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REPORT NO. RN-S-0280

TO

AEC - NASA SPACE NUCLEAR PROPULSION OFFICE

FINAL TEST REPORT FOR PHASE I-C,
COUNTERMEASURES
RADIATION EFFECTS PROGRAM (U)

MARCH 1966

NERVA PROGRAM

CONTRACT SNP-1

AEROJET-GENERAL CORPORATION

SACRAMENTO, CALIFORNIA

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National Aeronautics and Space Administration
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Attention: L. C. Corrington
Asst. Chief for Technical Operations

Subject: AGC Report RN-S-0280, Final Test Report for Phase
I-C, Countermeasures Radiation Effects Program (U),
Contract SNP-1

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During this phase of the program, pseudo-stable materials were irradiated in small quantities (1.8 grams) in both instrumented and non-instrumented containment capsules. Both pressure and temperature were monitored during irradiation of those samples in the instrumented capsules.

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MASTER

REPORT NO. RN-S-0280

FINAL TEST REPORT FOR PHASE I-C,
COUNTERMEASURES
RADIATION EFFECTS PROGRAM (U)

ROCKET ENGINE OPERATIONS - NUCLEAR

MARCH 1966

NERVA PROGRAM

CONTRACT SNP-1

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FOREWORD

This document presents the test results of Phase I-C of the Countermeasures Radiation Effects Program, Sub-Subtask 1.9.1, and represents the combined efforts of the Aerojet-General Corporation (REON and the Ordnance Research Division), the United States Army Picatinny Arsenal Ammunition Engineering Directorate, and the United States Army Picatinny Arsenal Explosives Research Laboratory.

This document is submitted in partial fulfillment of Contract SNP-1, Sub-task 1.9.

W. D. Stinnett
Program Manager
Rocket Engine Operations - Nuclear

TABLE OF CONTENTS

	<u>Page</u>
I. Introduction	1
II. Summary	3
III. Technical Discussion	11
A. Materials Irradiated	11
B. Irradiation Capsules	11
C. Radiation Environment	18
D. Weight-Loss Measurements	21
1. Primary Explosives	21
2. Booster Explosives	21
3. Main Charge Explosives	29
4. Igniters	29
5. Propellants	29
6. Mild Detonating Fuze (MDF)	30
E. Gas-Release Measurements	32
1. Instrumented Capsule Results	35
F. Thermal Stability	39
1. Differential Thermal Analysis and Melting Point	39
2. Thermogravimetric Analysis	53
3. Explosion Temperature	55
4. Vacuum Stability	61
G. Post-Irradiation Performance Measurements	67
1. Detonation Velocity and Plate Dent	67
2. Burning Rate of Propellant Strands	69
H. Detonator Development	71
References	74

TABLE OF CONTENTS (cont.)

<u>Appendix</u>	Appendices	<u>Page</u>
A	Calibration of Pressure Measurement System	A-3
B	Detail Gas Release Data and Calculated Results	B-3
C	Detail Weight-Loss Data	C-3
D	Instrumented Capsule Temperature Recorder Calibration	D-3
E	Accuracy of Detonation Velocity Test on Pressed Pellets	E-3
F	Explosion Temperature Procedure	F-3
G	Summary of Thin-Layer Chromatography of Explosive Materials	G-3

TABLES

<u>No.</u>	<u>Title</u>	<u>Page</u>
I	Phase I-C Data Summary	6
II	Pre-Irradiation Properties of Materials Tested in Phase I-C	12
III	5% Weight-Loss Exposure Limits	22
IV	Effects of Irradiation on Black Powder Pellets	31
V	Properties of MDF	32
VI	Gas Release Summary	33
VII	Major Radiolytic Gas Components	36
VIII	Instrumented Capsule Gas Release Data Summary	37
IX	Differential Thermal Analysis, Thermogravimetric Analysis, and Melting Point Data	41
X	Explosion Temperature Test Data	56
XI	Vacuum Stability Test Data	62
XII	Vacuum Stability Vs Temperature	66
XIII	Phase I-C MDF Detonation-Velocity and Plate-Dent Test Data Summary	68
XIV	Propellant Strand Burning Rate Summary	70
XV	Summary Propellant Properties	72

LIST OF FIGURES

<u>Figure No.</u>		<u>Page</u>
1	Countermeasures Materials Radiation and Temperature Tolerances (U)	4
2	Structural Formulas of Explosives (U)	14
3	Non-Instrumented Capsule Assembly	16
4	Instrumented Capsule Assembly	17
5	Sectioned AGY-10 Capsule after Detonation in Reactor (U)	19
6	Weight Loss of Primary Explosive (U)	23
7	Weight Loss of Booster Explosives (U)	24
8	Weight Loss of MDF (U)	25
9	Weight Loss of Main Charge Explosive (U)	26
10	Weight Loss of Igniters (U)	27
11	Weight Loss of Propellants (U)	28
12	AGC-10 Capsule Pressure and Temperature Record (U)	38
13	DTA Peak vs Exposure of Primary and Booster Explosives (U)	44
14	DTA Peak vs Exposure of Main Charge Explosives (U)	45
15	DTA Peak vs Exposure of Propellants and Igniters (U)	46
16	DTA Analysis of HNS Loaded MDF (CRD) (Prior to Irradiation)	48
17	DTA Analysis of NASA-1 Loaded MDF (CRD) (Prior to Irradiation)	49
18	DTA Analysis of DATB Loaded MDF (CRD) (Prior to Irradiation)	50
19	DTA Analysis of TATB Loaded MDF (CRD) (Prior to Irradiation)	51
20	DTA Analysis of HNS Loaded MDF of Sample AGI-7 Following Irradiation (U)	52
21	DATB/Ti DTA Compatibility Test (CRD)	54
22	AGA-7 Explosion Temperature Data	60
A-1	Pressure Measurement Panel Diagram	A-4
D-1	Instrumented Capsule Temperature Recorder Calibration for Phase I-C	D-3
D-2	Temperature Correction Chromel-Alumel Thermocouple Cold Junction at 0°C	D-4
E-1	Pressed Explosive Velocity Test Assembly	E-5
E-2	Detonation Velocity R. C. Mixer Box	E-6

I. INTRODUCTION

This phase of the Countermeasures Radiation Effects Program, REON Subtask 1.9.1, was concerned with a thorough evaluation of high-temperature stable explosives and propellants, and determination of their radiation tolerance limits. The most promising explosives and propellant from Phase IB were tested, as were four new propellants and four new explosives. Four explosives were tested in mild detonating fuse (MDF) form, two of which had not previously been available. The basic capsule design was modified from that used in previous phases to permit continuous monitoring of temperature and pressure during irradiation to determine threshold exposure limits. Two new tests (thermal gravimetric analysis and strand burning rate) were used to evaluate irradiated samples. Data obtained from this phase of the program resulted in the establishment of radiation exposure limits for the materials tested and will be used to select materials for the larger (80 gram sample) Phase II testing.

This program was performed jointly by Aerojet-General Corporation, U. S. Army, Picatinny Arsenal, and General Electric Co. (Irradiation Processing Operations). Samples were irradiated in the General Electric Test Reactor (Vallecitos Atomic Laboratory) at Pleasanton, California. Subsequent tests on irradiated samples were made by Aerojet-General and Picatinny Arsenal personnel in the GE Radiological Materials Laboratory. Test procedures have been reported in Addendum No. 4 (RN-S-0235) to AGC Report 2510, "Final Test Specifications for Phase IC of the Countermeasures Radiation Effects Program," published by Aerojet-General Corporation (REON) in July 1965.

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II. SUMMARY

Based on the results of the small-scale (1.8 to 3.6 grams) irradiations, which concluded with Phase I-C, the most promising candidate materials for the NERVA destruct system may be listed for each component. Figure 1 provides such a listing and includes the maximum radiation tolerance (based on 5% weight loss) and temperature limit for each material. This figure also describes the predicted large-diameter NERVA radiation exposure for each of the components (based on one hour of engine operation).

Two suitable main charge explosives have been selected: NASA-1 and TATB. NASA-1 has slightly higher temperature stability. However, its output (based on detonation velocity and density) is 80% of that of TATB.

The most radiation-stable booster material is ABH, with NONA having the highest temperature stability. Both of these materials were supplied to this program by the U.S. Naval Ordnance Laboratory. HNAB is sufficiently radiation and temperature stable to be considered. It also has the lowest EBW firing voltage (2,000 volts) of the three. HNAB was supplied by Sandia Corporation. KDNBF is considered the only radiation-stable primary explosive tested.

IB7158 (DATB/Polystyrene) is the most radiation-stable propellant tested. PPLA3223 (DATB/Viton) and AK14 ($KClO_4$ /Polyester) are tentative alternates. Because all three of these materials have similar formulations, there may be no alternate material available if they should not perform satisfactorily in the large-sample Phase II tests. For this reason, Picatinny Arsenal is currently investigating other propellant formulations incorporating the more radiation-resistant main charge explosives (TATB and NASA-1)

Each of the three igniter materials listed in Figure 1 functions differently than the other two: thus, selection will depend on specific application. Ignition can be achieved by a low-voltage firing unit using KDNBF pressed onto a bridgewire. High voltage ignition could employ a bridgewire in conjunction with one of the detonator materials. Black powder is suitable for pressurizing the propellant and

COMPONENT	SELECTED MATERIALS	MAXIMUM RADIATION TOLERANCE (5% WT LOSS)		TEMPERATURE LIMIT (MELTS OR EXPLODES IN 5 SECONDS) °C	PREDICTED LARGE DIAMETER NERVA MAX. EXPOSURE AFTER ONE HOUR RUN	
		GAMMA ergs/gm(C) x 10 ¹⁰	FAST NEUTRONS n/cm ² x 10 ¹⁶ E ≥ 1 Mev		GAMMA ergs/g (C) x 10 ¹⁰	FAST NEUTRONS n/cm ² x 10 ¹⁶
IGNITER	KDNBF	10.2	8.1	220	0.25	0.5
	BLACK POWDER	33.0	26.2	268		
	ALCLO	6.3	5.0	580		
PROPELLANT	IB7158 (DATB + POLYSTYRENE)	19.4	15.6	280	0.35	1.0
MILD DETONATING FUZE	NASA-1	12.2	9.7	258	0.35	1.0
DETONATOR	NONA ABH	10.8	8.6	310	0.35	1.0
		15.0	11.9	247		
MAIN CHARGE	NASA-1 TATB	25.7	20.4	285	0.5	2.0
		27.0	21.4	233		

Countermeasures Materials Radiation and Temperature Tolerances (U)

Figure 1

may be used to ignite it. ALCLO produces hot particles and may be required to ignite the propellant rapidly.

A complete summary of the test data obtained from Phase I-C (including the control and Phase I-B data where applicable) are presented in Table I. As a result of the small-scale irradiations, radiation-stable explosives, igniters, and propellants have been found and their approximate radiation damage thresholds determined. A larger capsule is being developed by Picatinny Arsenal to permit irradiation of 80-gram samples in Phase II. Tests conducted during Phase II will include: (1) heat buildup and decomposition rates of larger main-charge explosive samples; (2) closed bomb performance testing on larger propellant samples; and (3) irradiation and testing of a sufficient number of detonators to permit accurate evaluation of the effects of radiation on performance.

TABLE I
PHASE I-C DATA SUMMARY (u)

Material		Irradiation				Test Results							Remarks
		Capsule No.	Date Irrad.	Time Irrad. (hrs)	Max. Irrad Temp. °C	Gas Pressure, mm	Wt. Loss %	Thermal Stability					
								DTA Exotherm °C	10% Wt. Loss on TGA °C	5 sec Expl. Temp. °C	Melting Point °C	Vac. Stab. @ 200°C	
Type	Name	No.	Irrad.	(hrs)	Temp. °C								
Primary Explosives	KDNEF	AGK-0	-	0	-	0	0	211	210	194	*	# 2.55	Best primary explosive. P.A. Sample.
		-7	8-13-65	1	70-125								
		-8	8-13-65	2	125+	920	0.464	198	188	185	*	#10.95	
		-10	8-12-65	3	174	1138	1.62	188	188	170	*	#11+	
	Lead Styphnate	AGY-0	-	0	-	0	0	287		299	214	1.02	Burned
		-10	8-12-65	0.03	204	over 50 psig	-	--	--	--	--	--	
Booster Explosives	DPS (HNDS)	AGB-0	-	0	-	0	0	343	288	387	*	0.14	Sample impure by TLC
		-7	8-7-65	2	125+	2268	8.26	281	175	181	*	#19.10	
		-10	8-4-65	3.1	160	1830	11.4**	230	200	177	*	#22.10	
	HNAB	AGN-0	-	0	-	0	0	352	341	373	221	0.10	Sample deflagrated in 3 min at 200°C
		-7	8-16-65	2	70-125	1175	1.76	353	272	363	207	8.65	
		-10	8-12-65	3	115	1230	3.58**	353	311	329	205	12.43	
		-11	9-14-65	5.4	140	1700	7.52	340	252	306	185	23.40	
	HNS	AGV-0	-	0	-	0	0	343	317	385	□ 313	0.30	Sample I
		-2	10-1-64	2	70-125	1182	2.36	330	-	314	*	# 8.43	
		-7	8-6-65	2	125+	1229	2.20	341	276	307	□ 301	16.0	
		-1	10-4-64	3	125+	1600	3.8**	335	-	249	*	#11+	
		-8	8-5-65	3	125+	1585	4.28	335	232	251	*	21.6	
		-10	8-3-65	4	140	1460	5.80	330	250	256	*	22.8	
	NONA	AGJ-0	-	0	-	-	0	402	-	440	-	# 0.07	Sample I
		-0	-	0	-	0	0	397	316	436	*	0.58	
		-2	10-1-64	2	70-125	1092	2.57	365	-	360	*	#11.0	
		-1	10-2-64	3	125+	1636	5.11	360	-	303	*	6.47	
		-10	9-13-65	4	167	-	6.72 Δ	360	271	279	*	11.7	
		-7	9-17-65	6	125+	2547	9.87	369	248	231	*	40.0	
	ABH	AGAB-0	-	0	-	0	-	376	361	385	*	0.49	Sample I
		-7	9-15-65	3	125+	1525	4.20**	343	259	293	*	11.6	
		-10	9-13-65	6	183	1330	6.10	313	275	247	*	27.5	

* No true melting point on DTA.

** Weight loss based on gas volume.

VTS at 150°C.

L Melting point data from DTA, no melting point observed in capillary.

∠ Interpolated from gas volume and weight-loss data.

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TABLE I (cont.)

Material		Irradiation				Test Results						Remarks	
		Capsule No.	Date Irrad.	Time Irrad. (hrs)	Max. Irrad Temp. °C	Gas Pressure, mm	Wt. Loss %	Thermal Stability					
								DTA Exotherm °C	10% Wt. Loss on TGA °C	5 sec Expl. Temp. °C	Melting Point °C		Vac. Stab. @ 200°C
Type	Name												
Main Charge Explosives	NASA-1	AGA-0	-	0	-	0	0	398	409	417	*	## 0.22	
		-1	9-28-64	1/2	70	772	0.26	390	-	415	*	## 0.52	
		-2	10-5-64	2	70-125	945	1.03	388	-	374	*	0.51	
		-7	8-13-64	3	125+	1071	1.60**	389	371	379	*	3.35	
		-8	8-8-65	4	70-125	1194	1.78	388	356	352	*	4.33	
		-10	8-7-65	10	133	1500	7.00**	366	275	247	*	8.96	
	TATB	AGH-0	-	0	-	0	0	388	359	392	*	0.06	
		-2	10-4-64	2	70-125	751	0.45	365	-	287	*	1.05	
		-1	10-6-64 and 10-7-64	3	125+	814	0.78	360	-	253	*	# 5.44	
		-7	8-16-65	4	125+	1050	1.23**	358	263	259	*	14.91	
		-8	8-13-65	4	125+	1095	1.41	361	283	255	*	12.7	
		-10	8-9-65 and 8-12-65	10	163	1590	7.02**	348	247	233	*	11.28	
	DATB	AGW-0	-	0	-	0	0	358	-	403	280	0.05	Sample I
		-00	-	0	-	0	0	354	287	403	285	0.05	Sample II
		-1	10-5-64	2	125+	857	0.3	355	-	344	275	# 4.48	Sample I
		-7	8-9-65	3	70-125	1028	1.18*	353	255	342	278	11.15	Sample II
		-8	8-7-65	5	70-125	1531	3.60	345	260	301	258	12.88	Sample II
		-10	8-5-65	9-1/2	150	1770	9.47**	348	248	271	322	11+	Sample II
Igniters	Black Powder	AGS-0	-	0	-	0	0	328	282	324	□□128	# 0.47	
		-1	9-29-64	1/2	70-125	766	0.31	325	-	337	□□120	# 3.75	
		-2	10-8-64	2	70-125	755	0.21	324	-	298	□□115	# 1.58	
		-7	9-7-65	3	70-125	836	0.715	324	304	302	□□115	4.00	
		-8	8-13-65	5	125+	1014	2.04	308	165	282	□□117	6.30	
		-10	8-5-65	10.3	121	1140	5.39**	306	226	268	□□113	8.23	
	ALCLO (KClO ₄ /Al)	AGAL-0	-	0	-	0	0	457	500+	588+	□295	0.03	
		-7	9-15-65	2	70-125	2071	5.80	490	500+	571	□315	1.94	
		-10	9-13-65	1.1	94	900	0.90**	490	No Data	580	□303	7.23	

* No true melting point on DTA.

** Weight loss based on gas volume.

VTS at 150°C

VTS at 260°C

□□ Sulphur MP from DTA

□MP data from DTA, no MP observed in capillary.

TABLE I (cont.)

Material		Irradiation				Test Results								Remarks
Type	Name	Capsule No.	Date Irrad.	Time Irrad. (hrs)	Max. Irrad. Temp. °C	Gas Pressure, mm	Wt. Loss %	DTA Exotherm °C	10% Wt. Loss on TGA °C	5 sec Expl. Temp. °C	Melting Point °C	Vac. Stab. @ 200°C	Strand Burning Rate (in./sec)	
Propellants	IB 7169 (KClO ₄ /Polystyrene/ DOP)	AGG-0	-	0	-	0	0	435	397	593	292	0.38*	0.95	* 1.05 at PA.
		-7	8-2-65	2	70-125	2095	7.72**	355	351	376	310	1.42	-	Melted.
	AK-14 (KClO ₄ / Polyester Styrene)	AGE-0	-	0	-	0	0	495	368	406	298	0.58*	0.84	* Run at PA.
		-1	9-29-64	1/2	70-125	830	0.254	485	-	313	295	# 3.92	-	
		-8	8-12-65	1	70-125	1297	2.50	490	311	281	305	6.43	1.25	
		-9	9-12-65	1	70-125	1037	1.24	490	307	271	298	6.11	1.14	
		-2	9-30-64	2	125+	2263	8.05	468	-	319	298	# 0.62	-	
		-7	8-3-65	2	70+	2120	8.54φ	475	307	300	>288	3.08	3.08	
	PPIA 3223 (DATE/Viton)	AGG-0	-	0	-	0	0	353	290	388	278	0.68*	0.042Δ	* 1.22 @ PA.
		-8	8-13-65	1	70-125	944	1.70	351	271	377	273	4.68	0.063Δ	
		-9	9-14-65	1	70-125	1012	2.64	350	256	367	274	3.04	0.067Δ	
		-7	8-8-65	2	125+	1190	3.80	343	237	366	273	7.03	0.095Δ	
		-10	9-14-65	3-1/2	151	1410	8.27φ	333	224	313	270	11.00	0.067	
	IB 7158 (DATE/ Polystyrene + Butadiene)	AGG-0	-	0	-	0	0	340	290	387	277	0.49*	0.741 •	* 2.20 @ PA.
		-7	8-8-65	2	70-125	960	1.06	335	270	378	273	6.88	0.806 •	
		-8	8-12-65	1	70-125	866	0.64**	345	265	383	278	10.13	0.735 •	
		-9	9-12-65	1	125+	839	0.962φ	344	272	352	275	2.96	Not Available	
		-10	9-15-65	10	153	1310	13.10 φ	318	259	284	265	11.03	Not Available	
	HES 6573 (KClO ₄ / Ethyl Acrylate + Chlorovinyl Ether)	AGZ-0	-	0	-	0	0	352	331	408	293	0.46*	1.54	* 0.55 @ PA.
		-7	8-3-65	2	70-125	2406	6.01**	230	285	260	302	16.3	-	Turned to powder.

** Weight loss based on gas volume.

VTS at 150°C

□ Melting point data from DTA, no melting point observed in capillary.

Δ Tested at 1500 psi.

• Tested at 35,000 psi @ PA

φ Weight loss on strand.

TABLE I (cont.)

		Irradiation				Test Results						
Material		Capsule	Date	Time	Max.	Gas		DTA	Detonation	Velocity	Plate Dent	
Type	Name	No.	Irrad.	(hrs)	Temp. °C	Pressure, mm	Wt. Loss %	Exotherm °C		m/sec	in.	Remarks
Detonating Fuze	NASA-1	AGT-0	-	0	-	0	0	-		5401	0.006	
		-1	11-14-64	2	125+	756	2.03	-		4885	0.008	
		-2	11-14-64	3	125+	900	4.29**	-		4260	0.006	
		-7	8-3-65	4	125+	-	3.40	-		5008	0.004	
		-8	9-17-65	10	125+	-	19.11	-		***	***	
TATB		AGU-0	-	0	-	0	0	-		6765	0.014	° One strand failed to detonate, refired from opposite end.
		-7	8-7-65	4	125+	-	7.60	-		5871	0.009	
		-8	9-17-65	6	125+	-	9.45	-		5697 °	0.010	
HNS		AGI-0	-	0	-	0	0	316		5756	0.006	
		-8	9-17-65	3/4	125+	-	6.90	-		5101	0.006	
		-7	8-2-65	2	125+	-	30.6	298	Failed		0	
DATE		ACM-0	-	0	-	0	0	-		5787	0.014	Sample I
		-00	-	0	-	0	0	-		6337	0.014	Sample II
		-1	9-28-64	1/2	70-125	813	0.54	-		5724	0.014	Sample I
		-2	9-29-64	2	125+	979	2.80	-		6000	0.012	Sample I
		-7	8-8-65	4	125+	-	9.80	-		5463	0.010	Sample II
		-8	9-16-65	6	125+	-	12.2	-		5310	0.009	Sample II

** Weight loss based on gas volume.

*** Failed to detonate.

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III. TECHNICAL DISCUSSION

A. MATERIALS IRRADIATED

Materials were selected for Phase I-C tests on the basis of results obtained from earlier phases of the Countermeasures Radiation Effects Program and on development of new formulations since the selection of Phase I-B materials. Table II lists the materials tested in Phase I-C and summarizes their pertinent properties.

The explosives tested which have relatively high-temperature and radiation resistance also have similar molecular structures. The structural formulas of these materials are shown in Figure 2. All of these explosives have a benzene ring whose resonance imparts temperature and radiation stability, and all except KDNFB and NASA-1* have the trinitrobenzene grouping.

The purity of the explosive samples tested was checked by thin layer chromatography as reported in Appendix G. Most materials were found to be pure; however, some impurities were observed in NASA-1, HNAB and BDPS.

B. IRRADIATION CAPSULES

Both instrumented and noninstrumented irradiation capsules were used during this phase. The basic noninstrumented type is shown in Figure 3. A modified design to permit continuous measurement of pressure and temperature during irradiation is shown in Figure 4. Details of the loading and operating procedures, and of qualification testing have been given in the test specifications for this phase, RN-S-0235¹. The instrumented capsule is basically a standard capsule modified to include a hardened steel seal-ring which cuts the thermocouple wires in the event of

* NASA-1 is not included in Figure 2 since this material is supplied by SNPO-C and its formulation is proprietary.

1. Superscript indicates reference number listed on pages 74 and 75.

TABLE II

PRE-IRRADIATION PROPERTIES OF MATERIALS TESTED IN PHASE I-C (u)

Material		Capsule Letter	Heat of Explosion cal/g	Gas Volume from Explosion ml/g	Molecular wt	Detonation Velocity m/sec	Density at which Det Vel Measured	Crystal Density g/cu cm	Impact Sensitivity 50% Height, cm	Decomposition Temp, °C	Melting Point °C	Remarks
Type	Name											
Mock	Charcoal	Mock			12							
Primary Explosive	Lead Styphnate	Y	457	368	168	5200	2.9	3.02	12 cm	270	214	Lead styphnate
	KDNBF	K	725	604	225	--	-	2.21	8 cm	213	209	Potassium dinitrobenze furoxan
Booster Explosive	ABH	AB	~950	~780	868	7200	1.64	1.78	27 cm	370	-	Azobis hexanitro biphenyl
	HNAB	N	1050	~780	380	7700	-	1.80	49 cm	346	221	Hexanitroazobenzene
	HNDS	B	1100	~780	418	7200	-	1.78	62 cm	343	-	Hexanitrodiphenylsulfone
	HNS	V	~1000	746	450	6806	1.59	1.74	39 cm	343	-	Hexantro stillbene
	HNS (MDF)	I		3.43 gr/ft (3.11 wt% explosive)						328	256	Sheath melts
	NONA	J	~1000	794	635	7220	1.67	1.78	31 cm	397	-	Nonanitro terphenyl
	PETN	Reference	1385	790	316	8300	1.70	1.77	15 cm	211	141	Pentraerythritol tetranitrate
Main Charge Explosive	NASA-1	A	~1000	691	388	7000	1.62	1.85	102 cm	390	-	
	NASA-1 (MDF)	T		4.5 gr/ft (2.60 wt% explosive)						431	257	Sheath melts
	TATB	H	829	781	258	7700	1.75	1.938	320 cm	388	-	Triaminotrinitrobenzene
	TATB (MDF)	U		13.5 gr/ft (4.27 wt% explosive)						427	261	Sheath melts
	DATB	W	847	784	243	7250	1.65	1.837	320 cm	350	281	Diaminotrinitrobenzene
	DATB (MDF)	M		15.5 gr/ft (4.95 wt% explosive)							256	Sheath melts
Igniter	Black Powder	S	647	271				1.92	32 cm	328	120	Sulfur melts
	ALCLO	AL	1925	110				2.35	96 cm	~ 590	295	64% KClO ₄ /35% Al/1% Stearate (KClO ₄ melts)

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TABLE II (cont.)

Material		Capsule Letter	Heat of Explosion cal/g	Gas Volume from Explosion ml/g	Molecular wt	Burn Rate ¹⁸ at 1000 psi in./sec	Density at which Det Vel Measured	Cast Density (gm/cc)	Impact Sensitivity 50% Height	Decomposition Temp, °C	Melting Point °C	Remarks
Type	Name											
Propellant	AK-14	E	967	723	--	0.83		1.89	38 cm	485	295	74% KClO ₄ /25% Styrene-polyester/ 1% carbon black
	IB 7158	Q	618	477	--	no ignition		1.43	> 320 cm	340	277	75% DATB/25% Polystyrene-butadiene
	PPLA 3223	G	659	542	--	0.045		1.44	> 320 cm	353	273	75% DATB/25% Viton A
	IB 7169	C	687	627	--	0.82		1.71	~ 38 cm	486	295	75% KClO ₄ /22% Polystyrene unmodified/3% dioctyl phthalate
	HES 6573	Z	1022	210	--	0.79		1.93	~ 38 cm	352	290	84% KClO ₄ /15% Hycar 4021 (ethylacrylate-chlorovinyl ether)/ 1% Trimene Base

KDNBF

ABH

azobis (2, 2¹, 4, 4¹, 6, 6¹ hexanitrobiphenyl)

HNAB

2, 2¹, 4, 4¹, 6, 6¹ hexanitro azo benzene

HNDS

hexanitro diphenyl sulfone

Figure 2

Structural Formulas of Explosives (U)

NONA

2, 2', 2'', 4, 4', 4'', 6, 6', 6'' nonanitro terphenyl

HNS

2, 2', 4, 4', 6, 6' hexanitro stilbene

DATB

1, 3 diamino, 2, 4, 6, trinitro benzene

TATB

1, 3, 5, triamino, 2, 4, 6, trinitro benzene

Lead Styphnate

Figure 2, Continued
Structural Formulas of Explosives (U)

Figure 3

Non-Instrumented Capsule Assembly

Figure 4
Instrumented Capsule Assembly

deflagration, and an aluminum tube (containing the thermocouple wires) connecting the capsule to a pressure transducer and temperature recorder.

A total of 53 capsules were irradiated during this phase, 16 of which were instrumented. The first irradiation was performed July 13, 1965 on an instrumented capsule loaded with charcoal to check the design and operation of the capsules. In general, the capsule design and procedure were satisfactory. It was found that the tubing attached to the capsule could be coiled and loaded into the transfer cask; therefore, the operation of cutting the tubing at the GETR and the glove box were eliminated. The ice bath was replaced with a constant-temperature oven to increase the accuracy of measurement. The recorder input impedance was decreased to provide faster response, and a continuous two-pen Leeds and Northrup recorder replaced the Brown two-point printing millivolt recorder.

During irradiation of the AGY-10 (lead styphnate) capsule, the explosive deflagrated. The instrumented capsule completely contained the explosion. Temperature increased rapidly to 214°C and pressure at the transducer gradually increased to 50 psig. The vent valve was then manually opened to the evacuated tank and the pressure reduced to zero. The radioactivity of the tank and lines was about four mr/hr after venting: most of the radioactive material was confined in the capsule. When the capsule was opened, the blast cap and tube were found to have deformed to the extent that it is believed the explosive detonated. Photographs of the capsule after sectioning at the base of the blast cup are shown in Figure 5.

C. RADIATION ENVIRONMENT

The radiation environment which the large-diameter NERVA explosive destruct system is expected to experience is shown in Figure 1. These flux values are only approximate and depend on final system design and location. The basic philosophy of the Countermeasures Radiation Effects Program has been to determine maximum radiation tolerances of the materials tested rather than their performance after exposure to anticipated flux dosage.

BODY

RETAINER DISC

BLAST CUP IN TOP

Figure 5

Sectioned AGY-10 Capsule after Detonation in Reactor (U)

Test samples were loaded into 7075-T6 aluminum capsules similar to those used in previous testing. These were exposed to the radiation environment produced in the Z Trail Cable Facility of the General Electric Test Reactor in Pleasanton, California. The average flux rates to which the samples were exposed were: 3.85×10^8 R/Hr, or 3.38×10^{10} ergs/gm(C)/Hr gamma flux; 7.46×10^{12} n/cm²/sec fast neutron flux (above 1.0 Mev); and 8.32×10^{13} n/cm²/sec thermal neutron flux. Flux data for individual samples will be included in the GE report for Phase IC.

Gamma flux values ranged from 3.6 to 4.2×10^8 R/Hr during the Phase IB gamma traverses, depending upon the rod-bank position⁶. Since the uncertainty in the measurements was $\pm 15\%$, it was possible to calculate the gamma flux for Phase IC from the rod-bank position without making any additional traverses.

Integrated neutron doses for each material were obtained from flux wires imbedded in the samples. Nickel wires were used to measure the fast neutron dose using the $\text{Ni}^{58}(\text{n},\text{p})\text{C}_\text{o}^{58}$ reaction.¹⁴ These measurements were accurate to $\pm 15\%$ at the 95% confidence level. The fast neutron flux measurements ranged from 6.6 to 8.3×10^{12} n/cm²/sec ($E > 1.0$ Mev) in the samples irradiated. Thermal neutron dose was measured with an aluminum cobalt alloy wire by the $\text{Co}^{59}(\text{n})\text{Co}^{60}$ reaction to an accuracy of $\pm 10\%$. Measured fluxes ranged from 7.6 to 9.0×10^{13} n/cm²/sec in the Phase IC samples. These relatively small ranges of neutron flux rates attest to the accuracy of controls on irradiation conditions.

To convert the neutron flux to other energy thresholds, the following factors may be used: the intermediate flux (0.17 ev to 0.18 Mev) is 2.66 times the 1.0 Mev value; the fast flux above 0.18 Mev is 1.81 times the fast flux greater than 1.0 Mev.

Details of the GE test reactor and the methods of flux measurement have been given in previous reports on this program^{3, 6}.

D. WEIGHT-LOSS MEASUREMENTS

The weight-loss data from this phase, combined with the Phase IB data obtained at lower dose rates, are plotted in Figures 6, 7, 8, 9, 10, and 11. Each type of material is plotted on a separate graph for clarity: i.e., primary explosives, booster explosives, MDF, main charge explosives, igniters, and propellants. From these data, changes in density and gas release can be determined for any particular exposure, and changes in detonation velocity and blast effect can be predicted. To permit easier comparisons, the exposures required to produce approximately 5% weight loss were determined, and the materials listed in order of decreasing radiation stability in Table III.

The following conclusions can be made on the basis of the data shown in Figures 6 through 11 and Table III:

1. Primary Explosives

The most stable primary explosive is KDNBF. Lead styphnate is unacceptable in the high radiation environments anticipated for NERVA since the sample in the AGY-10 capsule exploded after two minutes of exposure to the GETR flux, and the AGY-5 sample exploded following the pulse of radiation in Phase ID. Lead styphnate's radiation susceptibility is probably due to the large absorption cross-section of the lead atoms in the molecule which leads to rapid heating as well as radiolytic decomposition.

2. Booster Explosives

The most stable booster explosive is ABH. The stabilities of HNAB, HNS and NONA were about the same, a little more than half that of ABH. HNDS is not recommended for further study since better materials are available. However, until a radiation-stable detonator is developed from ABH, HNAB and NONA continue to be of interest for this purpose, and HNS may be useful in booster pellets.

TABLE III

5% WEIGHT LOSS EXPOSURE LIMITS (u)

Materials in Order of Radiation Stability

Exposure to Produce

5% Weight Loss

Type	Material	Symbol	Reason for Evaluation	Gamma	Fast Neutrons	Supplier of Material
				10^{10} ergs/gm(c)	>1 Mev 10^{16} n/cm ²	
Primary Explosives	KDNBF	K	Best primary from Phase I	10.2	8.1	Picatinny
	Lead Styphnate	Y	Best primary from literature ¹⁶	0.1	0.1	Aerojet
Booster Explosives	ABH	AB	High temperature stability	15.0	11.9	NOL
	HNAB	N	Useful in EBW Detonator	13.4	10.2	Sandia
	HNS	V	Best booster from Phase IB	12.0	9.5	Picatinny
	NONA	J	Useful in EBW Detonator	10.8	8.6	NOL
	HNDS	B	Useful in EBW Detonator	4.6	3.7	Sandia
Main Charge Explosives	TATB	H	Second best explosive from Phase IB	27.0	21.4	Picatinny
	NASA-1	A	Highest temperature stability	25.7	20.4	NASA
	DATB	W	Best explosive from Phase IB	20.6	16.4	Picatinny
Igniters	Black Powder	S	Best igniter from Phase IB	33.0	26.2	Picatinny
	ALCLO	AL	High-temperature stability Good hot particle igniter	6.3	5.0	Aerojet
Propellants	IB7158 (DATB/ Polystyrene)	Q	Made from radiation stable materials	19.4	15.6	Picatinny
	PPLA3223 (DATB/Viton)	G	Higher temperature stability, easier ignition & higher impulse than IB 7158	8.1	6.4	Picatinny
	HES6573 (KClO ₄ /Acrylic)	Z	Commercially available, high temper- ature stability and impulse	5.9	4.7	Hercules ⁵
	AK-14 (KClO ₄ /Polyester- Styrene)	E	Best high-temperature propellant from Phase IB	5.5	4.4	Aerojet
	IB7169 (KClO ₄ / Polystyrene)	C	Highest temperature stability	4.9	3.9	Picatinny
Mild Detonating Fuze	NASA-1	T	Best MDF from Phase IB	12.2	9.7	NASA
	TATB	U	New sample	11.0	8.7	Picatinny
	DATB	M	Nearly as stable as NASA-1 in Phase IB	8.6	7.7	Picatinny
	HNS	I	New sample	2.0	1.6	Picatinny

Average flux: 3.38×10^{10} ergs/gm(c)/Hr gamma
 7.5×10^{12} n/cm²/sec (above 1.0 Mev)
 8.32×10^{13} n/cm²/sec thermal

Figure 6
Weight Loss of Primary Explosive (U)

Figure 7

Weight Loss of Booster Explosives (U)

Figure 8
Weight Loss of MDF (U)

Figure 9

Weight Loss of Main Charge Explosive (U)

Figure 10

Weight Loss of Igniters (U)

Figure 11
Weight Loss of Propellants (U)

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3. Main-Charge Explosives

The most stable main-charge explosives are TATB and NASA-1. The small difference in radiation exposure required to produce 5% weight loss is not significant: however, NASA-1 has a temperature stability about 25°C higher, and TATB has higher energy.

4. Igniters

The most stable igniter material is black powder. It was surprising that ALClO (an inorganic mixture of 35% aluminum and 64% potassium perchlorate with 1% of stearate lubricant) was not more stable. The low exposure limit for ALClO shows that $KClO_4$ is much less radiation stable than the KNO_3 oxidizer in black powder. Therefore, a more stable hot-particle igniter mix could probably be made from KNO_3 and aluminum. However, the location of the igniter in the rear of the projectile is not expected to require an igniter more stable than ALClO. It is anticipated that both ALClO and black powder will be used in the igniter since black powder is needed to ignite ALClO: in turn, ALClO is more effective than black powder for ignition of the radiation-stable propellants.

5. Propellants

The most radiation-stable propellant is IB7158 (75% DATB/ 25% Butadiene modified polystyrene). Due to the limited amount of data obtained on the propellants, only approximate exposure limits are shown in Table III. However, there is no question that IB7158 was better than the other propellants since its stability was more than double that of the others tested although additional development is required to optimize its composition. This should not affect its exposure limits appreciably because a surplus of all reactants is still present at the cut-off point. The low stability of $KClO_4$ limited the propellants containing it to less than two hours exposure. This also was the case with ALClO igniter mix.

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If black powder is to be used as a gun propellant, it must hold its shape though the melting point of the sulfur is exceeded. To investigate this, pellets of black powder pressed to 99% of maximum density were placed in the non-instrumented capsules. One pellet was broken during unloading of the AGS-8 capsule. Data on the remaining samples are shown in Table IV. Although the samples retained their shape very well, their density decreased appreciably: therefore, a change would probably occur in burning rate of large pellets. Since the temperature exceeded the melting point of sulfur (113°C), these pellets probably lost most of their strength while being irradiated. Therefore, black powder should be in the form of small-size graphited particles if it is to be used as a gun propellant.

6. Mild Detonating Fuze (MDF)

Although the stability (based on weight loss) of explosives in MDF form was reduced about 50%, their order of resistance was the same as that for pure explosives. The higher temperature reached by the explosive during irradiation (due to the absorption and secondary emission of radiant energy by the lead sheath) probably causes this. Strands were packed in coarse aluminum powder to help reduce the temperature by conduction and, as a result, no strands melted as they did in the Phase IB irradiations. In future work, use of aluminum-sheathed MDF should be investigated to reduce the heating problem.

The HNS sample lost 30% of its explosive weight, after only two hours of exposure time, and failed to detonate. After ten hours, the NASA-1 sample failed to detonate because 19% of its explosive was decomposed. The other samples detonated satisfactorily, although a weight loss of 12% produced marginal detonation of the DAIB-loaded MDF.

The percentage weight-loss of explosive in the MDF depends upon explosive loading and could not be measured directly for the MDF samples tested. A strand from the same length of MDF was sectioned and the average percent of explosives to total weight determined, as shown in Table V. These data were used in combination with the total weight loss to determine the percentage of explosive decomposed: thus, an error could be introduced by variations in loading density.

TABLE IV
EFFECTS OF IRRADIATION ON BLACK POWDER PELLETS (u)

Capsule No.	Pellet No.	Irradiation Time, hrs	Before Irradiation				After Irradiation					Remarks
			Length in.	Diam. in.	Weight gm	Density gm/cc	Length in.	Diam. in.	Weight gm	Density gm/cc	% Change in Density	
AGS-7	4	3	.393	.250	.6003	1.899	.417	.2605	.5957	1.638	13.7	Sharp corners, good appearance.
	5	3	.390	.250	.6004	1.918	.411	.2610	.5964	1.658	13.5	Sharp corners, good appearance.
AGS-8	7	5	.393	.250	.5985	1.896	.444	.268	.5939	1.450	23.6	Sharp corners, good appearance.
	8	5	.387	.250	.5996	1.920	-	-	-	-	-	Sample broken.

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TABLE V

Properties of MDF

Code No.	Explosive	Lot No.	MDF Properties			
			diameter, in.	wt.% explosive	grains expl./ft	Al Plate Dent, in.
AGT	NASA-1	15-HB	0.091	2.60	4.5	0.006
AGM-00	DATB	6801-2	0.125	4.95	15.5	0.014
AGM-0	DATB	1627	0.105	5.54	12.4	0.014
AGU	TATB	6802-2	0.125	4.27	13.5	0.014
AGI	HNS	6671-1	0.073	3.11	3.43	0.006

E. GAS-RELEASE MEASUREMENTS

Gas release from noninstrumented capsules was measured by determining the pressure in the capsules after irradiation had been completed. Data obtained on capsules (where both weight loss and gas volume were measured) were used to calculate the average gas volume per gram of material decomposed. These values were then used to calculate weight losses from the samples where weight loss could not be determined directly due to chipped ampules or the presence of thermocouples. The calculated weight losses, however, were less accurate and should only be used when these data were not obtained. Because of the small amount of explosive in the MDF samples, an accurate gas-pressure measurement and calculated weight loss could not be obtained on these capsules. Summaries of the measured gas volumes, volume of gas per gram of explosive converted to gas, and weight losses are shown in Table VI. Measured gas molecular weights are sensitive to errors in both gas volume and weight-loss measurements. Therefore, for the 13 samples where an accurate value was not obtained by measurements, an estimate based on the data from similar materials was used. A more accurate method would be to calculate this value from an analysis of the gas composition: however, the effort necessary to obtain this analysis could not be justified for this program.

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UNCLASSIFIED DATA—ALUMINUM CHLORIDE

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```
*Estimate
**Vial chipped, wt. loss high
#From strand, probably high
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34

TABLE VI (cont.)

Type	Sample No.	Material	Exposure Time, hr.	Gas Vol. at STP cc	cc gas/gm gas		Weight Loss, %		Average Gas Molecular Weight	Remarks
					Measured	Used in Calculations	Calculated from Gas	Measured		
Main Charge	AGA-7	NASA-1	3	20.35	-	711	1.60	-**	31.5	Gas vol. based on gas from explosion.
	AGA-8		4	28.24	877	711	2.18	1.78		
	AGA-10		8	90.18	-	711	7.00	-		
	AGH-7	TATB	4	17.44	-	785	1.24	-**	28.6	
	AGH-8		4	20.06	785	785	1.42	1.41		
	AGH-10		10	98.37	-	785	7.02	-		
	AGW-7	DATE	3	16.89	-	784	1.18	-**	28.6	
	AGW-8		5	49.05	752	784	3.45	3.60**		
	AGW-10		9.6	133.84	-	784	9.47	-		
	Propellants	AGC-7	IB-7169	2	86.75	-	627*	7.72	-**	
AGE-7		AK-14	2	89.77	-	726	6.80	8.54#	30.2	
AGE-8			1	34.52	751	726	2.61	2.50		
AGE-9			1	17.15	755	726	1.29	1.24		
AGG-7		PPIA 3223	2	13.07	190	600*	1.21	3.80	37.4	
AGG-8			1	10.89	350	600*	1.08	1.70		
AGG-9			1	16.85	346	600*	1.52	2.64		
AGG-10			3.6	75.42	-	600*	6.9	8.27#		
AGQ-7		IB 7158	2	12.79	580	580	1.06	1.06	38.6	
AGQ-8			1	7.05	-	580	0.64	0.880#		
AGQ-9			1	5.32	-	580	0.52	0.962#		
AGQ-10			10.1	63.98	-	580	5.62	13.1#		
AGZ-7		HES 6573	2	106.33	-	600*	6.01	-**		

Average Exposure rates were: 3.38×10^{10} ergs/gm(c)/Hr gamma
 7.5×10^{12} n/cm²/sec Faster neutrons (>1.0 Mev)
 8.32×10^{13} n/cm²/sec thermal neutrons

*Estimate
**Vial chipped, wt. loss high
#From strand, probably high

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The main types of gases expected to be produced are shown in Table VII. Observed molecular weights ranged from 27 to 37 for the materials which contained only carbon, hydrogen, nitrogen, and oxygen, which is in agreement with the expected gas compositions. Gas from propellants was higher in molecular weight (30 to 39) due to the presence of chlorine and HCl in the gases. The gas from black powder was high in molecular weight (51.7) due to the presence of SO₂. Although sulfur was also present, gas from dipicryl sulfone was lower in molecular weight (34.8), possibly due to its lower sulfur content, the higher radiation stability of the sulfone group, or an error in measurement.

1. Instrumented Capsule Results

The instrumented capsules permitted continuous monitoring of the temperature and rate of decomposition of the materials during irradiation. A typical record is shown in Figure 12, and a summary of the data obtained is given in Table VIII. The method of calibration of the pressure measurement is described in Appendix A. Detailed gas release data are presented in Appendix B.

Two capsules containing AGN (HNAB) explosive were used, thus providing an opportunity to check the reproducibility of the measurement system. The higher temperatures in the AGN-11 capsule are believed to be due to higher density of explosive packing which increased its volume rate of heat input. X-rays showed the AGN-11 explosive column was 1/4-in. shorter than AGN-10, confirming that the latter was of a higher density. The higher temperature, in turn, caused a higher rate of decomposition (1.34%/hr vs 1.26%/hr). A similar result was obtained by LASL¹³ where tests were made at -80°F and +100°F. The x-rays also showed that the AGN-11 thermocouple was touching the quartz tube while the AGN-10 thermocouple was centered. Since heat was flowing from the explosive out through the walls, the rate of temperature rise would be expected to be higher in the center as recorded (10°C/hr in center of AGN-10 vs 7°C/hr at edge of AGN-11). The higher density of the AGN-11 sample would also increase its thermal conductivity, thus tending to decrease its heat buildup rate. For these reasons, the rate of heat buildup and final temperatures must not be used for precise comparison.

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TABLE VII

MAJOR RADIOLYTIC GAS COMPONENTS¹³

<u>Gas</u>	<u>Molecular Weight</u>	<u>Remarks</u>
H ₂	2	
N ₂	28	Major component
N ₂ O	44	
NO	30	
CO	28	Major component
CO ₂	44	
SO ₂	64	Present only in gases from black powder and dipicryl sulfone
Cl ₂	70	} In gases from propellants
HCl	36	
HF	20	

The initial temperatures in Table VIII were obtained by straight line extrapolation of the temperature record to "zero time." For relatively non-reactive materials, this temperature was between 102° and 106°C. The low temperature for AGAL-10 can be explained by higher thermal conductivity due to aluminum content. The higher initial temperatures of the propellants and ABH are probably due to higher density or lower thermal conductivity since their rates of decomposition were not high. The high initial temperatures of KDNBF and lead styphnate, on the other hand, are probably due to higher rates of decomposition.

Although the rate of temperature increase was less at high temperatures (because of the increasing efficiency of heat removal) it provides a rough indication of relative stability - the least stable materials having the highest heat buildup rates. A more meaningful measurement is the rate of decomposition as measured by gas pressure buildup. The data show approximately a linear relationship of decomposition with integrated dosage, the effect of rising temperature

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TABLE VIII
INSTRUMENTED CAPSULE GAS RELEASE DATA SUMMARY (u)

Type	Material	Capsule	Irradiation Time, hrs.	Initial Temperature °C	Final Temperature °C	Average Rate of Temp. Rise °C/hr.	Final Pressure psi (1)	Average Rate of Decomposition wt%/hr.	Total Decomposition wt% (2)
Primary Explosives	KDNBF	AGK-10	3	127	174	15.7	12.1	4.0	4.60
	Lead	AGY-10	(2 min)	214+	204	642 (5) (3)	50+	-	-
	Styphnate								
Booster Explosives	ABH	AGAB-10	6	146	183	6.2	11.1	0.96	5.78
	HNAB	AGN-10	3	87	115	10.0	9.3	1.26	3.77
		AGN-11	5.4	102	140	7.0	18.4	1.34	7.27
	HNS	AGV-10	4	104	140	9.0	13.7	1.43	5.71
	NONA	AGJ-10	4	103	167	16.0	-	1.68 (6)	6.72 (6)
	HNS	AGB-10	3.1	102	160	18.7	21.0	3.6	11.2
Main Charge Explosives	TATB	AGH-10	10	115	163	4.8	15.9	0.66	6.64
	NASA-1	AGA-10	10	104	133	2.9	14.6	0.66	6.58
	DATB	AGW-10	9.5	104	150	4.8	19.7	0.84	7.97
Igniter	Black Powder	AGS-10	10.3	106	121	1.5	7.5	0.54	5.52
	ALCIO	AGAL-10	1.1	93	94	1.0	2.9	0.96	1.05
Propellants	IB7158 (DATE/PS)	AGQ-10	10	134	153 (4)	1.9	10.8	0.64	6.44
	PPLA3223 DATE/Viton	AGG-10	3.5	144	151	2.1	12.6	1.93	6.76

- (1) After capsule was cooled to reactor pool temperature of 39°C.
 (2) Based on gas volume.
 (3) Initial temperature rise, other samples report equilibrium rate.
 (4) Peak temperature reached 165°C, then reactor power change reduced it.
 (5) Sample deflagrated.
 (6) Based on noninstrumented capsules.

Figure 12

AGC-10 Capsule Pressure and Temperature Record (U)

being of only minor importance. For example, in the ABH sample, the high final temperature of 183°C and the high rate of temperature rise of 6°C/min are of less significance than the low rate of weight loss of 0.96%/hr at these high temperatures.

F. THERMAL STABILITY

Because of the high rate of gamma heating anticipated in the large-diameter NERVA engine destruct system, one of the objects of this program is to evaluate high temperature-stable materials. Assuming a typical gun and projectile design is used (as shown in Figure 1), the peak heating rate will occur in the main-charge explosive at the nose of the projectile. The heating rate at the rear of the projectile (where a base-detonating fuse and the hottest portion of the propellant are located) is about one-third of the peak rate, and at the rear of the gun about one-seventh. Therefore, the thermal stability of the main charge will determine the temperature limit for the entire system if no cooling is provided. However, since some cooling may be used, or the predicted flux profile may change, high-temperature stability is desirable for all components of the destruct system. Fortunately, most radiation-stable materials are also thermally stable. Because no single test adequately determines the thermal stability of propellants and explosives, five different tests were made. These were: (1) explosion temperature; (2) differential thermal analysis (DTA); (3) melting point; (4) thermogravimetric analysis (TGA); and (5) vacuum stability (VTS). Results of these tests are shown in Tables IX through XI.

The procedures used in making these tests have been described in detail in the test specifications (references 4, 7, and 8). Therefore, only a brief description of each is given in the following discussion.

1. Differential Thermal Analysis (DTA) and Melting Point

The differential thermal-analysis test heats a small 10-mg sample at a constant rate (20° C/min) and compares its temperature with a nonreactive control sample. This approximates the type of heating that will be produced by

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gamma and neutron heating in the large-diameter NERVA destruct system. Melting and decomposition temperatures can be determined by this method, since any reaction that evolves or absorbs heat is detected. The peak exotherm temperatures for each sample are recorded in Table IX. In the destruct system, once decomposition begins, temperatures would build up faster than they do in the DTA, since the heat generated is not continuously removed as it is in the DTA. Therefore, the highest "safe" temperatures will be less than the DTA peak temperatures. However, these values provide a useful comparison of relative thermal stabilities. The plots of DTA exotherm temperature-vs-exposure and integrated dosages are shown in Figures 13 through 15. Materials whose temperature stability is limited by melting are indicated on these plots.

The melting point test as performed by observation of a sample heated in a capillary tube is not as accurate as the DTA endotherm; however, it serves as a check on the DTA for materials which exhibit a small melting range. These include HNS, HNAB, DATB and lead styphnate. For mixtures where only one component melts (including black powder, ALClO, and the propellants) the DTA endotherm is the only way to obtain accurate melting point information. In most cases, the upper temperature limit of these materials is determined by their melting points rather than by their decomposition temperatures, since the change in volume and lack of strength upon melting would severely change design parameters. As indicated by Figure 13, lead styphnate has a high initial exotherm temperature, but its temperature is limited by melting point to less than 214°C , and it was ignited by the high flux rates used in this program. Therefore, KDNBF is the best primary explosive of those tested. Although its thermal stability is lower than most other materials, it should be possible to use it in detonators and igniters in locations where the temperature is below 150°C .

Referring again to Figure 13, NONA is the booster explosive with the highest temperature stability. ABH is similar to NONA, but about 20°C lower in temperature while HNS and HNAB are limited by their melting points to 315°C and 215°C , respectively. Dipicryl.sulfone (DPS) was damaged severely by the radiation: its temperature limit dropped lower than any of the other boosters and is of no further interest.

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TABLE IX
DIFFERENTIAL THERMAL ANALYSIS, THERMOGRAVIMETRIC ANALYSIS, AND MELTING POINT DATA (u)

Material	Code No.	Date	Time	Time Since End of Irradiation hr	Heating Rate °C/min	Endotherm °C	Exotherms				Melting Point °C	10% wt. Loss on TGA, °C	Remarks
							No. 1		No. 2				
							Start °C	Peak °C	Start °C	Peak °C			
KDNBF	AGK-0	8/5/65	-	-	20	-	193	211	-	-	209	210	
	AGK-7	8/17/65	1600	~ 91	20	-	185	198	-	-	194	188	
	AGK-8	8/18/65	1600	~ 112	20	-	165	188	-	-	182	188	
	AGK-10	8/17/65	1600	~ 118	50	-	155	182	-	-	173	175	
Lead Styphnate	AGY-0	1/14/65	-	-	20	214	235	287	-	-	214	-	
	AGY-10	-	-	-	-	-	-	-	-	-	-	-	Sample burned in reactor
DPS (HNDS)	AGB-0	8/5/65	-	-	20	-	290	343	344	348	322**	288	No MP on DTA
	AGB-7	8/9/65	1445	39	20	-	215	281	290	297	> 350**	175	No MP on DTA
	AGB-10	8/5/65	1510	26	20	-	200	230	285	307	201**	200	No MP on DTA
HNAB	AGN-0	8/5/65	-	-	20	215	300	352	367	370	221	341	
	AGN-7	8/17/65	1600	36	20	205	280	353	360	365	207	272	
	AGN-10	8/13/65	1700	18	20	196	290	353	362	375	205	311	
	AGN-11	9/15/65	1735	26	20	186	328	340	360	373	185	252	
HNS	AGV-0	10/13/64	-	-	20	315	315	343	347	352	313	317	
	AGV-7	8/6/65	1825	14	20	301	307	341	-	-	301#	276	# From DTA
	AGV-8	8/5/65	1605	11	20	100*	298	335	-	-	260**	232	Water contamination
	AGV-10	8/5/65	1430	44	20	-	293	330	-	-	255**	250	Water contamination
NONA	AGJ-00	9/13/65	-	-	20	210	355	397*	-	-	360+**	316	*Deflagrated
	AGJ-7	1/5/66	-	-	20	-	305	369	-	-	-	248	
	AGJ-10	9/14/65	1445	35	20	-	310	360*	-	-	360+**	271	*Deflagrated
ABH	AGAB-0	9/13/65	-	-	20	-	-	-	330	375	339**	361	
	AGAB-7	9/15/65	1806	16	20	-	-	-	260	343*	360+**	259	*Deflagrated
	AGAB-10	9/14/65	1527	22	20	-	250	313	328	345	360+**	275	

** No MP before decomposition on DTA

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TABLE IX (cont.)

DIFFERENTIAL THERMAL ANALYSIS, THERMOGRAVIMETRIC ANALYSIS, AND MELTING POINT DATA (u)

Material	Code No.	Date	Time	Time Since End of Irradiation hr	Heating Rate °C/min	Endotherm °C	Exotherms				Melting Point °C	10% wt, Loss on TGA, °C	Remarks
							No. 1		No. 2				
							Start °C	Peak °C	Start °C	Peak °C			
NASA-1	AGA-0	10/8/64	-	-	20	-	-	-	380	398*	360+**	409	*Deflagrated
	AGA-7	8/16/65	1600	75	20	-	264	268	368	389*	360+**	371	*Deflagrated
	AGA-8	8/9/65	1120	17	20	-	315	333	352	388*	360+**	356	*Deflagrated
	AGA-10	8/9/65	1105	45	20	-	-	-	285	366	360+**	275	
TATB	AGH-0	10/10/64	-	-	20	-	335	388*	-	-	360+**	359	*Deflagrated
	AGH-7	8/16/65	1600	15	20	273	294	358	-	-	350+**	263	
	AGH-8	8/13/65	1725	11	20	283	285	361	-	-	350+**	283	
	AGH-10	8/12/65	1145	10	20	277	300	348	-	-	350+**	247	
DATB	AGW-00	1/13/65	-	-	20	279	300	354	-	-	285	287	Polymorph @ 221
	AGW-7	8/9/65	~ 1600	~ 15	20	274	285	353*	-	-	278	255	*Deflagrate
	AGW-8	8/9/65	1305	40	20	274	302	345*	-	-	258	260	*Deflagrate
	AGW-10	8/6/65	1535	19	20	270	375	348*	-	-	322	248	*Deflagrate
Black Powder	AGS-0	7/15/65	-	0	20	128	295	328	350	415	128#	282	#Sulphur MP from DTA
	AGS-7	9/14/65	1405	178	20	115	285	324	355	417	115#	304	#Sulphur MP from DTA Sholder at 316°C
	AGS-8	8/18/65	1600	~ 117	20	117	287	308	360	410	117#	165	#Sulphur MP from DTA
	AGS-10	8/9/65	1240	118	20	113	230	306	358	392	113#	226	#Sulphur MP from DTA Sholder at 253
ALCLO	AGAL-0	9/13/65	-	-	20	295	440	457	-	-	360+	500+	
	AGAL-7	1/4/66	-	-	20	315	490	490	-	-	-	500+	
	AGAL-10	9/15/65	1825	42	20	303	465	490	-	-	360+	No Data	
IB7169	AGC-0	7/15/65	-	-	20	292	425	435	> 485		292#	397	#From DTA
	AGC-7	8/6/65	1445	87	20	310	315	355	425	470	310#	351	#From DTA

** No MP before decomposition on DTA

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CONFIDENTIAL

43

TABLE IX (cont.)
DIFFERENTIAL THERMAL ANALYSIS, THERMOGRAVIMETRIC ANALYSIS, AND MELTING POINT DATA (u)

Material	Code No.	Date	Time	Time Since End of Irradiation hr	Heating Rate °C/min	Endotherm °C	Exotherms				Melting Point °C	10% wt, Loss on TGA, °C	Remarks
							No. 1	No. 2	No. 3	No. 4			
AK14	AGE-0	7/15/65	-	-	20	298	350	387	420	495	298#	368	#From DTA
	AGE-7	8/1/65	1940	89	20	302	400	435	-	475	> 288	307	
	AGE-8	8/13/65	~1600	~ 30	20	305	405	375	425	490	305#	311	#From DTA
	AGE-9	1/5/66	-	-	20	298	340	365	425	490	298#	307	#From DTA
PPIA3223	AGG-0	7/14/65	-	-	20	278	290	353	-	-	278#	290	#From DTA Polymorph @ 218°
	AGG-7	8/9/65	~1600	~ 31	20	273	290	343	-	-	273#	237	#From DTA
	AGG-8	8/13/65	~1600	8	20	273	285	351	-	-	273#	271	#From DTA Polymorph @ 232°
	AGG-9	1/5/66	-	-	20	274	282	350	-	-	274#	256	#From DTA Polymorph @ 232°
	AGG-10	9/15/65	1910	21	20	270	277	333	-	-	270#	333	#From DTA Polymorph @ 245
	AGQ-0	7/14/65	-	-	20	277	297	340	-	-	277#	340	#From DTA Polymorph @ 223
IB7158	AGQ-7	8/9/65	1600	27	20	273	297	335	-	-	273#	335	#From DTA
	AGQ-8	8/13/65	1600	27	20	278	295	345	-	-	278#	345	#From DTA Polymorph @ 243
	AGQ-9	1/5/66	-	-	20	275	290	344	-	-	275*	272	
	AGQ-10	9/16/65	1600	~ 19	20	265	268	318	-	-	265#	318	#From DTA
	AGZ-0	7/14/65	-	-	20	293	315	352	370	465	293#	352	#From DTA
HES6573	AGZ-7	8/6/65	1910	109	20	302	190	230	370	400	302#	400	#From DTA
	AGI-0	6/2/65	-	-	10	262	-	-	328	360	-	-	-
HNS-MDF	AGI-7	9/14/65	-	-	20	245	270	298	335	360	-	-	-
	AGT-0	6/2/65	-	-	10	252, 262	410	431	-	-	-	-	-
DATB-MDF	AGM-0	6/2/65	-	-	10	258, 292	300	390	-	-	-	-	-
TATB-MDF	AGV-0	6/2/65	-	-	10	264, 300	350	427	-	-	-	-	-

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Figure 13

DTA Peak vs Exposure of Primary and Booster Explosives (U)

Figure 14
DTA Peak vs Exposure of Main Charge Explosives (U)

Figure 15

DTA Peak vs Exposure of Propellants and Igniters (U)

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From the DTA data on main charge explosives as noted (Figure 14), it can be seen that all the materials tested showed excellent stability. NASA-1 had the highest temperature stability, and TATB was only 10-25°C lower. The temperature limit of DATB is 270°C, its melting point.

Propellants and igniter DTA data are presented in Figure 15. Although many DTA exotherms were higher, the thermal stability of all these materials will probably be limited by the melting points of their oxidizers to below 270°C. Three propellants (AK-14, DATB/Viton, and DATB/Polystyrene) were irradiated for one hour and tested within a few days and again in four months to determine the effects of aging. These were the AGE-8 and -9, AGG-8 and -9, and AGQ-8 and -9 samples, respectively. No significant changes in DTA-analysis final peak-temperatures, occurred (i.e., temperatures agreed within 1°C).

The MDF samples were used for detonation velocity tests after irradiation: thus, the only post-irradiation thermal test was the DTA analysis on AGI-7 (HNS) after it failed to detonate. The DTA analyses shown in Figures 16 through 19 were made on pulverized samples prior to irradiation. These show that the lead melted in the range of 252° to 256°C without decreasing the explosive stability limit. The higher explosive decomposition temperatures compared to pure explosives are believed to be due to the dilution of the samples with the large amount of lead from the sheath.

The HNS-loaded MDF sample AGI-7 and the NASA-1 loaded sample AGI-8 were so severely damaged that they could not be detonated with a No. 6 blasting cap. The MDF was split and peeled back about 1.50-in. on the end near the blasting cap. Some of the explosive was scraped out of one of the remaining strands of AGI-7 and the DTA analysis shown in Figure 20 obtained. The melting point of the lead was about the same (i.e., 245° vs 256°C). This 11°C difference is believed to be due to the use of different DTA apparatus. The first exotherm peak was reduced from 360° to 298°C due to contamination of the sample with less stable products of irradiation-produced decomposition. Since there was still an exothermic reaction, it can be concluded that some undecomposed explosive was left though it failed to detonate. In Phase I-C irradiations, the MDF was packed in coarse aluminum powder

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MATERIAL = HNS/LEAD

DATE TESTED = 2 JUNE 65

$\Delta T = 12.5^{\circ}\text{C}/\text{IN}$

HEATING RATE = $8\text{-}10^{\circ}\text{C}/\text{MIN}$

$T_S = 15.5^{\circ}\text{C}$

Figure 16

DTA Analysis of HNS Loaded MDF (CRD)
(Prior to Irradiation)

Figure 17

DTA Analysis of NASA-1 Loaded MDF (CRD)
(Prior to Irradiation)

Figure 18

DTA Analysis of DATB Loaded MDF (CRD)
(Prior to Irradiation)

Figure 19
DTA Analysis of TATB Loaded MDF (CRD)
(Prior to Irradiation)

MATERIAL = HNS/LEAD

DATE TESTED = 14 SEPT 65

$\Delta T = 2.0^\circ\text{C}/\text{IN}$

HEATING RATE = $20^\circ\text{C}/\text{MIN}$

$T_S = 40^\circ\text{C}$

Figure 20

DTA Analysis of HNS Loaded MDF (U)
of Sample AGI-7 Following Irradiation

to increase conduction of the heat to the cooling water. This was successful in preventing any melting of the lead sheaths, but the temperature of the explosives in this configuration were undoubtedly higher than they were in the pure explosives (i.e., 180 to 240°C).

A DTA analysis was made on a 50/50 mixture of titanium powder and DATB to check compatibility with the proposed shell casing. The thermogram of this test is shown in Figure 21. No significant change from the pure DATB was detected: therefore, these materials appear to be compatible. Since this confirmed the results of the vacuum stability tests made at Picatinny Arsenal (which show that titanium is compatible with the candidate explosives), no further DTA tests were made on titanium mixtures.

2. Thermogravimetric Analysis (TGA)

The thermogravimetric analysis test is similar to the DTA in that it heats a small sample at a constant rate. Weight loss (instead of temperature difference) is measured as a function of temperature. This detects decomposition which results in gaseous products, and provides a quantitative measure of the amount and rate of decomposition at each temperature. To provide a basis for comparison with the other test results, the temperatures at which 10% weight loss occurred are recorded in Table IX. Samples containing DATB lost an excessive amount of weight because DATB sublimes before decomposition.

In addition to the relative thermal stability obtained from the 10% weight-loss temperature, an estimate of the activation energy, E, may be obtained by using the method developed by Horowitz and Metzger.¹⁷ Assuming all products are gaseous, they derived the following expression:

$$\ln \ln W_0/W = E\theta / RT_s^2,$$

Figure 21

DATB/Ti DTA Compatibility Test (CRD)

where:

W_0 = grams of reactant at initial time,
 W = grams of reactant at any time,
 E = energy of activation, cal/mol,
 R = gas constant = 1.9869 cal/mol °C,
 T_s = reference temperature at which $W/W_0 = 1/e = 0.368$
(read this value from the plot of $\ln \ln W/W_0$ vs T),
and $\Theta = (T - T_s)$ where T is the temperature corresponding
to W grams.

Activation energies may be determined by this method for use in predicting thermal stability of explosives in projectiles when their final shape and location are determined.

3. Explosion Temperature

In the explosion temperature test, a confined 40 mg sample is heated quickly by immersion in a molten metal bath. The time to explosion at a series of different temperatures is measured, and the results plotted to permit interpolation of the temperature which would cause an explosion in five seconds. A typical set of data are shown in Figure 22 and results are summarized in Table X. The slope of the line in Figure 22 provides an approximation of the activation energy and indicates that the activation energy was decreased by exposure to radiation. Samples which melt before reaching their explosion temperature (e.g., DATB) have misleadingly high explosion temperatures because the melting removes heat and delays the temperature buildup rate. For example, DATB has a higher explosion temperature than TATB, although the latter has a higher thermal stability when measured by slower heating-rate tests such as the DTA. The explosives whose melting caused high explosion temperatures are marked (*) in Table X.

The effect of decay time on explosion temperature was checked on the AGA 7 sample by re-firing one test 24 days after initial testing. Results of the eleven firings made four days after irradiation completion, and the last one 28 days after irradiation, are plotted in Figure 22. More data showing negligible changes in the results over two-day periods were obtained on samples AGK-7 and AGK-10.

TABLE X

EXPLOSION TEMPERATURE TEST DATA (u)

Material	Code No.	Date	Ending Time	Irradiation		Explosion Temperature Test				Change from Standard	
				Date	Time	Time from end of Irradiation hr	Approx. First Fire °C	5 Sec Explosion Temp. °C		°C	%
KDNEF	AGK-0	8/6/65	1122	-	-	-	190	194	-	-	-
	AGK-7	8/17/65	1723	8/13/65	2030	93	165	185	9	- 4.6	-
	AGK-8	8/18/65	1533	8/13/65	2345	112	150	170	24	-12.4	-
	AGK-10	8/17/65	1817	8/12/65	1751	120	140	169	25	-12.9	-
Lead Styphnate	AGY-0	1/13/65	2251	-	-	-	214	299*	-	-	-
	AGY-10	-	-	8/12/65	1404	Sample Burned in Reactor		-	-	-	-
DPS	AGB-0	8/5/65	2045	-	-	-	330	387	-	-	-
	AGB-7	8/9/65	1741	8/7/65	2345	42	151	181	206	-53.2	-
	AGB-10	8/5/65	1834	8/4/65	1336	29	143	177	210	-54.3	-
HNAB	AGN-0	8/5/65	2046	-	-	-	340	373*	-	-	-
	AGN-7	8/17/65	2020	8/16/65	0422	40	330	363*	10	- 2.7	-
	AGN-10	8/13/65	1718	8/12/65	2345	17	278	329*	44	-13.4	-
	AGN-11	9/16/65	1525	9/14/65	1555	47	266	306*	67	-17.9	-

*Explosion temperature is high due to melting of explosive.

TABLE X (cont.)
EXPLOSION TEMPERATURE TEST DATA (u)

Material	Code No.	Date	Ending Time	Irradiation		Time from end of Irradiation hr	Explosion Temperature Test			Change from Standard	
				Date	Time		Approx. First Fire °C	5 Sec Explosion Temp. °C		°C	%
HNS	AGV-0	8/2/65	1448	-	-	-	325	385*	-	-	
	AGV-7	8/6/65	1931	8/6/65	0452	15	265	307	78	-20.3	
	AGV-8	8/5/65	2009	8/5/65	0439	15	220	251	134	-34.8	
	AGV-10	8/5/65	1958	8/3/65	1812	50	205	256	129	-33.6	
NONA	AGJ-00	9/5/65	1911	-	-	-	384	436	-	-	
	AGJ-7	1/5/66	1548	9/17/65	0841		200	231	-	-	
	AGJ-10	9/14/65	1459	9/13/65	0320	36	240	279	157	-35.9	
ABH	AGAB-0	9/13/65	1522	-	-	-	325	385	-	-	
	AGAB-7	9/16/65	1511	9/15/65	0220	37	257	293	92	-23.8	
	AGAB-10	9/14/65	1709	9/13/65	1724	24	196	247	138	-35.9	
NASA I	AGA-0	9/26/64	1551	-	-	-	360	417	-	-	
	AGA-7	8/17/65	2031	8/13/65	1240	104	335	379	38	-9.1	
	AGA-8	8/9/65	1958	8/8/65	1815	26	290	352	65	-15.6	
	AGA-10	8/9/65	1924	8/7/65	1430	53	214	247	170	-40.7	
TATB	AGH-0	9/26/64	1409	-	-	-	350	392	-	-	
	AGH-7	8/17/65	2013	8/16/65	0045	43	255	259	133	-33.9	
	AGH-8	8/13/65	1709	8/13/65	0650	10	275	255	137	-35.0	
	AGH-10	8/12/65	1335	8/12/65	0146	12	214	233	159	-40.6	

* Explosion temperature is high due to melting of explosive.

TABLE X (cont.)
EXPLOSION TEMPERATURE TEST DATA (u)

Material	Code No.	Date	Ending Time	Irradiation Date	Time	Explosion Temperature Test			Change from Standard	
						Time from end of Irradiation hr	Approx. First Fire °C	5 Sec Explosion Temp. °C	°C	%
DATB	AGW-0	9/26/64	1015	-	-	-	350	403*	-	-
	AGW-7	8/9/65	1959	8/9/65	0120	19	284	342*	61	-15.1
	AGW-8	8/9/65	1938	8/7/65	2112	46	262	301*	102	-25.0
	AGW-10	8/6/65	1910	8/5/65	2010	23	230	271*	132	-32.5
Black Powder	AGS-0	10/7/64	1435	-	-	-	285	324	-	-
	AGS-7	9/14/65	1510	9/7/65	0430	179	281	302	22	-6.8
	AGS-8	9/10/65	1711	8/13/65	1900	672	260	282	42	-13.0
	AGS-10	8/9/65	1939	8/5/65	0100	115	255	268	56	-17.3
ALCLO	AGAL-0	9/6/65	1028	-	-	-	None	588+	-	-
	AGAL-7	1/5/66	1816	9/15/65	1330	-	560	571	-	-
	AGAL-10	9/17/65	1125	9/13/65	0024	107	575	580+	-	-
IB7169	AGC-0	7/30/65	1726	-	-	-	550	593	-	-
	AGC-7	8/6/65	1955	8/2/65	2335	92	320	376	217	-36.6
AK-14	AGE-0	10/9/64	1721	-	-	-	325 - 429	406	-	-
	AGE-7	8/6/65	1930	8/3/65	0257	89	325	300	106	-26.1
	AGE-8	8/13/65	1233	8/12/65	1028	26	360	281	125	-30.8
	AGE-9	1/5/66	1540	9/13/65	0536	-	246	271	-	-

* Explosion temperature is high due to melting of explosive.

TABLE X (cont.)

EXPLOSION TEMPERATURE TEST DATA (u)

Material	Code No.	Date	Ending Time	Irradiation		Explosion Temperature Test			Change from Standard	
				Date	Time	Time from end of Irradiation hr	Approx. First Fire °C	5 Sec Explosion Temp. °C	°C	%
PPLA3223	AGG-0	7/30/65	1635	-	-	-	355	388	-	-
	AGG-7	8/10/65	1112	8/8/65	0916	50	320	366	22	-5.7
	AGC-8	8/13/65	1723	8/13/65	0800	9	320	377	11	-2.8
	AGC-9	1/5/66	1606	9/14/65	0323	-	300	367	-	-
	AGC-10	9/16/65	1524	9/14/65	2156	41	255	313	-	-
IB7158	AGQ-0	7/30/65	1113	-	-	-	353	387	-	-
	AGQ-7	8/10/65	1115	8/8/65	1239	47	318	378	9	-2.3
	AGQ-8	8/13/65	1250	8/12/65	1256	24	315	383	4	-1.0
	AGQ-9	1/15/66	1611	9/12/65	0535	-	305	352	-	-
	AGQ-10	9/16/65	1711	9/15/65	2038	21	243	284	103	-26.6
HES6573	AGZ-0	7/31/65	1141	-	-	-	356	408	-	-
	AGZ-7	8/6/65	1911	8/2/65	0558	109	245	260	148	-36.3

Figure 22

AGA-7 Explosion Temperature Data

4. Vacuum Stability

The vacuum stability test is a very sensitive measure of long term (two-hour) stability at one temperature. Based on Phase I-B results, a temperature of 200°C was chosen for Phase I-C tests as this was estimated to be close to the stability limit. Small amounts of impurities (such as those produced by radiation damage) reduce the vacuum stability limit: therefore, it is a sensitive detector of radiation damage. Because of the small amount of each sample available, only one test could be made at 200°C.

Results of the vacuum stability tests are summarized in Table XI. If gas volume exceeds 10 cc/gm/hr, the sample is considered to be unstable at that temperature. Since several samples are run simultaneously in a single oven, it was necessary to test all samples at the same temperature. When larger samples are available, as they will be in Phase II, it would be desirable to repeat this test at lower temperatures until determination is made of the highest temperature limit the materials will achieve.

Examples of the effect of temperature on the vacuum stability test obtained by Picatinny Arsenal are given in Table XII. The test temperature of 200°C was chosen on the basis that all materials achieved this temperature before irradiation. Eventually, all explosives used in the destruct system will have to pass this test at the maximum temperature to which they will be subjected before they will be fully acceptable from a thermal stability standpoint.

Referring to Table XI, no primary explosive passed the 200°C vacuum stability test after being irradiated. The most stable of the remaining classes of materials based on the vacuum stability tests at 200°C agreed with the ordering obtained by DTA tests. However, it will be necessary to make future tests on booster and primary explosives at a lower temperature to obtain meaningful data.

TABLE XI
VACUUM STABILITY TEST DATA (u)

<u>Material</u>	<u>Code No.</u>	<u>Date</u>	<u>Time</u>	<u>Time Since Irradiation hr</u>	<u>Temp. of Test °C</u>	<u>Wt of Sample gm</u>	<u>Duration of Test hr</u>	<u>Gas Volume at STP cc</u>	<u>Average Gas Evolution Rate cc/gm/hr</u>	<u>Remarks</u>
KDNBF	AGK-0	8/6/65	1250	-	150	0.2000	2	1.02	2.55	PA sample
	AGK-7	8/17/65	1206	92	150	0.2000	2	4.38	10.95	
	AGK-8	8/18/65	1147	108	150	0.2000	2*	-	11 +	*Sample detonated
	AGK-10	8/17/65	1012	112	150	0.2000	2*	-	11 +	*Sample detonated in 6 min
Lead Styphnate	AGY-0	1/18/65	1252	-	200	0.2000	2	-	1.02	
	AGY-10	-	-	-	-	-	-	-	-	Sample burned in reactor
DPS	AGB-0	8/5/65	1845	-	200	0.2000	2	0.057	0.14	
	AGB-7	8/11/65	1417	86	150	0.2000	2	7.64	19.10	Sample tested at 200°C. Deflagrated @ 3 min
	AGB-10	8/11/65	1417	168	150	0.2000	2	8.84	22.10	Sample tested at 200°C. Deflagrated @ 3 min
HNAB	AGN-0	8/5/65	1845	-	200	0.2000	2	0.04	0.10	
	AGN-7	8/16/65	2153	18	200	0.2000	2	3.46	8.65	
	AGN-10	8/13/65	1815	18	200	0.2000	2	4.97	12.43	
	AGN-11	9/15/65	1617	24	200	0.2000	2	9.33	23.40	

TABLE XI (cont.)
VACUUM STABILITY TEST DATA (u)

<u>Material</u>	<u>Code No.</u>	<u>Date</u>	<u>Time</u>	<u>Time Since Irradiation hr</u>	<u>Temp. of Test °C</u>	<u>Wt of Sample gm</u>	<u>Duration of Test hr</u>	<u>Gas Volume at STP cc</u>	<u>Average Gas Evolution Rate cc/gm/hr</u>	<u>Remarks</u>
HNS	AGV-0	8/4/65	1705	-	200	0.2000	2	0.119	0.30	
	AGV-7	8/6/65	2020	15	200	0.2000	2	6.40	16.0	
	AGV-8	8/5/65	1845	14	200	0.2000	2	8.61	21.6	
	AGV-10	8/5/65	1845	48	200	0.2000	2	9.13	22.8	
NONA	AGJ-00	9/13/65	1600	-	200	0.2000	2	0.232	0.58	
	AGJ-7	1/6/66	1500	-	200	0.2951	1	10.26	40.00	Exceeded capacity of apparatus. Test stopped before gas lost.
	AGJ-10	9/14/65	1703	38	200	0.2000	2	4.67	11.7	
ABH	AGAB-0	9/13/65	1600	-	200	0.2000	2	0.197	0.49	
	AGAB-7	9/15/65	1702	15	200	0.2000	2	4.65	11.6	
	AGAB-10	9/16/65	1409	69	200	0.2000	2	11.00	27.5	
NASA I	AGA-0	9/26/64	1640	-	260	0.5000	40	4.27	0.22	
	AGA-7	8/16/65	2153	81	200	0.2000	2	1.34	3.35	
	AGA-8	8/9/65	1843	24	200	0.2000	2	1.77	4.33	
	AGA-10	8/9/65	1843	52	200	0.2000	2	3.58	8.96	

TABLE XI (cont.)
VACUUM STABILITY TEST DATA (u)

<u>Material</u>	<u>Code No.</u>	<u>Date</u>	<u>Time</u>	<u>Time Since Irradiation hr</u>	<u>Temp. of Test °C</u>	<u>Wt of Sample gm</u>	<u>Duration of Test hr</u>	<u>Gas Volume at STP cc</u>	<u>Average Gas Evolution Rate cc/gm/hr</u>	<u>Remarks</u>
TATB	AGH-0	10/9/64	1515	-	150	0.2200	2.33	0.056	0.11*	* 0.06 @ 200°C
	AGH-7	8/16/65	2153	21	200	0.2045	2	6.11	14.91	
	AGH-8	8/13/65	1815	11	200	0.2000	2	5.08	12.7	
	AGH-10	8/12/65	1450	13	200	0.2000	2	4.51	11.28	
DATB	AGW-00	10/3/64	1818	-	200	0.5000	40	0.935	0.05	
	AGW-7	8/9/65	1843	17	200	0.2000	2	4.46	11.15	
	AGW-8	8/9/65	1843	46	200	0.2000	2	5.15	12.88	
	AGW-10	8/6/65	2020	24	200	0.2000	2	7.07	17.70	
Black Powder	AGS-0	10/8/64	1613	-	150	0.2000	2.33	0.221	0.47*	* 1.30 @ 200°C
	AGS-7	9/14/65	1703	181	200	0.2000	2	1.60	4.00	
	AGS-8	9/13/65	1600	741	200	0.2000	2	2.52	6.30	
	AGS-10	8/11/65	1450	158	200	0.2000	2	3.29	8.23	
ALCLO	AGAL-0	9/13/65	1600	-	200	0.2000	2	0.012	0.03	
	AGAL-7	1/6/66	1500	-	200	0.2320	2	0.898	1.94	
	AGAL-10	9/17/65	1230	108	200	0.2000	2	2.89	7.23	

TABLE XI (cont.)

VACUUM STABILITY TEST DATA (u)

Material	Code No.	Date	Time	Time Since Irradiation hr	Temp. of Test °C	Wt of Sample gm	Duration of Test hr	Gas Volume at STP cc	Average Gas Evolution Rate cc/gm/hr	Remarks
IB7169	AGC-0	8/2/65	1700	-	200	0.2000	2	0.152	0.38*	*1.05 @ PA
	AGC-7	8/6/65	2020	93	200	0.2000	2	0.567	1.42	
AK-14	AGE-0	-	-	-	200	0.2000	2	-	0.58*	*Run at PA
	AGE-7	8/6/65	2020	89	200	0.1220	2	0.752	3.08	
	AGE-8	9/13/65	1600	1374	200	0.1000	2	1.29	6.43	
	AGE-9	1/6/66	1500	-	200	0.2120	2	2.596	6.11	
PPLA3223	AGG-0	8/2/65	1700	-	200	0.2000	2	0.27	0.68*	*1.22 @ PA
	AGG-7	8/10/65	1214	51	200	0.2000	2	2.81	7.03	
	AGG-8	8/12/65	1815	10	200	0.2000	2	1.87	4.68	
	AGG-9	1/6/66	1500	-	200	0.2436	2	1.48	3.04	
	AGG-10	9.16.65	1220	38	200	0.1000	2	2.20	11.00	
IB7158	AGQ-0	8/2/65	1700	-	200	0.2000	2	0.197	0.49*	*2.20 @ PA
	AGQ-7	8/10/65	1214	48	200	0.2000	2	2.75	6.88	
	AGQ-8	8/13/65	1425	50	200	0.2000	2	4.05	10.13	
	AGQ-9	1/6/66	1500	-	200	0.1534	2	0.908	2.96	
	AGQ-10	9/17/65	1230	40	200	0.2000	2	4.41	11.03	
HES6573	AGZ-0	8/2/65	1700	-	200	0.2000	2	0.186	0.46*	*0.55 @ PA
	AGZ-7	8/6/65	2020	110	200	0.2000	2	6.51	16.3	

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TABLE XII

VACUUM STABILITY VS TEMPERATURE

(Picatinny data on 0.2 gm sample over a 2 hour period)¹⁸

<u>Material</u>	<u>Temperature °C</u>	<u>Average ml gas/gm/hr</u>	<u>Remarks</u>
Black Powder	150	0.24	
	200	0.42	
	250	0.86	
	300	--	Burned in 8 min.
HES 6573	150	0.08	
	200	0.18	
	250	1.30	
	300	3.82	
	350	--	Failed in 30 min.
AK-14	150	0.16	
	200	0.18	
	250	0.19	
	300	1.77	
	350	--	Failed in 12 min

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G. POST-IRRADIATION PERFORMANCE MEASUREMENTS

Two types of post-irradiation performance tests were made. The detonation velocity and plate dents of MDF were measured and the burning rate of propellant strands was determined.

1. Detonation Velocity and Plate Dent

Since use of MDF is being contemplated in the destruct system, it was necessary to determine the effect of nuclear radiation on explosives in this form. The lead sheath provides some shielding from the primary gamma radiation, but thermal neutron reactions produce secondary radiation. This radiation heating increased the sample temperature to a maximum of 180° - 240°C during radiation. Detonation velocity and plate-dent measurements on MDF from both Phases I-B and I-C are shown in Table XIII. NASA-1 loaded MDF had the most radiation stability based on weight loss and temperature stability, but DATB-loaded MDF showed the least change in detonation velocity and plate dent. However, the DATB loading was triple that of NASA-1 and therefore its susceptibility to radiation damage was reduced. If loadings were the same, NASA-1 loaded MDF is expected to be the most radiation-stable material from a detonation-velocity and plate-dent standpoint. The least stable MDF was ~~that~~ loaded with HNS. After only two hours of irradiation it could not be detonated, and it lost 30.7% of the explosive weight.

There was not enough DATB-loaded MDF left from Phase I-B for the Phase I-C irradiation testing. Therefore, a different lot had to be used. The control tests on each lot are listed separately in Table V. The explosive loadings were 12.4 and 15.5 grains/ft, and the diameters were 0.105- and 0.125-in. for the first and second samples, respectively. As expected, the detonation velocity of the larger diameter MDF was higher. The plate-dent test was not sensitive enough to detect the difference.

TABLE XIII

PHASE I-C - MDF DETONATION-VELOCITY AND PLATE-DENT TEST DATA SUMMARY (u)

Material		Irradiation		Weight Loss %	Average Strand Velocity, m/sec				Diameter inches	Average Detonation Velocity		Plate Dent*		Remarks
Type	Name	Capsule No.	Time Irrad. (hrs)		Strand 1	Strand 2	Strand 3	Strand 4		m/sec #	% Change	in.	% Change	
Detonating Fuze	NASA-1	AGT-0	0	0	5391	5429	5370	5415	0.091	5401	--	0.006	--	
		-1	2	2.0	4970	4840	--	--	0.091	4885	-10	0.008	+29	
		-2	3	4.3	4980	3540	--	--	0.091	4260	-21	0.006	+20	
		-7	4	3.4	4849	5136	5040	--	0.091	5008	-7	0.004	-33	
		-8	10	19.1	--	--	--	--	0.091	Failed	--	--	--	
	TATB	AGU-0	0	0	6665	6752	6817	6825	0.125	6765	--	0.014	--	
		-7	4	7.6	5768	5975	--	--	0.125	5871	-13	0.009	-35	
		-8	6	9.4	5644	5750**	--	--	0.125	5697	-16	0.010	-29	
	HNS	AGI-0	0	0	5803	5766	5755	5698	0.073	5756	--	0.006	--	
		-8	3/4	6.9	5206	4887	5189	5124	0.073	5101	-11	0.006	0	
		-7	2	30.6	--	--	--	--	0.073	Failed	--	0	100	
	DATE***	AGM-0	0	0	5850	5700	5810	--	0.105	5787	--	0.014	--	Sample I
		-00	0	0	6327	6311	6334	6376	0.125	6337	--	0.014	--	Sample II
		-1	1/2	0.5	5837	5610	--	--	0.105	5724	-1	0.014	0	Sample I
		-2	2	2.8	5960	6040	--	--	0.105	6000	+4	0.012	-9	Sample I
		-7	4	9.8	5441	5485	--	--	0.125	5463	-9	0.010	-27	Sample II
		-8	6	12.2	5351	5279	--	--	0.125	5310	-16	0.009	-36	Sample II

*In 6061-T4 aluminum of 25 R_B hardness.

**Data from two pins on second firing, failed to fire on first try.

***Sample I supplied by LRL.

Sample II supplied by Picatinny Arsenal.

#Average of all strands tested, % change from unirradiated controls.

2. Burning Rate of Propellant Strands

Propellant performance in a gun can best be determined by a closed bomb test. This test requires more propellant (20 grams) than could be loaded into the Phase I-C capsules. Therefore, as an alternative, a 1.3-gram strand of each propellant was burned in a strand burner to determine burning rates. This test allowed for a comparison of candidate propellants to aid in selection of those to be tested in a closed bomb during Phase II, but the data cannot be used to predict gun performance.

Propellant-strand burning data are shown in Table XIV. The propellant which was degraded the least by radiation was the 75% DATB/25% Butadiene modified Polystyrene mixture, AGQ (IB7158). Propellant AGG (PPIA3223) also has 75% DATB, but the Viton binder is less stable and results in a larger change in burning rate. Aging had no significant effect on burning rate as shown by the results on AGE-8 (tested six days after irradiation) vs AGE-9 (tested 115 days later), and AGG-8 (tested in five days) vs AGG-9 (tested after 112 days). Reproducibility of the burning-rate test is also shown by these data and the duplicate tests on control samples.

The (KClO_4 /Polystyrene/DOP) strand AGC (IB7169) melted or softened so much that it could not be tested. Based on the thermocouple measurements on the other propellants, the temperature during radiation reached 150° to 160°C. Although the KClO_4 does not melt until 292°C, the binder (polystyrene plasticized with dioctylphthalate) apparently did, and the strand lost its shape. Surface area is an important factor in burning rate in a gun propellant: thus, melting, severe softening, or loss of strength of the binder is unacceptable.

AK-14 propellant had the same KClO_4 oxidizer (but a higher temperature stable polyester/styrene binder) and the strands maintained their form and strength very well. However, the radiation stability of KClO_4 was less than that of DATB, and so the weight losses and change in burning rates of the three propellants containing it were also higher. The polyacrylic binder used with KClO_4 in the AGZ (HES6573) propellant has relatively low radiation stability⁹, and decomposed after two hours of irradiation to the extent that the propellant strand turned to powder and could not be tested.

TABLE XIV

PROPELLANT STRAND BURNING RATE SUMMARY (u)

Propellant	Symbol	Irradiation			Burning Test				Weight Loss %
		Exposure hrs	Gamma 10^{10} ergs/gm(C)	Fast Neutrons (>1.0 MEV) 10^{16} n/cm ²	Pressure psig	Burning Rate at G.E. in./sec	Burning Rate at P.A. in./sec ¹⁸	Change %	
IB7169 (KClO ₄ /Polystyrene/DOP)	C-0	0	0	0	1000	{ 0.94 0.97 0.95 (2)	0.82	--	--
	-7	2	6.76	5.3	Sample Melted		$\sigma = 0.02$ (3)	--	--
AK-14 (KClO ₄ /Polyester-Styrene)	E-0	0	0	0	1000	{ 0.89 0.80 0.84 (2)	0.83	--	--
	-8	1	3.38	2.9	1000	1.25	$\sigma = 0.03$ (3)	+50	2.5
	-9	1	3.38	2.8	1000	1.14			1.24
	-7	2	6.76	5.5	1000	3.08		+267	8.54
PPLA3223 (DATB/Viton)	G-0	0	0	0	1500	{ 0.043 0.042 0.042 (2)	0.045	--	--
	-8	1	3.38	2.8	1500	0.063		+50	1.70
	-9	1	3.38	2.8	1500	0.067			2.64
	-7	2	6.76	5.3	1500	0.095		+126	3.80
	-10	3 $\frac{1}{2}$	11.8		1500	0.067		+60	8.27
IB7158 (DATB/Polystyrene + Butadiene)	Q-0	0	0	0	35,000	-- (1)	0.741	--	--
	-8	1	3.38	2.9	35,000	-- (1)	0.735	-1	0.64
	-9	1	3.38	2.8	35,000		(5)		0.96
	-7	2	6.76	5.0	35,000	-- (1)	0.806	+9	1.06
	-10	10	33.8		35,000	-- (1)	(5)		13.10
HES6573 (KClO ₄ /Ethyl Acrylate)	Z-0	0	0	0	1000	{ 1.38 2.10 1.14 1.54 (2)	0.79	--	--
	-7	2	6.76	5.3	Sample Crumbled		$\sigma = 0.02$ (3)	--	--

(1) Strand cannot be burned at 1500 psig.

(2) Average

(3) Standard deviation from many tests on standard propellants.

(4) E-9 was tested 115 days after irradiation, and G-9 was tested 112 days after to check effect of aging on results.

(5) Burning tests not completed.

A summary of additional data available on the propellants (obtained both at General Electric and Picatinny Arsenal) is shown in Table XV. As mentioned above, the AGQ (IB7158) burning rate was the least affected by radiation. Also, its burning rate changed relatively little when tested over the range from -74° to 204°C . The other propellants, except HES6573, had a large variation in burning rate over the same temperature range.

The impulse of AGQ (IB7158) propellant was relatively low. However, this is not a primary factor in selection of a propellant and will increase about 6% if the DATB content of the propellant is increased to 90% (based on specific impulse calculations).

H. DETONATOR DEVELOPMENT

Development of functioning detonators using the more radiation-stable explosives is required. Although EBW detonators are preferred for simultaneous detonation of multiple destruct charges and for safety reasons, it may not be possible to develop a radiation-stable, high-voltage firing unit and cable. Therefore, a low-voltage, hot-wire detonator is also of interest as backup.

EBW detonators would make use of small-particle-size booster explosives pressed onto the bridge wire. Based on the results of Phase I-C, the most radiation-stable booster explosive is ABH, while HNAB, HNS and NONA are about half as stable. However, NONA had the highest temperature stability (200°C) based on vacuum stability. Picatinny Arsenal is developing an EBW detonator using NONA. The present design calls for use of a 10,000-volt firing unit, which may be difficult to achieve in a radiation environment. Lockheed has developed an EBW detonator using 2000 volts to fire HNAB.² NOL and Aerojet-General are developing a detonator using ABH, and NOL has had successful firings at 10,000 volts.¹¹ The latter firing system is described in NOLTR 63-159.²⁰ A bruceton-type of EBW sensitivity test was made at NOL on ABH and the 50% firing voltage was 6,870 volts on a 1-mfd capacitor discharged through a 0.1 ohm, 3 mill gold bridgewire. This is similar to the requirements for firing a NONA-loaded EBW detonator. Although some work has been done with HNS, it has not been initiated successfully so far as is known.

TABLE XV

SUMMARY PROPELLANT PROPERTIES (u)
(PRE-IRRADIATION)

Propellant	Symbol	Impulse ft lb/lb	Gas Volume		Effect of Temperature on Burning Rate -74°C to 204°C	Effect of Radiation on Burning Rate	Radiation Exposure which Produces 5% wt. Loss	
			Combustion cc/gm	Radiolytic cc/gm			Gamma ergs/cm ² (c) x 10 ¹⁰	Fast Neutrons (> 1 MEV) n/cm ² x 10 ¹⁶
IB7158 (DATB/Polystyrene + Butadiene)	Q	137,000	477	580	Little Change	Little Change	19.4	15.6
PPLA3223 (DATB/Viton)	G	196,000	542	600*	Slow when Cold	Increased	8.1	6.4
AK-14 (KC10 ₄ /Polyester-Styrene)	E	186,000	723	751	Irratic	Increased	5.5	4.4
IB7169 (KC10 ₄ /Polystyrene-DOP)	C	227,000	627	627*	Low Melting Point	Melted	4.9	3.9
HES6573 (KC10 ₄ /ethyl acrylate)	Z	200,000	210	600*	Little Change	Crumbled	5.9	4.7
Black Powder	S	110,000	271	426	Irratic above MP of Sulfur (128°C)	Little Change	33.0	26.2

*Estimated, accurate measurement not obtained.

Hot-wire detonators have the advantage that they can be fired with a low voltage (e.g., 6 to 12 volts). Their disadvantages are that they have more "jitter" in their firing time, and are more hazardous because less energy is required to fire them. The bridgewire sensitivity of KDNBF was evaluated in Phase I³, and its 50% firing current found to be 425-375 ma depending on exposure to radiation. Based on preliminary testing at Aerojet-General, a satisfactory detonator can be made using KDNBF to initiate an HNAB booster pellet. The temperature limit of this system is the melting point of the KDNBF explosive (less than 170°C). KDNBF explosive output is about twice that of lead styphnate (44.8 gm of sand crushed vs 24 gm in the 200 gm sand bomb test). Therefore, the HNAB booster can be initiated directly from it.

REFERENCES

1. Final Test Specifications for Phase IC of the Countermeasures Radiation Effects Program, REON Report RN-S-0235, Aerojet-General Corporation, July 1965
2. Synthesis, Processing, and Evaluation of Hexanitroazobenzene for an EBW Detonator Explosive and Other Applications, W. C. Morgan, Lockheed Missiles and Space Company Report Number 72026, July 1964
3. Final Test Report for Phase I of the Countermeasure Radiation Effects Program, REON Report Number RN-S-0210, Aerojet-General Corporation, April 1965
4. Final Report for Phase IB of the Countermeasures Radiation Effects Program, REON Report No. RN-S-0217, Aerojet-General Corporation, April 1965
5. Development of High Temperature Resistant (Gun) Propellants, AFSC, Wright Patterson Air Force Base, Ohio, FA Report R-1703, AD 430-591, January 1964
6. Countermeasures Radiation Effects Program, Phase IB Data Summary and Final Report, General Electric Company, Vallecitos Atomic Laboratory Report GE1C-1011, March 1965
7. Final Test Specifications for Phase IB of the Countermeasures Radiation Effects Program, Addendum 2 to REON Report Number 2510, Aerojet-General Corporation, December 1965
8. Final Test Specifications for Phase I of the Countermeasures Radiation Effects Program, REON Report RN-S-0268, Aerojet-General Corporation, December 1963
9. J. F. Kircher and R. E. Bowman, Effects of Radiation on Materials and Components, pp 111, Reinhold Publishing Corporation, New York, 1964
10. H. Heller, Second Meeting of the Working Group on New Compositions Sub-Group 'O', Panel O-2, Tripartite Technical Cooperation Program, NOLTR 64-175, August 1963
11. J. E. Ablard, Naval Ordnance Laboratory, Silver Spring, Maryland, Letter Number 02502 to W. Voreck, December 3, 1965
12. Final Test Report for Phase ID of the Countermeasures Radiation Effects Program, REON Report RN-S-0268, Aerojet-General Corporation, November 1965
13. M. J. Urizar, E. D. Loughran, and L. C. Smith, The Effects of Nuclear Radiation on Organic Explosives, pp 55-64, Explosivestoffe, Number 3, 1962
14. W. H. Martin, and D. M. Clare, Determination of Fast Neutron Dose by Nickel Activation, Nuclear Science and Engineering, Vol. 18, 468-473, 1964

REFERENCES (cont.)

15. B. E. Watt, Energy Spectrum of Neutrons from Thermal Fission of U^{235} , Physical Review, Volume 87, Number 6, September 15, 1952
16. Oestmann, Effect of Nuclear Radiation on Explosives and Solid Propellants (Bibliography), REIC Memorandum 2C, June 15, 1959, (AD 342-563) (Secret-Restricted Data)
17. H. H. Horowitz, and G. Metzger, A New Analysis of Thermogravimetric Traces, Anal. Chem., Vol. 35, p 1464-1468, September 1963
18. E. Wurzel, and E. Daniels, Letter Number 2487 to J. Norman, June 7, 1965, from SMUPA-DE-3, Picatinny Arsenal
19. Final Test Specifications for Transient Nuclear Test (KIWI-TNT) of the Countermeasures Radiation Effects Program, REON Report Addendum 3 to RNS-2510, Aerojet-General Corporation, December 1964
20. Leopold, H. S., Initiation of Explosives by Exploding Wires, Naval Ordnance Laboratory, NOLTR 63-159, January 1963.
21. Analysis of Complex Explosive Mixtures by Means of Thin Layer Chromatography, NOLTR 65-207, November 29, 1965.

APPENDIX A

CALIBRATION OF PRESSURE MEASUREMENT SYSTEM

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Appendix A

CALIBRATION OF PRESSURE MEASUREMENT SYSTEM

Pressure in the instrumented capsules was measured by a precision "Heise" pressure gage accurate to ± 0.1 psi. To convert this measurement to gas volume at standard conditions, it was also necessary to know the total system volume and temperature. To do this, a cylinder was made to fit onto the capsule connection on the panel shown in Figure A-1. This was calibrated by weighing it empty and then filled with water to the end of the connector. The standard volume was evacuated prior to filling with water to avoid trapped air bubbles, and the volume from the connection to the closed valve plug filled with a measured amount of water from a hypodermic syringe. A total standard volume of 141.2 cc was obtained. This was then pressurized with air from the panel, the valve closed, and the panel pressure vented to atmospheric. Finally, the valve from the known volume to the panel was opened and the equilibrium pressure determined. Since all pressures were below 100 psig, the perfect gas law, $(\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2})$, was assumed to be correct. The work was done in a constant-temperature, air-conditioned room, so $T_1 = T_2$. Temperature corrections were not needed. This test was used to determine the volume of the pressure-measurement system at several pressures, and the following relationship fitted these data from 0 to 50 psig.

The volume of the panel is: Volume, cc = $29.2 \log (\text{psia} \mp 4.128) - 141.2$. This relationship was then used to calculate the system volume at the pressures observed during irradiation of the capsules.

A similar procedure was used to calibrate the system which measured the volumes of the noninstrumented capsules at RML.

Quantity		Description
1	1	Pressure Gauge, Heise 0-100 psi, 8-1/2" dial, .2 psi per division, 1/5 subdivided, with remote 5K potentiometer, 316 s.s. tube.
2	1	Vacuum Gauge, Marshalltown No. 22B, 2' dial size.
3	1	Vacuum Tank, 2000 cu. in., 12" x 24", s.s.
4	5	Needle Valve, Whitey No. OKS 2-316, 1/8" size, s.s. w/swagelok fittings.
5	1	Safety Head, screw type, Black, Sivalls & Bryson Assy No. SA-9; s.s. - 100 psia bursting pressure
6	1	Filter, Nupro "F" Series Inlet Filler, Cat. No. SS-2F-7, 5-10 microns, s.s.

Figure A-1

Pressure Measurement Panel Diagram

APPENDIX B

DETAIL GAS-RELEASE DATA AND CALCULATED RESULTS

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GAS RELEASE DATA
NONINSTRUMENTED CAPSULES (u)

Capsule No.	A-7	A-8	B-7	H-7	H-8	K-7	K-8	N-7	J-7	S-7	S-8	V-7	V-8	W-7
Pressure, mm Hg (P_1)	1071.32	1193.92	2268.33	1049.5	1094.52	919.84	1137.64	1174.95	2547.5	836.51	1013.66	1229.03	1585.52	1027.66
Volume, cc (V_1)	50.4	49.68	49.27	49.24	49.01	50.09	49.61	48.95	47.57	47.81	48.99	51.16	50.87	48.97
Temp. °K (T_1)	298.6	297.4	298.6	299.1	299.7	298.6	298.6	297.4	299.7	301.9	299.1	297.4	297.7	298.6
Gas Vol. at STP $P_1 V_1 (.3855)/T_1$	69.80	76.98	144.47	66.70	69.09	59.48	72.86	74.55	155.88	51.07	64.00	81.50	104.44	64.97
Loading Pressure mm Hg	762.76	762.76	764.54	764.79	764.79	762.00	762.00	764.54	766.32	762.00	762.76	759.46	765.56	763.27
Loading Temp. °K	299.7	299.7	299.7	294.7	294.7	297.4	297.4	300.8	299.7	299.1	299.1	298.6	299.1	299.7
Helium Vol. at STP cc	49.45	48.74	48.45	49.26	49.03	49.48	49.00	47.96	46.89	46.95	48.16	50.16	50.19	48.08
Gas from Explosive cc	20.35	28.24	96.02	17.44	20.06	10.00	23.86	26.59	108.99	4.12	15.84	31.34	54.25	16.89
Weight Loss Measured, grams	---	0.0322	0.1492	---	.0255	.0082	.0290	.0317	.1775	---	.0372	.0395	.0768	---
cc gas/gm Gas Measured	---	877	644	---	785	1220	824	838	614	---	426	793	706	---
cc gas/gm gas	711	711	644	781	781	824	824	838	611	434	434	793	793	784
Grams Gas	0.0286	0.0397	0.1492	0.02235	0.0257	0.0121	0.0290	0.0317	0.1780	0.0095	0.0365	0.0396	0.0685	0.0215
Grams Explosive	1.7867	1.8161	1.8058	1.8049	1.8136	1.7692	1.7806	1.8060	1.7788	1.8163	1.8188	1.7913	1.7954	1.8265
Wt. Loss % (Based on Gas)	1.60	2.18	8.27	1.24	1.42	0.685	1.625	1.755	10.0	0.524	2.01	2.21	3.82	1.18
% Wt. Loss Measured	---	1.778	8.26	---	1.406	0.464	1.625	1.755	9.87	0.715	2.045	2.20	4.28	---

GAS RELEASE DATA
NONINSTRUMENTED CAPSULES (u)
(CONTINUED)

Capsule No.	W-8	AL-7	C-7	E-7	E-8	G-7	G-8	Q-7	Q-8	Z-7	E-9	G-9	Q-9	AB-7
Pressure, mm Hg (P_1)	1530.96	2071.1	2095.38	2120.43	1296.7	1190.41	943.49	960.3	865.88	2405.75	1036.69	1011.93	838.96	1524.7
Volume, cc (V_1)	48.92	51.28	50.3	51.26	49.98	49.20	48.28	49.37	49.78	~ 50	49.0	48.82	49.1	45.99
Temp. °K (T_1)	297.4	299.7	298.0	298.9	298.6	299.1	299.7	299.7	298.6	298.6	301.9	297.4	297.4	297.7
Gas Vol. at STP $P_1 V_1 (.3875)/T_1$	97.08	136.61	136.34	140.18	83.67	61.68	58.59	60.98	55.65	~155.29	64.86	64.04	53.40	90.80
Loading Pressure mm Hg	763.27	762.54	766.54	763.02	763.02	763.78	763.78	763.02	763.02	766.54	762.5	762.5	762.5	764.7
Loading Temp. °K	299.7	305.2	299.7	299.1	299.1	298.0	298.0	301.3	301.3	299.7	301.9	304.1	300.2	294.1
Helium Vol. at STP cc	48.03	49.39	49.59	50.41	49.15	48.61	47.70	48.19	48.60	48.96	47.71	47.19	48.08	46.10
Gas from Explosive cc	49.05	87.22	86.75	89.77	34.52	13.07	10.89	12.79	7.05	106.33	17.15	16.85	5.32	44.70
Wt. Loss Measured, grams	.0652**	.1062	---	---	0.0459	.0687	.0311	.0194	---	---	0.0227	.0487	---	---
cc gas/gm Gas Measured	752**	821	---	---	751	190	350	580	---	---	755	346	---	---
cc gas/gm gas	784	821	627	726	726	600*	600*	580	580	~ 600*	726	600	580	600
Grams Gas	0.0626	0.1060	0.1381	0.1236	0.0476	0.0218	0.0198	0.0194	0.0116	0.152	0.0236	0.0281	0.0092	0.0746
Grams Explosive	1.8115	1.8300	1.7913	1.8150	1.8232	1.8085	1.8296	1.8215	1.8133	1.7688	1.8288	1.8460	1.7641	1.7775
Wt. Loss % (Based on Gas)	3.45	5.79	7.72	6.80	2.61	1.21	1.08	1.06	0.64	6.01	1.29	1.52	0.52	4.20
% Wt. Loss Measured	3.6*	5.80	---	8.55#	2.50	3.80	1.70	1.064	0.88	---	1.24	2.64	---	---

*Estimated

* *Vial chipped

#From strand, probably high

B-4

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GAS RELEASE DATA
INSTRUMENTED CAPSULES (u)

Capsule No.	A-10	B-10	G-10	H-10	J-10	K-10	N-10	N-11	Q-10	S-10	V-10	W-10	Y-10	AB-10	AL-10
Date	8-6-65	8-4-65	9-14-65	8-12-65	9-12-65	8-12-65	8-12-65	9-14-65	9-15-65	8-4-65	8-3-65	8-5-65	8-12-65	9-12-65	9-13-65
Irradiation Time hrs	8	3	3.6	10	4.33	3	3	5.38	10.13	10.3	4	9.5	0.03	6	1.12
Capsule Volume cc	70.11	68.41	67.70	69.51	64.17	68.61	68.91	68.02	68.32	70.11	69.81	69.51	70.76	66.51	68.32
Final Cooled Pressure, psig	14.6	21.0	12.6	15.9	---	12.1	9.3	18.4	10.8	7.5	13.7	19.7	50+	11.1	2.9
Panel Volume cc	22.13	24.65	21.27	22.68	---	20.99	19.59	23.72	20.41	18.58	21.73	28.45	---	20.56	15.68 13.30 13.38
Total Volume cc	92.24	93.06	88.97	92.19	---	89.60	88.50	91.74	88.73	88.69	91.54	97.96	---	87.07	84.00
Cooled Pressure psia	29.1	35.5	27.2	30.4	---	26.6	23.8	33.0	25.4	22.0	28.2	34.2	---	25.7	17.5 14.5 14.6
Total Gas Volume at STP	173.59	213.58	156.50	181.18	---	153.42	136.15	195.14	145.68	126.18	166.23	216.65	---	144.65	95.06
Helium Volume cc at STP	83.41	81.71	81.08	82.81	---	81.91	82.21	81.40	81.70	83.41	83.11	82.81	---	79.89	81.70
Explosive Gas Volume cc at STP	90.18	131.88	75.42	98.37	---	71.51	53.94	113.74	63.98	42.77	83.12	133.84	---	64.76	13.36
cc gas/gm gas at STP	711	644	600	781	611	824	838	838	580	434	793	784		600	821
Wt. Loss, gm from Gas	0.1268	0.2048	0.1257	0.1260	---	0.0868	0.0644	0.1357	0.1031	0.0985	0.1048	0.1707	---	0.1079	0.0163
Pressure in GETR psia	14.5	14.5	14.6	14.5	14.6	14.5	14.5	14.6	14.6	14.5	14.5	14.5	14.5	14.6	14.6
Sample Wt., gm	1.8108	1.8014	1.8209	1.7942	1.8013	1.7928	1.7984	1.8062	1.8349	1.8295	1.8028	1.8003	1.8113	1.7670	1.8166
% Wt. Loss from Gas	7.00	11.4	6.9	7.02	---	4.84	3.58	7.52	5.62	5.39	5.80	9.47	---	6.10	0.90

$$V = \frac{\log(P + 4.12835)}{0.034245} - 141.17$$

$$\text{Cooled Avg. Temp.} = \frac{68 \times (39 + 273)}{25 \times (25 + 273)} = \frac{21216}{7450} = \frac{28666}{68 + 25} = 308^{\circ}\text{K}$$

$$\text{Gas Vol. (STP)} = \frac{P_1 V_1 / 293}{308 / 14.7} = P_1 V_1 (0.06467)$$

APPENDIX C

DETAIL WEIGHT-LOSS DATA

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~~RESTRICTED DATA - ATOMIC ENERGY~~

DETAIL WEIGHT LOSS DATA ON EXPLOSIVES

S/N	<u>Before Irradiation</u>		<u>After Irradiation</u>		<u>%</u>
	<u>Total Wt.</u> gm	<u>Expl. Wt.</u> gm	<u>Total Wt.</u> gm	<u>Wt. Loss</u> gm	<u>Wt. Loss</u> gm
AGA-7	6.6567	1.7867	#	--	--
AGA-8	6.7471	1.8161	6.71485	0.03225	1.78
AGB-7	6.0448	1.8058	5.8956	0.1492*	8.26*
AGH-7	6.4890	1.8049	#	--	--
AGH-8	6.5122	1.8136	6.4867	0.0255	1.406
AGK-7	7.4892	1.7692	7.4810	0.0082	0.464
AGK-8	7.5840	1.7806	7.5550	0.0290	1.63
AGN-7	5.6758	1.8060	5.6441	0.0317	1.755
		1.2007 Δ	1.1921 Δ	0.0086 Δ	0.715 Δ
AGS-7	5.9694	1.8163	5.9253*	0.0441*	2.43*
AGS-8	6.9183	1.8188	6.8811	0.0372	2.045
AGV-7	6.1741	1.7913	6.1346	0.0395	2.20
AGV-8	6.4038	1.7954	6.3270	0.0768	4.28
AGW-7	6.5257	1.8265	#	--	--
AGW-8	6.4499	1.8115	6.3847	0.0652*	3.60*
AGAB-7	5.8859	1.7775	#	--	--
AGAL-7	6.9111	1.8300	6.8049	0.1062	5.80
AGJ-7	6.4475	1.7788	6.2720	0.1755	9.87

*Small chip in vial, weight loss is high.

#Vial badly chipped, not meaningful weight.

Δ Based on pellets.

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DETAILED WEIGHT LOSS DATA ON PROPELLANTS

S/N	Quartz Vials						Strands							
	Before Irradiation			After Irradiation			Before Irradiation				After Irradiation			
	Total Wt. gm	Expl Wt. gm	Total Wt. gm	Wt. Loss gm	Gross % Wt Loss		Length in.	Weight gm	Dia. in.	Dia. in.	Length in.	Weight gm	Wt. Loss gm	Net % Wt Loss
AGC-7	6.6084	1.7913	*	--	--		4.800	1.2245	.108 .110 .112	-- -- --	Strand melted			
AGE-8	6.9634	1.8323	6.9175	0.0459	2.50		3.530	1.2991	.123 .123	-- --	1.2672	0.0319	2.46	
AGE-7	6.3597	1.8150	*	-- 0.194*	-- 10.7*		3.525	1.3000	.123 .124 .123	-- -- --	End of Strand Broken Off			
AGC-7	6.6222	1.8085	6.5535	0.0687	3.80		4.855	1.3068	.122 .124 .123	.1225 .124 .124	Crooked			
AGC-8	7.5368	1.8296	7.5057	0.0311	1.70		4.860	1.3100	.120 .124 .122	.122 .127 .124	Strand Broken			
AGQ-7	7.1251	1.8215	7.1057	0.0194	1.065		4.925	1.2805	.120 .119 .120	.131 .129 .134	Crooked			
AGQ-8	7.1432	1.8133	*	--	--		4.932	1.2922	.122 .124 .119	.130 .127 .125	4.91	1.2808	0.0114	0.882
AGZ-7	7.5686	1.7866	*	--	--		3.404	1.3269	.124 .124	-- --	Strand Crumbled			

*Vial badly chipped

DETAIL WEIGHT LOSS DATA
PROPELLANTS
(CONT.)

S/N	Quartz Vials					Strands							
	Before Irradiation			After Irradiation		Before Irradiation				After Irradiation			
	Total Wt. gm	Expl Wt. gm	Total Wt. gm	Wt. Loss gm	Gross % Wt Loss	Length in.	Weight gm	Dia. in.	Dia. in.	Length in.	Weight gm	Wt. Loss gm	Net % Wt Loss
AGE-9	6.3681	1.8288	6.3454	0.0227	1.24	3.500	1.2914	.122 .122 .123	0.133 0.135 0.134	3.5	1.2752	0.0162	1.254
AGG-9	7.1766	1.8460	7.1279	0.0487	2.64	4.625	1.2552	.118 .120 .120	0.124 0.126 0.125	4.6	1.2326	0.0226	1.800
AGQ-9	6.9499	1.7641	*	---	--	3.820	0.9768	.120 .118 .120	0.124 0.125 0.126	3.8	0.9674	0.0094	0.962
AGG-10	N/A	1.8209	N/A	---	--	4.586	1.2293	.124 .124 .123			1.1276	0.1017	8.27
AGQ-10	N/A	1.8349	N/A	---	--	3.957	1.0106	.118 .120 .119			0.8782	0.1324	13.10

*Vial badly chipped

DETAIL WEIGHT LOSS DATA
MDF

S/N	Quartz Vials					Strands					
	Before Irradiation		After Irradiation			Before Irradiation			After Irradiation		
	Total Wt. gm	Expl. Wt. gm	Total Wt. gm	Wt. Loss gm	Gross % Wt. Loss	Length in.	Weight gm	Expl. Wt. gm	Weight gm	Wt. Loss gm	Net % Wt. Loss
AGI-7	19.5136	0.4277	19.3474*	(0.1662)*	(38.8)*	4.748	2.6868	.0836	2.6690	0.0178	21.3
						4.825	2.6292	.0818	2.5977	0.0335	41.0
						4.920	2.7767	.0864	2.7479	0.0288	33.4
						4.969	2.8035	.0872	2.7818	0.0217	24.9
						5.003	2.8510	.0887	2.8218	0.0292	33.0
AGI-8	19.7094	0.4327	20.351	-- From MDF 0.0299	-- From MDF 6.9	4.750	2.7747	.0863	2.7695	0.0052	6.0
						4.840	2.7131	.0844	2.7077	0.0054	6.4
						4.902	2.7676	.0861	2.7599	0.0077	8.9
						4.965	2.7316	.0850	2.7246	0.0070	8.23
						5.001	2.9232	.0909	2.9186	0.0046	5.07
AGM-7	22.7076	0.8306	22.6264	0.0812	9.76	4.910	8.3224	.4120	8.2812	0.0412	10.0
						5.000	8.4573	.4186	8.4186	0.0387	9.3
AGM-8	23.1895	0.8295	23.0884	0.1011	12.2	4.904	8.2817	.4099	8.2325	0.0492	12.0
						5.002	8.4765	.4196	8.4268	0.0497	11.8
AGT-7	24.4466	0.4893	24.4302	0.0164	3.36	4.758	4.5897	.1193	4.5846	0.0051	4.3
						4.806	4.6394	.1206	4.6341	0.0053	4.4
						4.904	4.7436	.1233	4.7385	0.0041	3.3
						5.006	4.8502	.1261	4.8457	0.0045	3.6
AGT-8	25.0391	0.4893	24.8987*	0.1404* From MDF 0.0935	-- From MDF 19.11	4.754	4.5835	.1192	4.5648	0.0187	15.7
						4.801	4.6392	.1206	4.6136	0.0256	21.2
						4.908	4.7476	.1234	4.7218	0.0258	20.9
						5.004	4.8495	.1261	4.8261	0.0232	18.4
AGU-7	23.3024	0.7289	23.2470	0.0554	7.60	4.893	8.4026	.3588	8.3731	0.0295	8.2
						5.006	8.6673	.3701	8.6374	0.0299	8.1
AGU-8	23.3938	0.7286	23.3251	0.0687	9.45	4.890	8.4283	.3599	8.3900	0.0383	10.6
						5.000	8.6338	.3687	8.6005	0.0333	9.0

*Vial Badly chipped

APPENDIX D

INSTRUMENTED CAPSULE TEMPERATURE RECORDER CALIBRATION

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REFERENCE JUNCTION AT 64°C

Figure D-1

Instrumented Capsule Temperature Recorder Calibration for Phase I-C

EXAMPLES		
INDICATED TEMP, °C	CORRECTION °C	ACTUAL TEMP, °C
410	10	400
375	8	367
255	4	251
155	3	152
-55	-5	-60

Figure D-2

Temperature Correction Chromel-Alumel Thermocouple
Cold Junction at 0°C

APPENDIX E

ACCURACY OF DETONATION VELOCITY TEST ON PRESSED PELLETS

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APPENDIX E

ACCURACY OF DETONATION VELOCITY TEST ON PRESSED PELLETS

The only detonation velocity tests made during Phase I-C were on MDF. A report on the accuracy of this test has been given in the Phase I-D report¹². The tests summarized on page E-4 were made to determine the accuracy of the detonation velocity measurements on irradiated pressed pellets of explosive.

A high-quality explosive of known performance was used for this work: pressed 9404 (94% HMX, 3% nitrocellulose, 3% chloroethyl phosphate). Samples were machined out of a large pressed billet to minimize variations in density or composition.

The average velocity was 8763.3 m/sec with a standard deviation of 115.4 m/sec for 24 tests. This agrees with the velocities reported for the same size and density of sample of 8754 m/sec by LRL. Detonation was initiated by a No. 6 blasting cap and boosted with a 1/4-in. dia x 1/4-in. long tetryl pellet. The 9404 samples were 0.250 ± 0.002 in. in diameter and 1.5-in. long, and had an average density of 1.84 gm/cc. Velocity was allowed to stabilize through the first 0.35-in. and then measured over the next 1.1-in. The samples were confined in a 0.256-in ID, 0.028-in. wall thickness aluminum tube and the space between the tube and the explosive was filled with silicone grease. The assembly is shown in Figure E-1. Detector probe spacing was determined by measuring the hole locations with a traveling microscope. Transit time was recorded on a Moran raster scope. The pin closures were converted to electrical pulses by the R.C. mixer box shown in Figure E-2.

The standard deviation of velocities was higher than the 68.5 m/sec obtained for the MDF tests. However, most of this can be explained by the shorter gage length of 1.1-in. vs 3.2-in. Similarly, the variation between individual point measurements over 0.3-in. lengths was higher than that of the velocities over the 1.1-in. lengths. The average velocities reported were obtained by dividing the total distance by the total time, as was done on the irradiated samples. Based on the standard deviation obtained, measured velocities are expected to be accurate within $\pm 2.6\%$ at a 95% confidence level.

DETONATION VELOCITY DATA ON PRESSED CHARGES

(9404 Explosive Cylinders 1/4-in. Diameter
Confined in Aluminum Tubes)

Test No.	9404 Density (gm/cc)	Velocity Between Individual Points, m/sec				Points Included in Average	Average Velocity (m/sec)
		1-2	2-3	3-4	4-5		
1	1.844	8504	8710	9796	-	1-4	8873.9
2	1.840		9051	8643	8566	1-5	8838.3
3	1.843		8515	7841	9559	2-5	8681.9
4	1.843		8654		9003	2-5	8868.7
5	1.839	8877	9207	8014	8224	1-5	8606.9
6	1.842	8763	8036	9517	8799	1-5	8633.0
7	1.842	8776	8782	8159	9660	1-5	8877.1
8	1.842	8986	8697	9005	8964	1-5	8903.8
9	1.843	8614	8716	8410	8759	1-5	8643.5
10	1.840	8992	8322	9360	9156	1-5	8903.4
11	1.839	-	8646	9276	8190	2-5	8611.5
12	1.840	9100	8414	8657	8433	1-5	8775.9
13	1.839	8210	9134	8012	9197	1-5	8663.7
14	1.843	9350	8219	9778	8852	1-5	8947.4
15	1.842	8720	9095	8512	8748	1-5	8786.9
16	1.846	8472	8701	9005	8750	1-5	8703.7
17	1.844	8734	9114	8340	8194	1-5	8603.7
18	1.840	8964		9289	8372	1-5	8933.8
19	1.842	9052	8957	8454	8594	1-5	8786.3
20	1.841	8610	9055	8498	9218	1-5	8867.0
21	1.841	8858	8475	8245	8781	1-5	8615.4
22	1.839	8611	8821	8536	8639	1-5	8661.1
23	1.840	9124	8669	8312	8595	1-5	8703.3
24	1.841	8893	8983	8671	8552	1-5	8780.8
Average		1.8415					8763.3
Standard Deviation, m/sec							115.4

Note: Components will be taped in place;
tape not shown for clarity.

Figure E-1

Pressed Explosive Velocity Test Assembly

Figure E-2

Detonation Velocity R. C. Mixer Box

APPENDIX F

EXPLOSION TEMPERATURE PROCEDURE

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APPENDIX F

EXPLOSION TEMPERATURE PROCEDURE

1. Weigh out twelve 40-mg charges of asbestos.
2. Put twelve blasting caps in wooden holder and mark holder with code of lot or explosive to be loaded.
3. Weigh out 40-mg charge of explosive on Roller Smith Balance.
4. Insert blasting cap in loading fixture.
5. Pour charge through funnel into cap in fixture (brush any loose explosive on top of funnel into cap).
6. Remove funnel part from loading fixture. If required brush loose explosive into cap. Insert No. 22 gas check - concave side up - in blasting cap with tweezers.
7. Remove blasting cap from loading fixture and insert in wooden holder. Repeat above procedure until twelve charges are loaded and inserted in wooden holder.
8. Insert blasting cap from step seven into loading fixture and insert assembly into guide block in loading press.
9. Press to a point indicating +20 (1,700 psi) on top of gauge. Remove assembly from press and insert a 40-mg weighing of asbestos into funnel. Tap or brush asbestos into cavity.
10. Remove funnel part and insert another No. 22 gas check - concave side up - into top of blasting cap.

11. Replace funnel part on loading fixture and place entire assembly into guide block in press.
12. Press to a point indicated by piece of black tape on gauge: +23 (2,000 psi) on bottom of gauge. Remove loading assembly from press and disassemble to remove loaded blasting cap. Insert loaded cap into wooden holder. (By cross-checking the weighings of asbestos, the caps with the gas checks just inserted in the top of the cap, and the ready loaded caps, a close count and check on correct assembly can be maintained.)
13. Crimp loaded assemblies by inserting a loaded cap into cavity in center of the left side of crimper located to the left of timer of explosion temperature equipment. Crimp by pulling handle towards you. When all caps are crimped, the loaded assemblies are ready for testing.
14. Prior to any operations made sure equipment is "on" by inserting four plugs into respective wall receptacles. Two are by four plug receptacle (22 L-g) under table by balance and other two are to right of table in two plug receptacle. (Remember: These plugs are to be removed at end of day or completion of test.)
15. By checking data of other explosion temperature tests with same material and looking at DTA plots you can judge lowest temperature at which to start testing.
16. Set temperature desired on Gardsman Temperature Indicator by turning knob just under center of scale in Gardsman Recorder. This will move red indicator to desired position. To increase or decrease temperature adjust knobs of dial indicating percent of maximum output. The two knobs indicate minimum output adjust on the left and percent of maximum output adjust on the right. Manipulation of the latter (knob on right) will increase temperature quickly, especially if above 75%.

17. Temperature of Wood's Metal Bath will be indicated by green indicator on Gardsman Scale. Do not heat too long or let maximum output knob indicate a high percent up to desired temperature. Because of inertia of system, the temperature will shoot over the desired temperature. Let temperature stabilize before starting test.
18. Take a crimped, loaded blasting cap and with knife edge of crimper gently pull handle to form top of cap into an oval shape. This serves two purposes: (a) To prevent cap from slipping through hole when inserted into assembly which will be swung over the furnace for insertion into Wood's Metal Bath; and (b) the wire with No. 25 gas check soldered to it will be inserted in knife switch and gas check force fitted on top of oval shaped loaded cap. Make sure knife switch is in to complete circuit.
19. When desired temperature is reached, swing entire assembly by moving handle until assembly hits microswitch and simultaneously falls into metal bath. Explosion will break circuit and time will be indicated on timer. Record explosion time, temperature, and time of day on appropriate forms. (Time of day is required to determine length of time from time of irradiation to time that test was conducted.)
20. Repeat until all loaded caps are tested. Following precautions should be observed:
 - A. Make sure thermocouple and hot lead wire are in metal bath before each test.
 - B. Make sure bath is of a level approximately 1/4-in. to 1/2-in. from top of furnace so cap will be inserted properly in the bath.
 - C. If sample does not fire, keep in bath for minimum of 180 seconds. If firing times have been obtained, unit might be a dud, then repeat test at same temperature (i.e. if unit fired at 300°, 320°, and no time is obtained at 340° repeat at last temperature).

- D. Explosion times should be started at a value of 10 seconds and decreasing time by increasing temperature by increments of 10°.
- E. If an explosion time is not obtained in first test hold to 180 seconds before removing. Increase temperature a minimum of 20° for next test. Once a time is obtained, then increase temperature by 10°. If an explosion time of -- 1.0 seconds is not obtained within last two tests, increase spacing of temperature to 20° on oven in last two tests to try to get times of 1 second or less.
- F. If you start test and obtain an explosion time of 6-7 seconds or less, you can cool metal bath by ladling out Wood's Metal into stainless steel pan and inserting solid Wood's Metal. If you want to go down 20° or more, ladle out more than 1-1/2-in. of Wood's Metal from pot. Do not put too much Wood's Metal in one small pan (--1/2-in.). In large pan more than 1-in. can be put without complications of removing and remelting. Make sure thermocouple and hot lead are in place. When ladling you can remove aluminum plate from top of pot for easier accessibility.

APPENDIX G

SUMMARY OF THIN LAYER
CHROMATOGRAPHY OF EXPLOSIVE MATERIALS

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Appendix G

Summary of Thin Layer Chromatography of Explosive Materials

Solutions of explosives in dimethylformamide spotted onto silica gel plates and developed with benzene. Those materials which showed visible evidence of separation are shown below.

		Remarks
HNAB		Impure
BDPS		Pure
ABH		Probably Pure**
HNS		Probably Pure**
TATB		Pure
DATB		Pure

* Those colors marked with an asterisk were brought out with a methanolic KOH spray. HNAB, and BDPS have at least two components and, as shown above, the HNAB has at least seven. This particular developer did not work for TATB or DATB.

[REDACTED]

Appendix G

Summary of Thin Layer Chromatography of Explosive Materials
(Continued)

KDNBF #1
SANDA

Probably
Pure**

KDNBF #2
Picatinny
Arsenal

Probably
Pure**

NASA-1

Impure

Lead
Styphnate

** There is a possibility that the material left in the original spot position could be due to an oxidation product produced in the preparation of the thin layer itself. Spectral analysis or some other identification process will be required to definitely identify the various fractions.

[REDACTED]