test item(s), spaced equally around the test item(s), one at each end and one at each side. These should be one to six inches from the surface of the test item(s).

1.3.1.1 **Thermocouple Locations (Internal)** — Internal thermocouples are located wherever necessary to obtain an accurate time-temperature history and accessibility permits.

1.3.2 **Time Records** — Complete time-to-event histories of each test will be kept. This record may be obtained from the thermocouple records, providing a continuous thermocouple recording is used. Ignition of the fuel will serve as zero time. When the temperature of the fire first exceeds 1000°F (as measured by one or more of the external thermocouples) is the time at which the test item(s) is considered engulfed in flame.

1.3.3 **Camera Coverage** — Color motion picture cameras should be used to cover each test. These cameras should be set up in such a location as to cover the test from at least two directions (90° apart). A normal (25 fps) and a high frame rate (48-200 fps) camera may be used to provide coverage. Still cameras are also used for documentary purposes.

1.3.4 **Pressure Measurements** — Pressure measurements may be taken to aid in determining the severity of the reaction(s) that occurs.

1.4 **DATA SHEET** — A complete data sheet describing the item under test, test configuration, weather conditions and test results should be kept.

1.5 **DEFINITION OF REACTIONS FOR EXPLOSIVE ORDNANCE AND ROCKET MOTORS** — These definitions are defined in NAVORD OP 5, Vol. 1, Third Revision and are repeated here:

A. **Detonation (cook-off)**. Munition performs in design mode. Maximum possible air shock formed. Essentially all of case 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.

B. ***Partial Detonation (cook-off).*** 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 extend of breakup of case into small fragments increase with increasing amount of explosive that 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.

C. ***Explosion (cook-off).*** 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 of carrier if munition is large bomb.

D. ***Deflagration (cook-off).*** 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.

APPENDIX B

BOMB FAST COOK-OFF PHASE 1

Test No. P1-1

Data Sheet

Device Tested: M117, 750 lb. bomb containing cavity hot-melt and H-6 explosive load; configured with a M904E2 nose fuze, T45E7 adapter booster, M990E1 base fuze and M131 low drag fin assembly.

Date of Test: 15 August 1967.

Bomb Position: 8 feet at the centerline above fuel surface.

Fuel: 2000 gallons of JP-5 jet aircraft fuel.

Pan Size: 20 X 30 feet.

Test Fire: The M117 bomb was seldom engulfed in flame due to fluctuation wing conditions.

Results: At 2 minutes 25 seconds after start of fire, the bomb deflagrated throwing the nose fuze about 100 feet forward of the bomb. The tail fuze was found 30 feet on the starboard side of the bomb. Evidently it was expelled, struck the test stand then glanced to this position. Examination revealed that the tail fuze had burned. The remainder of the bomb and unreacted explosive was found in the test pan. Figure B-1 is a post-test photograph of the nose and tail fuze, base plate and a portion of the bomb body.



FIGURE B-1

Nose and Tail Fuzes, Base Plate and a Portion of the M117 Bomb Body
Received After Fast Cook-Off Test No. P1-1

BOMB FAST COOK-OFF PHASE 1

Test No. P1-2

Data Sheet

Device Tested: MARK 81, 250 lb. bomb containing cavity hot-melt and H-6 explosive load; configured with a M904E2 nose fuze, T45E7 adapter booster, M990E1 tail fuze and conical tail fin assembly.

Date of Test: 15 August 1967.

Bomb Position: 8 feet at the centerline above fuel surface.

Fuel: 800 gallons of JP-5 aircraft fuel.

Pan Size: 25 X 16 feet.

Test Fire: The MARK 81 bomb was engulfed in flame 45 seconds after start of fire. The one thermocouple used to record flame temperature averaged 1000°F for the duration of the test.

Results: At 3 minutes 0 seconds after start of fire the bomb deflagrated. Large pieces of the bomb and unreacted explosive were scattered up to 60 feet distance from the test stand. At 7 minutes $\pm$ 5 seconds, the nose fuze deflagrated tossing a section of the bomb (with part of the fuze still attached) approximately 60 feet from the test pan. See Figure B-2 for a post-test view of the bomb body.



FIGURE B-2

A Section of the MARK 81 Bomb With the Nose Fuze and Booster Still Attached,
Found 60 Feet From Ground Zero After Fast Cook-Off Test No. P1-2

BOMB FAST COOK-OFF PHASE1

Test No. P1-3

Data Sheet

Device Tested: MARK 82, 500 lb. bomb containing cavity hot-melt and H-6 explosive load; configured with a M904E2 nose fuze, T45E7 adapter booster, M990E1 tail fuze and conical tail fin assembly.

Date of Test: 16 August 1967.

Bomb Position: 8 feet at the centerline above fuel surface.

Fuel: 1000 gallons of JP-5 jet aircraft fuel.

Pan Size: 18 X 35 feet.

Test Fire: The MARK 82 bomb was engulfed in flame 10 seconds after start of fire. The one thermocouple used to record flame temperature averaged 900°F for the duration of the test.

Results: At 4 minutes 0 seconds after start of fire the bomb deflagrated. Pieces of the bomb, bomb components and unreacted explosive were scattered up to 200 feet from the test site. At the time of reaction, a thermocouple located on the outside skin at the top of the bomb was reading 150°F. A second thermocouple under the tail fin assembly (on tail fin interface) was reading 215°F.

At 7 minutes 15 seconds, a second reaction was observed. The nose fuze/adapter booster, appeared to have partially detonated resulting in bomb nose damage as shown in Figure B-3.



FIGURE B-3

Forward Section of the MARK 82 Bomb After Fast Cook-Off Test No. P1-3
Notice the Condition of the Nose Section Indicating a Partial Detonation of the Nose Fuze/Adapter Booster.

BOMB FAST COOK-OFF PHASE 1

Test No. P1-4

Data Sheet

Device Tested: MARK 83, 1000 lb. bomb containing cavity hot-melt and H-6 explosive load; configured with a M904E2 nose fuze, T45E7 adapter booster, M990E1 tail fuze and conical tail fin assembly.

Date of Test: 16 August 1967.

Bomb Position: 8 feet at the centerline above fuel surface.

Fuel: 1000 gallons of JP-5 jet aircraft fuel.

Pan Size: 35 X 35 feet.

Test Fire: The MARK 83 bomb was engulfed in flames 9 seconds after start of fire. The one thermocouple used to record flame temperature averaged 1200°F for the duration of the test.

Results: At 2 minutes 55 seconds after start of fire, the bomb deflagrated. Portions of the bomb and unreacted explosive were scattered up to 250 feet from the test site. At the time of reaction thermocouples located on the rear fuze and tail fin interface had reached flame temperature.

At 8 minutes 15 seconds a second reaction was observed. The nose fuze/adapter booster, which were propelled 10 feet from the test site after the initial reaction, detonated.

The tail section was recovered with the burned out tail fuze still in position as shown in Figure B-4.



FIGURE B-4

**Tail Section of the MARK 83 Bomb After Fast Cook-Off Test No. P1-4
Notice the Burned Out Tail Fuze Still in Position.**

BOMB FAST COOK-OFF PHASE 1

Test No. P1-5

Data Sheet

Device Tested: AN-M65, 1000 lb. bomb containing cavity hot-melt and TNT explosive load; configured with a M904E2 nose fuze, base plug and T142 conical tail fin assembly.

Date of Test: 17 August 1967.

Bomb Position: 8 feet at the centerline above fuel surface.

Fuel: 1000 gallons of JP-5 jet aircraft fuel.

Pan Size: 35 X 35 feet.

Test Fire: The AN-M65 bomb was engulfed in flames 15 seconds after start of fire. The one thermocouple used to record flame temperature averaged 700°F for the duration of the test.

Results: At 4 minutes 5 seconds after start of fire, the bomb exploded. Large and small portions of the bomb (Figure B-5) and unreacted explosive were scattered up to 250 feet from the test site. At the time of reaction a thermocouple located on the bomb's outer skin was reading 340°F; at the tail fin interface the temperature was 330°F and 200°F at the base plug.

No other reactions were observed.



FIGURE B-5

Pieces of the AN-M65 GP Bomb That Were Recovered After Fast Cook-Off Test No. P1-5.

BOMB FAST COOK-OFF PHASE 1

Test No. P1-6

Data Sheet

Device Tested: M117, 750 lb. bomb without cavity hot-melt, containing TRITONAL explosive load; configured with a M904E2 nose fuze, T45E7 adapter booster and base plug. No tail fin assembly was employed.

Date of Test: 17 August 1967.

Bomb Position: 8 feet at the centerline above fuel surface.

Fuel: 1000 gallons of JP-5 jet aircraft fuel.

Pan Size: 35 X 35 feet.

Test Fire: The M117 bomb was engulfed in flames 12 seconds after start of fire. The one thermocouple used to record flame temperature averaged 1400°F for the duration of the test.

Results: At 2 minutes 55 seconds after start of fire, the bomb reacted in a partial detonation. Small fragments and large portions of the bomb were scattered over a large area. A section of the base fuze adapter was located 300 feet from the test site. Damage to the test pan is shown in Figure B-6.



FIGURE B-6

The Test Pan After Fast Cook-Off Test No. P1-6
Notice the Large Holes Made by Partial Detonation of the M117 Bomb.

BOMB FAST COOK-OFF PHASE 1A

Test No. P1A-1

Data Sheet

Device Tested: AN-M65, 1000 lb. bomb containing cavity hot-melt and Comp-B explosive load; configured with a M904E2 nose fuze, simulated adapter booster tail plug, and box tail fin assembly.

Date of Test: 23 August 1967.

Bomb Position: 8 feet at the centerline above fuel surface as shown in Figure B-7.

Fuel: 1000 gallons of JP-5 aircraft fuel.

Pan Size: 35 X 35 feet.

Test Fire: The AN-M65 bomb was engulfed in flame 36 seconds after start of fire. The one thermocouple used to record flame temperature averaged 1700°F for the duration of the test.

Results: At 1 minute 25 seconds after start of fire, the bomb detonated. Some of the fragments recovered after the test are pictured in Figure B-8. Witness panels placed adjacent to the bomb contained from 60 to 600 fragment holes per panel and were blown 150 to 250 feet from their original position. Some of the fragment holes in one of the 10 panels used are shown in Figure B-9.



FIGURE B-7

An AN-M65 Bomb as Configured for Phase 1A Fast Cook-Off Tests

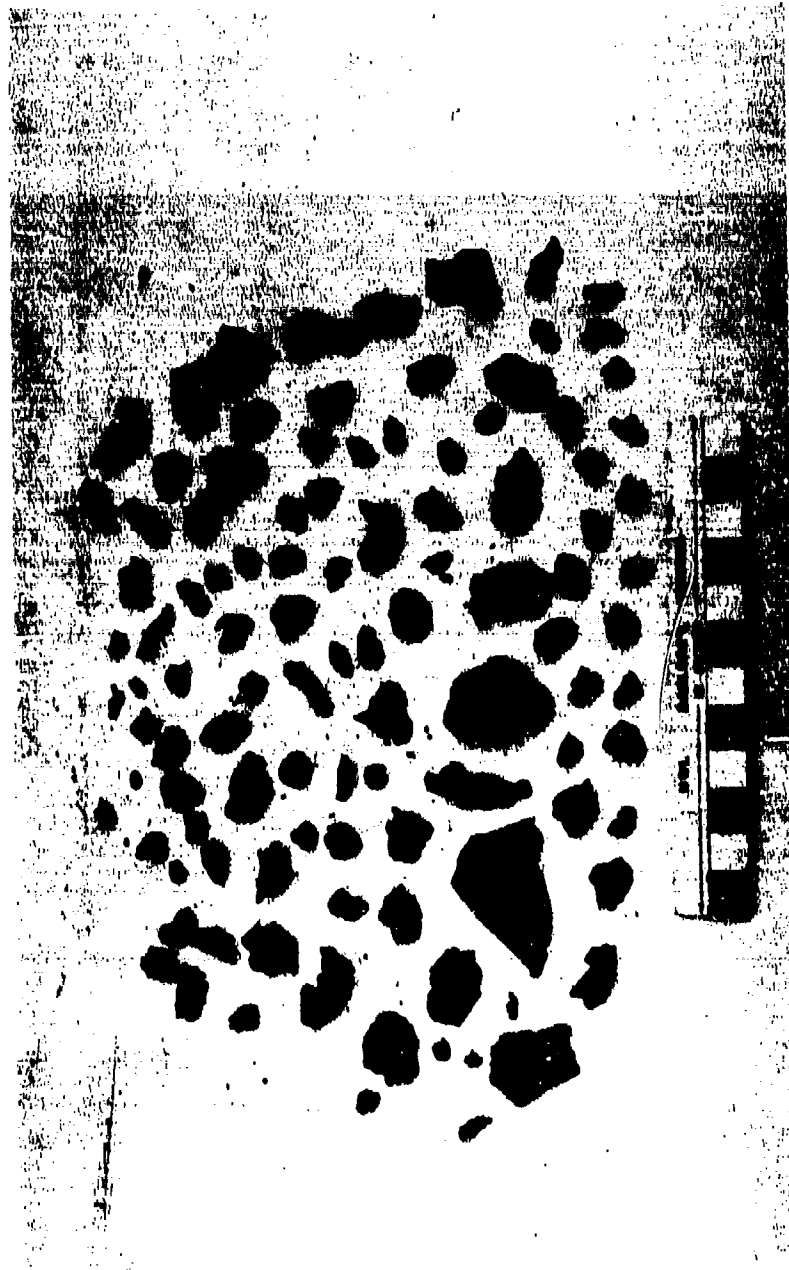


FIGURE B-8

Some of the Fragments Recovered After Fast Cook-Off Test No. PA1-1



FIGURE B-9

A Section of the Witness Panels Showing Fragment Holes Created
When the An-M65 Bomb Detonated in Fast Cock-Off Test No. P1A-1

BOMB FAST COOK-OFF PHASE 1A

Test No. P1A-2

Data Sheet

Device Tested: AN-M65, 1000 lb. bomb containing cavity hot-melt and Comp-B explosive load; configured with a M904E2 nose fuze, simulated adapter booster; tail fuze plug, and box tail fin assembly.

Date of Test: 28 August 1967.

Bomb Position: Bottom of bomb touching the fuel surface.

Fuel: 1000 gallons of JP-5 jet aircraft fuel.

Pan Size: 8 X 12 feet.

Test Fire: The AN-M65 bomb was engulfed in flames 12 seconds after start of fire. The one thermocouple used to record flame temperature averaged 1000°F for the duration of the test.

Results: At 2 minutes 10 seconds after start of fire, the bomb detonated leaving a crater 10 feet in diameter and 6 feet deep on the outer rim. Pictured in Figure B-10 is an overall view of the crater rim.



FIGURE B-10

Outer Rim of the Crater Left After the AN-M65 Bomb Detonated During
Fast Cook-Off Test No. P1A-2

BOMB FAST COOK-OFF PHASE 1A

Test No. P1A-3

Data Sheet

Device Tested: MARK 81, 250 lb. bomb containing cavity hot-melt and Comp-B explosive load; configured with a M904E2 nose fuze, T45E4 adapter booster, tail plug, and conical tail fins.

Date of Test: 14 August 1968.

Bomb Position: 3-1/2 feet at the centerline above fuel surface.

Fuel: 1000 gallons of JP-5 jet aircraft fuel.

Pan Size: 20 X 18 feet.

Test Fire: The MARK 81 bomb was engulfed in flames 45 seconds after start of fire.

Results: At 2 minutes 15 seconds after start of fire, the bomb exploded. Parts of the bomb that were recovered are shown in Figure B-11.

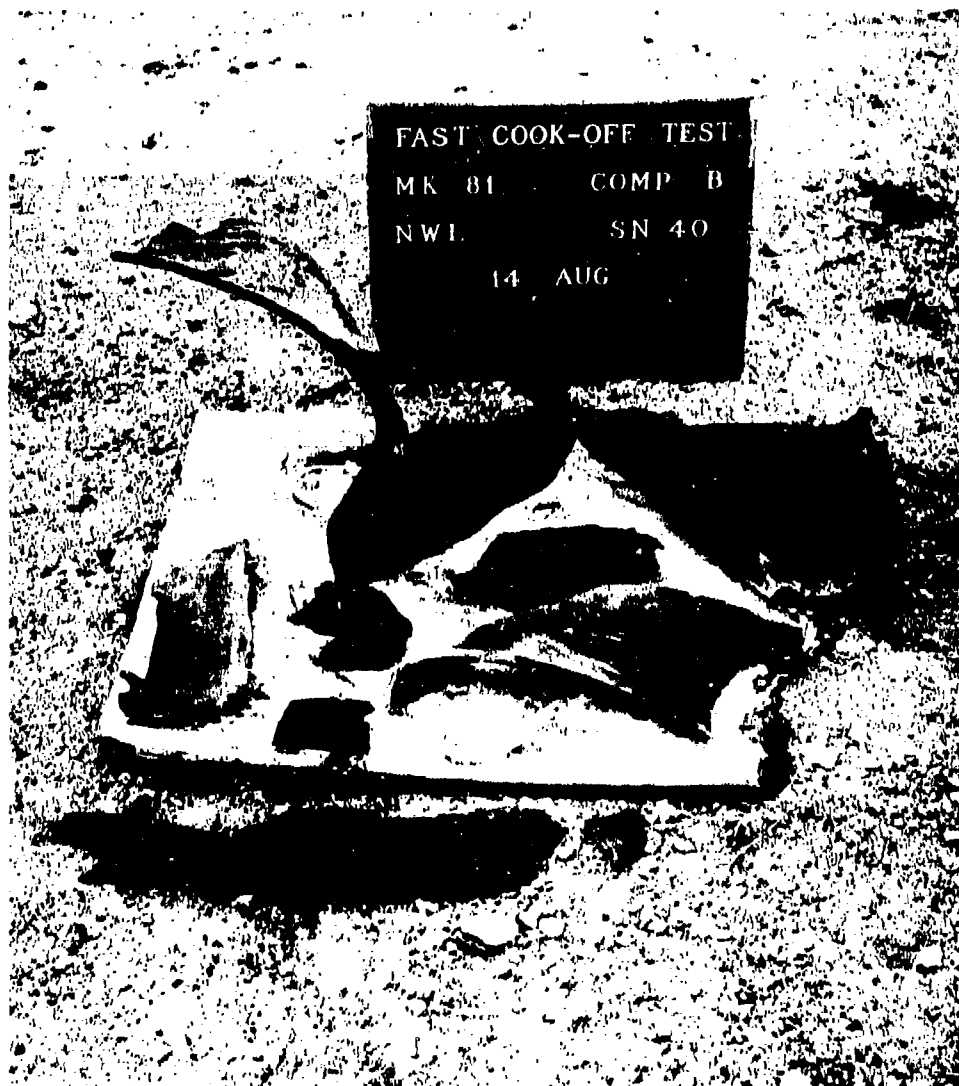


FIGURE B-11

Parts of the Comp-B Loaded MARK 81 Bomb Recovered After Exploding
During Fast Cook-Off Test No. P1A-3

BOMB FAST COOK-OFF PHASE 1A

Test No. P1A-4

Data Sheet

Device Tested: MARK 81, 250 lb. bomb containing cavity hot-melt and Comp-B explosive load; configured with a M904E2 nose fuze, T45E4 adapter booster, tail fuze plug, and conical tail fins.

Date of Test: 22 August 1968

Weather Conditions: Clear with 3-6 knot wind.

Bomb Position: 3-1/2 feet at the centerline above fuel surface.

Fuel: 1000 gallons of JP-5 jet aircraft fuel.

Pan Size: 20 X 18 feet.

Test Fire: The MARK 81 bomb was engulfed in flames 30 seconds after start of fire.

Results: At 1 minute 55 seconds after start of fire the bomb exploded. Nose fuze/adapter booster and nose section of the bomb were recovered after the test and are shown in Figure B-12. The fuze/booster combination did not react.



FIGURE B-12

Nose Fuze/Adapter Booster and Nose Section of the MARK 81 Comp-B Loaded Bomb
Recovered After Fast Cook-Off Test No. P1A-4

BOMB FAST COOK-OFF PHASE 1A

Test No. P1A-5

Data Sheet

Device Tested: M117, 750 lb. bomb containing cavity hot-melt and Comp-B explosive load; configured with a M904E2 nose fuze, T45E4 adapter booster, tail fuze plug and conical tail fins.

Date of Test: 15 August 1968.

Weather Conditions: Clear, temperature 85°F with 2-6 knot wind.

Bomb Position: 3-1/2 feet at the centerline above fuel surface.

Fuel: 1000 gallons of JP-5 jet aircraft fuel.

Pan Size: 20 X 18 feet.

Test Fire: The M117 bomb was engulfed in flames 30 seconds after start of fire.

Results: At 2 minutes 0 seconds after start of fire, the bomb detonated as evidenced by fragment holes and markings on a portion of the test stand recovered, Figure B-13. Many fragments were recovered. The test site was destroyed by the reaction.

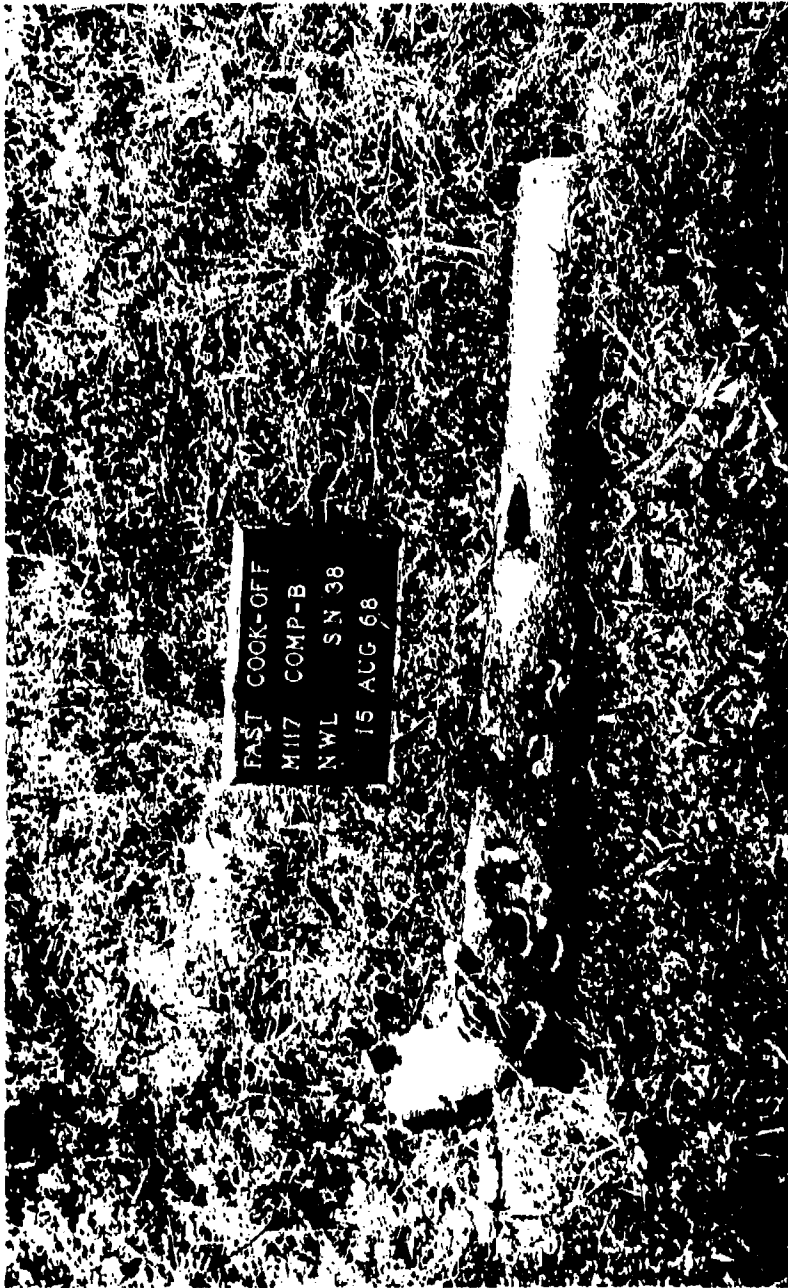


FIGURE B-13

A Portion of the Test Stand Recovered After Fast Cook-Off Test No. P1A-5
Notice the Fragment Holes and Marking Denoting a Detonation

BOMB FAST COOK-OFF PHASE 1A

Test No. P1A-6

Data Sheet

Device Tested: M117, 750 lb. bomb containing cavity hot-melt and Comp-B explosive load; configured with a M904E2 nose fuze, T45E4 adapter booster, tail fuze plug, and conical tail fins.

Date of Test: 30 August 1968.

Weather Conditions: Clear, temperature 70°F with 2-4 knot wind.

Bomb Position: 3-1/2 feet at centerline above the fuel surface.

Fuel: 1000 gallons of JP-5 jet aircraft fuel.

Pan Size: 20 X 18 feet.

Test Fire: The M117 bomb was engulfed in flames 35 seconds after start of fire.

Results: At 2 minutes 14 seconds after start of fire, the bomb detonated. The witness panels and test site were destroyed as evidenced in Figure B-14.

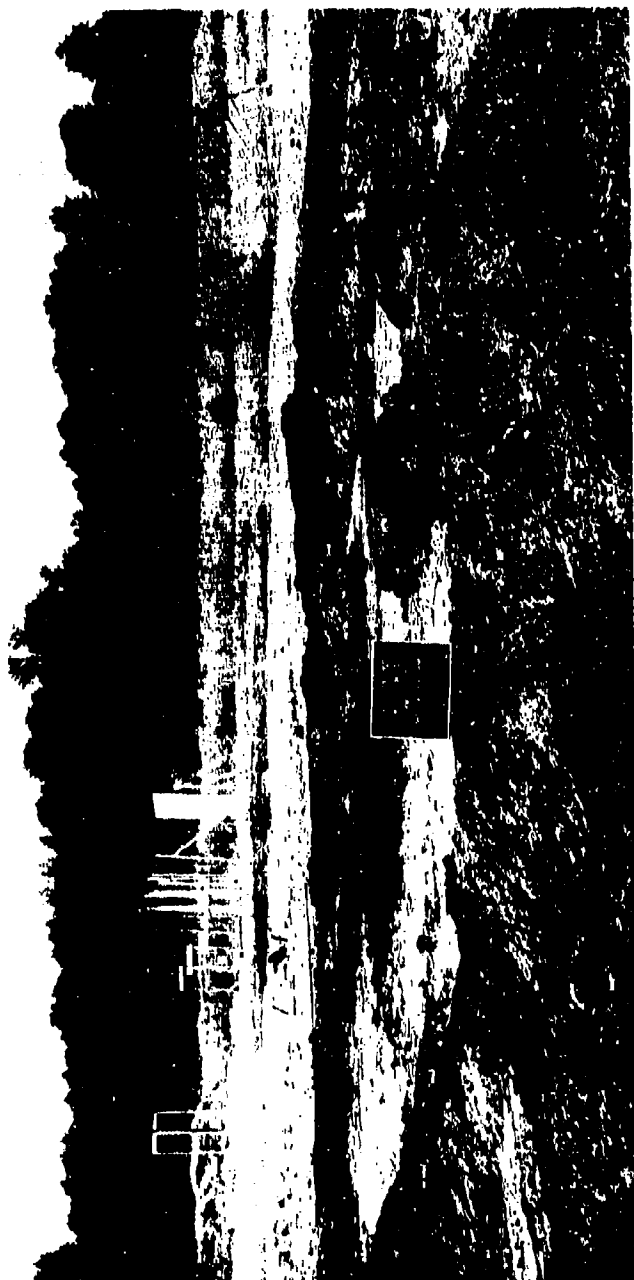


FIGURE B-14

Test Site After Fast Cook-Off Test No. P1A-6
Notice Destruction of the Witness Panels and Damage to the Test Site

APPENDIX C

BOMB FAST COOK-OFF PHASE 2

Test No. P2-1

Data Sheet

Device Tested: M117, 750 lb. instrumented bomb loaded with H-6 explosive; configured with a nose fuze plug, tail fuze plug and conical tail fins.

Date of Test: 7 February 1968.

Weather Conditions: Clear with 0-3 knot wind.

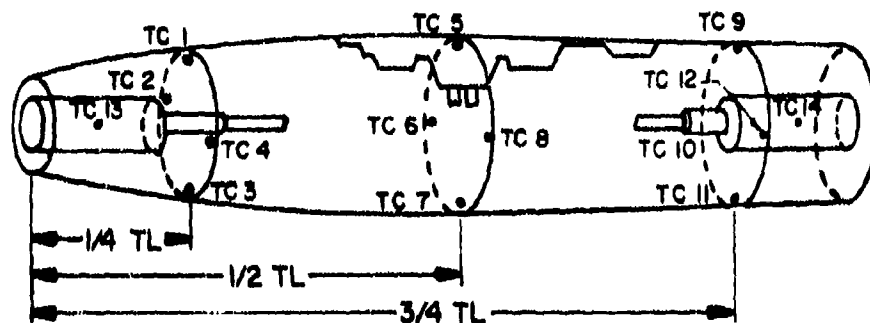
Bomb Position: 3-1/2 feet at the centerline above fuel surface.

Fuel: 500 gallons of JP-5 jet aircraft fuel.

Pan Size: 20 X 20 feet.

Test Fire: The M117 bomb was engulfed in flames 60 seconds after start of fire.

Results: At 3 minutes 35 seconds after start of fire, the bomb deflagrated. An overpressure of 1.8 psi was recorded 50 feet from the test site. Some unreacted explosive was found in the immediate area. A maximum temperature rise rate of 3.4°F/sec was recorded in the aft section of the bomb. Thermocouple locations are shown in Figure C-1 and complete time-temperature data are presented in Table C-1. A portion of the nose section recovered after the test is pictured in Figure C-2.



THERMOCOUPLES ARE LOCATED BETWEEN THE HOT MELT AND METAL CASE
 TL - TOTAL LENGTH OF BOMB

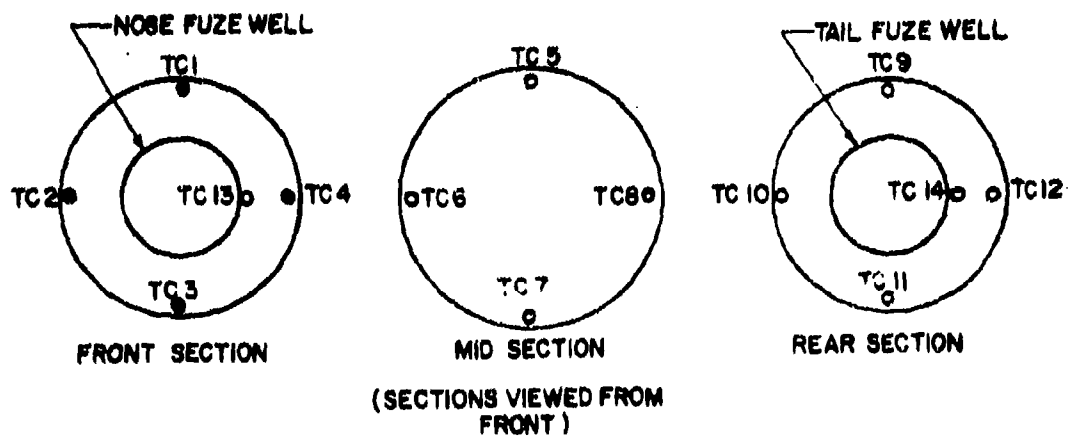


FIGURE C-1

Location of the Iron Constantan Thermocouples in Bombs Tested
 for Phase 2 of the Bomb Survivability in Fire Program

TABLE C-1
THERMOCOUPLE TEMPERATURE AND TIME DATA
FOR M117 BOMB TEST NO. P2-1

(Thermocouple Locations Are Given In Figure C-1)

Time (sec)	Thermocouple Number ¹											
	2	3	4	5	6	7	8	9	10	11	12 ²	13
	Temperature °F											
0-40	75	85	50	75	50	175	170	105	125	185	135	75
80	100	145	85	100	85	295	245	160	165	250	245	85
120	137	195	110	112	85	295	255	205	210	295	365	110
160	137	290	120	125	100	350	280	275	260	315	495	115
180	160	315	145	125	125	365	315	315	295	360	565	135
215 ³	170	330	160	125	370	375	320	315	300	365	565	137

¹ Thermocouple No. 1 data not listed because of very little temperature rise.

² Thermocouple used in calculating the maximum temperature rise rate of 3.4° F/sec.

³ Time of reaction.



FIGURE C-2

Nose Section of the M117 Bomb After Deflagration During Fast Cook-Off Test No. P2-1

BOMB FAST COOK-OFF PHASE 2

Test No. P2-2

Data Sheet

Device Tested: M117, 750 lb. instrumented bomb loaded with H-6 explosive; configured with nose plug, M990E1 tail fuze and conical tail fins.

Date of Test: 13 February 1968.

Weather Conditions: Clear with 0-4 knot wind.

Bomb Position: 3-1/2 feet at the centerline above fuel surface.

Fuel: 400 gallons of JP-5 jet aircraft fuel.

Pan Size: 20 X 20 feet.

Test Fire: The M117 bomb under test was engulfed in flames 30 seconds after start of fire and remained so for the duration of the test.

Results: At 3 minutes 20 seconds after start of fire the bomb deflagrated. An overpressure of .68 psi, 50 feet from the bomb was recorded. A maximum temperature rise rate of 3.9°F/sec was recorded in the bomb's tail section. Additional time-temperature data are presented in Table C-2 and a post test photograph is shown in Figure C-3.

TABLE C-2

THERMOCOUPLE TEMPERATURE AND TIME DATA
FOR M117 BOMB TEST NO. P2-2

(Thermocouple Locations Are Given In Figure C-2)

Time (sec)	Thermocouple Number ¹											
	2	3	4	5	6	7	8	9	10	11	12 ²	13
	Temperature °F											
0-40	50	50	50	50	50	60	50	50	70	70	50	50
80	100	125	50	130	90	175	205	130	155	245	150	50
120	195	200	78	230	150	260	240	225	275	315	230	65
160	280	285	105	330	200	390	315	400	360	390	305	65
190	330	335	142	415	248	435	385	495	370	485	385	65
200 ³	360	380	150	430	265	435	395	495	400	485	385	65

¹ Thermocouple No. 1 data are not listed because of very little temperature rise.

² Thermocouple used in calculating the maximum temperature rise rate of 3.9°F/sec.

³ Time of reaction.



FIGURE C-3

M117 Bomb After Test No. P2-2. Notice the Horizontal Split
That Generally Results When a Pressure Rupture Occurs

BOMB FAST COOK-OFF PHASE 2

Test No. P2-3

Data Sheet

Device Tested: M117, 750 lb. bomb loaded with H-6 explosive; configured with a M904E2 nose fuze, T45E4 adapter booster, M990E1 tail fuze and conical tail fins.

Date of Test: 5 April 1968.

Weather Conditions: Cloudy with no wind.

Bomb Position: 3-1/2 feet at the centerline above fuel surface.

Fuel: 1000 gallons of JP-5 jet aircraft fuel.

Pan Size: 20 X 20 feet.

Test Fire: The M117 bomb was engulfed in flames 50 seconds after start of fire. Because of no wind, the flames were directed straight up.

Results: At 3 minutes 35 seconds after start of fire, the bomb deflagrated and is shown in Figure C-4. Some unreacted explosive was scattered around the immediate area. The nose fuze and adapter booster were recovered in an unreacted condition (Figure C-5). The tail fuze was not recovered and there was no indication that it had reacted. Thermocouple instrumentation was lost 106 seconds into the test, consequently, no time-temperature data are presented.



FIGURE C-4

The M117 Bomb After Test No. P2-3

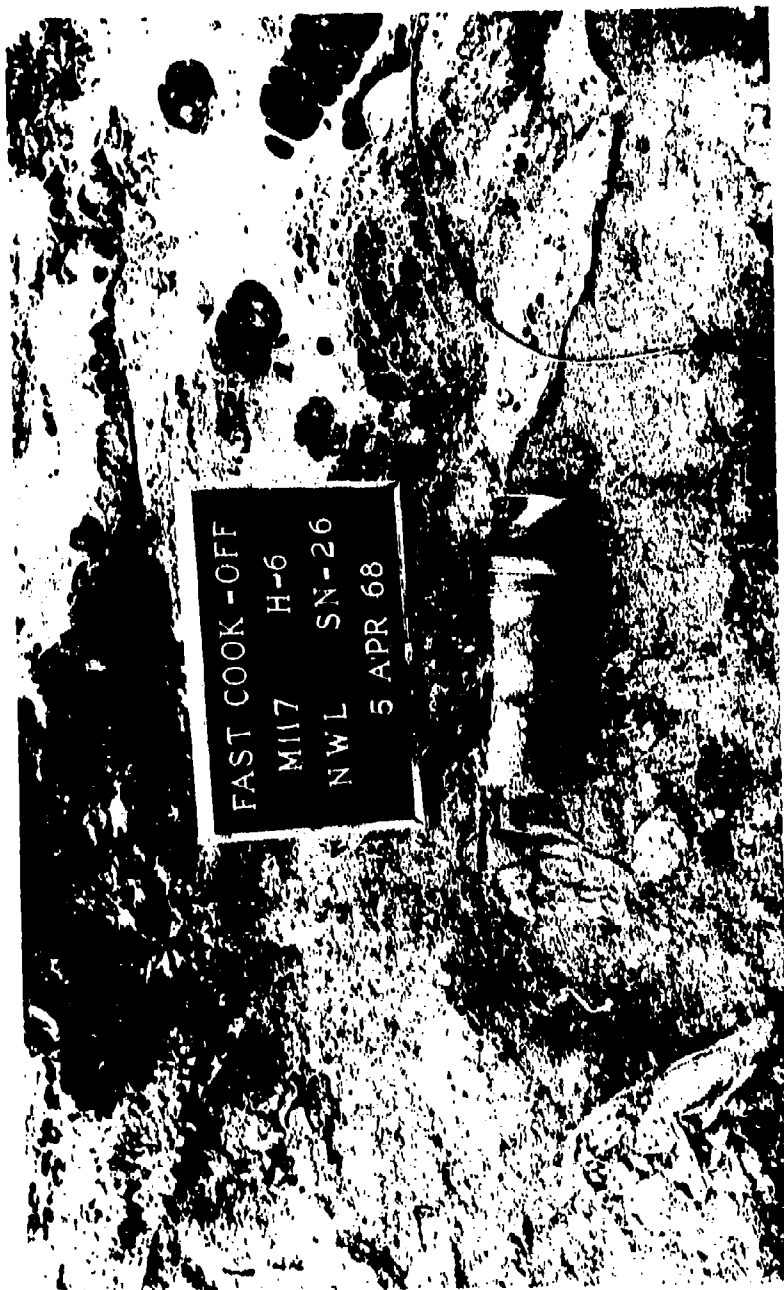


FIGURE C-5

The Unreacted Nose Fuze and Adapter Booster Recovered After Test No. P2-3

BOMB FAST COOK-OFF PHASE 2

Test No. P2-4

Data Sheet

Device Tested: M117, 750 lb. bomb loaded with TRITONAL explosive; configured with nose fuze plug, tail fuze plug and conical tail fins.

Date of Test: 9 February 1968.

Weather Conditions: Broken clouds with 0-3 knot wind.

Bomb Position: 3-1/2 feet at the centerline above fuel surface.

Fuel: 400 gallons of JP-5 jet aircraft fuel.

Pan Size: 20 X 20 feet.

Test Fire: The M117 bomb was engulfed in flames 20 seconds after start of fire and remained engulfed to reaction.

Results: At 2 minutes 55 seconds after start of fire the bomb deflagrated. An overpressure of 1.8 psi was recorded 50 feet from the test site. No fragments were produced and unreacted explosive was scattered around the test site. Large pieces of the bomb were found 50 feet from the point of reaction and are shown in Figures C-6 and C-7.



FIGURE C-6

Nose Section of the M117 Bomb After Fast Cook-Off Test No. P2-4



FIGURE C-7

Parts of the Tail Fin and Aft Plate

Also Shown Are Chunks of Unreacted Explosive After Fast Cook-Off Test No. P2-4.

BOMB FAST COOK-OFF PHASE 2

Test No. P2-5

Data Sheet

Device Tested: M117, 750 lb. instrumented bomb loaded with TRITONAL explosive; configured with a nose fuze plug, M990E1 tail fuze and conical tail fins.

Date of Test: 15 February 1968.

Weather Conditions: Broken clouds with 0-5 knot wind.

Bomb Position: 3-1/2 feet at the centerline above fuel surface.

Fuel: 400 gallons of JP-5 jet aircraft fuel.

Pan Size: 20 X 20 feet.

Test Fire: The M117 bomb was engulfed in flames 37 seconds after start of fire. Engulfment was intermittent because of fluctuating wind conditions.

Results: At 3 minutes 27 seconds the bomb deflagrated. Overpressures of from .35 to .54 psi were recorded 50 feet from the reaction. No fragments were produced and all parts of the bomb were found in the test pan. Unreacted explosive was scattered around the area. The bomb body after test is shown in Figure C-8 and the unreacted tail fuze in Figure C-9. Time-temperature data are presented in Table C-3.



FIGURE C-8

Body of the M117 Bomb After Fast Cook-Off Test No. P25



FIGURE C-9

The Unreacted M990E1 Tail Fuze Recovered After Fast Cook-Off Test No. P2-5

TABLE C-3

**THERMOCOUPLE TEMPERATURE AND TIME DATA
FOR M117 BOMB TEST NO. P2-5**

(Thermocouple Locations Are Given In Figure C-1)

Time (sec)	Thermocouple Number ¹								
	4	6	7	8	9 ²	10	11	12	13
	Temperature °F								
0-30	50	70	125	85	110	70	50	50	50
40	50	90	162	115	140	120	200	180	70
80	50	130	275	200	250	230	345	190	80
120	75	170	365	280	355	270	445	190	90
160	85	220	485	345	435	370	560	240	100
170	85	230	520	365	465	390	580	420	100
207 ³	95	250	590	380	525	450	525	370	130

¹Data from thermocouple Nos. 1, 2, 3, 5 and 14 are not listed because of very little temperature rise.

²Thermocouple used in calculating the maximum temperature rise rate of 3.3° F/sec.

³Time of reaction.

BOMB FAST COOK-OFF PHASE 2

Test No. P2-6

Data Sheet

Device Tested: M117, 750 lb. instrumented bomb loaded with TRITONAL explosive; configured with a M904E2 nose fuze, T45E7 adapter booster, M990E1 tail fuze and conical tail fins.

Date of Test: 3 April 1968.

Weather Conditions: Clear with 0-5 knot wind.

Bomb Position: 3-1/2 feet at the centerline above fuel surface.

Fuel: 800 gallons of JP-5 jet aircraft fuel.

Pan Size: 24 X 24 feet.

Test Fire: The M117 bomb was engulfed in flames 72 seconds after start of fire. Engulfment was intermittent because of fluctuating wind conditions.

Results: At 4 minutes 10 seconds after start of fire, the bomb deflagrated. No fragments were produced. Unreacted explosive was scattered around the test site. Neither the fuzes nor the adapter booster reacted. Time-temperature data are presented in Table C-4.

TABLE C-4
THERMOCOUPLE TEMPERATURE AND TIME DATA
FOR M117 BOMB TEST NO. P2-6

(Thermocouple Locations Are Given In Figure C-1)

Time (sec)	Thermocouple Number ¹						
	5	6	7	8	10	11 ²	12
	Temperature °F						
0-50	65	65	68	65	65	85	60
.80	75	88	105	85	100	135	80
120	135	145	180	145	190	245	225
160	180	230	280	215	260	315	325
200	210	260	415	295	365	388	410
240	225	438	655	360	430	525	460
250 ³	232	445	655	340	400	530	440

¹ Data from thermocouple Nos. 1, 2, 3, 4, 13 and 14 are not listed because of very little temperature rise.

² Thermocouple used in calculating the maximum temperature rise rate of 4.0°F/sec.

³ Time of reaction.

BOMB FAST COOK-OFF PHASE 2

Test No. P2-7

Data Sheet

Device Tested: MARK 81, 250 lb. instrumented bomb loaded with H-6 explosive; configured with a M904E2 nose fuze, T45E7 adapter booster, tail fuze plug, and conical tail fins.

Date of Test: 6 March 1968.

Weather Conditions: Clear with steady 2 knot wind.

Bomb Position: 3-1/2 feet at the centerline above fuel surface.

Fuel: 350 gallons of JP-5 jet aircraft fuel.

Pan Size: 20 X 20 feet.

Test Fire: Flame temperature at the MARK 81 bomb exceeded 1000°F within 30 seconds after start of fire and averaged 1360°F for the duration of the test.

Results: At 3 minutes 20 seconds after start of fire, the bomb deflagrated scattering unreacted explosive up to 30 feet from the test site. No fragments were produced but the bomb did break into several large pieces as shown in Figure C-10. The unreacted nose fuze and adapter booster are shown in Figure C-11. Time-temperature data are presented in Table C-5.



FIGURE C-10

Several Pieces of the MARK 81 Bomb After Reaction in a Deflagration
During Fast Cook-Off Test No. P2-7



FIGURE C-11

Unreacted Nose Fuze/Adapter Booster Still In Nose Section of the Bomb
After Fast Cook-Off Test No. P2-7

TABLE C-5

**THERMOCOUPLE TEMPERATURE AND TIME DATA
FOR MARK 81 BOMB TEST NO. P2-7**

(Thermocouple Locations Are Given in Figure C-1)

Time (sec)	Thermocouple Number ¹											
	2	3	4	5	6	7 ²	8	10	11	12	13	14
	Temperature °F											
0-30	50	55	50	50	50	55	50	50	50	65	50	50
60	50	80	65	80	60	95	75	60	70	125	60	50
80	50	130	70	110	62	140	115	75	175	160	70	50
120	50	185	75	155	68	200	195	105	290	235	75	50
160	60	245	90	205	80	360	135	155	395	285	75	55
190	60	295	110	250	105	475	190	215	415	335	85	65
200 ³	60	295	132	250	105	475	190	235	450	335	85	105

¹ Thermocouple Nos. 1 and 9 malfunctioned.

² Thermocouple used in calculating the maximum temperature rise rate of 3.9° F/sec.

³ Time of reaction.

BOMB FAST COOK-OFF PHASE 2

Test No. P2-8

Data Sheet

Device Tested: MARK 81, 250 lb. instrumented bomb loaded with H-6 explosive; configured with M904E2 nose fuze, T45E7 adapter booster, M990E1 tail fuze and conical tail fins.

Date of Test: 12 March 1968.

Weather Conditions: Intermittent rain with 0-5 knot wind.

Bomb Position: 3-1/2 feet at the centerline above fuel surface.

Fuel: 1000 gallons of JP-5 jet aircraft fuel.

Pan Size: 24 X 24 feet.

Test Fire: The MARK 81 bomb was engulfed in flames 28 seconds after start of fire. Engulfment was intermittent because of fluctuating wind conditions.

Results: At 3 minutes 20 seconds after start of fire the bomb deflagrated. No fragments were produced but unreacted explosive was scattered up to 50 feet from the test site. The bomb split longitudinally as shown in Figure C-12; also shown are the unreacted nose fuze/adaptor booster still positioned in the nose section of the bomb and the unreacted tail fuze shown in the center of the photograph. Time-temperature data are presented in Table C-6.



FIGURE C-12

The MARK 81 Bomb After Fast Cook-Off Test No. P2-8
Notice the Unreacted Nose Fuze/Adapter Booster in the Nose Fuze Well.
The Unreacted Tail Fuze Is Visible in the Center of the Picture.

TABLE C-6

THERMOCOUPLE TEMPERATURE AND TIME DATA
FOR MARK 81 BOMB TEST NO. P2-8

(Thermocouple Locations Are Given In Figure C-1)

Time (sec)	Thermocouple Number ¹											
	3	4	5	6	7	8	9	10	11 ²	12	13	14
	Temperature °F											
0-40	70	60	60	60	70	65	65	65	70	60	60	60
60	80	65	65	60	75	72	75	95	90	68	65	70
100	174	95	95	73	155	150	140	140	195	125	115	105
120	350	135	120	88	320	205	185	185	285	165	140 ⁵	130 ⁵
160	435 ³	210	200	125	460	300 ⁴	315	290	435	265	---	---
180	---	270	245	150	475	---	380	350	505	340	---	---
200 ⁶	---	290	250	155	470	---	387	365	485	375	---	---

¹ Thermocouple Nos. 1 and 2 malfunctioned.² Thermocouple used in calculating maximum temperature rise rate of 3.8°F/sec.³ Instrumentation lost at 160 seconds.⁴ Instrumentation lost at 135 seconds.⁵ Instrumentation lost at 120 seconds.⁶ Time of reaction.

BOMB FAST COOK-OFF PHASE 2

Test No. P2-9

Data Sheet

Device Tested: MARK 81, 250 lb. instrumented bomb loaded with TRITONAL explosive; configured with a M904E2 nose fuze, T45E7 adapter booster and conical tail fins.

Date of Test: 8 March 1968.

Weather Conditions: Cloudy with 0-3 knot wind.

Bomb Position: 3-1/2 feet at the centerline above fuel surface.

Fuel: 1000 gallons of JP-5 jet aircraft fuel.

Pan Size: 24 X 24 feet.

Test Fire: Flame temperature at the bomb exceeded 1000°F within 33 seconds after start of fire and averaged 1247°F for the duration of the test.

Results: At 2 minutes 55 seconds after start of fire, the bomb deflagrated scattering unreacted explosive up to 30 feet from the test site. No fragments were produced but the bomb did break up into several large pieces, none of which were thrown more than a few feet. The nose section with the unreacted nose fuze/adapter booster still intact was recovered and is shown in Figure C-13. Time-temperature data are presented in Table C-7.



FIGURE C-13

Nose Section of the MARK 81 Bomb With Unreacted Nose Fuze and Adapter Booster
Still Intact, After Fast Cook-Off Test No. P2-9

TABLE C-7

**THERMOCOUPLE TEMPERATURE AND TIME DATA
FOR MARK 81 BOMB TEST NO. P2-9**

(Thermocouple Locations Are Given In Figure C-1)

Time (sec)	Thermocouple Number ¹											
	2	3	4	6	7	8	9	10	11 ²	12	13	14
	Temperature °F											
0-30	50	55	55	60	60	55	55	60	60	60	50	50
60	78	125	100	105	155	105	100	145	175	120	110	90
80	97	175	133	150	225	150	225	170	250	165	140	115
100	130	230	175	220	260	190	255	270	305	255	135	100
120	160	285	210	265	335	232	315	355	385	270	125	95
140	220	355	270	330	420	270	380	420	445	360	65	75
160	280	400	310	405	450	320	380	440	495	400	65	62
170	302	420	330	455	470	350	375	440	505	380	65	60
175 ³	302	405	343	462	440	350	375	440	540	380	65	60

¹ Thermocouple No. 1 not listed because of low readings and TC 5 malfunctioned.

² Thermocouple used in calculating the maximum temperature rise rate of 3.5°F/sec.

³ Time of reaction.

BOMB FAST COOK-OFF PHASE 2

Test No. P2-10

Data Sheet

Device Tested: MARK 81, 250 lb. instrumented bomb loaded with TRITONAL explosive; configured with a M904E2 nose fuze, T45E7 adapter booster, M990E1 tail fuze and conical tail fins.

Date of Test: 14 March 1968.

Weather Conditions: Cloudy with 0-6 knot wind.

Bomb Position: 3-1/2 feet at the centerline above fuel surface.

Fuel: 1000 gallons of JP-5 jet aircraft fuel.

Pan Size: 24 X 24 feet.

Test Fire: Flame temperature at the bomb exceeded 1000°F within 52 seconds after start of fire and averaged 1270°F for the duration of the test.

Results: At 2 minutes 55 seconds after start of fire, the bomb deflagrated scattering unreacted explosive around the test site. No fragments were produced. Time-temperature data are presented in Table C-8.

TABLE C-8

**THERMOCOUPLE TEMPERATURE AND TIME DATA
FOR MARK 81 BOMB TEST NO, P2-10**

(Thermocouple Locations Are Given In Figure C-1)

Time (sec)	Thermocouple Number ¹						
	3	4	5	6	7	9	11
	Temperature °F						
0-40	60	50	45	50	60	70	70
60	90	52	55	65	90	110	110
80	150	70	80	90	185	170	200
100	255	90	110	120	285	235	305
120	380	115	150	170	365	330	360
140	480	200	200	225	440	390	375 ²
160 ³	565	290	225	250	460	385	---

¹ Thermocouple No. 1 not listed because of low reading and TC's 2, 8, 10, 12, 13 and 14 malfunctioned.

² Thermocouple failed at 130 seconds.

³ All instrumentation failed at 160 seconds.

BOMB FAST COOK-OFF PHASE 2

Test No. P2-11

Data Sheet

Device Tested: MARK 82, 500 lb. bomb loaded with H-6 explosive; configured with a M904E2 nose fuze, T45E7 adapter booster and conical tail fins.

Date of Test: 27 June 1969.

Weather Conditions: Cloudy with 2-4 knot wind.

Bomb Position: 3-1/2 feet at the centerline above fuel surface.

Fuel: 800 gallons of JP-5 jet aircraft fuel.

Pan Size: 35 X 35 feet.

Test Fire: Flame temperature at the bomb exceeded 1000°F within 30 seconds after start of fire and averaged 1540°F for the duration of the test.

Results: At 3 minutes 6 seconds after start of fire the bomb exploded scattering burning and unreacted explosive up to 150 feet in all directions. The bomb body broke into several pieces, the pieces were found up to 100 feet from the test site. The nose fuze/adapter booster combination did not react.

BOMB FAST COOK-OFF PHASE 2

Test No. P2-12

Data Sheet

Device Tested: MARK 82, 500 lb. instrumented bomb loaded with H-6 explosive; configured with a M904E2 nose fuze, T45E7 adapter booster and conical tail fins.

Date of Test: 19 March 1968.

Weather Conditions: Overcast with 2-5 knot wind.

Bomb Position: 3-1/2 feet at the centerline above fuel surface.

Fuel: 1000 gallons of JP-5 jet aircraft fuel.

Pan Size: 24 X 24 feet.

Test Fire: The MARK 82 bomb was engulfed in flames 32 seconds after start of fire. Engulfment was intermittent because of fluctuating wind conditions.

Results: At 3 minutes 0 seconds after start of fire, the bomb deflagrated. Unreacted explosive was scattered up to 40 feet from the test site. No fragments were produced. Time-temperature data are presented in Table C-9.

TABLE C-9

**THERMOCOUPLE TEMPERATURE AND TIME DATA
FOR MARK 82 BOMB TEST NO. P2-12**

(Thermocouple Locations Are Given In Figure C-1)

Time (sec)	Thermocouple Number ¹									
	3	4	5	6	7	8	9	10	11	12
	Temperature °F									
0-40	60	60	60	64	60	60	80	70	55	60
60	90	68	75	75	75	100	110	90	55	60
80	160	90	120	95	105	150	195	140	150	170
100	235	140	200	135	140	220	290	200	270	240
120	335	205	270	170	235	255	260	295	380	310
140	395	270	310	205	300	300	445	370	515	360
160	450	235	350	257	342	405	515	425	550 ²	420
163 ³	456	240	353	261	350	415	522	428	---	425

¹Data from thermocouple Nos. 1, 2, 13 and 14 are not listed because of very little temperature rise.

²Thermocouple failed at 150 seconds.

³Recorder failed at 163 seconds.

BOMB FAST COOK-OFF PHASE 2

Test No. P3-13

Data Sheet

Device Tested: MARK 82, 500 lb. instrumented bomb loaded with H-6 explosive; configured with a M904E2 nose fuze, T45E7 adapter booster, M990E1 tail fuze and conical tail fins.

Date of Test: 20 March 1968.

Weather Conditions: Clear with 2-6 knot wind.

Bomb Position: 3-1/2 feet at the centerline above fuel surface.

Fuel: 800 gallons of JP-5 jet aircraft fuel.

Pan Size: 24 X 24 feet.

Test Fire: The MARK 82 bomb was engulfed in flames approximately 40 seconds after start of fire. Engulfment was intermittent because of fluctuating wind conditions.

Results: At 3 minutes 42 seconds after start of fire the bomb deflagrated. Unreacted explosive was scattered all around the test site. No fragments were produced by the reaction. The nose fuze/adapter booster and tail fuze did not react. Time-temperature data are presented in Table C-10.

TABLE C-10

THERMOCOUPLE TEMPERATURE AND TIME DATA FOR MARK 82 BOMB TEST NO. P2-13

(Thermocouple Locations Are Given In Figure C-1)

Time (sec)	Thermocouple Number ¹											
	3	4	5	6	7	8	9	10	11	12	13	14
	Temperature °F											
0-30	60	65	60	65	75	70	65	103	80	75	65	65
60	70	82	78	80	112	100	85	120	125	115	65	95
90	105	122	88	105	168	138	108	163	186	145	65	120
120	145	170	100	125	270	170	138	218	305	165	65	160
150	200	230	135	150	440	214	170	270	385	295	65	165 ³
180	290	280	154 ²	170	520	260	218	310	435	340	65	---
210	415	308	---	210	570	340	280	330	535	380	65	---
222 ⁴	480	325	---	228	615	356	300	340	585	400	64	---

¹Data from thermocouple Nos. 1 and 2 are not listed because of very little temperature rise.²Thermocouple failure at 170 seconds.³Thermocouple failure at 130 seconds.⁴Time of reaction.

BOMB FAST COOK-OFF PHASE 2

Test No. P2-14

Data Sheet

Device Tested: MARK 82, 500 lb. instrumented bomb loaded with TRITONAL explosive; configured with a M904E2 nose fuze, T45E7 adapter booster and conical tail fins.

Date of Test: 21 March 1968.

Weather Conditions: Clear with no wind.

Bomb Position: 3-1/2 feet at the centerline above fuel surface.

Fuel: 800 gallons of JP-5 jet aircraft fuel.

Pan Size: 24 X 24 feet.

Test Fire: The MARK 82 bomb was engulfed in flames 22 seconds after start of fire and remained engulfed to reaction.

Results: At 2 minutes 56 seconds after start of fire the bomb deflagrated. No fragments were produced, but unreacted explosive was found around the test site. Nose fuze/adapter booster did not react. Time-temperature data are presented in Table C-11.

TABLE C-11

**THERMOCOUPLE TEMPERATURE AND TIME DATA
FOR MARK 82 BOMB TEST NO. P2-14**

(Thermocouple Locations Are Given In Figure C-1)

Time (sec)	Thermocouple Number ¹							
	3 ²	4	6	7	8	9	10	11
	Temperature °F							
0-40	60	60	75	65	65	60	60	60
60	65	80	115	75	85	60	65	70
80	105	115	205	95	125	85	90	95
100	225	163	285	140	185	130	135	140
120	370	205	335	150	265	205	195	185
140	445	255	385	335	360	315	255	320
160	555	395	435	410	410	430	365	415
176 ³	588	405	445	435	395	480	444	438

¹ Thermocouple Nos. 5 and 12 malfunctioned. Data from thermocouple Nos. 1, 2, 13 and 14 are not listed because of very little temperature rise.

² Thermocouple used in calculating the maximum temperature rise rate of 5.3°F/sec.

³ Time of reaction.

BOMB FAST COOK-OFF PHASE 2

Test No. P2-15

Data Sheet

Device Tested: MARK 82, 500 lb. instrumented bomb loaded with TRITONAL explosive; configured with a M904E2 nose fuze, T45E7 adapter booster, M990E1 tail fuze and conical tail fins.

Date of Test: 29 March 1968.

Weather Conditions: Clear with 0-3 knot wind.

Bomb Position: 3-1/2 feet at the centerline above fuel surface.

Fuel: 800 gallons of JP-5 jet aircraft fuel.

Pan Size: 24 X 24 feet.

Test Fire: The MARK 82 bomb was engulfed in flames 26 seconds after start of fire and remained engulfed to reaction.

Results: At 3 minutes 5 seconds after start of fire, the bomb deflagrated. Unreacted explosive was scattered around the test site. Upon examination the explosive was found to have partially melted and mixed with the melted asphalt hot-melt. No fragments were produced. At 5 minutes 20 seconds a second reaction, more violent than the first, was observed. This second reaction was believed to be the nose fuze/adaptor booster exploding. Time-temperature data are presented in Table C-12.

TABLE C-12

**THERMOCOUPLE TEMPERATURE AND TIME DATA
FOR MARK 82 BOMB TEST NO. P2-15**

(Thermocouple Locations Are Given In Figure C-1)

Time (sec)	Thermocouple Number ¹							
	5	6	7	8	9	10	11 ²	12
	Temperature °F							
0-40	70	65	65	75	68	70	65	95
60	80	65	80	95	75	80	80	105
80	105	65	115	120	95	105	125	125
100	125	95	155	165	115	148	185	170
120	145	125	215	215	135	187	255	205
140	165	145	255	245	155	240	365	245
160	185	180	355	305	195	285	425	275
180	215	235	385	375	248	340	415	305 ³
185 ⁴	215	333	420	410	265	375	385	---

¹ Thermocouple Nos. 3 and 4 malfunctioned; thermocouple Nos. 1, 2, 13 and 14 were not monitored.

² Thermocouple used in calculating maximum temperature rise rate of 4.0° F/sec.

³ Thermocouple failed at 180 seconds.

⁴ Time of reaction.

BOMB FAST COOK-OFF PHASE 2

Test No. P2-16

Data Sheet

Device Tested: MARK 83, 1000 lb. instrumented bomb loaded with H-6 explosive; configured with a M904E2 nose fuze, T45E4 adapter booster and conical tail fins.

Date of Test: 10 April 1968.

Weather Conditions: Overcast with no wind.

Bomb Position: 3-1/2 feet at the centerline above fuel surface.

Fuel: 800 gallons of JP-5 jet aircraft fuel.

Pan Size: 24 X 24 feet.

Test Fire: The MARK 83 bomb was engulfed in flames 24 seconds after start of fire and remained engulfed to reaction.

Results: At 3 minutes 13 seconds after start of fire, the bomb deflagrated. No fragments were produced; however, unreacted explosive was found 100 feet from the test site. The nose fuze/adapter booster did not react. Time-temperature data are presented in Table C-13.

TABLE C-13

THERMOCOUPLE TEMPERATURE AND TIME DATA
FOR MARK 83 BOMB TEST NO. P2-16

(Thermocouple Locations Are Given In Figure C-1)

Time (sec)	Thermocouple Number ¹							
	4	5	6	7 ² Temperature °F	8	9	10	11
0-30	60	60	65	60	40	55	50	50
40	60	75	82	97	45	70	65	80
60	60	100	120	165	55	100	100	140
80	70	118	170	200	70	118	140	185
100	83	135	200	255	89	140	170	215
120	97	150	225	305	108	165	200	255
140	115	178	260	340	130	190	240	305
160	135	218	295	390	155	224	280	345
180	178	257	310	418	185	300	320	365
193 ³	200	278	315	430	200	345	335	372

¹ Data for thermocouple Nos. 1, 2, 3, 13 and 14 were not reduced because of very little temperature rise.² Thermocouple used in calculating the maximum temperature rise rate of 2.3° F/sec.³ Time of reaction.

BOMB FAST COOK-OFF PHASE 2

Test No. P2-17

Data Sheet

Device Tested: MARK 83, 1000 lb. instrumented bomb loaded with H-6 explosive; configured with a M904E2 nose fuze, T45E4 adapter booster, M990E1 tail fuze and conical tail fins.

Date of Test: 12 April 1968.

Weather Conditions: Clear with no wind.

Bomb Position: 3-1/2 feet at the centerline above fuel surface.

Fuel: 800 gallons of JP-5 jet aircraft fuel.

Pan Size: 24 X 24 feet.

Test Fire: The MARK 83 bomb was engulfed in flames 19 seconds after start of fire and remained engulfed to reaction.

Results: At 2 minutes 32 seconds after start of fire the bomb deflagrated, splitting longitudinally as shown in Figure C-14. Some of the unreacted explosive collected at the test area and the unreacted tail fuze are shown in Figure C-15. Time-temperature data are presented in Table C-14.



FIGURE C-14

MARK 83 Bomb Reacted In a Deflagration, Splitting Longitudinally
Fast Cook-Off Test No. P2-17



FIGURE C-15

Unreacted Explosive to the Right of the Sign and Unreacted Tail Fuze to the Left
Fast Cook-Off Test No. P2-17

TABLE C-14

**THERMOCOUPLE TEMPERATURE AND TIME DATA
FOR MARK 83 BOMB TEST NO. P2-17**

(Thermocouple Locations Are Given In Figure C-1)

Time (sec)	Thermocouple Number ¹							
	5	6	7 ²	8	9	10	11	12
	Temperature °F							
0-30	55	55	60	55	55	55	60	60
40	70	90	90	90	55	90	90	105
60	112	165	200	153	50	130	175	175
80	169	200	210	210	92	180	235	242
100	195	227	305	305	195	215	320	282
120	205	322	430	415	205	250	405	365
140	230	425	522	400	247	280	470	450
152 ³	242	490	580	550	270	300	510	500

¹ Thermocouple data for TC's 2, 3, 4, 13 and 14 were not reduced because of very little temperature rise.

² Thermocouple used in calculating the maximum temperature rise rate of 5.2°F/sec.

³ Time of reaction.

BOMB FAST COOK-OFF PHASE 2

Test No. P2-18

Data Sheet

Device Tested: MARK 83, 1000 lb. instrumented bomb loaded with TRITONAL explosive; configured with a M904E2 nose fuze, T45E4 adapter booster and conical tail fins.

Date of Test: 17 April 1968.

Weather Conditions: Cloudy with 0-2 knot wind.

Bomb Position: 3-1/2 feet at the centerline above fuel surface.

Fuel: 800 gallons of JP-5 jet aircraft fuel.

Pan Size: 24 X 24 feet.

Test Fire: The MARK 83 bomb was engulfed in flames 37 seconds after start of fire. Engulfment was intermittent because of fluctuating wind conditions.

Results: At 3 minutes 19 seconds after start of fire, the bomb deflagrated breaking into several large pieces; the largest section is shown in Figure C-16. Unreacted explosive was scattered up to 75 feet from the test site. Time-temperature data are presented in Table C-15.



FIGURE C-16

Largest Section of the MARK 83 Bomb Remaining
After Fast Cook-Off Test No. P2-18

TABLE C-15

THERMOCOUPLE TEMPERATURE AND TIME DATA
FOR MARK 83 BOMB TEST NO. P2-18

(Thermocouple Locations Are Given In Figure C-1)

Time (sec)	Thermocouple Number ¹							
	5	6	7	8 ² Temperature °F	9	10	11	12
0-30	60	70	65	65	68	70	65	45
40	60	72	65	70	70	75	65	40
60	70	95	98	110	110	115	98	80
80	88	136	160	190	180	180	160	160
100	110	185	205	283	245	227	220	260
120	145	140	226	393	300	255	280	380
140	185	172	172	450	373	320	355	440
160	235	122	122	440	388	350	385	445
180	280	162	162	430	405	380	415	452
199 ³	305	188	188	420	412	400	430	458

¹ Thermocouple data from TC's 2, 3, 4, 13 and 14 were not reduced because of very little temperature rise.² Thermocouple used in calculating the maximum temperature rise rate of 4.2°F/sec.³ Time of reaction.

BOMB FAST COOK-OFF PHASE 2

Test No. P2-19

Data Sheet

Device Tested: MARK 83, 1000 lb. instrumented bomb loaded with TRITONAL explosive; configured with a M904E2 nose fuze, T45E4 adapter booster, M990E1 tail fuze and conical tail fins.

Date of Test: 18 April 1968.

Weather Conditions: Overcast with 2-4 knot wind.

Bomb Position: 3-1/2 feet at the centerline above fuel surface.

Fuel: 800 gallons of JP-5 jet aircraft fuel.

Pan Size: 24 X 24 feet.

Test Fire: The MARK 83 bomb was engulfed in flames approximately 30 seconds after start of fire.

Results: At 2 minutes 56 seconds after start of fire the bomb deflagrated, scattering unreacted explosive around the test area. Neither the nose fuze/adapter booster combination nor the tail fuze reacted. Time-temperature data are presented in Table C-16.

TABLE C-16

**THERMOCOUPLE TEMPERATURE AND TIME DATA
FOR MARK 83 BOMB TEST NO. P2-19**

(Thermocouple Locations Are Given In Figure C-1)

Time (sec)	Thermocouple Number ¹								
	4	5	6	7	8	9	10	11 ²	12
	Temperature °F								
0-20	62	85	90	70	68	72	80	85	
40	68	105	120	80	75	85	98	115	
60	88	135	152	100	90	115	130	170	³
80	125	165	182	135	120	165	185	250	
100	178	232	190	162	241	208	220	326	
120	188	325	230	195	241	240	275	395	
140	250	360	282	243	197	288	310	415	
160	290	370	230	348	240	340	365	405	
176 ⁴	385	350	240	363	250	350	382	395	

¹ Data from thermocouple Nos. 2, 3, 13 and 14 were not reduced because of very little temperature rise.

² Thermocouple used in calculating the maximum temperature rise rate of 3.9° F/sec.

³ Malfunction.

⁴ Time of reaction.

BOMB FAST COOK-OFF PHASE 2

Test No. P2-20

Data Sheet

Device Tested: MARK 84, 2000 lb. instrumented bomb loaded with H-6 explosive; configured with nose fuze plug, tail fuze plug, and conical tail fins.

Date of Test: 9 April 1968.

Bomb Position: 3-1/2 feet at the centerline above fuel surface.

Fuel: 700 gallons of JP-5 jet aircraft fuel.

Pan Size: 24 X 24 feet.

Test Fire: The MARK 84 bomb was engulfed in flames 20 seconds after start of fire.

Results: At 3 minutes 31 seconds after start of fire the bomb deflagrated. The base fuze plug was blown out of the bomb. The bomb case remained intact and was thrown 750 feet from the test site. Approximately 100 pounds of unreacted explosive was scattered about the test site. A maximum temperature rise rate of 4.1°F/sec was recorded in the aft section of the bomb. Additional time-temperature data are presented in Table C-17.

TABLE C-17

**THERMOCOUPLE TEMPERATURE AND TIME DATA
FOR MARK 84 BOMB TEST NO. P2-20**

(Thermocouple Locations Are Given In Figure C-1)

Time (sec)	Thermocouple Number ¹									
	1	2	3	4	9	10	11	12 ²	13	14
	Temperature °F									
0-30	50	50	50	50	50	50	50	50	50	50
60	50	55	60	50	50	100	160	110	50	50
90	50	60	70	60	100	180	290	230	50	50
120	50	65	100	60	100	300	400	320	50	50
150	50	65	120	80	130	440	490	470	50	50
180	60	70	120	100	150	520	600	570	110	100
211 ³	60	80	135	120	170	500	600	675	130	130

¹ Center section of bomb (TC's 5, 6, 7 and 8) was not instrumented.

² Thermocouple used in calculating the maximum temperature rise rate of 4.1°F/sec.

³ Time of reaction.

BOMB FAST COOK-OFF PHASE 2

Test No. P2-21

Data Sheet

Device Tested: MARK 84, 2000 lb. instrumented bomb with H-6 explosive load; configured with a M904E2 nose fuze, T45E7 adapter booster, M990E1 tail fuze, and conical tail fins.

Date of Test: 11 April 1968.

Bomb Position: 3-1/2 feet at the centerline above fuel surface.

Fuel: 800 gallons of JP-5 jet aircraft fuel.

Pan Size: 24 X 24 feet.

Test Fire: The MARK 84 bomb was engulfed in flames 8 seconds after start of fire.

Results: At 3 minutes 2 seconds after start of fire the bomb deflagrated, blowing out the end plate. This reaction was followed by 4 minutes of explosive burning out the base end. At 6 minutes 30 seconds another reaction, more violent than the first was observed. The second reaction was believed to be the nose fuze exploding. Time-temperature data for the test are presented in Table C-18.

TABLE C-18

**THERMOCOUPLE TEMPERATURE AND TIME DATA
FOR MARK 84 BOMB TEST NO. P2-21**

(Thermocouple Locations Are Given In Figure C-1)

Time (sec)	Thermocouple Number ¹									
	1	2	3	4	9	10 ²	11	12	13	14
	Temperature °F									
0-30	40	40	40	40	40	40	40	40	40	40
60	90	60	160	80	90	140	210	105	40	60
90	130	90	210	120	150	260	350	170	100	60
120	155	130	350	160	220	490	440	240	120	60
150	170	240	365	270	320	510	480	320	110	60
170	180	205	370	290	330	490	510	375	110	60
182 ³	190	210	340	300	360	490	510	400	105	50

¹ Center section of bomb (TC's 5, 6, 7 and 8) was not instrumented.

² Thermocouple used in calculating the maximum temperature rise rate of 4.6° F/sec.

³ Time of reaction.

BOMB FAST COOK-OFF PHASE 2

Test No. P2-22

Data Sheet

Device Tested: MARK 84, 2000 lb. instrumented bomb with H-6 explosive load; configured with a M904E2 nose fuze, T45E7 adapter booster, tail fuze plug, and conical tail fins.

Date of Test: 17 April 1968.

Bomb Position: 3-1/2 feet at the centerline above fuel surface.

Fuel: 600 gallons of JP-5 jet aircraft fuel.

Pan Size: 24 X 24 feet.

Test Fire: The MARK 84 bomb was engulfed in flames 90 seconds after start of fire. The long time to engulfment was attributed to fuel ignition difficulties.

Results: At 5 minutes 2 seconds after start of fire the bomb deflagrated, rupturing the bomb case. The nose fuze blew out and was observed burning. Time-temperature data from the test are presented in Table C-19.

TABLE C-19

THERMOCOUPLE TEMPERATURE AND TIME DATA
FOR MARK 84 BOMB TEST NO. P2-22

(Thermocouple Locations Are Given In Figure C-1)

Time (sec)	Thermocouple Number ¹									
	1	2	3	4	9	10	11	12 ²	13	14
	Temperature °F									
0-20	70	70	70	70	70	70	70	70	70	70
60	70	80	75	70	80	90	70	70	70	70
100	70	90	80	70	80	100	100	80	70	70
140	75	110	110	80	80	165	280	160	80	80
180	80	180	200	90	100	220	390	260	80	80
220	90	210	200	110	115	285	³	390	140	90
260	100	305	220	130	160	450	---	610	150	140
302 ⁴	120	380	260	260	230	580	---	720	205	190

¹Center section of bomb (TC's 5, 6, 7 and 8) was not instrumented.²Thermocouple used in calculating the maximum temperature rise rate of 3.5°F/sec.³Thermocouple failed after 180 seconds.⁴Time of reaction.

BOMB FAST COOK-OFF PHASE 2

Test No. P2-23

Data Sheet

Device Tested: MARK 84, 2000 lb. instrumented bomb with TRITONAL explosive load; configured with a M904E2 nose fuze, T45E7 adapter booster, M950E1 tail fuze, and conical tail fins.

Date of Test: 19 April 1968.

Bomb Position: 3-1/2 feet at the centerline above fuel surface.

Fuel: 800 gallons of JP-5 jet aircraft fuel.

Pan Size: 24 X 24 feet.

Test Fire: The bomb was engulfed in flames 30 seconds after start of fire.

Results: At 4 minutes 57 seconds after start of fire the bomb deflagrated, rupturing the bomb case. At 11 minutes 15 seconds the nose fuze deflagrated. Post-test examination showed the unreacted tail fuze still in the bomb case. Time-temperature data from the test are presented in Table C-20.

TABLE C 20

THERMOCOUPLE TEMPERATURE AND TIME DATA
FOR MARK 84 BOMB TEST NO. P2-23

(Thermocouple Locations Are Given In Figure C-1)

Time (sec)	Thermocouple Number ¹									
	1	2	3	4	9	10	11 ²	12	13	14
	Temperature °F									
0-20	40	40	40	40	40	40	40	40	40	40
60	40	45	70	65	50	50	70	80	40	50
100	40	60	140	120	80	85	110	155	40	80
140	50	75	300	210	90	120	170	220	40	40
180	50	90	350	320	110	170	240	300	40	40
220	70	70	350	350	80	190	280	330	60	60
260	310	170	320	320	130	290	340	370	60	300
297 ³	340	270	320	320	140	370	540	380	60	300

¹ Center section of bomb (TC's 5, 6, 7 and 8) was not instrumented.² Thermocouple used in calculating the maximum temperature rise rate of 2.2°F/sec.³ Time of reaction.

BOMB FAST COOK-OFF PHASE 2

Test No. P2-24

Data Sheet

Device Tested: MARK 84, 2000 lb. instrumented bomb with TRITONAL explosive load; configured with a M904E2 nose fuze, T45E7 adapter booster, tail fuze plug, and conical tail fins.

Date of Test: 23 April 1968.

Bomb Position: 3-1/2 feet at the centerline above fuel surface.

Fuel: 800 gallons of JP-5 jet aircraft fuel.

Test Fire: The MARK 84 bomb was engulfed in flames 40 seconds after start of fire.

Results: At 3 minutes 31 seconds after start of fire, the bomb deflagrated rupturing the bomb case. Unreacted explosive was scattered around the test site. The nose fuze did not react but had burned. Time-temperature data from the test are presented in Table C-21.

TABLE C-21

**THERMOCOUPLE TEMPERATURE AND TIME DATA
FOR MARK 84 BOMB TEST NO. P2-24**

(Thermocouple Locations Are Given In Figure C-1)

Time (sec)	Thermocouple Number ¹									
	1	2	3	4	9	10	11 ²	12	13	14
	Temperature °F									
0-20	40	40	40	40	40	40	40	40	40	40
60	40	40	90	50	60	130	150	80	40	40
90	50	55	165	50	100	310	180	130	40	100
120	60	60	235	60	160	510	480	200	120	90
150	70	70	280	80	220	610	560	310	110	105
180	75	170	370	190	310	580	590	380	130	110
211 ³	150	190	420	200	360	300	650	360	165	110

¹ Center section of bomb (TC's 5, 6, 7 and 8) was not instrumented.

² Thermocouple used in calculating the maximum temperature rise rate of 3.2°F/sec.

³ Time of reaction.

BOMB FAST COOK-OFF PHASE 2

Test No. P2-25

Data Sheet

Device Tested: MARK 84, 2000 lb. instrumented bomb with TRITONAL explosive load; configured with a nose fuze plug, tail fuze plug, and conical tail fins.

Date of Test: 25 April 1968.

Bomb Position: 3-1/2 feet at the centerline above fuel surface.

Fuel: 630 gallons of JP-5 jet aircraft fuel.

Test Fire: The MARK 84 bomb was engulfed in flames 70 seconds after start of fire.

Results: At 4 minutes 24 seconds after start of fire the bomb deflagrated. Unreacted explosive was scattered around the test site. Time-temperature data from the test are presented in Table C-22.

TABLE C-22

THERMOCOUPLE TEMPERATURE AND TIME DATA
FOR MARK 84 BOMB TEST NO. P2-25

(Thermocouple Locations Are Given In Figure C-1)

Time (sec)	Thermocouple Number ¹									
	1	2	3	4	9	10	11 ²	12	13	14
	Temperature °F									
0-20	40	40	40	40	40	40	40	40	40	40
60	50	50	40	40	40	40	50	40	40	40
100	50	50	50	50	50	50	60	70	40	40
140	50	50	70	60	80	80	120	130	50	40
180	50	60	80	70	165	250	200	190	70	60
220	50	75	110	90	255	430	330	320	80	50
250	70	85	110	210	360	475	460	440	70	55
264 ³	80	90	155	215	390	530	560	475	70	55

¹ Center section of bomb (TC's 5, 6, 7 and 8) was not instrumented.² Thermocouple used in calculating the maximum temperature rise rate of 3.5°F/sec.³ Time of reaction.

BOMB FAST COOK-OFF PHASE 2

Test No. P2-26

Data Sheet

Device Tested: Live M904E2 nose fuze, T45E7 adapter booster, and M990E1 tail fuze installed in an inert MARK 81 bomb with conical tail fins.

Date of Test: 27 March 1968.

Weather Conditions: Cloudy; temperature 65°F with 0-4 knot wind.

Bomb Position: 3-1/2 feet at centerline above fuel surface.

Fuel: 800 gallons of JP-5 jet aircraft fuel.

Pan Size: 35 X 35 feet.

Test Fire: The fuze and booster under test were engulfed in flame 40 seconds after start of fire. The fire was out in approximately 5 minutes.

Results: At 9 minutes (4 minutes after the test fire went out) the nose fuze/adapter booster combination detonated splitting open the bomb nose section as shown in Figure C-17. Fragments were scattered over a large area of the test site. The tail fuze did not react, remaining in the bomb tail section.



FIGURE C-17

**Damage Sustained In the Nose Section of a MARK 81 Bomb
When the Nose Fuze/Adapter Booster Combination Detonated
After Fast Cook-Off Test No. P2-26
Notice the Tail Fuze Still In Position.**

BOMB FAST COOK-OFF PHASE 2

Test No. P2-27

Data Sheet

Devices Tested: Live M904E2 nose fuze and T45E7 adapter booster installed in an inert MARK 81 bomb with tail fuze plug and conical tail fins.

Date of Test: 28 February 1969.

Weather Conditions: Overcast with 2-6 knot wind.

Bomb Position: 4 feet at the centerline above fuel surface.

Fuel: 800 gallons of JP-5 jet aircraft fuel.

Pan Size: 35 X 35 feet.

Test Fire: The nose fuze and adapter booster under test were engulfed in flame 30 seconds after start of fire. The fire was out in approximately 5 minutes.

Results: At 6 minutes 10 seconds the nose fuze caught fire, and at 6 minutes 26 seconds the fuze was violently ejected from the bomb. A photograph of the recovered fuze is shown in Figure C-18. The adapter booster did not react, remaining in the bomb's nose section.



FIGURE C-18

M904E2 Nose Fuze Recovered After Fast Cook-Off Test No. P2-27

BOMB FAST COOK-OFF PHASE 2

Test No. P2-28

Data Sheet

Device Tested: Live M904E2 nose fuze with an inert T45E7 adapter booster installed in an inert MARK 82 bomb with tail fuze plug and conical tail fins.

Date of Test: 11 February 1970.

Weather Conditions: Clear with 8-9 knot southwest wind.

Bomb Position: 3-1/2 feet at the centerline above fuel surface.

Fuel: 1000 gallons of JP-5 jet aircraft fuel.

Pan Size: 35 X 35 feet.

Test Fire: The nose fuze under test was engulfed in flame 30 seconds after start of fire and the average flame temperature at the fuze was 1660°F during the test.

Results: At 4 minutes 27 seconds after start of fire, the nose fuze deflagrated propelling itself approximately 30 feet from the bomb. That portion of the fuze recovered after the test is shown in Figure C-19.

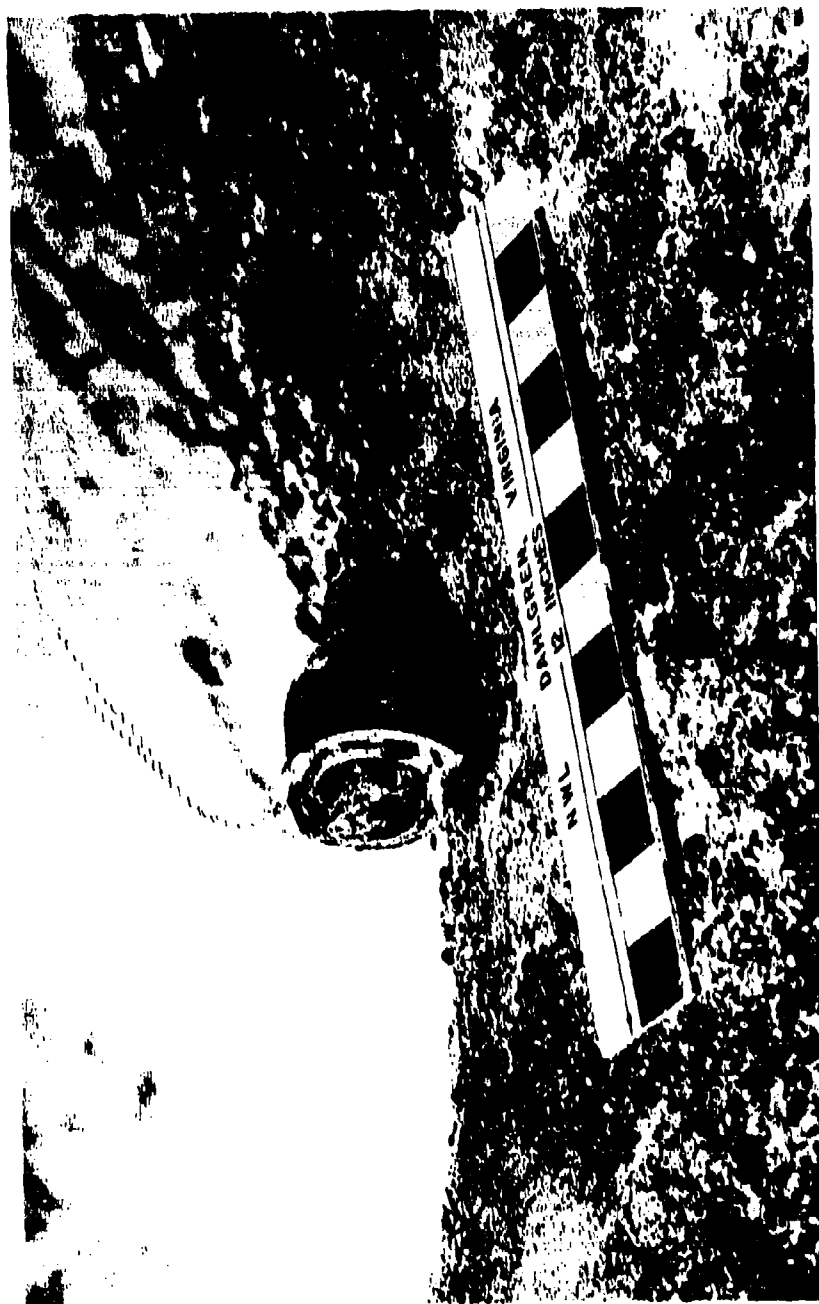


FIGURE C-19

M904E2 Nose Fuze After Fast Cook-Off Test No. P2-28

Notice Absence of the Fuze Booster Which Was Destroyed When the Fuze Reacted.

BOMB FAST COOK-OFF PHASE 2

Test No. P2-29

Data Sheet

Device Tested: Live M904E2 nose fuze and inert T45E7 adapter booster installed in an inert MARK 82 bomb with tail fuze plug and conical tail fins.

Date of Test: 10 February 1970

Weather Conditions: Rain and cold with 3 knot wind.

Bomb Position: 3-1/2 feet at the centerline above fuel surface.

Fuel: 1000 gallons of JP-5 jet aircraft fuel.

Pan Size: 35 X 35 feet.

Test Fire: The nose fuze under test was engulfed in flame 38 seconds after start of fire and the average flame temperature at the fuze was 1685°F during the test.

Results: At 3 minutes 48 seconds after start of fire, the nose fuze deflagrated propelling itself out of the bomb a distance of approximately 35 feet. It was found in much the same condition as the fuze in Test No. P2-28.

BOMB FAST COOK-OFF PHASE 2

Test No. P2-30

Data Sheet

Device Tested: Live M904E2 nose fuze and inert T4SE7 adapter booster installed in an inert MARK 82 bomb with tail fuze plug and conical tail fins.

Date of Test: 9 February 1970.

Weather Conditions: Raining and cold with 2 knot wind.

Bomb Position: 3-1/2 feet at the centerline above fuel surface.

Fuel: 1000 gallons of JP-5 jet aircraft fuel.

Pan Size: 35 X 35 feet.

Test Fire: The nose fuze under test was engulfed in flame 45 seconds after start of fire and the average flame temperature at the fuze was 1615°F during the test.

Results: At 4 minutes 0 seconds after start of fire the nose fuze deflagrated propelling itself out of the bomb case a distance of approximately 35 feet. It was found in much the same condition as the fuzes in Test Nos. P2-28 and P2-29.

BOMB FAST COOK-OFF PHASE 2

Test No. P2-31

Data Sheet

Device Tested: Live T45E7 adapter booster, an inert M904E2 nose fuze installed in an inert MARK 82 bomb with tail fuze plug and conical tail fins.

Date of Test: 25 June 1970.

Weather Conditions: Clear with 1-2 knot wind.

Bomb Position: 3-1/2 feet at the centerline above fuel surface.

Fuel: 1200 gallons of JP-5 jet aircraft fuel.

Pan Size: 35 X 35 feet.

Test Fire: The adapter booster under test was engulfed in flame 30 seconds after start of fire and the average flame temperature at the booster was 1695°F during the test.

Results: At 7 minutes 38 seconds after start of fire, the adapter booster deflagrated ejecting the inert fuze and aluminum sleeve of the booster forward a distance of 100 feet. The nose section of the bomb and ejected aluminum sleeve are shown in Figure C-20.



FIGURE C-20

Nose Section of MARK 82 Bomb and the Ejected Aluminum Sleeve From the T45E7
Adapter Booster After Fast Cook-Off Test No. P2-31

BOMB FAST COOK-OFF PHASE 2

Test No. P2-32

Data Sheet

Device Tested: Live T45E7 adapter booster and inert M904E2 fuze installed in an inert MARK 82 bomb with tail fuze plug and conical tail fins.

Date of Test: 24 June 1970.

Weather Conditions: Clear with 0-3-½ knot wind.

Bomb Position: 3-1/2 feet at the centerline above fuel surface.

Fuel: 1200 gallons of JP-5 jet aircraft fuel.

Pit Size: 35 X 35 feet.

Test Fire: The adapter booster under test was engulfed in flame 30 seconds after start of fire and the average flame temperature at the booster was 1925°F during the test.

Results: At 8 minutes 9 seconds after start of fire, the adapter booster deflagrated ejecting the inert fuze. The adapter booster and its aluminum sleeve remained in the bomb nose.

BOMB FAST COOK-OFF PHASE 2

Test No. P2-33

Data Sheet

Device Tested: Live T45E7 adapter booster and inert M904E2 nose fuze installed in an inert MARK 82 bomb with tail fuze plug and conical tail fins.

Date of Test: 23 June 1970.

Weather Conditions: Partly cloudy with 5-6 knot wind.

Bomb Position: 3-1/2 feet at the centerline above fuel surface.

Fuel: 1200 gallons of JP-5 jet aircraft fuel.

Plt Size: 35 X 35 feet.

Test Fire: The adapter booster under test was engulfed in flames 30 seconds after start of fire and the average flame temperature at the booster was 1780°F during the test.

Results: At 8 minutes 4 seconds after start of fire, the adapter booster deflagrated ejecting the inert fuze and aluminum sleeve of the booster approximately 70 feet from the test stand.

BOMB FAST COOK-OFF PHASE 2

Test No. P2-34

Data Sheet

Device Tested: Live M990E1 tail fuze installed in an inert MARK 82 bomb with conical tail fins.

Date of Test: 14 December 1970.

Weather Conditions: Clear and cold with 2-3 knot wind.

Bomb Position: 3-1/2 feet at the centerline above fuel surface.

Fuel: 1500 gallons of JP-5 jet aircraft fuel.

Pit Size: 35 X 35 feet.

Test Fire: The tail fuze under test was engulfed in flame 14 seconds after start of fire and the average flame temperature at the fuze was 1713°F for 8.5 minutes at which time the flame temperature dropped below 1000°F. Fire was out at 11.5 minutes.

Results: At 22 minutes after start of test, the tail fuze deflagrated causing a bulge in the aft section of the bomb as seen in Figure C-21; however, the reaction was not so intense as to blow off the tail fin assembly. Figure C-22 is a photograph showing several pieces of the tail fuze recovered after the test.



FIGURE C-21

Aft Section of the MARK 82 Bomb After Fast Cook-Off Test No. P2-34
Notice the Bulge Caused by the Deflagration That Occurred.



FIGURE C-22

Parts of the M990E1 Tail Fuze Recovered After Fast Cook-Off Test No. P2-34

BOMB FAST COOK-OFF PHASE 2

Test No. P2-35

Data Sheet

Device Tested: Live M990E1 tail fuze installed in an inert MARK 82 bomb with conical tail fins.

Date of Test: 15 December 1970.

Weather Conditions: Clear and cold with 4-5 knot wind.

Bomb Position: 3-1/2 feet at the centerline above fuel surface.

Fuel: 2000 gallons of JP-5 jet aircraft fuel.

Pan Size: 35 X 35 feet.

Test Fire: The tail fuze under test was engulfed in flame 12 seconds after start of fire and the average flame temperature at the fuze was 1878°F for 8 minutes, at which time the temperature dropped below 1000°F. Fire out at 15 minutes.

Results: At 32 minutes 20 seconds after start of test, the tail fuze deflagrated causing a bulge in the aft section of the bomb; however, the reaction was not so intense as to blow off the tail fin assembly. The results were very much the same as those of Test No. P2-34.

BOMB FAST COOK-OFF PHASE 2

Test No. P2-36

Data Sheet

Device Tested: Live M990E1 tail fuze installed in an inert MARK 82 bomb with conical tail fins.

Date of Test: 16 December 1970.

Weather Conditions: Intermittent rain with 2-3 knot wind.

Bomb Position: 3-1/2 feet at the centerline above fuel surface.

Fuel: 2000 gallons of JP-5 jet aircraft fuel.

Pit Size: 35 X 35 feet.

Test Fire: The tail fuze under test was engulfed in flame 20 seconds after start of fire and the average flame temperature at the fuze was 1660°F for 8 minutes, at which time the temperature dropped below 1000°F. Fire out at 15 minutes.

Results: At 33 minutes and 35 seconds after start of test, the tail fuze deflagrated causing a bulge in the aft section of the bomb; however, the reaction was not so intense as to blow off the tail fin assembly. Results were much the same as those of Test Nos. P2-34 and P2-35.

BOMB FAST COOK-OFF PHASE 2

Test No. P2-37

Data Sheet

Devices Tested: Three live M990E1 tail fuzes individually installed in three separate inert MARK 82 bombs without tail fins.

Date of Test: 20 January 1971.

Weather Conditions: Cold with 6-8 knot wind.

Bomb Position: Three bombs were suspended 3-1/2 feet at their centerline above fuel surface and positioned 3 feet apart. They were lined up side by side, tail to nose as in Figure C-23.

Pit Size: 35 X 35 feet.

Test Fire: All three tail fuzes under test were engulfed in flame 65 seconds after start of fire and the average flame temperature at these three fuzes was 1700°F for 15 minutes, at which time the test fire burned out.

Results: At 16 minutes 54 seconds after start of test, the tail fuze in the bomb to the right in Figure C-23 deflagrated causing the aft section of the bomb to bulge slightly. At 19 minutes 30 seconds, the second fuze to the left in Figure C-23 deflagrated much as the first fuze. At 23 minutes 15 seconds, the tail fuze in the center bomb deflagrated much as the other two had. A post-test photograph of the test is shown in Figure C-24.



FIGURE C-23

Bombs Positioned for Fast Cook-Off Test No. P2-37



FIGURE C-24

Post-Test Photograph After Fast Cook-Off Test No. P2-37
All the Fuzes Deflagrated. The Fuzed Bomb to the Right Reacted First
Followed by the One on the Left and Then Finally the Center Fuze.

BOMB FAST COOK-OFF PHASE 2

Test No. P2-38

Data Sheet

Device Tested: Comp-B loaded M1 thin walled fuze extender, 36 inches long, and T45E7 adapter booster with an inert fuze, installed in an inert MARK 81 bomb, no tail fuze or fins installed.

Date of Test: 9 July 1968.

Weather Conditions: Clear and warm with no wind.

Bomb Position: 3-1/2 feet at the centerline above fuel surface.

Fuel: 1000 gallons of JP-5 jet aircraft fuel.

Pan Size: 30 X 30 feet.

Test Fire: Because of ignition malfunction flame engulfment of fuze extender and adapter booster took 2 minutes.

Results: At 7 minutes 2 seconds after start of fire the fuze extender deflagrated blowing out the inert nose fuze and dislodging the extender from the bomb. The adapter booster did not react and is shown in Figure C-25.



FIGURE C-25

Nose Section of the MARK 82 Bomb After Fast Cook-Off Test No. P2-38
Notice the Unreacted Adapter Booster Still In Position.

BOMB FAST COOK-OFF PHASE 2

Test No. P2-39

Data Sheet

Device Tested: Comp-B loaded M1 thin walled fuze extender, 36 inches long, M904E2 nose fuze and T45E7 adapter booster, installed in an inert MARK 81 bomb. No tail fuze or fins installed.

Date of Test: 10 July 1968.

Weather Conditions: Hot, clear day with 0-4 knot wind.

Bomb Position: 3-1/2 feet at the centerline above fuel surface.

Fuel: 1000 gallons of JP-5 jet aircraft fuel.

Pan Size: 30 X 30 feet.

Test Fire: The nose fuze, fuze extender and adapter booster were engulfed in flames 30 seconds after start of fire.

Results: At 2 minutes 15 seconds after start of fire the fuze extender deflagrated blowing out the nose fuze and dislodging itself from the bomb. Both the nose fuze (Figure C-26) and adapter booster were recovered live after the test.



FIGURE C-26

The Unreacted Nose Fuze Recovered After Fast Cook-Off Test No. P2-39

BOMB FAST COOK-OFF PHASE 2

Test No. P2-40

Data Sheet

Device Tested: Comp-B loaded M1 thin walled fuze extender, 36 inches long, M904E2 nose fuze and T45E4 adapter booster, installed in an inert MARK 81 bomb. No tail fuze or fins installed.

Date of Test: 23 July 1968.

Weather Conditions: Warm, clear day with 3-6 knot wind.

Bomb Position: 3-1/2 feet at the centerline above fuel surface.

Fuel: 1000 gallons of JP-5 jet aircraft fuel.

Pan Size: 30 X 30 feet.

Test Fire: Because of wind conditions the fuze extender, nose fuze and adapter booster were only intermittently engulfed in flame.

Results: At approximately 3 minutes after start of fire, the fuze extender deflagrated ejecting the nose fuze which struck the test stand with some force, as shown in Figure C-27. At approximately 36 minutes after the test, second reaction took place when the adapter booster exploded, splitting open and ejecting the fuze extender from the bomb; Figure C-28.



FIGURE C-27

Notice Damage to the Test Stand When the Nose Fuze Was Ejected
After the Fuze Extender Deflagrated During Fast Cook-Off Test No. P2-40

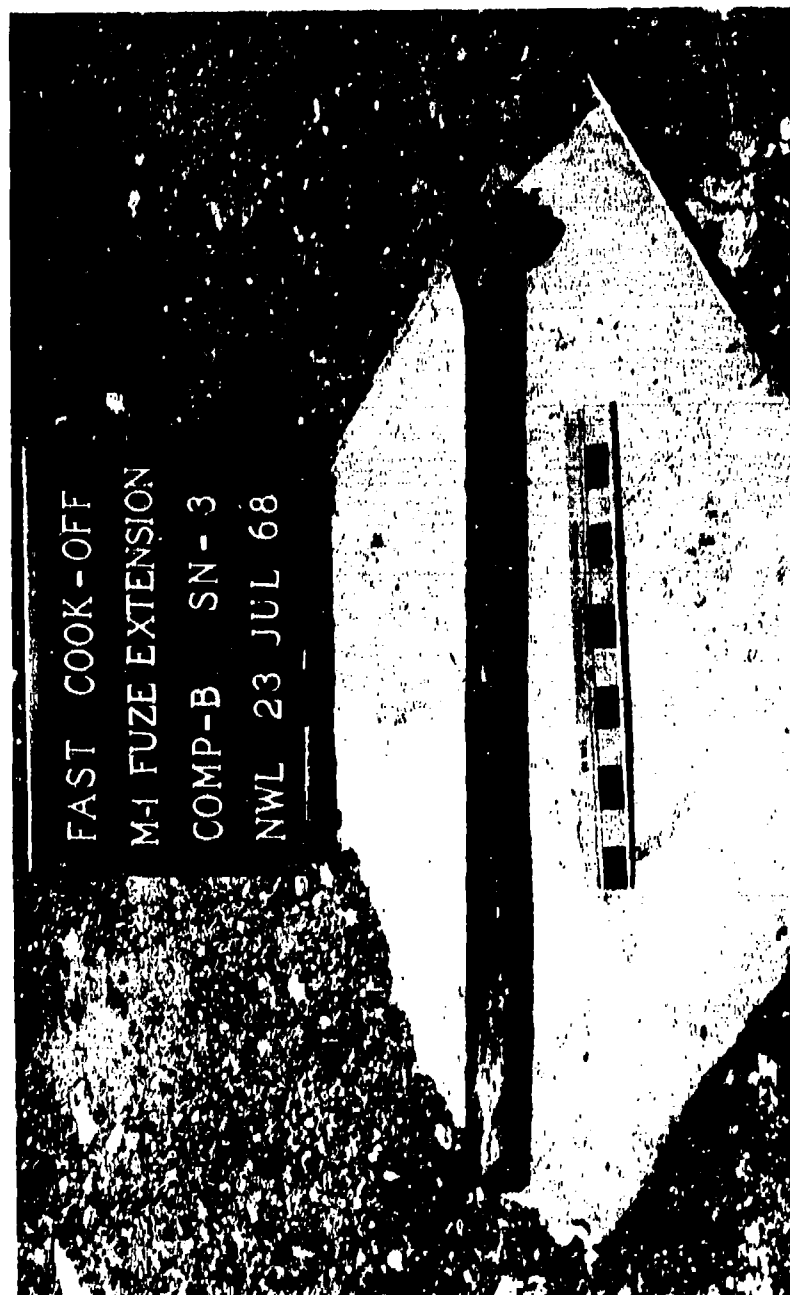


FIGURE C-28

A Second Reaction Split the M1 Fuze Extender When the Adapter Booster Exploded
Approximately 36 Minutes After Start of Fast Cook-Off Test No. P2-40

BOMB FAST COOK-OFF PHASE 2

Test No. P2-41

Data Sheet

Device Tested: Comp-B loaded M1 thick walled fuze extender, 36 inches long, M904E2 nose fuze and T45E4 adapter booster, installed in an inert MARK 81 bomb. No tail fuze or fins installed.

Date of Test: 25 July 1968.

Weather Conditions: Hot, slightly cloudy day with 4-6 knot wind.

Bomb Position: 3-1/2 feet at the centerline above fuel surface.

Fuel: 1000 gallons of JP-5 jet aircraft fuel.

Pan Size: 30 X 30 feet.

Test Fire: Because of wind conditions the fuze extender, nose fuze and adapter booster were not engulfed in flame until 2 minutes after start of test.

Results: At 3 minutes 30 seconds after start of fire, a detonation occurred in one of the live components. The resulting damage to the bomb is shown in Figure C-29. Because of the short time to reaction, it is felt that the fuze extender initiated the reaction.



FIGURE C-29

Damage Resulting When One of the Live Components In the Bomb Detonated
During Fast Cook-Off Test No. P2-41

BOMB FAST COOK-OFF PHASE 2

Test No. P2-42

Data Sheet

Device Tested: Comp-B loaded thick walled fuze extender, 36 inches long, M904E2 nose fuze and T45E4 adapter booster, installed in the tail of an inert MARK 82 bomb. No tail fuze or fins installed. The bomb tail section was used because of extensive damage to the threads in the nose.

Date of Test: 6 August 1968.

Weather Conditions: Warm, cloudy day with 2-5 knot wind.

Bomb Position: 3-1/2 feet at the centerline above fuel surface.

Fuel: 1000 gallons of JP-5 jet aircraft fuel.

Pan Size: 30 X 30 feet.

Test Fire: The nose fuze, fuze extender and adapter booster were engulfed in flame 40 seconds after start of fire and remained so for the duration of the test.

Results: At 3 minutes 38 seconds after start of fire, a detonation occurred in one of the live components. The resulting damage to the tail section of the bomb is shown in Figure C-30. As in the preceding test, it is felt that the fuze extender initiated the reaction.



FIGURE C-30

Damage to the Inert Bomb Used In Fast Cook-Off Test No. P2-42
After One of the Live Components Detonated

BOMB FAST COOK-OFF PHASE 2

Test No. P2-43

Data Sheet

Device Tested: Comp-B loaded thick walled fuze extender, 18 inches long, M904E2 nose fuze and T45E4 adapter booster, installed in an inert MARK 82 bomb. No tail fuze or fins installed.

Date of Test: 1 August 1968.

Weather Conditions: Clear with 3-6 knot wind.

Bomb Position: 3-1/2 feet at the centerline above fuel surface.

Fuel: 1000 gallons of JP-5 jet aircraft fuel.

Pan Size: 30 X 30 feet.

Test Fire: The nose fuze, fuze extender and adapter booster were intermittently engulfed in flame because of the varying wind conditions during the test.

Results: At 4 minutes 25 seconds after start of fire either the nose fuze or fuze extender exploded, blowing the remainder of the fuze extender (Figure C-31) out of the bomb. At 7 minutes 30 seconds the adapter booster deflagrated and burned.

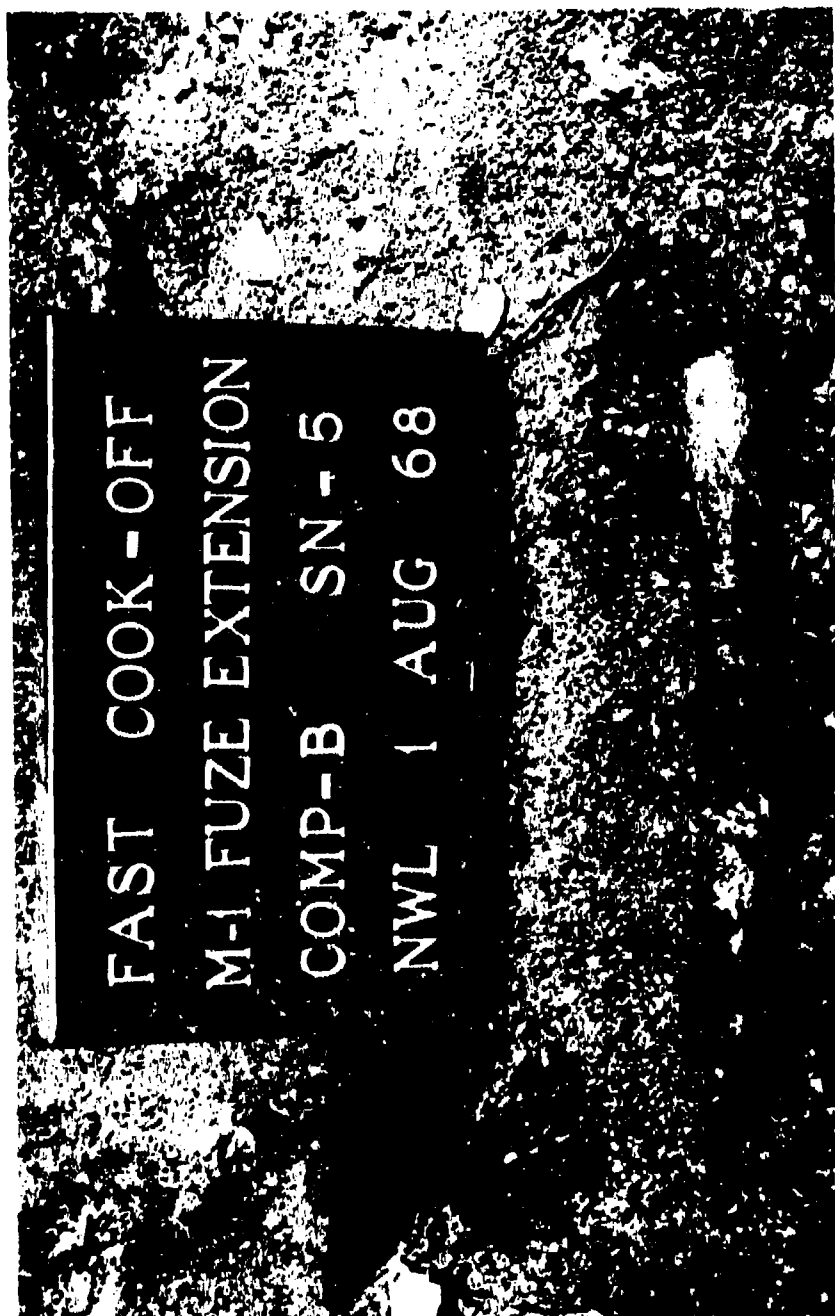


FIGURE C-31

A Portion of the M1 Fuze Extender Recovered
After Fast Cook-Off Test No. P2-43

BOMB FAST COOK-OFF PHASE 2

Test No. P2-44

Data Sheet

Device Tested: Comp-B loaded thick walled fuze extender, 18 inches long, M904E2 nose fuze and T45E4 adapter booster, installed in an inert MARK 81 bomb. No tail fuze or fins installed.

Date of Test: 8 August 1968.

Weather Conditions: Broken clouds with 2-5 knot wind.

Bomb Position: 3-1/2 feet at the centerline above fuel surface.

Fuel: 1000 gallons of JP-5 jet aircraft fuel.

Pan Size: 30 X 30 feet.

Test Fire: The nose fuze, fuze extender and adapter booster were engulfed in flame 28 seconds after start of fire.

Results: At 2 minutes 25 seconds after start of fire, a detonation occurred in one of the life components. The resulting damage to the bomb is shown in Figure C-32. Because of the short time to reaction, it is felt that the fuze extender initiated the reaction.



FIGURE C-32

Bomb Damage Resulting When the Components Detonated
During Fast Cook-Off Test No. P2-44

BOMB FAST COOK-OFF PHASE 2A

Test No. P2A-1

Data Sheet

Device Tested: M117, 750 lb. instrumented bomb loaded with TRITONAL explosive; configured with a M904E2 nose fuze, T45E4 adapter booster and conical tail fins.

Date of Test: 25 April 1968.

Weather Conditions: Cloudy with 0-4 knot wind.

Bomb Position: 9 inches at the centerline above fuel surface.

Fuel: 500 gallons of JP-5 jet aircraft fuel.

Pan Size: 24 X 24 feet.

Test Fire: The M117 bomb was engulfed in flames 23 seconds after start of fire and remained engulfed for 3 minutes at which time the fire was out.

Results: At 5 minutes 25 seconds after start of test (2 minutes 25 seconds after fire was out), the bomb deflagrated. Nose fuze/adaptor booster did not react. Time-temperature data from the first 3 minutes of test show a maximum temperature rise rate of 4.3°F/sec.

BOMB FAST COOK-OFF PHASE 2A

Test No. P2A-2

Data Sheet

Device Tested: M117, 750 lb. bomb loaded with H-6 explosive; configured with M904E2 nose fuze, T45E4 adapter booster and conical tail fins.

Date of Test: 2 July 1968.

Weather Conditions: Hot and clear with 2-4 knot wind.

Bomb Position: 9 inches at the centerline above fuel surface.

Fuel: 1000 gallons of JP-5 jet aircraft fuel.

Pan Size: 30 X 30 feet.

Test Fire: The M117 bomb was engulfed in flames approximately 20 seconds after start of fire and remained engulfed to reaction.

Results: At 3 minutes 0 seconds after start of fire the bomb deflagrated, breaking into several large pieces. The nose fuze/adapter booster did not react and remained in the bomb's nose fuze well as shown in Figure C-33.



FIGURE C-33

The M117 Bomb After Deflagrating During Test No. P2A-2
Notice the Nose Fuze/Adapter Boosters Still In the Nose Fuze Well

BOMB FAST COOK-OFF PHASE 2A

Test No. P2A-3

Data Sheet

Device Tested: MARK 84, 2000 lb. bomb loaded with TRITONAL explosive; configured with M904E2 nose fuze, T45E4 adapter booster, tail fuze plug and conical tail fins.

Date of Test: 30 April 1968.

Weather Conditions: Clear with no wind.

Bomb Position: 12 inches at the centerline above fuel surface.

Fuel: 800 gallons of JP-5 jet aircraft fuel.

Pan Size: 24 X 24 feet.

Test Fire: The MARK 84 bomb was engulfed in flames approximately 5 seconds after start of fire.

Results: At 3 minutes 37 seconds after start of fire the bomb exploded. Witness panels were blown down and the base plate was found 1500 feet from the test site. The test stand was damaged.

BOMB FAST COOK-OFF PHASE 2A

Test No. P2A-4

Data Sheet

Device Tested: MARK 84, 2000 lb. bomb loaded with H-6 explosive; configured with a M904E2 nose fuze, T45E7 adapter booster, tail fuze plug and conical tail fins.

Date of Test: 26 April 1968.

Weather Conditions: Clear with no wind.

Bomb Position: 12 inches at the centerline above fuel surface.

Fuel: 820 gallons of JP-5 jet aircraft fuel.

Pan Size: 24 X 24 feet.

Test Fire: The MARK 84 bomb was engulfed in flames 8 seconds after start of fire.

Results: At 3 minutes 23 seconds after start of fire, the bomb deflagrated. Approximately 7 minutes later the nose fuze/adaptor booster exploded throwing the bomb out of the test pit. A large amount of unreacted explosive was found scattered around the test area.

BOMB FAST COOK-OFF PHASE 2B

Test No. P2B-1

Data Sheet

Device Tested: MARK 81, 250 lb. bomb loaded with H-6 explosive; configured with nose fuze plug, tail fuze plug and conical tail fins. Bomb was suspended under an aircraft wing in a racked to aircraft simulation.

Date of Test: 2 September 1970.

Weather Conditions: Clear with 2 knot wind.

Bomb Position: 3 feet 9 inches at the centerline above the fuel surface and 2 feet 4 inches at the centerline below the wing.

Fuel: 800 gallons of JP-5 jet aircraft fuel.

Pan Size: 35 X 35 feet.

Test Fire: Flame temperature at the MARK 81 bomb exceeded 1000°F within 20 seconds after start of fire and averaged 1860°F till reaction.

Results: The wing structure was observed melting and falling into the test pit 1 minute 21 seconds after start of fire. At 2 minutes 6 seconds the bomb exploded. Numerous pieces of unreacted explosive were scattered about the test site. Several large pieces of the bomb were found approximately 30 feet from ground zero and are shown in Figure C-34. The wing structure was completely destroyed with only puddles of melted aluminum remaining.



FIGURE C-34

Tail Fins and Several Pieces of the MARK 81 Bomb Recovered
After Fast Cook-Off Test No. P2B-1

BOMB FAST COOK-OFF PHASE 2B

Test No. P2B-2

Data Sheet

Device Tested: MARK 81, 250 lb. bomb loaded with H-6 explosive; configured with nose fuze plug, tail fuze plug and conical tail fins. Bomb was suspended under an aircraft wing in a racked to aircraft simulation.

Date of Test: 4 September 1970.

Weather Conditions: Partly cloudy with 12-15 knot wind.

Bomb Position: 3 feet 9 inches at the centerline above the fuel surface and 2 feet 4 inches at the centerline below the wing.

Fuel: 800 gallons of JP-5 jet aircraft fuel.

Pan Size: 35 X 35 feet.

Test Fire: Flame temperature at the MARK 81 bomb exceeded 1000°F within 23 seconds after start of fire and averaged 1765°F till reaction.

Results: At 1 minute 50 seconds after start of fire, the bomb exploded. Numerous pieces of unreacted explosive were scattered about the test site. Several large pieces of the bomb were found in the test pit. The wing structure was completely destroyed. The remains are shown in Figure C-35.



FIGURE C-35

What Remained of the Wing Structure After
Fast Cook-Off Test No. P2B-2

BOMB FAST COOK-OFF PHASE 2B

Test No. P2B-3

Data Sheet

Device Tested: MARK 81, 250 lb. bomb loaded with H-6 explosive; configured with nose fuze plug, tail fuze plug and conical tail fins. Bomb was suspended under an aircraft wing in a racked to aircraft simulation.

Date of Test: 30 September 1970.

Weather Conditions: Partly cloudy with 6-10 knot wind.

Bomb Position: 3 feet 9 inches at the centerline above the fuel surface and 2 feet at the centerline below the wing.

Fuel: 800 gallons of JP-5 jet aircraft fuel.

Pan Size: 35 X 35 feet.

Test Fire: Flame temperature at the MARK 81 bomb exceeded 1000°F within 32 seconds after start of fire and averaged 1825°F till reaction.

Results: At 2 minutes 4 seconds after start of fire, the bomb exploded. Several large pieces of the bomb were found approximately 40 feet from ground zero and are pictured in Figure C-36. Numerous pieces of unreacted explosive were scattered about the test site.



FIGURE C-36

Parts of the MARK 81 Bomb Recovered After Fast Cook-Off Test No. P2B-3

BOMB FAST COOK-OFF PHASE 2B

Test No. P2B-4

Data Sheet

Device Tested: MARK 82, 500 lb. bomb loaded with H-6 explosive; configured with nose fuze plug, tail fuze plug and conical tail fins. Bomb was suspended under an aircraft wing in a racked to aircraft simulation.

Date of Test: 24 August 1970.

Weather Conditions: Clear with 8 knot wind.

Bomb Position: 3 feet 9 inches at the centerline above the fuel surface and 2 feet 4 inches at the centerline below the wing.

Fuel: 800 gallons of JP-5 jet aircraft fuel.

Pan Size: 35 X 35 feet.

Test Fire: Flame temperature at the MARK 82 bomb exceeded 1000°F within 14 seconds after start of fire and averaged 1860°F till reaction.

Results: At 2 minutes 12 seconds after start of fire, the bomb exploded. Pieces of the bomb were found 750 feet from ground zero. Unreacted explosive was found scattered about the test site. Several of the recovered pieces of the bomb are shown in Figure C-37.



FIGURE C-37

Several Pieces of the MARK 82 Bomb That Were Recovered After Fast Cook-Off Test No. P2B-4

BOMB FAST COOK-OFF PHASE 2B

Test No. P2B-5

Data Sheet

Device Tested: MARK 82, 500 lb. bomb loaded with H-6 explosive; configured with nose fuze plug, tail fuze plug and conical tail fins. Bomb was suspended under an aircraft wing in a racked to aircraft simulation.

Date of Test: 25 August 1970.

Weather Conditions: Clear with 5-10 knot wind.

Bomb Position: 3 feet 9 inches at the centerline above the fuel surface and 2 feet at the centerline below the wing.

Fuel: 800 gallons on JP-5 jet aircraft fuel.

Pan Size: 35 X 35 feet.

Test Fire: Flame temperature at the MARK 82 bomb exceeded 1000°F within 17 seconds after start of fire and averaged 1950°F till reaction.

Results: The wing structure was observed burning 55 seconds after start of fire and falling into the pit at 1 minute 10 seconds. The bomb deflagrated 2 minutes 4 seconds into the test. Very little explosive was found at the test area, since most of it remained in the bomb and burned as seen in Figure C-38.



FIGURE C-38

MARK 82 Bomb After Fast Cook-Off Test No. P2B-5
Notice Burned Explosive Remaining In the Bomb Case.

BOMB FAST COOK-OFF PHASE 2B

Test No. P2B-6

Data Sheet

Device Tested: MARK 82, 500 lb. bomb loaded with H-6 explosive; configured with nose fuze plug, tail fuze plug and conical tail fins. Bomb was suspended under an aircraft wing in a racked to aircraft simulation.

Date of Test: 21 September 1970.

Weather Conditions: Clear with no wind.

Bomb Position: 3 feet 9 inches at the centerline above the fuel surface and 2 feet 2 inches at the centerline below the wing.

Fuel: 800 gallons of JP-5 jet aircraft fuel.

Test Fire: Flame temperature at the MARK 82 bomb exceeded 1000°F within 16 seconds after start of fire and averaged 1780°F till reaction.

Results: At 2 minutes 12 seconds after start of fire the bomb exploded tossing unreacted explosive about the immediate test area. Several pieces of the bomb case were found approximately 55 feet from ground zero. Figure C-39 pictures some of the larger pieces of the bomb case recovered after the test.



FIGURE C-39

Several of the Larger Pieces of the MARK 82 Bomb Recovered After Fast Cook-Off Test No. P2B-6

BOMB FAST COOK-OFF PHASE 2B

Test No. P2B-7

Data Sheet

Device Tested: MARK 84, 2000 lb. bomb loaded with H-6 explosive; configured with a M904E2 nose fuze, T45E4 adapter booster, M990E1 tail fuze and conical tail fins. Bomb was suspended under an aircraft wing in a racked to aircraft simulation.

Date of Test: 15 August 1968.

Weather Conditions: Clear with 1-2 knot wind.

Bomb Position: 3 feet 6 inches at the centerline above the fuel surface and 2 feet at the centerline below the wing.

Fuel: 700 gallons of JP-5 jet aircraft fuel.

Pan Size: 24 X 24 feet.

Test Fire: The MARK 84 bomb was engulfed in flames within 30 seconds after start of fire and remained engulfed till reaction.

Results: Shortly after the fire was started, magnesium in the wings structure and covering was observed burning (sparkling). At 3 minutes 38 seconds the bomb reacted in a partial detonation which destroyed the test pan and A-frame stand supporting the bomb. Bomb fragments were found several thousand feet from ground zero. Very little unreacted explosive was found. Because of the order of reaction, it is felt that the nose fuze/adapter booster may have initiated the reaction.

BOMB FAST COOK-OFF PHASE 2B

Test No. P2B-8

Data Sheet

Device Tested: MARK 84, 2000 lb. bomb loaded with TRITONAL explosive; configured with a M904E2 nose fuze, T45E4 adapter booster, M990E1 tail fuze and conical tail fins. Bomb was suspended under an aircraft wing in a racked to aircraft simulation.

Date of Test: 29 August 1968.

Weather Conditions: Clear with no wind.

Bomb Position: 3 feet 6 inches at the centerline above the fuel surface and 2 feet at the centerline below the wing.

Fuel: 630 gallons of JP-5 jet aircraft fuel.

Pan Size: 24 X 24 feet.

Test Fire: The MARK 84 bomb was engulfed in flames within 25 seconds after start of fire and remained engulfed till reaction.

Results: One minute after start of fire magnesium in the wing's structure and covering was observed burning (sparkling). At 3 minutes 30 seconds the bomb deflagrated. Large chunks of unreacted explosive were in the test area. The nose and tail fuzes and adapter booster were recovered live. The nose section of the bomb after reaction is shown in Figure C-40.



FIGURE C-40

Nose Section of the MARK 84 Bomb After Fast Cook-Off Test No. P2B-8
Notice the Unreacted Adapter Booster In the Foreground.

APPENDIX D

BOMB FAST COOK-OFF PHASE 3

Test No. P3-1

Data Sheet

Device Tested: MARK 81 bomb inert loaded with Filler-E and thermocouples as shown in Figure D-1.

Date of Test: 2 October 1968.

Weather Conditions: Broken clouds with 3-5 knot wind.

Test Fire: Flame temperature recording equipment failed. A visual inspection of the fire indicated very little flame engulfment of the bomb due to the wind.

Test Procedures: One minute 30 seconds after start of test the fire was removed and the bomb was allowed to air cool. Temperature data were taken for 5 minutes.

Results: Time-temperature data are presented as follows:

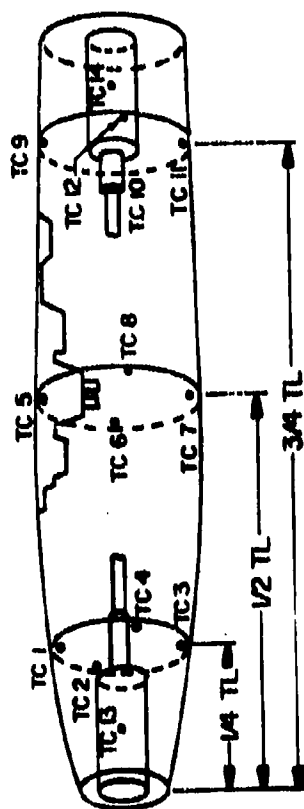
Time (sec)	Thermocouple Number ¹							
	1	6	7	8	9	10	11	12
Temperature °F								
0-20	60	62	61	62	60	60	60	63
50	110	110	80	110	105	115	105	110
70	158	150	160	150	155	156	145	149
90 ²	213	211	214	212	210	216	200	211
120	257	256	262	258	257	264	247	261
150	255	255	260	256	257	262	250	261
180 ³	267	269	271	269	264	274	264	270
210	265	267	268	263	263	272	263	269
240	264	266	262	261	262	268	260	268

¹ Thermocouple Nos. 2, 3, 4 and 5 were not monitored.

² At 90 seconds fire was removed from bomb.

³ At approximately 180 seconds maximum bomb interface temperatures were reached.

At approximately 20 seconds into the test interface temperatures (between bomb casing and hot melt) began to rise at the rate of $2.3^{\circ}\text{F}/\text{sec}$. At 1 minute 30 seconds the fire was removed; internal temperatures continued to rise for 1 minute 30 seconds to a maximum of 271°F . The air cooling rate was $0.17^{\circ}\text{F}/\text{sec}$. Thermocouples located on the nose and tail fuze wells indicated very slow but constant temperature rise rate. A maximum temperature of 165°F on the nose well and 105°F on the tail well after 5 minutes were recorded.



THERMOCOUPLES ARE LOCATED BETWEEN THE HOT MELT AND METAL CASE

TL - TOTAL LENGTH OF BOMB

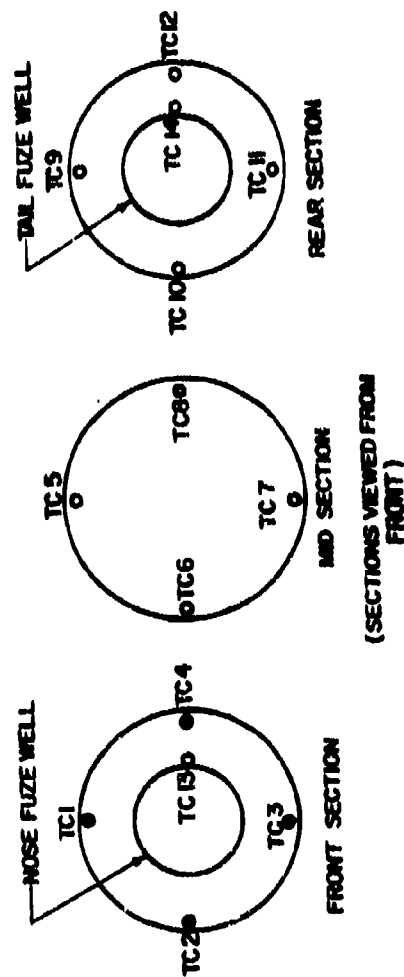


FIGURE D-1

Thermocouple Locations for Fast Cook-Off Tests Phase 3 and 3A

BOMB FAST COOK-OFF PHASE 3

Test No. P3-2

Data Sheet

Device Tested: MARK 81 bomb inert loaded with Filler-E and thermocoupled as shown in Figure D-1.

Date of Test: 7 October 1968.

Weather Conditions: Clear with 0-1 knot wind.

Test Fire: Flame temperature at the bomb exceeded 1000°F 35 seconds after start of fire and averaged 1590°F to removal of fire.

Test Procedures: Two minutes 20 seconds after start of test the fire was removed and the bomb was allowed to air cool. Temperature data were taken for 5-1/2 minutes.

Results: Time-temperature data are presented as follows:

Time (sec)	Thermocouple Number ¹							
	1	7	8	9	10	11	12	13
	Temperature °F							
0-30	63	61	64	68	68	67	67	61
60	158	127	157	156	161	158	157	82
90	302	250	303	307	310	295	298	120
120	401	378	401	411	410	385	402	162
140 ²	489	436	480	493	483	455	485	193
170 ³	503	487	497	497	506	490	499	213
200	461	469	455	452	465	454	463	224
220	433	449	434	436	435	428	437	230

¹ Thermocouple Nos. 2, 3, 4, 5 and 6 were not monitored.

² At 140 seconds fire was removed from bomb.

³ At approximately 170 seconds maximum bomb interface temperatures were reached.

At approximately 30 seconds into the test bomb interface, temperatures began to rise at the rate of $3.6^{\circ}\text{F}/\text{sec}$. At 2 minutes 20 seconds the fire was removed, interface temperatures continued to rise for approximately 30 seconds to a maximum of 506°F . The air cooling rate was $0.5^{\circ}\text{F}/\text{sec}$. Thermocouples located on the nose and tail fuze wells indicated a very slow temperature rise on the tail well but a $1^{\circ}\text{F}/\text{sec}$ rise rate on the nose well.

BOMB FAST COOK-OFF PHASE 3

Test No. P3-3

Data Sheet

Device Tested: MARK 81 bomb inert loaded with Filler-E and thermocoupled as shown in Figure D-1.

Date of Test: 9 October 1968.

Weather Conditions: Scattered clouds with 3-5 knot wind.

Test Fire: Extremely poor fire because of the wind. Flame temperatures never exceeded 900°F.

Test Procedure: Two minutes 15 seconds after start of test, the fire was removed and the bomb allowed to air cool. Temperature data were taken for 6 minutes.

Results: Time-temperature data are presented as follows:

Time (sec)	Thermocouple Number, ¹						
	5	7	8	9	10	11	12
Temperature °F							
0-40	61	63	62	62	62	62	62
80	97	97	95	95	98	98	97
100	139	141	141	137	141	135	140
120	189	190	186	183	190	187	190
135 ²	210	211	210	208	215	211	216
160 ³	266	266	262	261	269	263	264
190	216	221	216	212	222	218	221
210	209	213	208	204	214	211	213
250	197	199	197	189	199	197	196

¹ Thermocouple Nos. 1, 2, 3, 4 and 6 were not monitored.

² At 135 seconds fire was removed from bomb.

³ At approximately 160 seconds bomb interface temperatures were reached.

At approximately 50 seconds into the test bomb interface temperatures began to rise at a rate of $2.1^{\circ}\text{F}/\text{sec}$. At 2 minutes 15 seconds, the fire was removed; internal temperatures continued to rise for 25 seconds to a maximum of 269°F . The air cooling rate was $0.27^{\circ}\text{F}/\text{sec}$. No data were obtained on the nose or tail fuze wells.

BOMB FAST COOK-OFF PHASE 3

Test No. P3-4

Data Sheet

Device Tested: MARK 81 bomb inert loaded with Filler-E and thermocoupled as shown in Figure D-1.

Date of Test: 11 October 1968.

Weather Conditions: Clear with no wind.

Test Fire: Flame temperature at the bomb exceeded 1000°F, 10 seconds after start of fire and averaged 1720°F to removal of fire.

Test Procedures: One minute 30 seconds after start of test, the first was removed and the bomb was allowed to air cool. Temperature data were taken for 1 hour.

Results: Time-temperature data are presented as follows:

Time (sec)	Thermocouple Number ¹							
	5	7	8	9	10	11	12	13
Temperature °F								
0-15	76	72	72	77	76	72	74	61
30	175	170	172	176	174	170	174	69
45	271	260	266	270	266	264	268	86
60	358	350	358	363	359	353	360	106
75	411	405	414	417	410	401	415	126
90 ²	475	472	478	485	473	470	467	144
120 ³	482	474	479	489	474	473	476	158
150	457	452	455	465	451	450	453	170
180	437	423	431	440	427	432	430	199

¹ Thermocouple Nos. 1, 2, 3, 4 and 6 were not monitored.

² At 90 seconds fire was removed from bomb.

³ At approximately 120 seconds maximum bomb interface temperatures were reached.

At approximately 15 seconds into the test bomb interface temperature began to rise at the rate of $5.2^{\circ}\text{F}/\text{sec}$. At 1 minute 30 seconds, the fire was removed; internal temperatures continued to rise for 30 seconds to a maximum of 489°F . The air cooling rate for the next 4 minutes was $0.39^{\circ}\text{F}/\text{sec}$. Temperature recordings were continually made for one hour that showed a substantial drop in cooling rate. That is, from 6 to 30 minutes the cooling rate was $.14^{\circ}\text{F}/\text{sec}$ and from 30 to 60 minutes this rate dropped to $0.039^{\circ}\text{F}/\text{sec}$.

BOMB FAST COOK-OFF PHASE 3

Test No. P3-5

Data Sheet

Device Tested: MARK 81 bomb inert loaded with Filler-E and thermocoupled as shown in Figure D-1.

Date of Test: 14 October 1968.

Weather Conditions: Overcast with 0-1 knot wind.

Test Fire: Flame temperature at the bomb exceeded 1000°F, 40 seconds after start of fire and averaged 1370°F to removal of fire.

Test Procedures: Two minutes 15 seconds after start of test, the fire was removed and the bomb allowed to air cool. Temperature data were taken for 5-1/2 minutes.

Results: Time-temperature data are presented as follows:

Time (sec)	Thermocouple Number ¹							
	5	7	8	9	10	11	12	13
Temperature °F								
0-30	62	61	62	63	62	63	62	60
60	148	146	147	152	151	142	146	72
90	281	276	280	288	281	266	276	90
120	378	372	120	382	378	357	367	115
135 ²	418	410	408	422	410	392	407	138
170 ³	433	427	430	436	429	414	421	303
200	411	406	410	415	407	399	404	284
230	391	389	389	397	392	380	383	266
260	382	380	381	386	384	370	372	264

¹ Thermocouple Nos. 1, 2, 3, 44 and 6 were not monitored.

² At 135 seconds fire was removed from bomb.

³ At approximately 170 seconds maximum bomb interface temperatures were reached.

At approximately 30 seconds into the test interface temperatures began to rise at the rate of $3.9^{\circ}\text{F}/\text{sec}$. At 2 minutes 15 seconds, the fire was removed; internal temperatures continued to rise for 35 seconds to a maximum of 271°F . The air cooling rate was $0.6^{\circ}\text{F}/\text{sec}$.

BOMB FAST COOK-OFF PHASE 3

Test No. P3-6

Data Sheet

Device Tested: MARK 81 bomb inert loaded with Filler-E and thermocoupled as shown in Figure D-1.

Date of Test: 18 October 1968.

Weather Conditions: Clear with 2-4 knot wind.

Test Fire: Flame temperature at the bomb exceeded 1000°F, 60 seconds after start of fire and averaged 1360°F to removal of fire.

Test Procedures: One minute 45 seconds after start of test, the fire was removed and the bomb allowed to air cool. Temperature data were taken for one hour 6 minutes.

Results: Time-temperature data are presented as follows:

Time (sec)	Thermocouple Number ¹							
	5	7	8	9	10	11	12	13
	Temperature °F							
0-45	62	61	60	62	60	60	60	60
75	104	107	103	103	106	105	102	104
90	166	166	162	154	166	156	163	159
105 ²	226	225	222	217	225	220	220	221
135 ³	261	258	253	252	259	254	254	244
165	249	248	238	244	250	247	247	240
225	223	231	230	223	233	231	228	231

¹ Thermocouple Nos. 1, 2, 3, 4 and 6 were not monitored.

² At 105 seconds fire was removed from bomb.

³ At approximately 135 seconds maximum interface temperatures were reached.

At approximately 60 seconds into the test bomb interface temperatures began to rise at the rate of $3.3^{\circ}\text{F}/\text{sec}$. At 1 minute 45 seconds, the fire was removed; internal temperature in the bomb continued to rise for 30 seconds to a maximum of 261°F . The air cooling rate for the next 3 minutes was $0.4^{\circ}\text{F}/\text{sec}$. Temperature recordings were continually made for one hour 6 minutes that showed a substantial drop in cooling rate. That is, from 21 to 66 minutes the rate was $0.093^{\circ}\text{F}/\text{sec}$.

BOMB FAST COOK-OFF PHASE 3A

Test No. 3A-1

Data Sheet

Device Tested: Cooling effect of two FULLJET 30° injector type sprinkler nozzles positioned applying water at the rate of .03 gal/ft²/min onto a Filler-E loaded MARK 81 bomb which was thermocoupled as shown in Figure D-1.

Date of Test: 16 January 1969.

Weather Conditions: Sunny with 25 knot wind.

Test Fire: Flame temperature at the bomb exceeded 1000°F, 45 seconds after start of fire and averaged 2000°F during the time sprinklers were OFF. During the time sprinklers were ON, the flame temperature averaged 1560°F.

Test Procedures: One minute after start of test, the sprinkler system was turned on and remained on for two minutes before being turned off. At 4 minutes 15 seconds into the test the fire was removed from the bomb.

Results: All thermocouples located in the bomb indicated a temperature rise rate of from 4.5 to 5.0°F/sec during the entire 4+ minutes of the test. No change in temperature rise rate was noted when the sprinklers were turned off. A maximum temperature of 735°F was recorded at the bomb interface. No water was observed impinging on the bomb.

BOMB FAST COOK-OFF PHASE 3A

Test No. P3A-2

Data Sheet

Device Tested: Cooling effect of two FULLJET 30° injector type sprinkler nozzles applying water at the rate of 0.03 gal/ft²/min onto a Filler-E loaded MARK 81 bomb which was thermocoupled as shown in Figure D-1.

Date of Test: 29 January 1969.

Weather Conditions: Sunny with 1-2 knot wind.

Test Fire: Flame temperature at the bomb exceeded 1000°F, 12 seconds after start of fire and averaged 2050°F during the time sprinklers were OFF. During the time sprinklers were ON, the flame temperature averaged 1560°F.

Test Procedure: At 52 seconds after start of test, the sprinkler system was turned on and remained on for the duration of the test. At 3 minutes into the test the fire was removed from the bomb; sprinklers were still on.

Results: All thermocouples located in the bomb indicated a temperature rise rate of from 5.0 to 5.5°F/sec during the 3+ minutes of the test. No change in temperature rise rate was noted when the sprinklers were turned off or during the time they were on. A maximum temperature of 773°F was recorded at the bomb interface. No water was observed impinging on the bomb.

BOMB FAST COOK-OFF PHASE 3A

Test No. P3A-3

Data Sheet

Device Tested: Cooling effectiveness of two FULLJET 30° injector type sprinkler nozzles applying water at the rate of 0.48 gal/ft²/min onto a Filler-E loaded MARK 81 bomb which was thermocoupled as shown in Figure D-1.

Date of Test: 15 April 1969.

Weather Conditions: Sunny with steady 2 knot wind.

Test Fire: Flame temperature at the bomb never exceeded 1000°F. Temperature averaged 550°F during the time sprinklers were OFF and 350°F during the time they were ON.

Test Procedure: One minute after start of fire, the sprinklers were turned on and remained on for the duration of the test.

Results: Thermocouples located in the bomb indicated a temperature rise rate of 1.7°F/sec during the entire test. No change in temperature rise rate was noted when the sprinklers were turned on. A maximum temperature of 239°F was recorded in the bomb at 2 minutes into the test. Water was not observed impinging on the bomb during the test.

BOMB FAST COOK-OFF PHASE 3A

Test No. P3A-4

Data Sheet

Device Tested: Cooling effectiveness of two FULLJET 30° injector type sprinkler nozzles applying water at the rate of 0.48 gal/ft²/min onto a Filler-E loaded MARK 81 bomb which was thermocoupled as shown in Figure D-1.

Date of Test: 17 April 1969.

Weather Conditions: Foggy with 0-3 knot wind.

Test Fire: Flame temperature at the bomb exceeded 1000°F, 40 seconds after start of fire and averaged 1400°F during time sprinklers were OFF. While sprinklers were ON the flame temperature averaged 750°F at the bomb.

Test Procedure: One minute after start of fire, the sprinklers were turned on and remained on for the duration of the test.

Results: All thermocouples located in the bomb indicated a temperature rise rate of 3.4°F/sec before and after sprinkler system was activated. A maximum temperature of 352°F at the bomb interface was recorded. Neither visual observation nor film review could conclusively show water impinging on the bomb.

BOMB FAST COOK-OFF PHASE 3A

Test No. P3A-5

Data Sheet

Device Tested: Water cooling effect of a single flush deck nozzle (Grinnell S-110-438) positioned 3-1/2 feet directly under a Filler-E loaded MARK 81 bomb. Water pressure on the system was 60 psi. The bomb was instrumented as shown in Figure D-1.

Date of Test: 15 September 1969.

Weather Conditions: Sunny with 0-2 knot wind. Temperature 78°F.

Test Fire: Flame temperature at the bomb exceeded 1000°F, 15 seconds after start of fire and averaged 1560°F during time the flush deck nozzles were OFF. While flush deck nozzles were ON, flame temperature averaged 930°F at the bomb.

Test Procedure: One minute after start of fire the single flush deck nozzle was turned on and remained on for 5-1/2 minutes. At 4 minutes, the fire began to die down and was out at 5 minutes. For the first minute of the test, a maximum temperature rise rate of 3.5°F/sec was recorded.

Results: Thermocouple No. 7 recordings show a definite cooling of the bomb in that area. This was the area where water from the center plume of the nozzle directly impinged on the bomb. All other areas of the bomb showed a temperature rise rate of from 0.1 to 1.5°F/sec. After the fire was out a cooling rate of 1.8°F/sec was observed on TC7 while the rest of the bomb was cooled at the rate of approximately 0.6 to 0.8°F/sec.

BOMB FAST COOK-OFF PHASE 3A

Test No. P3A-6

Data Sheet

Device Tested: Water cooling effect of two flush deck nozzles (Grinnell S-110-438) positioned 3-1/2 feet beneath and one on either side, 10 feet from a Filler-E loaded MARK 81 bomb. Water pressure on the system was 75 psi. The bomb was instrumented as shown in Figure D-1.

Date of Test: 16 September 1969.

Weather Conditions: Fair with 1-5 1/2 knot winds. Temperature 79°F.

Test Fire: Flame temperature at the bomb exceeded 1000°F, 15 seconds after start of fire. Temperature was approximately 1450°F until nozzles were activated (after 56 seconds) at which time flame temperature dropped to approximately 750°F for the remainder of the test.

Test Procedure: At 56 seconds after start of fire the nozzles were turned on and remained on for 2 minutes 16 seconds. The fire was removed from the bomb at 1 minute 51 seconds.

Results: The temperature rise rate in the bomb was 2.1°F/sec for the first minute of the test. When the water was turned on the rise rate was 1.8°F/sec and when the flame was removed the process was reversed and a cooling rate of 1.0°F/sec was recorded.

BOMB FAST COOK-OFF PHASE 3A

Test No. P3A-7

Data Sheet

Device Tested: Water cooling effect of two flush deck nozzles (Grinnell S-110-438) positioned 3-1/2 feet beneath and one 10 feet on either side of a Filler-E loaded MARK 81 bomb. Water pressure on the system was 75 psi. The bomb was instrumented as shown in Figure D-1.

Date of Test: 17 September 1969.

Weather Conditions: Fair with 0-1 1/2 knot wind. Temperature 77°F.

Test Fire: Flame temperature at the bomb exceeded 1000°F, 10 seconds after start of fire. Temperature was at about 1500°F until nozzles were activated (after 54 seconds) at which time flame temperature dropped to approximately 600°F for the remainder of the test.

Test Procedure: At 54 seconds after start of fire, the nozzles were turned on and remained on for 3 minutes 23 seconds. The fire was removed from the bomb at 1 minute 28 seconds.

Results: None of the thermocouples in the bomb showed a significant decrease in the temperature rise rate of 1.6°F/sec. After the fire was removed from the bomb (nozzles remaining on) a temperature decrease of 0.2°F/sec was recorded.

BOMB FAST COOK-OFF PHASE 3A

Test No. P3A-8

Data Sheet

Device Tested: Cooling effect of water being applied over an inert Filler-E loaded instrumented MARK 81 bomb at the rate of 60 gpm. The water was applied by firemen from a hand-held 1-1/2-inch fire hose.

Date of Test: 13 August 1969.

Weather Conditions: Broken clouds with 3-6 knot wind; temperature 82°F.

Test Fire: Flame temperature at the bomb exceeded 1000°F, 30 seconds after start of fire. At 1 minute 40 seconds when water was applied to the bomb, the flame temperature was 1290°F. Bomb remained engulfed in flame for the duration of the test.

Test Procedure: One minute 40 seconds after start of test, firemen standing approximately 65 feet from the bomb started applying water from a hand-held 1-1/2-inch fire hose directly onto the bomb. Firemen were positioned at an angle of 10°-15° to the tail of the bomb. A standard nozzle producing a fairly tight stream of water was used. The rate of flow was 60 gpm.

Results: A maximum heating rate of 4.6°F/sec was recorded on the bottom midsection of the bomb (TC7 of Figure D-1). When the interface temperature at the point reached 325°F, firemen began applying water onto the bomb making sure that the water was completely covering the outside surface. In about 10 seconds, the bomb began to cool at the rate of 5°F/sec and at 5 minutes into the test had temperature stabilized at approximately 110°F as seen in Figure D-2.

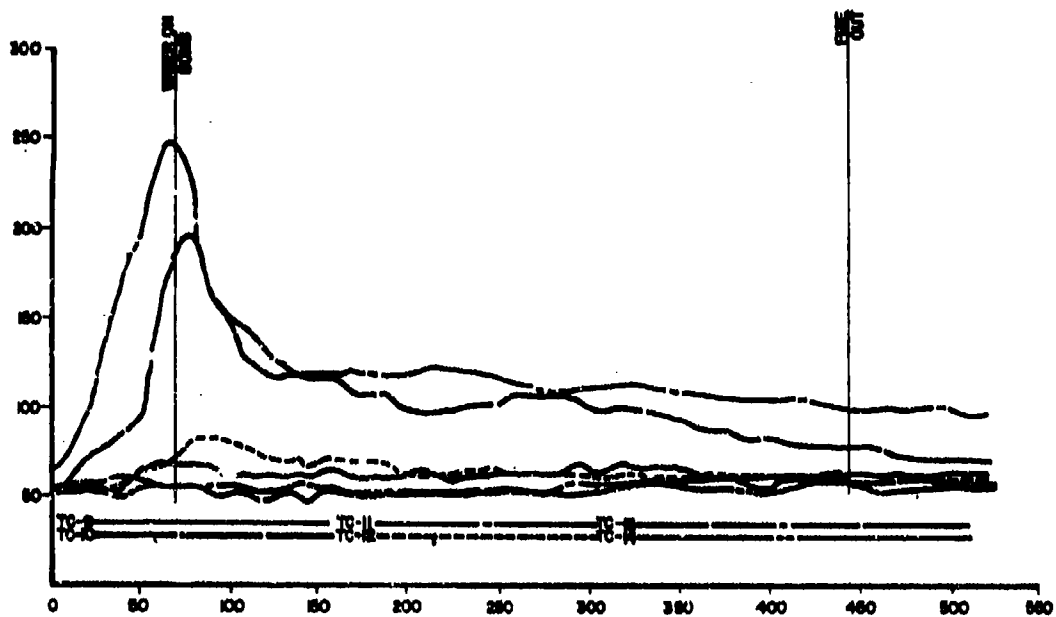
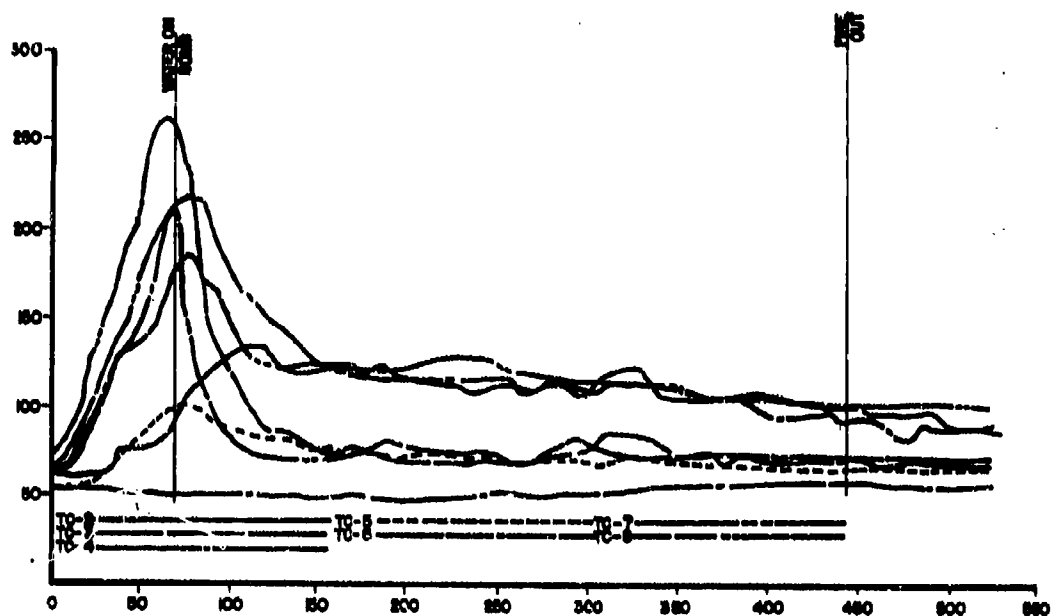


FIGURE D-2

Time-Temperature Graph of Bomb Heating and Cooling Rates
for Bomb Cook-Off Test No. P3A-8

BOMB FAST COOK-OFF PHASE 3A

Test No. P3A-9

Data Sheet

Device Tested: Cooling effect of water being applied over an inert Filler-E loaded instrumented MARK 81 bomb at the rate of 60 gpm. The water was applied by firemen from a hand-held 1-1/2-inch fire hose.

Date of Test: 19 September 1969.

Weather Conditions: Fair with 5-12 knot wind; temperature 70°F.

Test Fire: Flame temperature at the bomb exceeded 1000°F within 30 seconds after start of fire. At 1 minute 10 seconds when water was applied to the bomb, the flame temperature was 1190°F. Bomb remained engulfed in flames for the duration of the test.

Test Procedure: One minute 10 seconds after start of test, firemen standing approximately 50 feet from the bomb started applying water from a hand-held 1-1/2-inch fire hose directly onto the bomb. Firemen were positioned at an angle of 45°-50° to the tail of the bomb. A standard nozzle producing a fairly tight stream of water was used. The rate of flow was 60 gpm.

Results: A maximum heating rate of 3.4°F/sec was recorded on the bottom midsection of the bomb (TC7 of Figure D-1). When the interface temperature at this point reached 260°F (1 minute 10 seconds), firemen began applying water onto the bomb making sure that the water was completely covering the outside surface. The bomb then began to cool at the rate of 2.6°F/sec and at 2 minutes 30 seconds was at approximately 130°F. Cooling continued but at a much slower rate, as can be seen in Figure D-3, until a stabilizing temperature of approximately 110°F was reached.

BOMB FAST COOK-OFF PHASE 3A

Test No. P3A-10

Data Sheet

Device Tested: Cooling effect of water being applied over an inert Filler-E loaded instrumented MARK 81 bomb at the rate of 95 gpm. Water was applied by firemen from a hand-held 1-1/2-inch fire hose.

Date of Test: 8 September 1970.

Weather Conditions: Clear with 0-3 knot wind; temperature 94°F.

Test Fire: Flame temperature at the bomb exceeded 1000°F within 30 seconds after start of fire. At 1 minute 35 seconds when water was applied to the bomb, flame temperature was at 1250°F. Bomb remained completely engulfed in flames for the duration of the test.

Test Procedure: One minute 30 seconds after start of test, firemen standing approximately 70 feet from the bomb started applying water from a hand-held 1-1/2-inch fire hose directly onto the bomb. Firemen were positioned at an angle of 30°-35° to the nose of the bomb. A standard nozzle producing a fairly tight stream of water was used. The rate of flow was 95 gpm.

Results: A maximum heating rate of 3.4°F/sec was recorded at the bottom midsection of the bomb (TC7, Figure D-1). When the interface temperature at TC7 reached 370°F (1 minute 35 seconds), firemen began applying water onto the bomb making sure that the water was completely covering the bomb's outside surface. Temperature in the bomb continued to climb for 25 seconds to a maximum of 415°F. The bomb then began to cool at the rate of 2.5°F/sec and at about 5 minutes had begun to stabilize at approximately 120°F as seen in Figure D-4.

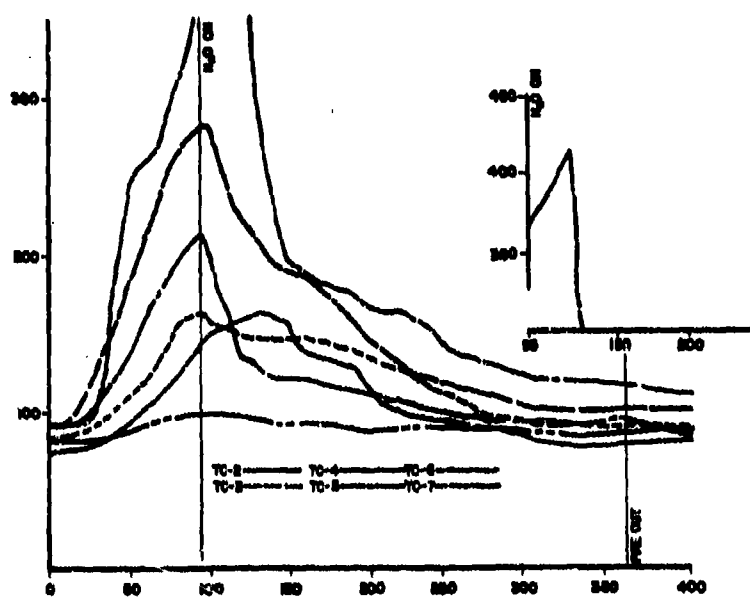
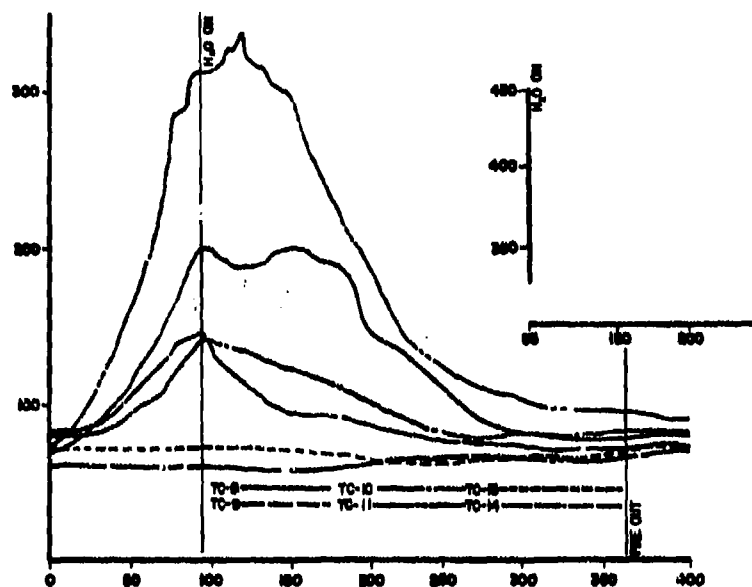


FIGURE D-4
Time-Temperature Graph of Bomb Heating and Cooling Rates
for Bomb Cook-Off Test No. P3A-10

BOMB FAST COOK-OFF PHASE 3A

Test No. P3A-11

Data Sheet

Device Tested: Cooling effect of two FULLJET 30° injector type sprinkler nozzles positioned on either side of a Filler-E loaded MARK 81 bomb and dispensing a 6% solution of "lightwater" at the rate of .03 gal/ft²/min. The bomb was thermocoupled as shown in Figure D-1.

Date of Test: 11 August 1969.

Weather Conditions: Clear with 5-7 knot wind; temperature 80°F.

Test Fire: Three minutes 15 seconds after start of fire the sprinkler system was turned on (bomb internal temperature 250°F) and remained on for the duration of the test. An average flame temperature of 1300°F was recorded after a 2-minute fire build-up time. No change in flame temperature was noted when sprinklers were activated. At the .03 gal/ft²/min rate of application the fire was not put out.

Results: All thermocouples located in the bomb indicated a temperature rise rate of 1.4 to 1.7°F/sec during the first 6+ minutes of the test. No change in bomb temperature rise rate was noted when the sprinklers were on or off and the bomb engulfed in flame. A maximum temperature of 508°F was recorded at the bomb interface. None of the lightwater was observed impinging on the bomb. After fire was removed the cooling rate was approximately .8°F/sec. (Lightwater was impinging on the bomb.)

BOMB FAST COOK-OFF PHASE 3A

Test No. P3A-12

Data Sheet

Device Tested: Cooling effect of two FULJET 30° injector type sprinkler nozzles positioned on either side of a Filler-E loaded MARK 81 bomb and dispensing a 6% solution of "lightwater" at the rate of .03 gal/ft²/min. The bomb is thermocoupled as shown in Figure D-1.

Date of Test: 12 August 1969.

Weather Conditions: Clear with 0-3½ knot wind; temperature 80°F.

Test Fire: At 40 seconds after start of test, the flame temperature had exceeded 1000°F. Internal temperature of the bomb was 250°F at 1 minute 31 seconds at which time the sprinkler system was activated. At 1 minute 54 seconds, the flame was removed from the bomb and at 3 minutes the sprinkler system was turned off.

Results: All thermocouples located in the bomb indicated a temperature rise rate of 3.0 to 3.2°F/sec, during the first 2 minutes of the test. No change in bomb temperature rise rate was noted when the sprinklers were on or off and the bomb engulfed in flame. A maximum temperature of 680°F was recorded at the bomb interface. None of the lightwater was observed impinging on the bomb. After the fire was out, the cooling rate was approximately .7°F/sec. (Lightwater was impinging on the bomb.)

BOMB FAST COOK-OFF PHASE 3A

Test No. P3A-13

Data Sheet

Device Tested: Cooling effect of two FULLJET 30° injector type sprinkler nozzles positioned on either side of a Filler-E loaded MARK 81 bomb and dispensing a 6% solution of "lightwater" at the rate of .03 gal/ft²/min. The bomb is thermocoupled as shown in Figure D-1.

Date of Test: 15 August 1969.

Weather Conditions: Clear with 0-1 knot wind; temperature 83°F.

Test Fire: At 34 seconds after start of test, the flame temperature exceeded 1000°F. Internal temperature of the bomb was 250°F at 1 minute 12 seconds at which time the sprinkler system was activated. At 2 minutes 5 seconds, the flame was removed from the bomb and at 3 minutes the sprinkler system was turned off.

Results: All thermocouples located in the bomb indicated a temperature rise rate of 3.0 to 3.5°F/sec during the first 2+ minutes of the test. No change in bomb temperature rise rate was noted when the sprinklers were on or off and bomb engulfed in flame. A maximum temperature of 710°F was recorded at the bomb interface. None of the light water was observed impinging on the bomb but rather appeared to be vaporized by the flames. After the fire was out, the cooling rate was approximately 1.0°F/sec. (Lightwater was impinging on the bomb.)

BOMB FAST COOK-OFF PHASE 3A

Test No. P3A-14

Data Sheet

Device Tested: Lightwater cooling effect of a single flush deck nozzle (Grinnell S-110-438) positioned 3-1/2 feet directly below a Filler-E loaded MARK 81 bomb. Pressure at the nozzle was 75 psi. Bomb was instrumented as shown in Figure D-1.

Date of Test: 18 August 1969.

Weather Conditions: Light rain with 1-3 knot wind; temperature 83°F.

Test Fire: Average flame temperature for the first 1 minute 10 seconds of the test was 1310°F at which time the nozzle was activated. The flame temperature at the bomb then dropped to approximately 950°F and at 2 minutes 26 seconds the lightwater had extinguished the fire.

Results: For the first 1 minute 10 seconds of the test, a maximum temperature rise rate of 3.5°F/sec was recorded at the bomb interface. At this time, the flush deck nozzle was turned on, the temperature rise rate then decreased to 1.5°F/sec. At approximately 1 minute 40 seconds, the thermocouples located in the area where the deck nozzles center plumb was impinging (TC's 7 and 8) show a cooling rate of 4.1°F/sec. At 2 minutes 25 seconds, the lightwater had successfully extinguished the fire. With the nozzle still on, the bomb began to cool at approximately 0.5°F/sec. At 4 minutes into the test, no stabilization of bomb temperature was apparent (temperature ranged from 70°F to 250°F).

BOMB FAST COOK-OFF PHASE 3A

Test No. P3A-15

Data Sheet

Device Tested: Lightwater cooling effect of a single flush deck nozzle (Grinnell S-110-438) positioned 3-1/2 feet directly below a Filler-E loaded MARK 81 bomb. Pressure at the nozzle was 60 psi. Bomb was instrumented as shown in Figure D-1.

Date of Test: 19 August 1969.

Weather Conditions: Light rain with 3-6 knot wind; temperature 78°F.

Test Fire: All flame temperature data were lost due to a recording malfunction. However, the internal bomb temperatures would indicate a good test.

Results: For the first 1 minute 40 seconds of the test, a maximum temperature rise rate of 2.3°F/sec was recorded at the bomb interface. The flush deck nozzle was then turned on and the temperature rise rate decreased to 1.1°F/sec. At approximately 2 minutes, the thermocouple on the bottom rear section of the bomb (TC 11) where the nozzle's center plumb was impinging showed a cooling rate of 3.2°F/sec. At 2 minutes 35 seconds, the lightwater had successfully extinguished the fire. With the nozzle still on, the bomb began to cool at approximately 0.7°F/sec. At 5-1/2 minutes into the test, no stabilization of bomb temperature was apparent (temperatures ranged from 65°F to 180°F).

BOMB FAST COOK-OFF PHASE 3A
Test No. P3A-16
Data Sheet

Device Tested: Lightwater cooling effect of a single flush deck nozzle (Grinnell S-110-438) positioned 3-1/2 feet directly below a Filler-E loaded MARK 81 bomb. Pressure at the nozzle was 60 psi. Bomb instrumented as shown in Figure D-1.

Date of Test: 2 August 1969.

Weather Conditions: Fair with 3-4 knot wind; temperature 78°F.

Test Fire: All flame temperature data were lost because of equipment malfunction. However, the internal bomb temperature would indicate a good test.

Results: For the first 1 minute 12 seconds of the test, a maximum temperature rise rate of 3.5°F/sec was recorded at the bomb interface. The flush deck nozzle was then turned on and the temperature rise rate decreased to 2.7°F/sec. The thermocouple on the bottom center section of the bomb (TC 7) where the nozzle center plumb was impinging showed a cooling rate of 5.5°F/sec. At approximately 2 minutes into the test, the lightwater had successfully extinguished the fire. With the nozzles still on, the bomb began to cool at the rate of 0.7°F/sec. At 4 minutes into the test, no stabilization of bomb temperature was apparent. (Temperature ranged from 65°F to 295°F.)

BOMB FAST COOK-OFF PHASE 3A

Test No. P3A-17

Data Sheet

Device Tested: Cooling effects of light water being applied over an inert Filler-E loaded instrumented MARK 81 bomb at the rate of 60 gpm. Lightwater applied by firemen from a hand held 1-1/2 fire hose.

Date of Test: 21 August 1969.

Weather Conditions: Broken clouds, wind 3-8 knots; temperature 80°F.

Test Fire: Flame temperature at the bomb exceeded 1000°F within 25 seconds after start of fire. At 1 minute 35 seconds when light water was applied over the bomb, flame temperature was 1150°F. Lightwater completely extinguished the fire in approximately 2 minutes.

Test Procedure: One minute 35 seconds after start of test, firemen positioned approximately 50 feet from the bomb started applying a 6% mixture of light water from a hand held 1-1/2-inch fire hose directly onto the bomb. Firemen were positioned at an angle of 45° to 50° to the nose of the bomb. The nozzle was adjusted to throw a wide spray rather than a tight stream.

Results: A maximum heating rate of 3.2°F/sec was recorded along the bottom of the bomb (TC's 3, 7 and 11 of Figure D-1) and its left side (TC's 4 and 8) for the first 1 minute 35 seconds of the test, at which time lightwater was applied to the bomb from the left side. Lightwater was applied at the rate of 60 gpm from a 1-1/2-inch hand-held fire hose by firemen. The lightwater was observed to be covering the entire bomb as in the water test, however, cooling was observed only on the left side when direct impingement took place. The bottom portion of the bomb continued to heat at approximately 3°F/sec. At 3 minutes 50 seconds, the lightwater had completely extinguished the fire, lightwater was continually applied and a cooling rate of 2.8°F/sec was observed as can be seen in Figure D-5.

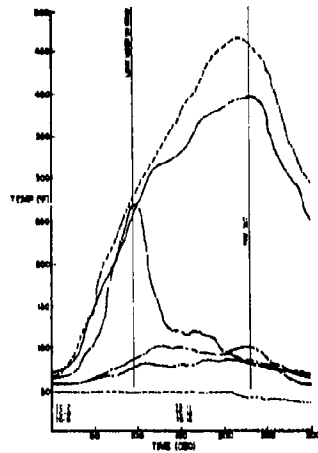
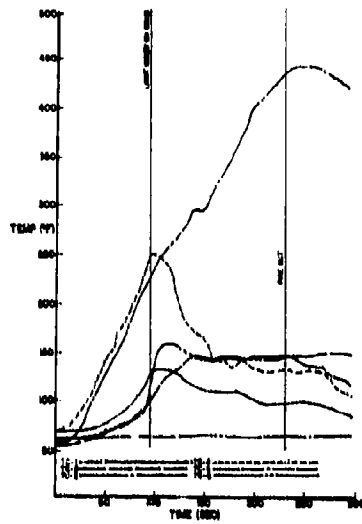


FIGURE D-5

**Time-Temperature Graph of Bomb Heating and Cooling Rates
for Bomb Cook-Off Test No. P3A-17**

BOMB FAST COOK-OFF PHASE 3A

Test No. P3A-18

Data Sheet

Device Tested: Cooling effects of lightwater being applied over an inert Filler-E loaded instrumented MARK 81 bomb at the rate of 50 g.p.m. "Lightwater" applied by firemen from a hand-held 1-1/2-inch fire hose.

Date of Test: 16 October 1960.

Weather Conditions: Clear with 4 knot wind; temperature 58°F.

Test Fire: Flame temperature at the bomb exceeded 1000°F within 30 seconds after start of fire. At 1 minute 20 seconds, when lightwater was applied over the bomb, flame temperature was at 1500°F. Application of the lightwater completely extinguished the fire in approximately 4 minutes.

Test Procedure: One minute 20 seconds after start of test, firemen positioned approximately 50 feet from the bomb began applying a 6% mixture of lightwater from a hand-held 1-1/2-inch fire hose directly onto the bomb. Firemen were standing at an angle of 35° to 40° to the nose of the bomb. The nozzle was adjusted to throw a tight stream rather than a wide spray.

Results: A maximum heating rate of 2.2°F/sec was recorded along the left side and bottom of the bomb (TC's 4, 8 and 11, Figure D-1). At 1 minute 20 seconds, firemen began applying lightwater over the surface of the bomb. Several of the thermocouples (TC's 8, 4 and 3) recorded cooling in their areas, however, the remaining thermocouples continued to rise in temperature as shown in Figure D-6.

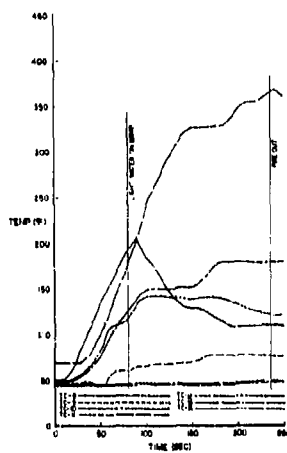
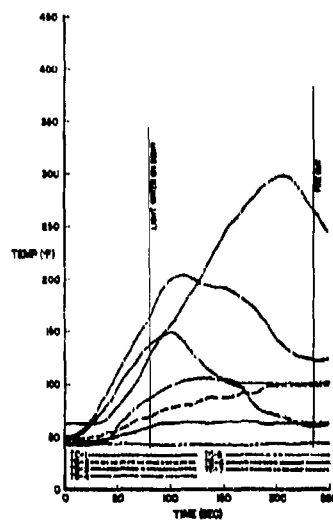


FIGURE D-6

Time-Temperature Graph of Bomb Heating and Cooling Rates
for Bomb Cook-Off Test No. P3A-18

BOMB FAST COOK-OFF PHASE 3A

Test No. P3A-19

Data Sheet

Device Tested: Cooling effect of lightwater being applied over an inert Filler-E loaded instrumented MARK 81 bomb at the rate of 60 gpm. Lightwater applied by firemen from a hand held 1-1/2-inch fire hose.

Date of Test: 30 October 1969.

Weather Conditions: Broken clouds with 4-8 knot wind; temperature 40°F.

Test Fire: Flame temperature at the bomb exceeded 1000°F within 27 seconds after start of fire. At one minute 38 seconds, when lightwater was applied over the bomb, flame temperature was at 1750°F. The application of lightwater extinguished the fire in approximately 2-1/2 minutes.

Test Procedure: At 1 minute 38 seconds after start of test, firemen positioned approximately 50 feet from the bomb began applying a 6% mixture of lightwater from a 1-1/2-inch fire hose directly onto the bomb. Firemen were standing at an angle approximately 45° to the tail of the bomb. The nozzle was adjusted to throw a tight stream of water rather than a wide spray.

Results: A maximum heating rate of 3.2°F/sec was recorded along the bottom and left side (due to wind) of the bomb. At 1 minute 38 seconds, firemen began applying lightwater to the bomb at the rate of 60 gpm. Most of the thermocouples began to show a decrease in temperature (see Figure D-7) with the exception of TC 4 (Figure D-1). This area of the bomb did not begin to cool until the fire was practically extinguished.

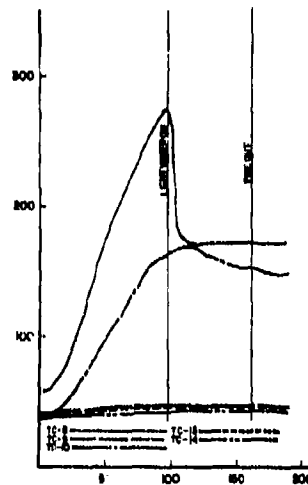
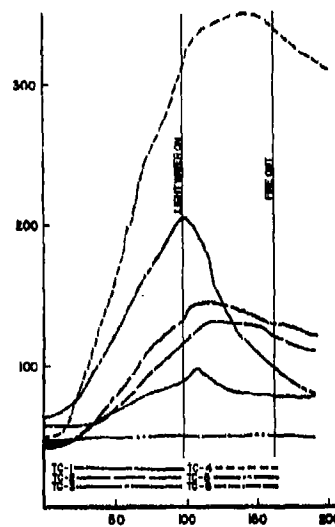


FIGURE D-7

**Time-Temperature Graph of Bomb Heating and Cooling Rates
for Bomb Cook-Off Test No. P3A-19**

BOMB FAST COOK-OFF PHASE 3A

Test No. P3A-20

Data Sheet

Device Tested: Cooling effect of lightwater being applied over an inert Filler-E loaded instrumented MARK 82 bomb at the rate of 95 gpm. Lightwater applied by firemen from a hand-held 1-1/2-inch fire hose.

Date of Test: 15 July 1970.

Weather Conditions: Clear with steady 3 knot wind; temperature 80°F.

Test Fire: Flame temperature at the bomb never reached 1000°F. At one minute 8 seconds after start of test, lightwater was applied over the bomb. Within 30 seconds, the fire began to die down due to the lightwater, and at 2 minutes 8 seconds the fire was removed from the test pan.

Test Procedure: At 1 minute 8 seconds after start of test, firemen positioned approximately 50 feet from the bomb began applying a 6% mixture of lightwater from a 1-1/2-inch fire hose directly onto the bomb. Firemen were standing at an angle approximately 15° to the nose of the bomb. The nozzle was adjusted to throw a tight stream of lightwater rather than a wide spray.

Results: A maximum heating rate of 3.2°F/sec was recorded along the bottom and right side of the bomb. At 1 minute 8 seconds, lightwater was applied at the rate of 95 gpm over the bomb's surface. Internal temperature of the bomb began to level off but no decrease in temperature was noted. See Figure D-8. Thermocouple locations are shown in Figure D-1.

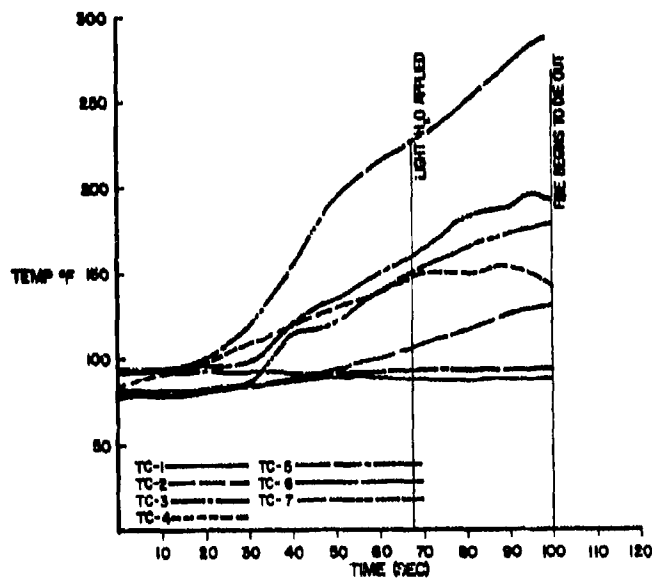
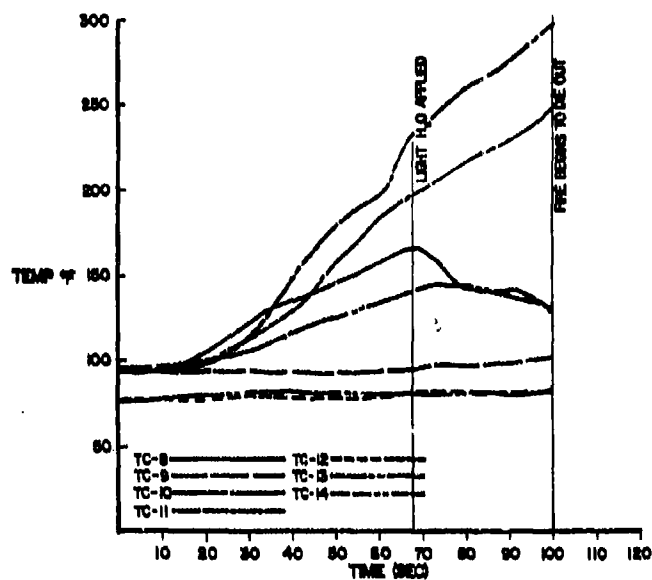


FIGURE D-8

Time-Temperature Graph of Bomb Heating and Cooling Rates
for Bomb Cook-Off Test No. P3A-20

BOMB FAST COOK-OFF PHASE 3A

Test No. P3A-21

Data Sheet

Device Tested: Cooling effects of lightwater being applied over an inert Filler-E loaded instrumented MARK 82 bomb at the rate of 95 gpm. Lightwater applied by firemen from a 1-1/2-inch hand held fire hose.

Date of Test: 28 July 1970.

Weather Conditions: Clear with no wind; temperature 80°F.

Test Fire: Flame temperature at the bomb exceeded 1000°F, 15 seconds after start of fire. At 1 minute 20 seconds, at which time lightwater was applied to the bomb, the flame temperature was 1810°F. The application of lightwater rapidly decreased the flame's intensity and had extinguished it by 3 minutes 45 seconds into the test.

Test Procedure: At 1 minute 20 seconds after start of test firemen positioned approximately 50 feet from the bomb began applying a 6% mixture of lightwater from a 1/2-inch hand-held fire hose onto the bomb, from an angle of 40° to the bomb nose. The hose nozzle was adjusted to throw a tight stream of lightwater.

Results: A maximum heating rate of 3.6°F/sec was recorded over much of the bomb's surface. When lightwater was first directed onto the bomb, cooling took place in the left forward portion of the bomb (maximum lightwater was applied). As lightwater began covering the fire surface, the fire began going out and at this point a temperature decrease of 1.4°F/sec was observed. Time-temperature data are presented in Figure D-9 and thermocouple locations are shown in Figure D-1.

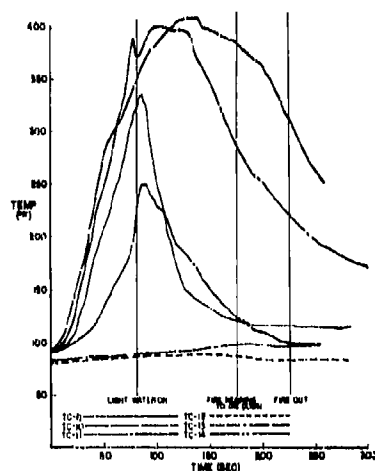
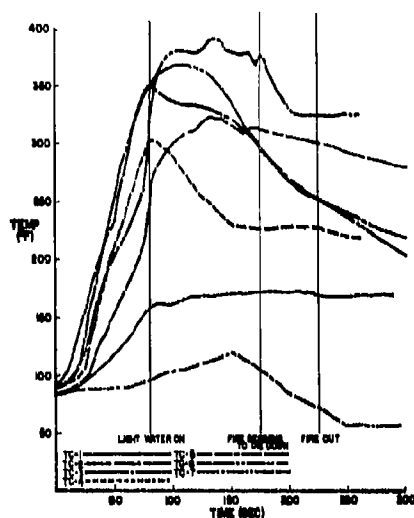


FIGURE D-9

Time-Temperature Graph of Bomb Heating and Cooling Rates
for Bomb Cook-Off Test No. P3A-21

BOMB FAST COOK-OFF PHASE 3A

Test No. P3A-22

Data Sheet

Device Tested: Cooling effects of lightwater being applied over an inert Filler-E loaded instrumented MARK 82 bomb at the rate of 95 gpm. Lightwater applied by firemen from a 1.5-inch hand-held hose.

Date of Test: 20 August 1970.

Weather Conditions: Clear with 3 knot wind; temperature 80°F.

Test Fire: Flame temperature at the bomb exceeded 1000°F within 15 seconds after start of fire. At 1 minute 10 seconds, at which time light water was applied to the bomb, the flame temperature was 1970°F. The application of lightwater rapidly decreased the flame intensity and had extinguished the fire by 2 minutes 5 seconds into the test.

Test Procedure: At 1 minute 10 seconds after start of test, firemen positioned approximately 50 feet from the bomb began applying a 6% mixture of lightwater from a 1-1/2-inch hand-held fire hose onto the bomb. Lightwater was applied from an angle of 45° to the nose of the bomb (right side). The hose nozzle was adjusted to throw a tight stream of lightwater.

Results: A maximum heating rate of 4.7°F/sec was recorded over the right side and bottom portions of the bomb. When lightwater was applied the temperature at the bomb interface continued to climb for the most part until the fire was almost out at which time the bomb began to cool at 2.5°F/sec as can be seen in Figure D-10. Thermocouple locations are shown in Figure D-1.

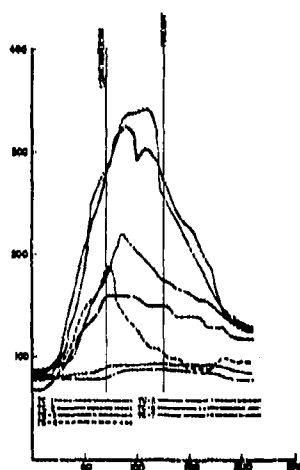
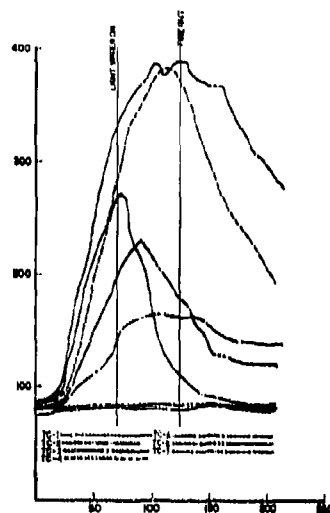


FIGURE D-10

Time-Temperature Graph of Bomb Heating and Cooling Rates
for Bomb Cook-Off Test No. P3A-22

APPENDIX E

BOMB FAST COOK-OFF TEST PHASE 4

Test No. P4-1

Data Sheet

Device Tested: MARK 81 250 lb bomb loaded with TRITONAL explosive; configured with a M904E2 nose fuze and T45E4 adapter booster. No tail fuze or fins installed. The bomb was instrumental as shown in Figure E-1.

Date of Test: 22 October 1968.

Weather Conditions: Cloudy with no wind. Temperature 65°F.

Bomb Position: Horizontal and 3 feet 4 inches at its centerline above the fuel surface.

Fuel: 400 gallons of JP-5 jet aircraft fuel.

Pan Size: 24 X 24 feet.

Test Fire: Flame temperature at the bomb exceeded 1000°F twenty seconds after start of fire and averaged 1730°F at time of removal of fire.

Test Procedure: The live bomb under test was pre-heated for 1 minute 50 seconds at which time the fire was removed.

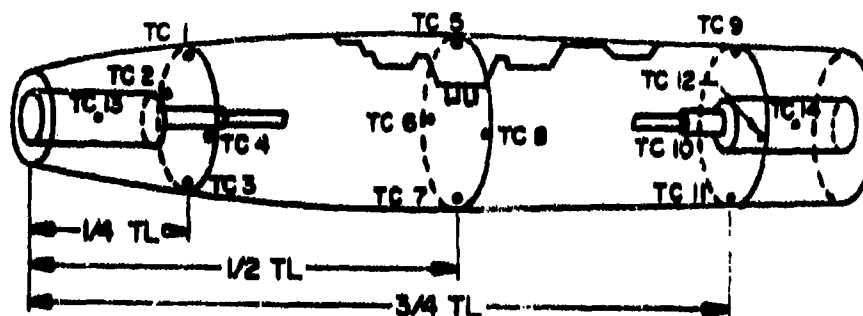
Results: At 1 minute 56 seconds after start of test, the bomb deflagrated. The nose fuze/adapter booster did not react. Time-temperature data recorded to reaction was as follows:

Time (sec)	Thermocouple Number ¹							
	5	7	8	9	10	11	12	13
Temperature °F								
0-20	64	91	113	107	109	105	106	106
40	80	170	218	206	210	208	200	212
60	106	238	315	302	308	304	306	299
80	147	309	400	379	383	380	381	387
100	214	381	479	473	469	467	366	456
110 ²	248	429	518	507	495	523	506	488
116 ³	277	450	541	526	514	544	526	512

¹ Thermocouple Nos. 1, 2, 3, 4, 6 and 14 were not monitored.

² Fire removed from bomb.

³ Bomb deflagrated.



THERMOCOUPLES ARE LOCATED BETWEEN THE HOT MELT AND METAL CASE
 TL-TOTAL LENGTH OF BOMB

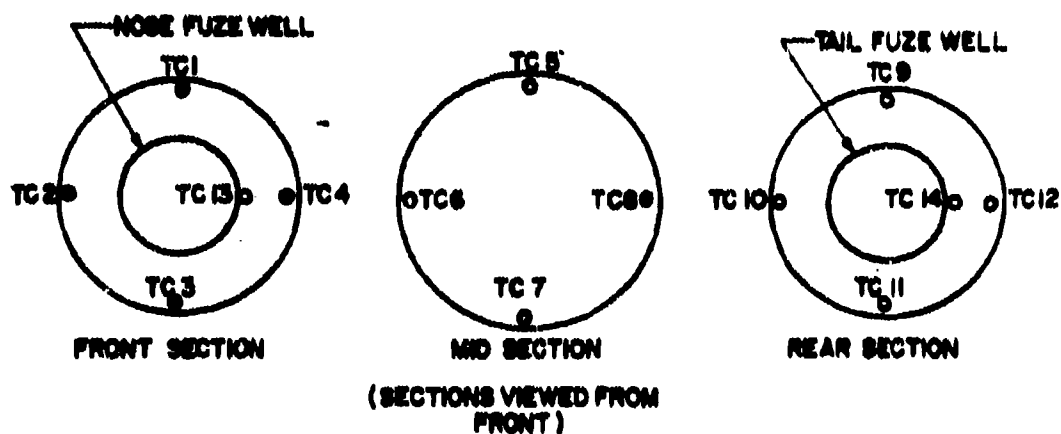


FIGURE E-1

Thermocouple Locations for Fast Cook-Off Tests Phase 4

A maximum temperature rise rate of $4.7^{\circ}\text{F}/\text{sec}$ was observed and, Thermocouple No. 5 disregarded, the average internal temperature of the bomb at the time of reaction was 516°F .

BOMB FAST COOK-OFF TEST PHASE 4
Test No. P4-2
Data Sheet

Device Tested: MARK 81, 250 lb bomb loaded with TRITONAL explosive. No fuzes, boosters or tail fins were installed. The bomb was instrumented as shown in Figure E-1.

Date of Test: 30 October 1968.

Weather Conditions: Overcast with 1 knot wind.

Bomb Position: Horizontally 3 feet 4 inches at its centerline above the fuel surface.

Fuel: 400 gallons of JP-5 jet aircraft fuel.

Pan Size: 24 X 24 feet.

Test Fire: No data available because of instrumentation failure.

Test Procedures: The bomb under test was pre-heated for 1 minute 30 seconds at which time the fire was removed and the bomb was allowed to air cool. Temperature data was taken for 15 minutes.

Results: No reaction of the bomb took place. Time-temperature data recorded are presented as follows:

Time (sec)	Thermocouple Number ¹											
	1	3	4	5	6	7	8	9	10	11	12	14
	Temperature °F											
0-30	156	158	156	140	140	140	141	144	140	147	144	140
75	368	368	371	367	365	355	359	376	366	374	365	374
90 ²	371	388	390	388	387	376	379	394	385	396	382	391
105 ³	386	394	390	393	391	386	386	399	390	398	388	393
165	360	368	383	367	363	357	366	369	364	371	367	365
240	298	306	364	301	299	301	305	301	303	309	304	304
600	---	---	299	199	199	204	201	199	200	202	203	203
900	---	---	269	170	173	177	174	172	173	175	186	175

¹ Thermocouple Nos. 2 and 13 malfunctioned.

² Fire removed from bomb.

³ Maximum internal temperature reached in the bomb.

A maximum temperature rise rate of $5.5^{\circ}\text{F}/\text{sec}$ and an air cooling rate of $0.5^{\circ}\text{F}/\text{sec}$ was recorded. The maximum temperature reached was 399°F at about 1 minute 45 seconds, 15 seconds after the fire was removed.

BOMB FAST COOK-OFF TEST PHASE 4

Test No. P4-3

Data Sheet

Device Tested: MARK 81, 250 lb bomb loaded with H-6 explosive; configured with 904E2 nose fuze and T45E4 adapter booster. No tail fin installed. The bomb was instrumented as shown in Figure E-1.

Date of Test: 25 October 1968.

Weather Conditions: Clear with one knot wind. Temperature 65°F.

Bomb Position: Horizontally suspended 3 feet 4 inches at its centerline above the fuel surface.

Fuel: 400 gallons of JP-5 jet aircraft fuel.

Pan Size: 24 X 24 feet.

Test Fire: Flame temperature at the bomb exceeded 1000°F 30 seconds after start of test and averaged 1920°F to removal of fire.

Test Procedure: The bomb under test was pre-heated for 1 minute 28 seconds at which time the fire was removed and the bomb was allowed to air cool. Temperature data were taken for over six minutes.

Results: The bomb did not react. Time-temperature data recorded and presented as follows:

Time (sec)	Thermocouple Number													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Temperature °F														
0-40	106	154	157	149	200	172	189	181	179	187	176	182	165	182
60	278	232	235	221	296	251	270	261	259	270	255	262	237	261
80	329	331	332	310	387	334	344	337	337	346	336	341	308	338
100	339	340	342	322	380	334	339	333	335	340	328	337	304	336
140	322	324	328	308	358	317	321	315	314	322	305	318	288	315
220	296	298	306	283	326	290	294	293	289	294	283	293	266	291
300	271	271	281	262	299	270	272	270	265	272	262	269	245	267
380	250	250	257	244	275	250	252	251	245	251	244	251	229	247

A maximum temperature rise rate of $4.6^{\circ}\text{F}/\text{sec}$ and a cooling rate of $0.2^{\circ}\text{F}/\text{sec}$ was recorded. The maximum temperature reached was 387°F at 1 minute 40 seconds, that is, 12 seconds after fire was removed.

BOMB FAST COOK-OFF PHASE 4

Test No. P4-4

Data Sheet

Device Tested: MARK 81, 250 lb bomb loaded with H-6 explosive; configured with M904E2 nose fuze and T45E4 adapter booster. No tail fin installed. The bomb was instrumented as shown in Figure E-1 and was the same bomb used in test P4-3.

Date of Test: 28 October 1968.

Weather Conditions: Cloudy with 3 knot wind.

Bomb Position: Horizontally suspended 3 feet 4 inches at its centerline above the fuel surface.

Fuel: 400 gallons of JP-5 jet aircraft fuel.

Pan Size: 24 X 24 feet.

Test Fire: Flame temperature at the bomb exceeded 1000°F, 60 seconds after start of test and averaged 1170°F to reaction.

Test Procedure: The bomb under test was to be heated for 1-1/2 minutes and then the fire removed, however, the gate on the test pan did not function and the bomb remained exposed to cook-off.

Results: At 2 minutes 8 seconds into the test the bomb deflagrated. Time-temperature data recorded up to reaction are listed as follows:

Time (sec)	Thermocouple Number													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Temperature °F														
0-20	67	64	64	64	65	68	64	68	63	66	64	66	64	66
40	86	86	86	84	97	100	94	95	89	97	90	93	92	94
60	126	127	129	124	146	149	142	138	132	143	133	141	137	137
80	170	172	174	168	199	202	185	185	177	191	177	185	180	184
100	210	214	216	207	250	252	228	228	223	232	219	228	225	227
120	250	253	252	246	291	293	263	264	257	269	253	263	262	261
128	267	271	272	266	304	305	276	276	269	283	264	286	275	274

A maximum temperature rise rate of $2.6^{\circ}\text{F}/\text{sec}$ was recorded. The maximum temperature reached in the bomb was 305°F at the time of reaction.

BOMB FAST COOK-OFF PHASE 4

Test No. P4-5

Data Sheet

Device Tested: MARK 81, 250 lb bomb loaded with H-6 explosive; configured with steel nose and tail plug. The bomb was instrumented as shown in Figure E-1.

Date of Test: 1 November 1968.

Weather Conditions: Clear with 1-1½ knot wind.

Bomb Position: Horizontally suspended 3 feet 4 inches at its centerline above the fuel surface.

Fuel: 400 gallons of JP-5 jet aircraft fuel.

Pan Size: 24 X 24 feet.

Test Fire: Flame temperature at the bomb exceeded 1000°F within 30 seconds after start of test and averaged 1932°F to reaction.

Test Procedure: The bomb under test was to be heated for 2-1/2 minutes and then the fire removed, however, the bomb reacted before the elapsed time.

Results: At 2 minutes 15 seconds into the test, the bomb deflagrated. Time-temperature data recorded up to reaction are listed as follows:

Time (sec)	Thermocouple Number													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
0-15	67	66	68	66	68	68	68	67	66	69	67	68	66	65
30	100	99	104	100	105	106	106	104	109	117	106	106	102	103
45	150	153	149	152	163	165	163	157	166	184	153	167	157	155
60	235	242	248	242	254	253	253	243	257	287	251	258	246	239
75	307	319	327	320	335	330	324	316	338	374	325	334	325	317
90	378	393	398	393	406	399	394	387	405	448	393	401	399	387
105	444	460	463	459	473	459	458	453	473	517	452	466	467	451
120	502	514	524	518	531	510	513	512	534	581	510	519	527	510
135	548	550	564	561	572	562	553	550	577	628	557	564	574	552

BOMB FAST COOK-OFF PHASE 4

Test No. P4-6

Data Sheet

Device Tested: MARK 81, 250 lb bomb loaded with H-6 explosive; configured with steel nose and tail plug. The bomb was instrumented as shown in Figure E-1.

Date of Test: 8 November 1968.

Weather Conditions: Cloudy with 1-2 knot wind.

Bomb Position: Horizontally suspended 3 feet 4 inches at its centerline above the fuel surface.

Fuel: 400 gallons of JP-5 jet aircraft fuel.

Pan Size: 24 X 24 feet.

Test Fire: Flame temperature at the bomb exceeded 1000°F within 15 seconds after start of test and averaged 1795° to reaction.

Test Procedure: The bomb under test was heated to reaction and time-temperature data recorded.

Results: At 2 minutes 15 seconds into the test the bomb deflagrated. Time-temperature data recorded up to reaction are listed as follows:

Time (sec)	Thermocouple Number													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
	Temperature °F													
0-15	70	71	69	72	68	72	68	70	71	70	70	66	72	72
30	118	122	118	122	113	113	119	121	111	114	115	108	112	111
45	164	167	163	167	159	157	160	165	157	158	157	149	160	156
60	223	228	223	230	211	213	221	221	223	215	212	203	215	209
75	286	290	280	287	276	273	285	283	276	280	273	262	282	272
90	362	368	347	362	360	366	372	372	367	365	349	352	378	358
105	441	442	421	440	438	444	443	441	436	431	422	436	457	436
120	523	525	492	517	512	520	525	524	526	517	495	507	532	512
135	576	578	556	570	560	572	571	568	576	565	543	542	580	561

A maximum temperature rise rate of $4.7^{\circ}\text{F}/\text{sec}$ was noted. Notice the good correlation of data between this test and test P4-5. The flame temperatures, time to reaction and temperature rise rates are very similar.

BOMB FAST COOK-OFF PHASE 4

Test No. P4-7

Data Sheet

Device Tested: MARK 81, 250 lb bomb loaded with H-6 explosive; configured with steel nose and tail plug. The bomb was instrumented as shown in Figure E-1.

Date of Test: 19 November 1968.

Weather Conditions: Overcast with 1-3 knot wind.

Bomb Position: Horizontally suspended 3 feet 4 inches at its centerline above the fuel surface.

Fuel: 400 gallons of JP-5 jet aircraft fuel.

Pan Size: 24 X 24 feet.

Test Fire: Flame temperature at the bomb exceeded 1000°F approximately 33 seconds after start of test and averaged 1745°F to removal of fire.

Test Procedure: The bomb under test was pre-heated for 1 minute 30 seconds at which time the fire was removed and the bomb allowed to air cool.

Results: No reaction of the bomb took place. Time-temperature data recorded are presented as follows:

Thermocouple Number

Time (sec)	1	2	3	4	5	6	7	8	9	10	11	12	13
	Temperature °F												
0-30	71	71	71	71	69	68	71	71	71	68	69	71	71
60	161	163	157	164	161	155	162	164	159	158	158	163	158
90 ¹	307	316	303	321	316	302	273	317	310	315	304	317	311
110 ²	349	356	344	359	360	342	356	358	356	357	344	362	358
140	339	340	334	346	349	339	347	346	349	345	340	351	348
170	329	329	325	332	333	326	333	334	333	333	329	338	333
210	309	310	305	313	312	305	314	312	312	312	310	317	314

¹ Fire removed from bomb.

² Maximum temperatures reached.

A maximum temperature rise rate of $4.7^{\circ}\text{F}/\text{sec}$ and an air cooling rate of $0.45^{\circ}\text{F}/\text{sec}$ was recorded. The maximum temperature reached was 369°F at approximately 1 minute 50 seconds, that is, 20 seconds after the fire was removed.

BOMB FAST COOK-OFF PHASE 4

Test No. P4-8

Data Sheet

Device Tested: MARK 81, 250 lb bomb loaded with H-6 explosive; configured with steel nose and tail plug. The bomb was instrumented as shown in Figure E-1.

Date of Test: 25 November 1968.

Weather Conditions: Broken clouds with 1-5 knot wind.

Bomb Position: Horizontally suspended 3 feet 4 inches at its centerline above fuel surface.

Fuel: 400 gallons of JP-5 jet aircraft fuel.

Pan Size: 24 X 24 feet.

Test Fire: Flame temperature at the bomb exceeded 1000°F approximately 20 seconds after start of test and averaged 1570°F to reaction.

Test Procedure: The bomb under test was heated to reaction and time-temperature data recorded.

Results: At 2 minutes 40 seconds into the test, the bomb defragrated, Time-temperature data recorded up to reaction are listed as follows:

Time (sec)	Thermocouple Number													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
0-15	60	60	60	60	62	61	60	63	64	62	61	61	61	61
45	100	98	90	100	100	99	56	105	100	100	103	104	97	98
75	173	166	149	175	173	174	95	181	173	171	176	178	175	166
105	262	244	210	261	257	262	125	264	258	252	254	253	256	245
135	303	310	267	336	332	338	173	337	333	317	322	320	334	318
160	335	342	297	366	362	368	233	365	365	354	346	341	369	347

A maximum temperature rise rate of 2.8°F/sec was computed.

BOMB FAST COOK-OFF PHASE 4

Test No. P4-9

Data Sheet

Device Tested: MARK 81, 250 lb bomb loaded with H-6 explosive; configured with steel nose and tail plug. The bomb was instrumented as shown in Figure E-1.

Date of Test: 3 December 1968.

Weather Conditions: Clear with 0-1 knot wind.

Bomb Position: Horizontally suspended 3 feet 4 inches at its centerline above the fuel surface.

Fuel: 400 gallons of JP-5 jet aircraft fuel.

Pan Size: 24 X 24 feet.

Test Fire: Flame temperature at the bomb exceeded 1000°F approximately 10 seconds after start of test and averaged 1843°F to removal of fire.

Test Procedure: The bomb under test was pre-heated for 1 minute 22 seconds at which time the fire was removed and the bomb allowed to air cool. Temperature data were taken for a total of 2 minutes at which time the bomb reacted.

Results: At 1 minute 22 seconds into the test, flame was removed from the bomb. At 2 minutes the bomb deflagrated. This was an excellent example of an explosive exothermic reaction. Time-temperature data collected follows:

Thermocouple Number¹

Time (sec)	1	2	3	4	5	7	8	9	10	11	12	13	14
	Temperature °F												
0-15	80	78	82	77	74	73	75	75	75	76	72	73	73
30	161	152	164	157	154	146	158	154	153	159	156	154	151
45	249	238	252	246	238	229	244	237	238	244	239	234	232
60	333	316	331	327	321	291	327	323	316	327	323	321	311
75	399	385	400	394	388	355	393	391	383	391	390	389	375
90	440	430	445	438	439	418	444	441	435	442	440	439	429
105	436	423	438	433	436	420	436	438	426	434	436	435	420
120	420	423	428	431	427	425	427	429	424	425	428	431	413

¹ Thermocouple 6 malfunctioned.

A maximum temperature rise rate of $4.9^{\circ}\text{F}/\text{sec}$ was computed. Then the fire was removed, the temperature continued to climb for approximately 23 seconds on all thermocouples. At this time a temperature decrease of $0.5^{\circ}\text{F}/\text{sec}$ was noted on all thermocouples except TC 7. Thermocouple 7 continued to show a temperature rise until the bomb deflagrated. This was the only bomb cooling tests in which an explosive exothermic reaction was observed.

APPENDIX F

BOMB FAST COOK-OFF TEST PHASE 5

Test No. P5-1

Data Sheet

Device Tested: MARK 81, 250 lb. bomb loaded with H-6 explosive; configured with M904E2 nose fuze and T45E7 adapter booster. No tail fuze or fins were installed.

Date of Test: 13 May 1969.

Weather Conditions: Clear with 0-2 knot wind, gusting to 4 knots.

Bomb Position: Horizontally 6 feet at its centerline above the fuel surface.

Fuel: 1000 gallons of JP-5 jet aircraft fuel.

Pan Size: 35 X 35 feet.

Test Fire: Flame temperature at the bomb exceeded 1000°F approximately 40 seconds after start of fire and averaged 1670°F for the first 4 minutes of the test.

Test Procedure: The live bomb under test was pre-heated, then remotely dropped.

Results: At 2 minutes, the pre-heated bomb was dropped 6 feet onto the steel deck. No reaction occurred at impact; however, the bomb did react in a deflagration at about 5 minutes into the test. The nose fuze/adapter booster did not react.

BOMB FAST COOK-OFF TEST PHASE 5

Test No. P5-2

Data Sheet

Device Tested: MARK 81, 250 lb bomb loaded with H-6 explosive; configured with M904E2 nose fuze and T45E7 adapter booster. No tail fuze or fins were installed.

Date of Test: 16 May 1969.

Weather Conditions: Clear with 1-2 knot wind.

Bomb Position: Horizontally 6 feet at its centerline above the fuel surface.

Fuel: 1000 gallons of JP-5 jet aircraft fuel.

Pan Size: 35 X 35 feet.

Test Fire: Flame temperature at the bomb exceeded 1000°F approximately 25 seconds after start of fire and averaged 1770°F for the duration of the test.

Test Procedure: The live bomb under test was pre-heated, then remotely dropped.

Results: At 1 minute 30 seconds, the pre-heated bomb was dropped 6 feet onto the steel deck. No reaction occurred at impact; however, the bomb did react in an explosion at 2 minutes 28 seconds into the test. The nose fuze/adapter booster exploded at 4 minutes 20 seconds.

BOMB FAST COOK-OFF TEST PHASE 5

Test No. P5-3

Data Sheet

Device Tested: MARK 81, 250 lb bomb loaded with TRITONAL explosive; configured with M904E2 nose fuze and T45E7 booster. No tail fuze or fins were installed.

Date of Test: 6 June 1969.

Weather Conditions: Clear with 2-4 knot wind.

Bomb Position: Horizontally 6 feet at its centerline above the fuel surface.

Fuel: 1000 gallons of JP-5 jet aircraft fuel.

Pan Size: 35 X 35 feet.

Test Fire: Flame temperature at the bomb exceeded 1000°F approximately 50 seconds after start of fire and averaged 1050°F for the duration of the test.

Test Procedures: The live bomb under test was pre-heated then remotely dropped.

Results: At 2 minutes, the pre-heated bomb was dropped 6 feet onto the steel deck. No reaction occurred at impact; however, the bomb did deflagrate at about 4 minutes into the test. The nose fuze/adaptor booster did not react.

BOMB FAST COOK-OFF TEST PHASE 5

Test No. P5-4

Data Sheet

Device Tested: MARK 81, 250 lb bomb loaded with TRITONAL explosive; configured with live M904E2 nose fuze and T45E7 booster. No tail fuze or fins were installed.

Date of Test: 10 June 1969.

Weather Conditions: Cloudy with 2-4 knot wind; temperature 72°F.

Bomb Position: Horizontally 6 feet at its centerline above the fuel surface.

Fuel: 1000 gallons of JP-5 jet aircraft fuel.

Pan Size: 35 X 35 feet.

Test Fire: Flame temperature at the bomb exceeded 1000°F approximately 40 seconds after start of fire and averaged 1400°F for the duration of the test.

Test Procedure: The bomb under test was pre-heated, then remotely dropped.

Results: At 2 minutes, the pre-heated bomb was dropped 6 feet onto the steel deck. No reaction occurred at impact; however, the bomb did deflagrate at 3 minutes 51 seconds into the test. The nose fuze/adaptor booster did not react.

BOMB FAST COOK-OFF TEST PHASE 5

Test No. P5-5

Data Sheet

Device Tested: Three live MARK 31 bombs loaded with H-6 explosive; configured with live M904E2 nose fuzes and T45E7 adapter boosters. No tail fuzes or fins were installed. The bombs were racked to a triple ejection rack (TER) that was loaded with live MARK 2 MOD 1 impulse cartridges.

Date of Test: 27 February 1969.

Weather Conditions: Cloudy with 2 knot wind, gusting to 11 knots.

Bomb Position: The bottom bomb on the rack was 4 feet at its centerline above the fuel surface.

Fuel: 800 gallons of JP-5 jet aircraft fuel.

Pan Size: 24 X 24 feet.

Test Fire: Flame temperature at the ejection rack and the bombs exceeded 1000°F approximately 30 seconds after start of fire and averaged 1320°F for the duration of the test.

Test Purpose: Three bombs were racked to the TER rack which contained live ejection cartridges to determine the order of reaction when exposed in a fire environment.

Results: At approximately 2 minutes, the TER began to melt releasing the bombs onto the deck. At 2 minutes 58 seconds, the first bomb deflagrated followed by the second at 4 minutes 24 seconds and the last at 5 minutes 19 seconds. The ejection cartridges were heard to deflagrate intermittently after the first bomb reaction. Remains of the bombs are shown in Figure F-1 and of the TER as Figure F-2.



FIGURE F-1

Three MARK 81 Bombs and Unreacted H-6 Explosive
That Remained After Fast Cook-Off Test No. P5-5



FIGURE F-2

Remains of the TER Rack After Fast Cook-Off Test No. P5-5

BOMB FAST COOK-OFF TEST PHASE 5

Test No. P5-6

Data Sheet

Device Tested: Three inert MARK 81 bombs loaded with Filler-E; one bomb fuze with live M904E2 nose fuze and T45E7 adapter booster. The other two bombs were unfuzed and none of the bombs had tail fuzes or fins installed. The bombs were racked to a triple ejection rack (TER) that was loaded with live MARK 2 MOD 1 impulse cartridges.

Date of Test: 9 April 1969.

Weather Conditions: Clear with 4-6 knot wind; temperature 70°F.

Bomb Position: The bottom bomb on the rack was 4 feet at its centerline above the fuel surface (see Figure F-3).

Fuel: 1400 gallons of JP-5 jet aircraft fuel.

Pan Size: 35 X 35 feet.

Test Fire: Flame temperature at the ejection rack exceeded 1000°F 15 seconds after start of fire and averaged 1560°F for the duration of the test.

Test Purpose: To determine the time to reaction of ejection cartridges and bomb nose fuzes when both are installed on a TER and exposed in a fire environment.

Results: At approximately 2 minutes, the TER had melted releasing the bombs and cartridges. At 2 minutes 47 seconds, the first cartridge deflagrated followed by the nose fuze/booster deflagrating at 7 minutes 36 seconds. A second cartridge deflagrated at 9 minutes 6 seconds. No other reactions occurred. Post-test photograph is shown as Figure F-4.



FIGURE F-3

Three Inert MARK 81 Bombs as Installed on a TER Rack and
Positioned for Fast Cook-Off Test No. P5-6



FIGURE F-4

Remnants of the TER Rack After Fast Cook-Off Test No. P5-6.

APPENDIX G

SUPPORTING TASKS

1. Quick Fire Starting

Objective: To determine a method whereby the quickest ignition across the entire fuel surface of the test fire could be obtained.

Approach and Tests: Lighter, more volatile fuels were poured over the surface of JP-5 fuel and ignited. The time to total surface ignition was then compared to a standard test of JP-5 without a starter. The test configuration consisted of a 5 X 5 foot pan with 1 inch of water to insure a flat surface. Five gallons of JP-5 jet fuel was then poured over the water surface and remotely ignited by electrical squibs in powder bags placed at each corner of the test pan.

Results:

Test	Starters Poured Over JP-5	Time to Total Ignition (Sec)
STANDARD	JP-5 Fuel without starter	25
1	.3 gallons gasoline	8
2	150cc ether	7
3	200cc ether	6
4	300cc ether	5
5	1 pint of 190 Proof Alcohol	25
6	.5 gal. gasoline + 150cc ether	3

Conclusion: The pouring of regular grade gasoline and ether over the JP-5 fuel surface, proved to be the best combination for quick fire starting; however, ignition should be accomplished as soon after their addition to the JP-5 as possible. If a delay of 7 to 10 minutes is experienced, the gasoline and ether mix completely with the jet fuel and no benefits are derived.

Subsequent experiments using AN/414 thermite incendiary grenades as an ignition source were conducted. The thermite grenades did not improve the time to total ignition, but were adopted for use because they burn longer with more intensity and consequently are more reliable.

2. Wind Effects

Objective: Heat measuring instruments were positioned within the flames of still and wind blown JP-5 fuel fires to determine the effect of wind on flame intensity.

Approach: A fire research project, designed to measure radiant heat flux and temperatures within a large JP-5 fuel fire, was conducted at NWL; Reference 1. A literature search produced a report, Reference 2, on temperature distribution within aircraft fuel fires. Information from the above two sources along with flame temperature data from all phases of the weapons survivability in fire program were used to determine wind effects.

Conclusion: It was concluded that in a no-wind condition maximum heat boundaries in a jet fuel fire lie between 1.5 and 6.0 feet above the fuel surface in the horizontal plane and 2 feet within the luminous flame boundary in the vertical plane (Figure G-1). As the wind velocity increases (2-4 knots), this upper boundary begins to shift in the direction of the wind (Figure G-2), and at winds in excess of approximately 15 knots the heat pattern¹ begins to disperse. Tests in winds up to 30 knots did not indicate any major changes in the fire environment at the lower boundary. (From fuel level up to 1.5 feet in the horizontal plan.) A slight increase in the burning rate of the JP-5 fuel in a high wind condition was noted.

No tests were conducted in the test pan when winds were in excess of 3 knots, because of the shift in the luminous flame boundary which prevented complete flame engulfment of the bomb under test. Tests were successfully conducted in the test pit in winds up to 20 knots.

¹The 3 dimensional heat pattern can be viewed as overlapping cylinders of heat, that have maximum temperature in the center and minimum temperatures at the luminous flame boundary.

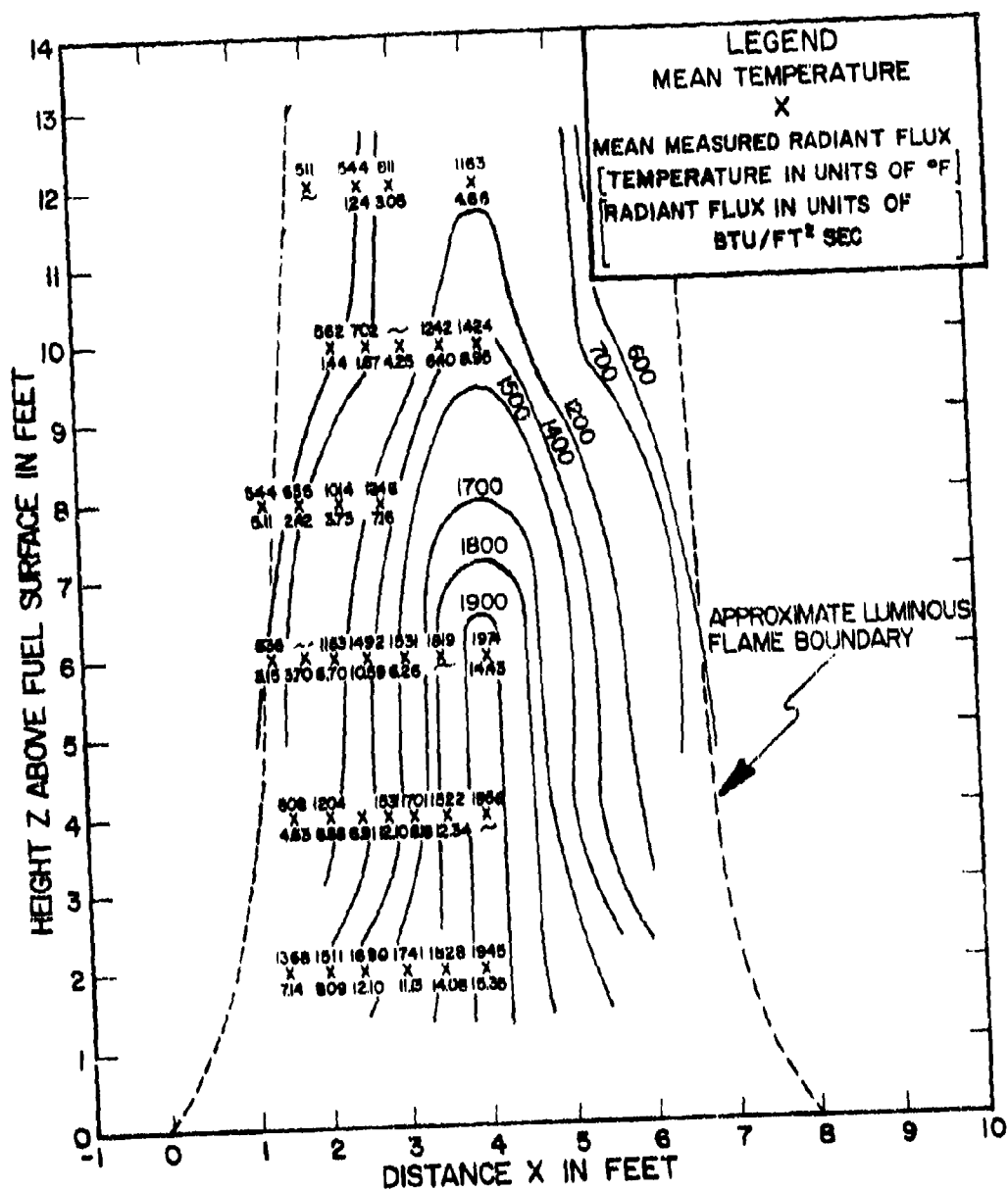


FIGURE G-1

Temperature Distribution Within a JP-5 Jet Fuel Fire
Under a No-Wind Condition the Flames Are Directed Straight Up.

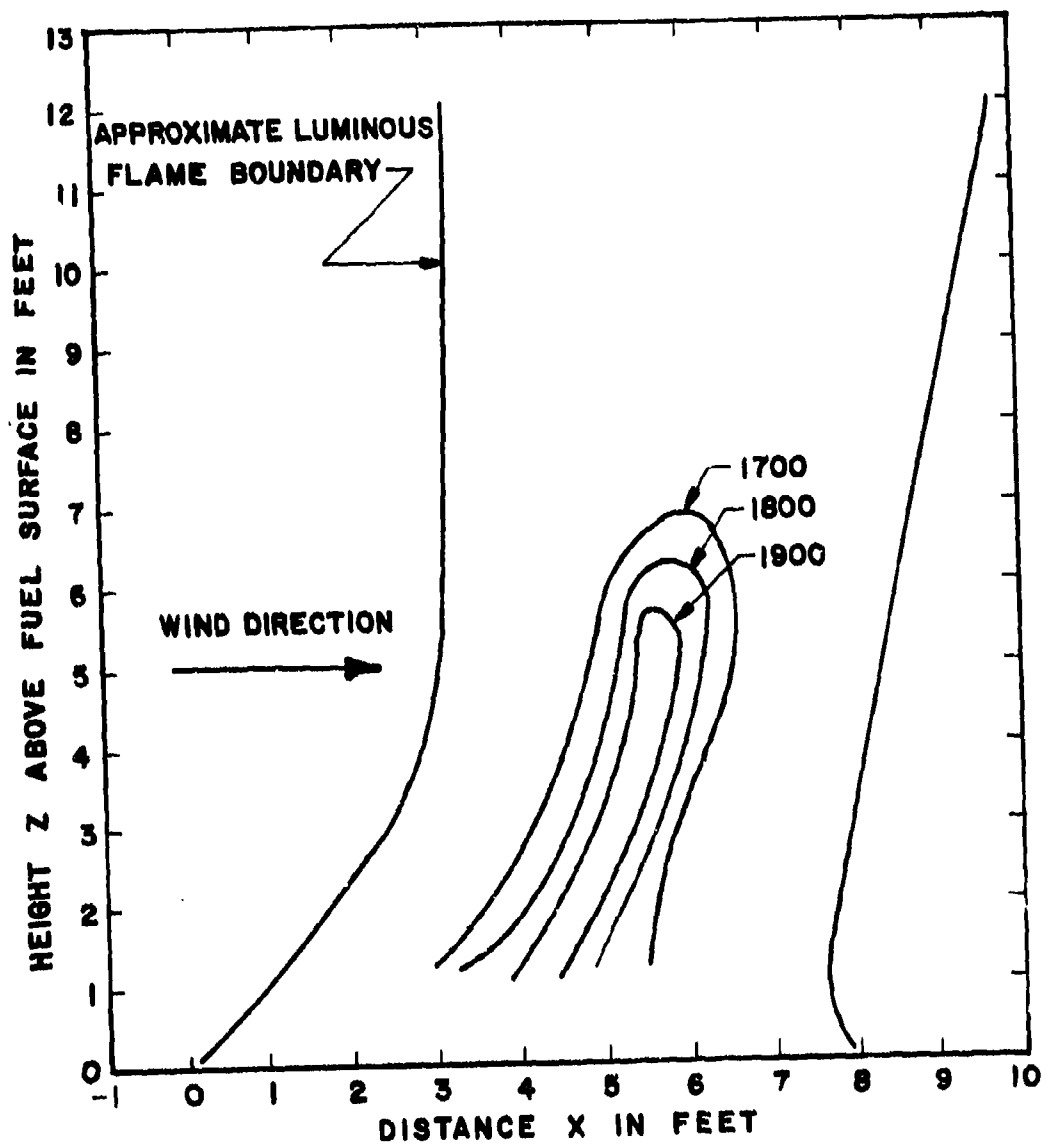


FIGURE G-2

Wind Conditions Bending the Flames Luminous Boundry and
the Temperature Distribution Within the Boundry

3. Internal Thermocouple Design

Objective: To develop a method for mounting thermocouples internally, and passing the leads via an external connector, without defeating the integrity of the bomb case.

Approach: In order to obtain the most accurate interface temperature data (surface between bomb skin and hot-melt), the interior surface of the bomb were thoroughly cleaned with a reliable solvent removing any foreign substance such as grease, rust, cavity paint, or hot-melt. Thermocouples employed are manufactured at NWL, Dahlgren using iron-constantan, Type J, AWG No. 24 asbestos and fiber glass coated calibrated wire. The iron-constantan wires were thoroughly cleaned, twisted together and then welded, forming a bead junction. The thermocouples were then secured to the interface by welding, cementing, or taping with Scotch brand aluminum foil tape No. 425.

The charging tubes were removed from the bomb and the thermocouple leads brought out of the bomb through the charging tube plug hole, located between the forward and after hanger lugs. The hole was then sealed with an epoxy and asbestos sealant creating a high pressure and flame proof closure. Iron-constantan thermocouples were chosen as the temperature measuring device because they are more accurate at the lower temperatures than chromel-alumel thermocouples.

4. Selection of Inert Filler

Objective: To find a filler material that closely matches H-6 and TRITONAL's thermal properties (specific heat, conductance, melting point, etc).

Approach and Results:

Personnel at the Naval Weapons Station, Yorktown in the EER and D Division were contacted about a substitute filler that was castable, inert, non-toxic and closely simulated the physical and thermic properties of H-6 and TRITONAL explosives. They recommended such a material called Filler-E. Filler-E was developed by Filtman Research and Engineering Laboratories, Picatinny Arsenal. A complete description of the material can be found in Reference 3.

Conclusion: After several tests and a study of Reference 3, Filler-E was selected as the inert material to be used in the program.

5. Water and Foam Rates-Apparatus Design

Objective: To design a system that would simulate the NBC washdown system currently found aboard aircraft carriers.

Approach: The NBC washdown system that currently exists on carriers was reproduced in the slant pan using 3/4-inch Grennell S-110.438 flush deck nozzles. In the main body of this report, a complete description of the system is presented and pictured (Figures 8-14) under Phase 3, specific configurations, procedures and results. The flow rate of 0.03 gal/ft²/min that the NBC system is capable of dispensing was duplicated. In addition, the flow rate was increased to 0.48 gal/ft²/min to deliberately overtest.

6. Evaluation of Fire Retardant Paints

Test Problem: Ordnance has a relatively short cook-off time when subjected to extreme heat such as would be encountered during flame envelopment. It is felt that perhaps the cook-off time could be significantly increased if the exterior of the ordnance were painted with a fire retardant paint, instead of the paint presently used. It is the purpose of this project, therefore, to test and evaluate a number of fire retardant paints in an effort to establish whether or not certain paints in current development would significantly increase the cook-off time.

Description of Fire Retardant Paints:

Fire retardant paints are paints that either prevent or delay the ignition of a substrate or prevent or delay loss of integrity of the substrate when exposed to fire.

The fire retardant paints tested were primarily of the intumescent type. Three characteristics of this type of paint are responsible for intumescence. These are a carbonific, an intumescent catalyst, and a blowing agent (Reference 4). Starches and polyhydric alcohols are most frequently used as carbonifics, although sugars and polyhydric phenols may also be

used. The function of the carbonific is to provide large quantities of carbon material. Ammonium and amine salts, organic esters, and amido forms of mineral acids are suitable as intumescent catalysts; however, salts of phosphoric acids are most commonly utilized. Organic amides and amines and chlorinated paraffins are used as blowing agents.

Basically, the intumescence of the paint occurs in the following manner. The intumescent catalyst decomposes upon the addition of heat, releasing the dehydrating agent that reacts with the carbonific. The carbonific, which contains a large percentage of carbon, chars as a result of this dehydration. Simultaneously with the dehydration of the carbonific, the blowing agent releases large quantities of gas that greatly expands the char. However, for intumescence to occur, it is necessary for these reactions to occur in the sequence described and at certain temperatures. The dehydrating agent must react with the carbonific to produce the char prior to the release of gas by the blowing agent. The char must also be produced before the carbonific is decomposed by fire. However, dehydration of the carbonific must not occur prior to an actual fire condition. A salt of the dehydrating agent is therefore used, which decomposes to form the dehydrating agent when subjected to the heat of a fire.

Procedure:

The test set-up used for evaluating fire retardant paint is designed to simulate a condition to which ordnance might be subjected, due to a fire caused by the inadvertent ignition of a jet fuel spill. Hollow metal cylinders were used to simulate the ordnance. A 20 X 20 foot JP-5 jet fuel fire was used to simulate the fire resulting from a fuel spill. A distance of approximately 3-1/2 feet from the fuel surface to the cylinder is a representative distance from the fuel spill to ordnance attached to a plane wing. One hundred fifty gallons of JP-5 fuel is used for each test, and 10 gallons of gasoline, spread on top of the jet fuel in order to obtain minimum ignition time for the entire 20 X 20 foot surface.

The hollow test cylinders were of the following dimensions; sixteen inches in length, five inches in outside diameter and three-sixteenths of an inch in wall thickness. Paint was applied to the cylinder at various thicknesses. The temperature of each

cylinder was recorded by four thermocouples spotwelded in the center of the cylinder and spaced at 90° intervals. The cylinders were supported on a pipe, which was supported by reinforcing rods attached to an "A" frame. The end of the cylinders were insulated by asbestos plugs, which also supported the cylinders on the pipe. The thermocouple wires were contained in a pipe and in a double wall conduit that extends from the end of the pipe past the 20 X 20 foot fire area.

Due to the variation of the fire from test to test and the fact that fire retardant paints are evaluated by comparing the temperatures recorded in the fire retardant painted cylinder with the temperatures recorded in the OD painted standard cylinder, it is necessary that both cylinders be subjected to the same conditions (e.g. same heat flux). Therefore, an OD painted cylinder was used in each flame enveloping test.

It was felt that perhaps a cylinder containing a simulated explosive material would more accurately represent ordnance than the hollow cylinder used. A cylinder containing such a material was therefore tested in the flame with an empty cylinder. The time-temperature curves of this test do not indicate a necessity for replacing the empty cylinders with cylinders containing a simulated explosive material.

Results:

The heat flux density for each standard cylinder tested was calculated using the following equation:

$$\frac{\partial \gamma}{\partial \tau} = \frac{2 q b}{\rho c (b^2 - a^2)}$$

where

$\frac{\partial \gamma}{\partial \tau}$ = slope of the time-temperature curves

q = heat flux density

ρ = density of cylinder material

c = specific heat of cylinder material

a = inside radius of the cylinder

b = outside radius of the cylinder

The values of $\partial\gamma/\partial\tau$ were obtained from the time-temperature graphs using the temperatures recorded in the standard cylinder. The values of q calculated for each test indicate that the wind conditions cannot be neglected in evaluating the fire retardant paints. When no wind was present during the test, the values of q calculated are two to three times greater than those values calculated when wind was present. Therefore, no tests were conducted unless winds were under 3 knots. The effectiveness of the fire retardant paints in increasing the cook-off time of ordnance was determined by comparing the time necessary for the fire retardant paint cylinder to reach an arbitrary temperature of 400°F with the time necessary for the standard to reach 400°F.

For each test, the temperatures recorded by each thermocouple were presented in the form of a time-temperature curve. The results are also expressed in a graph of T_s/T_{od} versus time, where T_s is the absolute temperature of standard cylinder. The values for T_s and T_{od} are obtained using the time-temperature curves with the lowest time corresponding to 400°F. The vertical line extending from the time axis represents the time at which T_s is equivalent to 400°F. The percentage time increase for each fire retardant paint to reach 400°F was also obtained from the time-temperature curve with the lowest time corresponding to 400°F.

7. Computer Studies and Analysis

Objective:

The heat transfer computer program written simulates the cook-off process and can be used to predict time to bomb cook-off time under a variety of flame enveloping conditions.

This program is written in FORTRAN IV for the CDC 6700 computer system. A list of definition of input variables and a sample data card layout is also included.

```

PROGRAM CHTABXINPIT,OUTPUT<
DIMENSION DAMX5<,RADX2000<,EXPL10X3<,WEAP10X3<,BX20<,JX16<
DIMENSION POSX16<
COMMON/SHNR/THETAX5<,TX2000,2<,DXX5<,ZXX5<,OXX5<,R,CKX5<,K,FX5<,
1QR1,FPSILN,ABSORP,SIGMA,TF,M,TO,1,TC,K3,1PTX5<,ALPHAX5<,PTX5<,
2CX5<,DT,BLDT,FK,TIM,TF1,QR,B1,HM1,HM2,OMX600<,KK,TM,XMX5<,PTX5<,
3,BFK,OCI,ORT,ORT,ORT,ORT,RATIO,HC,L3
500 READ 3,K,R,KK
3 FORMAT X13,F15.5,I3<
IFXK,FQ,0< GO TO 555
DO 5 I#1,K
READ 1, RHOX15<,CKX15<,THETAX15<,DAMX15<,CX15<
5 CONTINUE
1 FORMATX5F10.6<
DO 501 K1#1,KK
READ 7,FXK1<,7XK1<,XMXK1<,OXK1<
501 CONTINUE
7 FORMATX2F10.2,2F10.6<
READ 4, TO,TC,TF1,FPSILN,ABSORP,DI,QR1,HM,TM
4 FORMATX3F10.4,6F5.2<
HC#0.00134**PI.666/PI<*.195
READ 6, V,TIME,DT
6 FORMATX4.1,F7.2,F5.4<
READ 8, EXPLID
READ 8, WEAPID
8 FORMAT X3A8<
READ 105,BLDT
105 FORMATX7.3<
10 FORMATX25H1EXPLOSIVE IDENTIFICATION,4X,3A8//22H WEAPON IDENTIFICAT
1ION,4X,3A8<
11 FORMATX60H0THE FOLLOWING TABLE IS A TEMPERATURE HISTORY OF THE WAR
1HEAD///<
12 FORMATX6H DEPTH,10X,16X2X,F5.2</6H XCM.<,5X,5HFLAME/10H TIMEYSEC<,
11X,5HTEMP.<
13 FORMATX1H ,F7.2,2X,F6.1,1X,16X1X,F6.1<<
16 FORMATX//65H A CRITICAL TEMP HAS BEEN REACHED WITHIN THE EXPLOSIV
1F AT RADIUS#,F5.2,18H AND BETWEEN TIME#,F7.2,4H SEC,10H AND TIME#,
2F7.2,4H SEC<
17 FORMATX1H0,75H LAYER THICKNESS DENSITY SPEC.HEAT THERM. CON
1 ALPHA FOURIER MOD.<
18 FORMATX1H0,3HDI#,F5.2,5X,3HDT#,F10.4,3X,6HPTX1<#,F7.1,2X,6HPTX2<#,
1F7.1,2X,6HPTX3<#,F7.1,2X,6HPTX4<#,F7.1,2X,7HFPSILN#,F7.5,2X,
27HABSORP#,F5.3<
19 FORMATX1H ,I3,6X1X,F10.5<<
26 FORMATX31HOTF#XTF1-TO<***TIM/BLDT<***3<ETO,10X,5HBLDT#,F7.2<
106 FORMATX1H0,2HH#,F10.5,2X,3HQR#,F10.5,2X,6HDX1<#,F7.5,2X,
16HDX2<#,F7.5,2X,6HDX3<#,F7.5,2X,6HDX4<#,F7.5,2X,3HHM#,F7.4,
22X,3HTM#,F8.3<
CTR #0.0
SIGMA # 1.356E-12
MAXT #IFIXTIME/DT<
TIM#-DT
N#1.0
DO 15 I#1,K
ALPHAXI<#CKXI</RHOXI<#CXI<<
DXXI<#SORTXALPHAXI<#DT/THETAXI<<
IPTXI<#IFIXDAMXI</DXXI<<
PTXI<#FLDPTXI<#PTXI<<
DXXI<#DAMXI</PTXI<

```

```

      THETA1<#ALPHA1<#DT/#DX1<#*2<
      N#N#IPTX1<
15  CONTINUE
      JX1<#1
      JX2<#3
      JX3<#5
      JX4<#IPTX1<#1
      JX5<#JX4<#1
      JX6<#JX5<#1
      JX7<#IPTX1<#IPTX2<
      JX8<#JX7<#1
      JX9<#JX8<#1
      JX10<#IPTX1<#IPTX2<#IPTX3<
      JX11<#JX10<#1
      JX12<#JX11<#1
      JX13<#JX12<#1
      JX14<#JX13<#10
      JX15<#JX14<#10
      JX16<#75
      DO 840 LL#1,600
840  OMXL<#0.
      L3#K-1
      RFK#THETA13</CKXL3<
      HM1#RH0X3<#DX3<#HM/2.
      HM2#HM1*2.
      BT#HC#DX1</# CKX1<
      FK#TF1-TO</BLDT
      RADX1<#0.0
      ICRIT #0
      OCT # 0.0
      ORT # 0.0
C-----SET TEMP INITIALLY TO CONSTANT-----
      DO 201 INIT#1,N
      TXINIT,2<#T0
      201 TXINIT,1<#T0
C-----EVALUATE TEMPERATURE IN LAYERS AND THROUGH INTERFACES-----
      DO 600 MJ#1,MAXT
      J#2
      TIM #TIMEDT
      M#0
C-----COMPUTE LAYER TEMPERATURES-----
      CALL LAYER#ICRIT<
      IF #ICRIT.FD,1<GO TO 420
C-----CHECK FOR PRINTOUT TIME-----
      IF#AMODXCTR,V<<175,147,175
147 IF#CTR.NF,0.< GO TO 167
      I#1.
      I#0.
      DO 160 I#1,K
      I#IPTX14<#16
      DO 165 MP#15,16
      RADXMP#1<#RADXMP<#DX14<
165 CONTINUE
      I#I#1
160 CONTINUE
      PRINT 10, EXPLID,WEAPID
      PRINT1R,DT,PTX1<,PTX2<,PTX3<,PTX4<,FPS1LN,ABSORP
      PRINT106,HC,OR1,DX1<,DX2<,DX3<,DX4<,HM,TM
      PRINT 26,BLDT

```

```

PRINT 17
DO 171 I9#1,K
PRINT 19, I9,DAMX19<,RHDX19<,CX19<,CKX19<,ALPHAX19<,THETA19<
171 CONTINUE
PRINT107,%FXK5<,K5#1,KK<
107 FORMATX1H0,17HACTIVATION ENERGY,5X1X,F15.5<<
PRINT108,%7XK5<,K5#1,KK<
108 FORMATX1H ,1AHCOLLISION NUMBER,5X1X,F15.5<<
PRINT109,%XMXK5<,K5#1,KK<
109 FORMATX1H ,13HMASS FRACTION,4X,5X6X,F10.5<<
PRINT 110,%XK5<,K5#1,KK<
110 FORMATX1H ,16HHEAT OF REACTION,5X6X,F10.5<<
PRINT 11
DO 111 J7#1,16
JA#JXJ7<
111 PDSXJ7<#RADXJ6<
PRINT 12, %PDSXJ6<,JA#1,16<
167 DO 168 J8#1,16
J1#JXJ8<
168 RXJ8<#TXJ1,1<
PRINT 13,TIM,TF,%RXJ8<,J8#1,16<
175 CTR#CTREL.
DO 600 ISFT#1,N
TXISFT,1<#TXISFT,2<
600 CONTINUE
GO TO 500
420 DO 425 JJ#1,16
J1#JXJJ<
425 RXJJ<#TXJ1,2<
PRINT 13,TIM,TF,%RXJJ<,J8#1,16<
TIM#TIM-DT
PRINT 16,RADXK3<,TIM,TIMR
GO TO 500
555 CONTINUE
STOP
END
SUBROUTINE LAYERXICRIT<
COMMON/SUBR/THETA%5<,TX2000,2<,DX%5<,Z%5<,DX%5<,R,CK%5<,K,FX%5<,
1OR1,FPSILN,ABSORP,SIGMA,TF,M,TO,I,TC,K3,1PT%5<,ALPHA%5<,PHI%5<,
2CX%5<,DT,RLDT,FK,TIM,TF1,QR,RJ,HM1,HM2,QM%600<,KK,TM,YM%5<,DT%5<,
3,RFK,OCI,ORI,OCI,ORT,OT,RATIND,HC,L3
FX<#X0.1514-0.17162F-3*X60.37984F-5*X*X-0.1827F-7*X*X*X
160.43595F-10*X*X*X*X</241.9
GX<#X0.5198F0.105*X1.-EXP%X375.-X</20.<<</241.9
DO 250 L1#1,K
L2#L161
IFXL1.GT.1<GO TO 750
140 JEXTIM,GF,RLDT<GO TO 141
143 TF#FK*TIM*TIM*TIM/XRLDT*BLDT<6TO
QR#SIGMA*TF*TF*TF*TF
GO TO 142
141 TF#TF1
QR#QR1
142 TS2#TX1,1<#TX1,1<
TS4#TS2*TS2
TX1,2<#TX1,1<62.*THETA%1<#TX2,1<-X1.8A1<#TX1,1<6A1*TFR
1DX%1<#ABSORP#QR/CK%1<-DX%1<#FPSILN*SIGMA*TS4/CK%1<<
TSS # TX1,1<6TX1,2<<#0.5
TS44 # TSS*TSS*TSS*TSS

```

```

ORI # ABSORP*OP - EPSILN*SIGMA*T*44
OCT # HC*TF=TSS<
OCT # OCT E OCT*DI
ORT # ORT E ORI*DI
OT # ORT E OCT
RATIOO # OCT/OT
750 CONTINUE
M#M#IPTXL1<
IFXL1-L3<122,120,119
122 IFXL1.F0.1<GD TO 121
I#162
121 TX1,2<#THFTAXL1<#TX1I61,1<8TXI-1,1<AX1./THFTAXL1<-2.<#TX1,1<<
IFXABSXTX1,2<-TO<.LF.0.01<GD TO 400
IFX1.F0.M<GD TO 124
I#161
GD TO 121
124 IFXL1.F0.2<GD TO 125
TXM61,2<#TXM61,1<E2.*DT*CKXL1<#TXM,1<-TXM61,1<</DXXL1<
1-CKXL2<#TXM61,1<-TXM62,1<</DXXL2<</RRHDXL1<#CXL1<#DXXL1<
2RRHDXL2<#CXL2<#DXXL2<<
GD TO 250
125 TSTAR#TXM61,1<8TXM62,1<</2.<#1.8-460.
IFXTSTAR.GT.375.<GD TO 241
CKO#FXTSTAR<
GD TO 118
241 CKO#GXTSTAR<
118 TXM61,2<#TXM61,1<E2.*DT*CKXL1<#TXM,1<-TXM61,1<</DXXL1<
1-CKO#TXM61,1<-TXM62,1<</DXXL2<</RRHDXL1<#CXL1<#DXXL1<
2RRHDXL2<#CXL2<#DXXL2<<
GD TO 250
120 I#162
TST1#TXI-1,1<#1.8-460.
TST2#TXI,1<#1.8-460.
TST3#TXI61,1<#1.8-460.
IFXTST1.GF.375.< GD TO 436
CK1#FXTST1<
FN1#REF*CK1
GD TO 434
436 CK1#GXTST1<
FN1#REF*CK1
434 IFXTST2.GF.375.< GD TO 437
CK2#FXTST2<
FN2#REF*CK2
GD TO 433
437 CK2#GXTST2<
FN2#REF*CK2
GD TO 433
431 CK1#CK2
CK2#CK3
FN1#FN2
FN2#FN3
TST3#TXI61,1<#1.8-460.
433 IFXTST3.GF.375.< GD TO 432
CK3#FXTST3<
FN3#REF*CK3
GD TO 435
432 CK3#GXTST3<
FN3#REF*CK3
435 TX1,2<#TXI,1<#FN2*TXI-1,1<8TXI61,1<-2.*TX1,1<<E0.25*EFD- 1 <#

```



```

      T%I-1,1<-T I%I,1<<
      IF%ARS%T%I,2<-T%I,1,F,0.01<G% I% 400
      IF%I.F%I,M<G% I% 135
      I#I%I
      G% I% 431
135 TSTAR#%T%M,1<ET%M%1,1<</2.<#1.8-440.
      IF%TSTAR.GF.375.<G% I% 240
      CK4#F%TSTAR<
      G% I% 136
240 CK4#G%TSTAR<
136 TSTF#%T%M%1,1<ET%M%1,1<ET%M%2,1<</2.</2.
      AF#0.
      D%726 LL#1,KK
727 AF#AF%XM%L<#RH%L2<#%L<#7%L<#F%P%-F%L</%R%T%I<<
      L#I
      IF%T%M%1,1<.LT.TM <G%I%701
      IF%OM%L<.GF.HM1<G%I%701
      OM%L<#OM%L<ET%CK4#%T%M,1<-T%M%1,1<</DX%L1<-DT%CK%L2<#
      1%T%M%1,1<-T%M%2,1<</DX%L2<EDT%DX%L2<#AF/2.
      IF%OM%L<.GT.HM1<G%I%702
      T%M%1,2<#T%M%1,1<
      G%I%250
702 T%M%1,2<#T%M%1,1<ET%2.#%OM%L<-HM1</%RH%L1<#C%L1<#DX%L1<E
      RH%L2<#C%L2<#DX%L2<<
      G%I%250
701 T%M%1,2<#T%M%1,1<ET%2.#%OM%L<-HM1</%RH%L1<#C%L1<#DX%L1<E
      1-CK%L2<#%T%M%1,1<-T%M%2,1<</DX%L2<EAF%DX%L2<</2.</
      2%RH%L1<#C%L1<#DX%L1<E%RH%L2<#C%L2<#DX%L2<<
      G% I% 250
119 I#I%2
713 AF#0.
      D%727 LL#1,KK
727 AF#AF%XM%L<#RH%L1<#%L<#7%L<#F%P%-F%L</%R%T%I,1<<<
      IF%T%I,1<.LT.TM <G%I%126
      L#L%I
      IF%OM%L<.GF.HM2<G%I%126
      OM%L<#OM%L<E%CK%L1<#DT%T%I%1,1<ET%I-1,1<-2.%T%I,1<</DX%L1<
      1%DT%DX%L1<EAF
      IF%OM%L<.GT.HM2<G%I%127
      T%I,2<#T%I,1<
      G%I%127
711 T%I,2<#T%I,1<E%OM%L<-HM2</%RH%L1<#C%L1<#DX%L1<<
      G%I%127
126 T%I,2<#THETA%L1<#%T%I%1,1<ET%I-1,1<E%I./THETA%L1<-2.<#T%I,1<<<
      1THETA%L1<#DX%L1<#DX%L1<#AF/CK%L1<
      IF%ARS%T%I,2<-T%I,1,F,0.01<G% I% 127
712 IF%I.F%I,M<G% I% 128
      I#I%I
      G% I% 713
128 I#I%I
      T%I,2<#T%I-1,2<
127 M%MM-1PT%L1<E1
      D% 137 K3#M2,M
      IF%T%K3,2<.LT.TC<G% I% 137
      ICRIT%I
      G% I% 400
137 CONTINUE
250 CONTINUE
400 RETURN
      END

```

Card

1 K (I3)	R (F15.5)				
2 RHO(1) (F10.6)	CK(1) (F10.6)	PT(1) (F10.6)			
E(1) (E10.5)	Z(1) (E10.5)	DAM(1) (F10.6)			
C(1) (F10.6)	Q(1) (F10.6)				
3 RHO(2) (F10.6)	CK(1) (F10.6)	PT(1) (F10.6)			
E(1) (E10.5)	Z(1) (E10.5)	DAM(1) (F10.6)			
C(1) (F10.6)	Q(1) (F10.6)				
4 RHO(3) (F10.6)	CK(1) (F10.6)	PT(1) (F10.6)			
E(1) (E10.5)	Z(1) (E10.5)	DAM(1) (F10.6)			
C(1) (F10.6)	Q(1) (F10.6)				
5 TO(F10.4)	TC(F10.4)	TF1(F10.4)			
EPSILN(F10.4)	HC(F10.4)	QRI(F10.4)			
6 V(F4.1)	TIME(F7.2)	DT(F5.4)			
7 EXPLID(3A8)					
8 WEAPID(3A8)					
9 J(1)	J(2)	J(3)	J(4)	J(5)	J(6)
J(7)	J(8)	J(9)	J(10)	J(11)	J(12)
J(13)	J(14)	J(15)	J(16)		
10 BLDT (F7.3)					

Definition of Input Variables

Card 1:

1. K is the number of different material layer in the ordnance. For the present program K is always 3.
2. R is the gas constant in calories/ $^{\circ}$ Kelvin ($R=1.987 \text{ Cal}/^{\circ}\text{K}$).

Card 2:

1. RHO is the density of the outer layer in gm/cm^3 .
2. CK is the thermal conductivity, in $(\text{cal}/\text{cm sec}) ^{\circ}\text{K}$, of the outer layer.
3. PT is the number of spaces chosen within the outer layer for numerical calculation. (See attachment page G-19 for more details.)
4. E is the activation energy in calories. E will be zero for all layers except the explosive layer.
5. Z is called the collision number or frequency factor in seconds^{-1} . Z will be zero except for the explosive.
6. DAM = thickness of outer layer in cm.
7. C is the heat capacity in $\text{cal}/\text{gm}^{\circ}\text{K}$.
8. Q is the heat of reaction cal/gm . Q is zero except for the explosive.

Card 3:

All definitions are the same as in Card 2 except for the second or middle layer.

Card 4:

All definitions are the same as in Card 2 except for the explosive layer.

Card 5:

1. TO (F) is the initial constant temperature of the ordnance item. Generally assumed to be that of the air temperature.
2. TC (F) is called the critical temperature of the explosive. It can be any relative large number (generally 10000). The temperature of the explosive will jump instantaneously from low temperatures (400-450°F) to very high temperatures. Thus, TC is a measure to indicate the reaction.
3. TGI (°F) is the average maximum flame temperature.
4. EPSILN (no units) is the emissivity of the ordnance surface. Since the ordnance surface is covered with a soot layer within a few seconds after immersion in the flame, EPSILN is assumed to have a constant value of 0.99 which is the emissivity of the soot.
5. HC is the connection coefficient Btu/hr ft² °F. The best value for this at the present time is 10.5 Btu/hr ft² °F.
6. QRI is the maximum radiant, flux is Btu/ft² sec. The best average value for QRI is 13.5 Btu/ft²sec.

Card 6:

1. V is a number chosen to determine printout times. See definition¹ of DT for more details.
2. TIME (sec)² is a number to limit the running time of the program in the event of no reaction.
3. DT is the time interval over which numerical calculations are performed. The smaller DT is chosen, the more accurate is the numerical calculations, but it takes more computer running time. For DT equal to 0.0625 sec., the computer running is approximately one-half the calculated cook-off time.

¹ V must be chosen as some whole number. Then V DT will give the seconds between printout of the calculated temperatures (i.e., for DT = 0.0625 and V = 80, $V \text{ DT} = 5.0$ so that temperatures are printed out every 5 seconds.)

² TIME is chosen such that MAXT = TIME/DT is the number of time steps to be taken in the program unless a reaction is reached first (i.e., TIME = 625 sec, DT = 0.0625 sec MAXT = 10000. The program will stop after 10000 time steps of 0.0625 secs even if a reaction has not been reached.)

Card 7:

1. EXPLID identification of explosive (such as H-6).

Card 8:

1. WEAPID identification of weapon (such as MK 82).

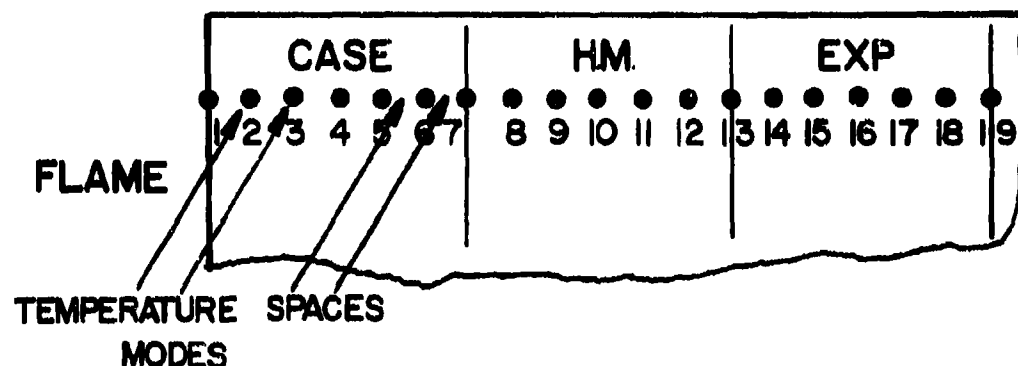
Card 9:

The J's identify the location (or temperature modes) where the temperatures are to be printed out. It is not feasible to print out all temperatures calculated. The attachment will help to identify the number of the temperature modes.

Card 10:

BLDT (sec) is the time for the flame to buildup to quasi a steady-state condition.

ATTACHMENT:



PT for each layer is the number of spaces in that layer. It must be chosen to meet the following condition:

$$\alpha \frac{DT}{(DX)^2} < 1/2$$

where

$$\alpha = \frac{CK}{RHO \cdot C} \text{ and}$$

$$DX = \frac{DAM}{PT}$$

therefore

$$\frac{CK \cdot DT \cdot (PT)^2}{RHO \cdot C \cdot (DAM)^2} < 1/2$$

The computer program will be unstable if this condition is not met. Temperatures are calculated at the modes as indicated by dots in the diagram. Sixteen of these temperatures can be printed out by setting the J's equal to the integers by the mode you want printed.

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APPENDIX H

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11. SUPPLEMENTARY NOTES

12. SPONSORING MILITARY ACTIVITY

13. ABSTRACT

The bomb survivability in fire program was initiated to determine the hazards that exist when bombs are exposed in a carrier flight deck fire (fast cook-off) and to investigate methods of minimizing or eliminating these hazards.

All M117, AN-M65 and MARK 80 series bombs employed in the program were exposed in a JP-5 jet fuel fire environment that simulated a flight deck conflagration

The severity of reaction, time to reaction and, when pertinent, internal time-temperature information were obtained. Also determined from the program were: (1) relationship of bomb size, explosive load and fuzing configuration to cook-off time and severity of reaction, (2) influence of aircraft structure on bomb cook-off time and severity of reaction, (3) likelihood of bomb cook-off after abbreviated heating periods, (4) adequacy of water and aqueous film forming foam (light-water) as cooling measures for preventing bomb cook-off, and (5) effect of elevated temperatures on bombs subjected to accidental ejection from parked aircraft or other accidental drops on board ship.

The results of supporting tasks investigating quick fire starting, wind effects, internal thermocouple design, inert filler, water and light-water rates apparatus design, ejection cartridge cook-off, evaluation of fire retardant paints and computer studies and analysis are also presented.

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(PAGE 1)

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