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NUCLEAR ROCKET OPERATIONS

SACRAMENTO PLANT

REPORT NO. RN-S-0368

TO

AEC-NASA SPACE NUCLEAR PROPULSION OFFICE

FINAL TEST REPORT FOR PHASE I-A
OF THE COUNTERMEASURES RADIATION
EFFECTS PROGRAM (U)

NERVA PROGRAM

MARCH 1967

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REPORT NO. RN-S-0368

**FINAL TEST REPORT FOR PHASE I-A
OF THE COUNTERMEASURES RADIATION
EFFECTS PROGRAM (U)**

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ABSTRACT

Phase I-A concludes small-scale radiation effects testing of pseudo-stable materials in the NERVA Countermeasures Radiation Effects Program; a joint effort of Picatinny Arsenal and Aerojet-General Corporation, with irradiation of samples and subsequent physical and chemical testing conducted at the General Electric Test Reactor. This report summarizes all testing accomplished to date. Included are detailed test results of Phase I-A, which evaluated several new explosives and some prototype detonator designs.

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I. INTRODUCTION

(U) One major concern in the developing technology for use of nuclear-rocket propulsion is safety in both ground and flight operations. The buildup of radioactive materials in the reactor during operation makes it necessary to consider what, where, and even whether any of this material would return to create a hazard on Earth. Studies are underway to provide a flight safety system that would result in controlled, limited, or no deposits of radioactive particles on Earth. Several systems and concepts are being investigated that would require the use of explosives, propellants, igniters, and related components. Therefore, the Countermeasures Radiation Effects Program was established by Aerojet-General Corporation to determine which explosives and propellants are best for use in the nuclear-radiation environment developed in the NERVA engine and to determine the exposure limits of these materials.

(U) Several postoperational destruct systems under consideration call for separation of the radioactive components, primarily the reactor, from the remainder of the flight system by ordnance devices. The reactor could then be broken up by explosive charges into particles small enough to minimize the nuclear hazard, placed in a higher orbit, or brought out of orbit and landed in a controlled area by using rocket motors. In any case, radiation-stable explosives and propellants may be required in a flight vehicle.

(U) The Countermeasures Radiation Effects Program was performed jointly by Aerojet-General Corporation, the U.S. Army Picatinny Arsenal, and General Electric Co. (Irradiation Processing Operations). Samples were irradiated in the GE Test Reactor (Vallecitos Nuclear Center), Pleasanton, California. Subsequent physical and chemical 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 References 6, 7, 8, 9, and 10, the final test specifications for the Countermeasures Radiation Effects Program, published by Aerojet-General Corporation.

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II. SUMMARY

(U) The Countermeasures Radiation Effects Program, Aerojet Sub-subtask 1.9.1, involved small-scale tests on 1.8 gm samples of explosives and propellants loaded into capsules small enough (2-1/8 in. in diameter x 9 in. long) to be irradiated in the GE Test Reactor (GETR), Z-Trail Cable Facility. The program has comprised five subphases. The first, Phase I, involved testing of readily available standard materials; Phase I-B, evaluation of high-temperature-stable materials; Phase I-C, determination of exposure limits for the best materials from Phase I-B; Phase I-D, determination of the effects of a pulse of radiation from the KIWI-TNT reactor excursion test. Phase I-A, the last to be conducted, was concerned with preliminary testing of radiation-stable detonators and evaluation of three new high-temperature-stable explosives.

(U) The same explosive tests were performed during Phase I-A as in Phase I-C; i.e., differential thermal analysis (DTA), thermogravimetric analysis (TGA), melting point (MP), vacuum stability, weight loss, and gas release. In addition, irradiated detonators were test-fired and the plate dents were measured.

(U) All materials tested in this program are listed in Table 1 by type, in their relative order of radiation stability. These results are based on small sample sizes and a limited number of tests performed. More data are required to accurately determine the effects of radiation on the materials and configurations chosen for use in NERVA.

(CRD) Two important properties of pseudostable materials exposed to reactor radiation are radiation stability and temperature stability. These properties are summarized for each material tested in the bar charts of Figures 1 through 5 inclusive. Because of excessive damage at high rates, some samples of TNT, KDNBF, M-6, T-36, and T-28 were irradiated at 3.4×10^{10} ergs/gm(c)/hr gamma rate, about one-fourth of the peak rate. In Phase I-A, all but the last three detonator capsules to be irradiated were exposed to the peak gamma flux of

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Table 1
Materials Evaluated (U)

Type of Explosives	Designation	Tested in Phases						Composition	Results
		I	IA	IB	IC	ID			
Main Charge	TATB			X	X	X	1, 3, 5-triamino-2, 4, 6-trinitrobenzene	Highest radiation stability	
	Z-TACOT			X	X	X	Tetranitrodibenzo-1, 3a, 4, 6a-tetraazapentalene	Highest temperature stability	
	DATB	X		X	X	X	1, 3-diamino-2, 4, 6-trinitrobenzene		
	TNN		X				1, 4, 5, 8-tetranitronaphthalene		
	ONT		X				2, 2'', 4, 4', 4'', 6, 6', 6''-octanitroterphenyl	High temperature stability	
	TNB		X				1, 3, 5-trinitrobenzene	Highest heat capacity, melts	
	TNT	X					1, 3, 5-trinitrotoluene	Low cost, low melting (82°C)	
	HMX	X					95% HMX (1, 3, 5, 7-tetranitro-1, 3, 5, 7-tetrazacyclooctane) 5% EXON 461 (polyvinyl chloride)	Highest energy	
Booster	ABH		X		X		Azobis (2, 2', 4, 4', 6, 6'-hexanitrobiphenyl)	High radiation stability	
	HNAB		X		X		2, 2', 4, 4', 6, 6'-hexanitroazobenzene	Lowest firing voltage EBW	
	HNS			X	X	X	2, 2', 4, 4', 6, 6'-hexanitrostilbene	Not EBW sensitive	
	NONA		X	X	X		2, 2', 2'', 4, 4', 4'', 6, 6', 6'' nonanitro-m-terphenyl	Highest temperature stability	
	DIPAM			X			3, 3'-diamino-2, 2', 4, 4', 6, 6'-hexanitrobiphenyl		
	HNDS				X		2, 2', 4, 4', 6, 6'-hexanitrodiphenylsulfone		
	TETRYL	X					2, 4, 6-trinitrophenyl-methylnitramine	Burned during irradiation	
	PETN	X					Pentaerythritol-tetranitrate	Lowest radiation stability	
Primary	KDNBF	X			X		Potassium dinitrobenzofuroxan	Highest radiation stability, MP211°C	
	NASA-2 L. S.			X		X	Proprietary information Lead styphnate	Highest temperature stability	
Igniters	Black Powder			X	X	X	74% KNO ₃ /10. 4% S/15. 6% C	Highest radiation stability; erratic above MP of sulfur (120°C)	
Propellants	ALCLO				X		64% KClO ₃ /35% Al/1% calcium stearate	Highest temperature stability	
	IB7158				X		75% DATB/25% polystyrene-butadiene copolymer	Low burning rate, low impulse	
	PPLA 3223				X	X	75% DATB/25% viton A (polyvinylidene fluoride)	Low burning rate, low impulse	
	AK-14				X	X	74% KClO ₄ /1% carbon/25% polyester-styrene copolymer	Castable	
	ANP 3095	X		X			65% NH ₄ ClO ₄ /15% Al/19. 5% polyurethane/0. 5% Fe ₂ O ₃	Castable	
	HES 6573				X		84% KClO ₄ /16% hycar 4021 (ethyl acrylate-chlorovinyl ether copolymer)		
	IB 7169				X		75% KClO ₄ /25% polystyrene-diethylphthalate		
	M-6	X					86% nitrocellulose/10% dinitrotoluene/3% dibutylphthalate/1% diphenylamine/trace K ₂ SO ₄	Standard Gun Propellant	
	T-28	X					66. 25% nitrocellulose/25% nitroglycerine/6% ethyl centralite/ 0. 75% BNO ₃ /0. 7% KNO ₃ /0. 3% graphite	Standard Gun Propellant	
	T-36	X					28. 3% nitrocellulose/22. 5% nitroglycerine/47. 7% nitroguanadine/1. 5% ethyl centralite/0. 3% cryolite/ 0. 1% graphite	Standard Gun Propellant	

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Figure 1 - Relative Stability of Primary Explosives (u)

RADIATION STABILITY
(EXPOSURE TO PRODUCE 5% WT LOSS)

MP - IS THE MELTING POINT OF EXPLOSIVE, AND
 SETS THE UPPER USEABLE TEMPERATURE

Figure 2 - Relative Stability of Booster Explosives (u)

Figure 3 - Relative Stability of Main-Charge Explosives (u)

RADIATION STABILITY
 (EXPOSURE TO PRODUCE 5% WT LOSS)

TEMPERATURE STABILITY

Figure 4 - Relative Stability of Igniter Materials (u)

EST - TEMPERATURE LIMITS BASED ON STABILITY OF COMPONENTS

Figure 5 - Relative Stability of Propellants (u)

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5.6×10^{10} ergs/gm(c)/hr, as compared with the 3.4×10^{10} ergs/gm(c) peak during the earlier phases. This increase resulted from a power increase in the GETR from 30 to 50 Mw. The last three detonator capsules were exposed to 8.6×10^9 ergs/gm(c)/hr, about one-tenth the 50-Mw gamma rate in the peak flux position. Detailed exposure rates and analyses are given in the individual reports on each phase (Ref. 2, 3, 4, 5). Because Phase I-A has not been reported previously, a detailed summary of test results is given in Table 2.

(CRD) The most radiation-stable primary explosive tested was KDNBF (Figure 1). Its DTA exotherm occurs at the melting point, so it is less temperature stable than the other primary explosives tested. The relatively low radiation stability of lead styphnate and NASA-2 explosives is believed to be due to their high-atomic-weight metal atoms. The NASA-2 explosive sample was supplied by a NASA vendor, and its composition is not to be revealed. Primary explosives are of interest because they are needed to make hot-wire-initiated detonators and squibs.

(CRD) The most radiation-stable booster explosive is ABH, and the most temperature-stable is NONA as shown in Figure 2. Exploding-bridgewire (EBW) detonators can be made from all of the booster explosives except HNS (Ref. 20, 22, 23, 24). Detonators loaded with the three best explosives, NONA, HNAB, and ABH, were fabricated and irradiated in Phase I-A. The ABH explosive decomposed more rapidly than the others once its stability limit was exceeded. The two capsules of ABH exposed to the 50-Mw flux (5.6×10^{10} ergs/gm(c) gamma) burned in less than 30 min. Although the other two explosives malfunctioned, they lost less than 3% of the explosive weight and did not deflagrate during irradiation. HNAB has a lower temperature limit because of its melting point, but its radiation stability is good. Because it can be initiated at a relatively low voltage, it is superior to ABH for most applications.

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Table 2
Summary of Phase I-A Results (U)

Material		Irradiation							Test Results										
Type	Name	Capsule No.	Date Irrad (1966)	Time Irrad (min)	Irrad Temp (°C)	Integrated Dosage			Decomposition		Thermal Stability				Detonator Performance				
						Gamma (ergs/gm (C) x10 ¹⁰)	Neutrons Fast >0.18Mev (n/cm ² x10 ¹⁶)	Neutrons Thermal (n/cm ² x10 ¹⁷)	Gas Pressure (mm Hg)	Weight Loss (%)	DTA Exotherm (°C)	10% Wt Loss on TGA (°C)	5 sec Explosion Temp (°C)	Melting Point (°C)	Vacuum Stability @200°C (ml/gm/hr)	Firing Voltage (kv)	Aluminum Plate Dent (in.)	Function Time (µsec)	Rating
Expl. TNN	AEN-0	-	0	--	-	-	-	-	-	375	278	372	352	0					1
	AEN-1	10/28	81	141 to 234	7.2	12.2	7.48	1439.9(7)	4.59	308	287	325	> 360	6.20					
	AEN-2	11/1	40	141 to 160	3.6	5.64	3.57	784.1	0.132	381	249	372	> 360	3.04					
Expl. ONT	AEO-0	-	0	--	-	-	-	-	-	395	338	409	~ 348	0					2
	AEO-1	10/28	54	198 to 250	4.9	7.12	4.76	1181.8(7)	3.00	393	335	352	> 360	2.80					
	AEO-2	10/31	30	198 to 236	2.7	4.42	2.81	921.4	0.515	393	361	369	> 360	1.68					
Expl. TNB	AET-0	-	0	--	-	-	-	-	-	353(5)	187	449(3)	123-124	(2)					3
	AET-1	10/29	40	170 to 197+	3.6	5.77	3.63	1296.6(7)	4.63	355(5)	198	~400(3)	109-113	(2)					
	AET-2	11/1	20	170 to 190+	1.8	2.68	1.76	1033.9	1.24	356(5)	218	~487(3)	117-120	(2)					
Det. ABH	DAB-0	-	0	--	-	-	-	-	-	387	329	360	350	-0.04	9	0.075	3.7		3
	DAB-1	10/29	120	(4)	10.9	16.56	10.08	13797.3	(4)	-	-	-	-	-					
	DAB-2	10/31	30	(4)	2.7	4.14	2.52	10808.7	(4)	-	-	-	-	-					
	DAB-3	11/3	120	70 to 125	2.6(1)	1.03(1)	0.76(1)	3858.9	0.41	-	-	-	-	-					
Det. NONA	ADJ-0	-	0	--	-	-	-	-	-	392	375	415	> 360	0.044	14	0.025-0.057		14.5	
	ADJ-1	10/29	120	105 to 126	10.9	17.0	10.08	3318.5	15.30(6)	361	330	329	> 360	-					
	ADJ-2	10/31	30	105 to 116	2.7	4.12	2.42	1287.4	2.86(6)	377	360	383	> 360	-					
	ADJ-3	11/3	120	70 to 125	2.6(1)	1.14(1)	0.918(1)	747.3	0.76(6)	-	-	-	-	-					
Det. HNAB	ADN-0	-	0	--	-	-	-	-	-	375	296	355	221-221.5	0.187	6	0.091	5.0		1
	ADN-1	10/29	60	85 to 97	5.4	8.00	4.83	1664.2	6.26(6)	365	194	341	203-206	-					
	ADN-2	11/1	30	85 to 93	2.7	3.95	2.47	761.3(8)	2.13(6)	365	242	333	212-215	-					
	ADN-3	11/3	120	70 to 125	2.6(1)	1.32(1)	0.938(1)	780.4	0.68(6)	-	-	-	-	-					
<div>(1) 35 in. off bottom, reduced flux. (2) VTS not run, high vapor pressure (3) Boiling caused erratic results (4) Sample burned. (5) Endotherm at boiling point, no exotherm could be determined. (6) Average for four detonators. (7) Corrected for panel volume at pool temperature. (8) Puncture apparatus plugged up.</div>																			

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(CRD) The most-radiation-stable main-charge explosives were TATB and TACOT. TATB has more energy output, about the same as that of Composition B, and TACOT has better temperature stability. Because of the change in power level of the GE test reactor from 30 to 50 Mw, the last three samples, TNB, ONT, and TNN, were irradiated only at the higher level of dose rate and the resultant higher temperature. Data on NONA and HNAB at both rates were used to determine that decomposition approximately doubled for the same dose at the higher rate. This factor was used to estimate the stability of the three Phase I-A explosives at the lower rate. Since these limits are estimated, the bars for these materials are shown as broken lines in Figure 3.

(CRD) The most-radiation-stable material tested was black powder, which is an inorganic mixture of sulfur, charcoal, and potassium nitrate. However, when the sulfur melts at 120°C, performance becomes erratic. This erratic performance is not serious in an igniter but does make the material undesirable for use in the main propellant charge. The relatively low stability of ALCL₄ (aluminum and potassium perchlorate) is due to the susceptibility of KClO₄ to radiation damage and is consistent with the low stability of propellants containing KClO₄ and NH₄ClO₄, which results primarily from the high-thermal-neutron cross section of chlorine (33.6 barns). Propellants could be made more radiation-stable with KNO₃.

(CRD) Standard gun propellants containing nitrocellulose and nitroglycerine were very unstable under both radiation and heat exposure. The composite propellants containing KClO₄ were limited by relatively poor radiation stability, although they had high temperature stability. The most-radiation-stable propellant tested combined one of the best explosives (DATB) with a binder.

(U) A total of nine capsules of detonators were irradiated, three for each type of explosive. Four EBW detonators were irradiated in each capsule, and their weight loss and firing characteristics were determined. Booster explosives were less stable than the main-charge explosives but are not likely to

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limit the exposure of a destruct system because they can be located farther from the source of radiation.

(CRD) When exposed to 5.6×10^{10} ergs/gm(c) gamma at peak flux, the detonators loaded with ABH burned in less than 30 min. and, although the other explosives lost less than 3% of their weight at the same dose, the material was thermally decomposed around the center pin of the detonator and could not be made to detonate.

(U) A temperature survey was then made by using a capsule with a thermocouple attached to the center pin of a dummy detonator. This survey showed that the center pin reached a temperature above the decomposition temperature of the explosives at peak flux. The design of subsequent detonators will have to be modified to use lower-atomic-weight pins of aluminum and, possibly, higher-thermal-conductivity beryllium-oxide insulators to reduce this problem.

(CRD) The last capsule of each type of detonator was irradiated for 2 hr at 8.6×10^9 ergs/gm(c)/hr gamma so the center-pin temperature would not exceed 250°C. After this exposure, the detonators lost less than 1% of their weight and fired normally. ABH detonators were affected the least by this exposure.

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III. TECHNICAL DISCUSSION

A. MATERIALS IRRADIATED

(CRD) The materials tested in each subphase of this program are shown in Table 1 and their properties are given in Table 3. Readily available materials were tested in Phase I. The standard materials used in guns and projectiles include HMX and TNT for bursting charges, Teteryl and PETN in detonators, and M-6, T-28, and T-36 smokeless powder in gun propellants. Three of the materials were included because of their radiation stability (Ref. 6) and possible use in a destruct system: (1) DATB, (2) KDNBF, and (3) a solid-rocket propellant containing polyurethane, aluminum, and NH_4ClO_4 (Aerojet designation: ANP-3095).

(CRD) The results of Phase I made it apparent that high-temperature stability and benzenoid resonance structure were desirable in attaining high radiation stability, and a series of high-temperature-stable materials were tested in Phase I-B (Ref. 7).

(CRD) Phase I-C was used to determine threshold exposure limits by using the instrumented-capsule and additional data on the best materials from Phase I-B. These materials were: TATB, TACOT, and DATB for bursting charges; HNS and NONA booster explosives; and black powder and KClO_4 -polyester-styrene (AK-14) propellants. In addition, three new high-temperature-stable booster explosives, five new high-temperature-stable propellants, and one primary explosive (lead styphnate) were evaluated (Ref. 9).

(CRD) Phase I-D was used to determine the effects of a pulse of radiation from the KIWI-TNT reactor excursion on most of the materials tested in Phase I-B: TATB, TACOT, DATB, HNS, lead styphnate, AK-14, black powder, DATB-Viton, and ANP-3095. Exposure levels were relatively low, and only lead styphnate was affected measurably (Ref. 5).

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Table 3
Properties of Materials Tested (U)

Type	Designation	Performance				Sensitivity		Thermal Stability		10% Wt Loss on TGA (°C) ⁽²⁾	Particle Size Surface Area (cm ² /gm)
		Detonation Velocity (m/sec)	Density for Detonation Velocity (gm/cc)	Maximum Density (gm/cc)	Chapman Jouguet Pressure (kbar)	50% Impact Height (cm) ⁽¹⁾	5-Sec Explosion Temperature (°C)	DTA Peak (°C) ⁽²⁾	Melting Point (°C)		
Explosives: Main Charge	TATB	7700 ⁽⁵⁾	1.754	1.938	259 ⁽⁴⁾	>320	392	388	--	359	
	TACOT	7000 ⁽⁵⁾	1.625	1.85	209 ⁽⁴⁾	101	417	398	--	409	
	DATB	7500 ⁽⁵⁾	1.800	1.837	251	>320	403	354	280 ⁽⁹⁾	287	
	TNN	7013 ⁽¹⁵⁾	1.71	1.8	202 ⁽¹⁴⁾	100	372	375	270 ⁽⁸⁾	278	
	ONT	7062 ⁽¹⁵⁾	1.65	1.8	222 ⁽¹⁴⁾	60	409	395	--	338	
	TNB	7350 ⁽⁴⁾	1.66	1.69	214 ⁽⁴⁾	103	449	353 ⁽³⁾	123	187	
	TNT	6950 ⁽⁶⁾	1.64	1.654	190 ⁽⁶⁾	160	475	338	81	--	
	HMX	9000	1.85	1.9	367	30 ⁽¹⁾ 13.5 ⁽⁷⁾	286	308	--	--	
Booster	ABH	7088 ⁽¹⁴⁾	1.68	1.78	216 ⁽¹⁴⁾	27	360-385	375	--	361	38,700
	HNAB	8720 ⁽¹⁴⁾	1.70	1.8	314 ⁽¹⁴⁾	49	355-373	352	221	341	31,000
	HNS	6806 ⁽¹⁵⁾	1.590	1.74	--	39	385	343	313 ⁽¹⁰⁾	317	
	NONA	7220 ⁽¹⁵⁾	1.666	1.78	--	31	415-440	397	--	316	600
	DIPAM	7540 ⁽¹⁵⁾	1.690	1.79	--	132	371	312	295	--	
	HNDS	8300 ⁽¹⁴⁾	1.68	1.78	294 ⁽¹⁴⁾	62	387	343	--	288	
	Tetryl	7850 ⁽⁴⁾	1.71	1.73	250 ⁽⁴⁾	35	257	--	130	--	
	PETN	8300 ⁽⁴⁾	1.70	1.77	305 ⁽⁴⁾	11 ⁽¹⁾ 8.1 ⁽⁷⁾	225	233	141	--	
Primary	KDNBF	--	--	2.21	--	3 ⁽⁷⁾	194	211	209	210	
	NASA-2	--	--	3.94	--	12	375	380	--	--	
	Lead Styphnate	--	--	3.02	--	12	299	287	214	--	
Igniters	Black Powder	--	--	1.90	--	32	324	328	128	282	
	ALCLO	--	--	2.35	--	96	>588	457	--	500+	
Propellants	IB 7158	0.74 ⁽¹³⁾	1.43			>320	387	340 ⁽⁹⁾	277	340	
	PPLA 3223	0.042 ⁽¹²⁾	1.44			>320	388	353 ⁽⁹⁾	278	290	
	AK 14	0.84 ⁽¹¹⁾	1.89			15 ⁽⁷⁾	406	387	298	368	
	ANP 3095	0.39 ⁽¹¹⁾	1.74			11 ⁽⁷⁾	317	260	235	--	
	HES 6573	1.54 ⁽¹¹⁾	1.93			15 ⁽⁷⁾	408	352	293	352	
	IB 7169	0.95 ⁽¹¹⁾	1.71			15 ⁽⁷⁾	593	435	292	397	
	M-6	--	1.60			6.6 ⁽⁷⁾					
	T-28	--	1.62			5.4 ⁽⁷⁾					
	T-36	--	1.66			6.6 ⁽⁷⁾					

(1) Type-12 tooling, 2 kg hammer

(2) Heating rate 20°C/min nitrogen atmosphere.

(3) Boiling point.

(4) Ruby Code Calculation NOL (Ref 18)

(5) 1/4 in. diameter in Al tube (Ref 3)

(6) Experimental data, LASL (Ref 17)

(7) Picatinny Arsenal Machine 2 lb hammer, in

(8) Polymorphic phase transition, no M. P.

(9) Polymorphic phase transition at 228°C

(10) HNS was contaminated with 2, 2', 4, 4', 6, 6' hexanitro bibenzyl - recrystallized HNS melts at 319°C, and has a 50% impact height of 61 cm (Ref 19).

(11) Burning rate of a 1/8 in. diameter strand at 1000 psig.

(12) Burning rate of a 1/8 in. diameter strand at 1500 psig

(13) Burning rate of a 1/8 in. diameter strand at 35,000 psig.

(14) Ruby Code Calculation at Aerojet using NOL data for graphate

(15) Measured by Aerojet in 1/4 in ID, Al tubes

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(U) Phase I-A was delayed until radiation-resistant detonators were available. In addition to detonators, three new high-temperature-stable explosives were tested in Phase I-A (Ref 10). Other materials have been described in detail in previous reports (Ref. 2, 3, 4, 9, 10) but more information on Phase I-A is included in the following discussion.

1. New Explosives

(CRD) On the basis of their impact sensitivity, the three new high-temperature-stable explosives tested in Phase I-A are in the main-charge category. Two of the explosives, 1,4,5,8 tetranitronaphthalene (TNN) and 2,2'',4,4',4'',6,6',6'' octanitroterphenyl (ONT), were recently synthesized by Naval Ordnance Laboratory and have 15 to 20°C higher thermal stability than NONA (Ref. 1). The third, 1,3,5 trinitrobenzene (TNB), was not tested before because of its relatively low melting point of 123°C. However, the additional heat capacity due to its heat of fusion of 22 cal/gm (Ref. 12), makes this explosive able to withstand more gamma heating than any of the others; so the design modifications necessary to make it possible to contain a liquid may be worthwhile. All three explosives have the polynitro aromatic structure found to be most radiation-stable in prior phases of this program (Ref. 2, 3) and, therefore, had good possibilities for increased radiation stability (Figure 6).

2. Detonators

(CRD) Three EBW detonators and one hot-wire detonator were developed and tested by using the radiation-stable explosives from prior phases, NONA, ABH, HNAB, and KDNBF. Prior to large-scale testing in Phase II, a few detonators were fabricated and irradiated in Phase I-A to determine the gross effects of radiation exposure and the potential problem areas. Larger quantities should be fabricated, irradiated in the large Phase II capsule, and tested before specific effects of irradiation can be determined. Details of the detonator designs are discussed in Section III,C,6.

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1, 3, 5 TRINITROBENZENE

TNB
 (EASTMAN 639-43)
 MW 213

1, 4, 5, 8 TETRANITRONAPHTHALENE

TNN
 (NOL LOT 1458-4-P-7)
 MW 316

2, 2', 4, 4', 6, 6', 6'' OCTANITROTERPHENYL

ONT
 (NOL LOT 96-7524-57)
 MW 590

TETRANITRODIBENZO 1, 3a, 4, 6a TETRAAZAPENTALENE

Z-TACOT
 MW 388
 NASA-1

3, 3' DIAMINO 2, 2', 4, 4', 6, 6' HEXANITROBIPHENYL

DIPAM
 MW 454
 (NOL LOT 251-67-2C)

Figure 6 - Chemical Structure of Explosives (u)

B. RADIATION ENVIRONMENT

1. NERVA Engine Radiation

(U) The radiation to which the various destruct-system components will be exposed depends on the NERVA reactor design and the component locations, neither of which has been firmly established; therefore, irradiation tests were made in this program to determine the exposure limits in a similar flux field. Maximum flux profiles for a 4180-Mw shielded design are shown in Figures 7 and 8.

2. GETR Z-Trail Cable Radiation

(U) The peak fluxes produced in the GETR Z-Trail Cable Facility (Figure 9) are presented in Table 4. Although it would have been desirable to do all the Phase I testing at one flux level, the GETR power level was increased from 30 to 50 Mw just prior to Phase I-A so that these samples were exposed at a higher rate. The average flux values shown in Table 4 varied $\pm 10\%$ because of the rod bank position for individual samples. The exact flux rates and exposures for Phase I-A are shown in Appendix A. Gamma fluxes for Phase I-A were calculated from the power level and rod bank position to an accuracy of $\pm 15\%$ at a 95% confidence limit. These calculations were normalized by a series of gamma traverses during Phase I and Phase I-B. In the traverses, the gamma flux was measured by using a cavity-type gamma-sensitive chamber (GE No. 8NA15) developed by GE-NEPS for this program. The sensitive portion of the chamber was 0.25 in. in dia and 2.5 in. long and was installed inside a dummy capsule so that it read the same flux as that to which the samples were exposed.

(U) Integrated neutron doses for each material were obtained from flux wires embedded in the samples. Nickel wires were used to measure the fast-neutron dose by using the $N^{58}(n,p)Co^{58}$ reaction (Ref. 18). These

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Figure 7 - Full-Power Fast-Neutron Flux for the NERVA Engine

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Figure 8 - Full-Power Gamma Dose Rates for the NERVA Engine

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Figure 9 - GETR Z-Trail Cable Facility

Table 4
Average Fluxes Used in Irradiation at the GETR (U)

GETR Power Level	Position in Z Trail Cable	Neutron Flux (10^{12} n/cm ² /sec)				Gamma Flux		
		Fast >1 Mev	Fast >0.9 Mev	Intermediate 0.17 ev to 0.18 Mev	Thermal	(R/Δr) x 10 ⁸	(ergs/gm'c)/hr) x 10 ¹⁰	watts/gm'
30 MW	Peak ⁽¹⁾	7.46	8.1	19.9	83.2	3.85	3.36	1.08
	Reduced ⁽²⁾	1.33	1.44	3.56	19.7	1.1	0.96	0.32
50 MW	Peak ⁽³⁾	12.7	13.9	33.7	145	6.2	5.44	1.75
	Reduced ⁽⁴⁾	0.89	0.97	2.34	12.1	1.5	1.31	0.44

(1) Average Phase I-C peak flux, used in Phases I and IB.

(2) Used in Phase I on KD NBF and propellants.

(3) Average Phase I-A.

(4) Used in Phase I-A for third set of detonator capsules.

measurements were accurate to $\pm 15\%$ at the 95% confidence level. Fast-neutron fluxes above 0.18 Mev are 1.81 times greater than the flux above 1.0 Mev. Epithermal intermediate flux (between 0.17 ev and 0.18 Mev) is 2.66 times the 1.0 Mev value.

(U) Thermal-neutron integrated doses were measured with aluminum-cobalt-alloy wires by the $\text{Co}^{59}(\text{n})\text{Co}^{60}$ reaction to an accuracy of $\pm 10\%$. Details of the methods used for flux measurement have been given in previous reports (Ref. 4, 18).

(U) Disintegration rates of Co^{60} and Co^{58} were determined by gamma spectrometry to an accuracy of $\pm 5\%$. Constants used to calculate the fluxes were:

$$\begin{aligned}\text{Cd ratio for } \text{Co}^{59} &= 12, \\ \text{Cross section for } \text{Co}^{59} &= 31 \text{ barns}, \\ \text{Cross section for } \text{Ni}^{58} &= 0.0923 \text{ barns}.\end{aligned}$$

Capsules at the peak-flux position had a fairly uniform dose rate; however, at the reduced-flux positions, neutron dosage varied by as much as a factor of three from one end of the sample to the other, whereas gamma flux varied by a factor of two (Ref. 18). For this reason, irradiations were not made at reduced flux levels unless necessary to prevent the samples from being excessively damaged. Typical gamma and neutron traverses are shown in Figures 10 and 11, and typical energy distribution of gamma flux is tabulated in Figure 10. Neutron energy distribution is shown in Figure 12.

3. Mock-Detonator Temperature Traverse

(U) Since 80 to 90% of the heating comes from gamma irradiation, the temperature profile obtained (Figure 13) by a traverse with a dummy detonator is similar to the gamma-flux distribution curve. To make this traverse, a

Figure 10 - Typical Z-Trail-Cable Gamma Traverse

Figure 11 - Typical Axial Thermal-Neutron Flux Variation

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Figure 12 - Typical Energy Distribution of the Neutron Flux
in the Z-Trail-Cable Facility

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Figure 13 - Mock-Detonator Temperature Traverse (u)

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copper-constantan thermocouple was soldered to the center pin of a mock-up detonator located in a mock-up capsule, as illustrated in Figure 14. Although heat input was removed by the flow of cooling water past the capsule in the Z-trail cable tube, the temperature of the center pin reached 570°C in the peak-flux position. Because this temperature was above the decomposition temperature of the explosives and above the melting point of the solder used to attach the bridgewire, the last set of detonator capsules was irradiated with the center of the capsule 35 in. from the bottom of the Z-trail cable tube to reduce the radiation dose rate. In this position, the pin temperatures ranged from 150 to 225°C, which caused the solder to melt on the detonators in the highest flux; as a result, bridgewire resistance increased but was still less than 2 ohms. The firing of the detonators was not affected because the high voltages and currents used would cause the detonators to fire even with a small gap in the circuit.

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Figure 14 - Mockup of Detonator Loaded Capsule Used for Thermocouple Traverse

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C. RADIATION EFFECTS

(U) After the explosives and detonators had been irradiated in the GETR Z-trail cable facility, the capsules were transferred to the reactor canal and allowed to decay for at least 1 hr. They were then transferred to the hot cells in the Radiological-Materials Laboratory (RML) where the noninstrumented capsules were perforated in a sealed system that permitted measurement of the final capsule gas pressure and internal capsule volume. After perforation, one end of the capsule was machined off and the samples were removed. The instrumented capsules were disassembled by removing the steel cap screws. Quartz vials containing the explosive samples were transferred to the basement laboratory at the RML for analysis. In Phase I-A, this analysis included weight loss, radioactivity, appearance, explosion temperature, vacuum stability, melting point, DTA, and TGA. Detonation velocities, plate dents, and impact sensitivities of the explosives and strand burning rates of the propellants were determined in some of the prior phases.

(CRD) The radioactivities of the explosive samples were 3 mr/hr for TNN, up to 50 mr/hr for TNB, and up to 900 mr/hr for ONT. ONT was apparently contaminated with an element susceptible to neutron activation, such as bromine or chlorine. The irradiation generally darkened the samples because of the formation of color centers and decomposition products and produced a static charge due to ionization. TNN was turned almost black, and TNB and ONT were turned brown. The activity of the tube assemblies was higher than that of the explosives because of the activity of the quartz vial, flux, and temperature monitors, but was not over 1 R/hr. Because the explosives primarily contain carbon, hydrogen, nitrogen, and oxygen, their activity decays rapidly and, after a few months, is low enough for the samples to be handled in ordinary laboratory facilities. Weights of all the capsule parts are given in Appendix G, but neutron activation was not calculated because prior phases had demonstrated that capsules could be handled safely.

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1. Instrumented Capsules

(CRD) Three instrumented capsules were irradiated with each containing one of the three new explosives, TNN, ONT, and TNB, to determine their exposure limits. The irradiations were to be stopped when the pressure reached 12 psig, which would be equivalent to approximately 5% decomposition of the explosive.

(CRD) To avoid excessive thermal decomposition, a 250°C temperature limit was also established. Temperature buildup of the ONT sample was so rapid that 250°C was reached at a pressure of 10 psig. Temperature buildup might have limited TNB exposure time if a loose thermocouple connection had not lowered the indicated temperature. The higher temperatures produced by the higher flux levels when the reactor was operating at 50 Mw cut the exposure limits (total dose) of NONA and HNAB approximately in half.

(CRD) Temperatures and pressures developed in the three instrumented capsules are shown in Figures 15, 16, and 17. The plots of pressure and temperature vs time show that a rapid temperature rise first occurs because of gamma heating. The temperature starts to level off, as it would with an inert material; but then, as temperatures continue to rise, the effect of exothermic explosive decomposition becomes apparent, and the rate of decomposition starts to increase again. The most stable explosive was TNN, which withstood 81 min of exposure at the peak flux. Molten TNB was the least stable; this result agrees with thermal-decomposition results in which the decomposition products are much more effective in catalyzing further explosive decomposition when they are in solution rather than in the solid state (Ref. 1).

(U) A summary of the data obtained from the instrumented capsules is shown in Table 5. Weight loss was calculated from the gas pressure developed, the temperature, and capsule volume. The initial charge of helium in the capsule was subtracted from the total final gas volume to obtain the radiolytic

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Figure 15 - AEN-1 Instrumented-Capsule Record (u)

Figure 16 - AET-1 Instrumented-Capsule Record (u)

Figure 17 - AEO-1 Instrumented-Capsule Record (u)

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Table 5
Instrumented-Capsule Gas-Release Data (U)

	Explosive		
	TNN	ONT	TNB
Capsule	AEN-1	AEO-1	AET-0
Irradiation Time, min	81	54	40
Final Pressure, psig*	12.0	9.7	12.0
Final Temperature Before Cooling, °C	234	250	208**
Final Temperature Cooled in Pool, °C	47	47	46
Capsule Volume, cc	75.7	75.7	75.5
GETR Panel Temperature, °C	25	25	25
Final Cooled Pressure, psig	9.5	6.0	9.0
Panel Volume at Cooled Pressure, cc	37.4	37.0	37.3
Radiolytic Gas Volume, cc	69.6	43.86	65.92
Gas/gm Gas, cc	829	800†	800†
Calculated Weight Loss, gm	0.084	0.055	0.082
Sample Weight, gm	1.8364	1.8208	1.7806
Weight Loss, %	4.59	3.00	4.63
Average Rate of Temperature Increase, °C/min	1.6	0.6	**
<p>*Barometer 14.7 mm Hg for all tests. **Erratic temperature record indicates a loose connection caused low temperature measurements. †Measured volumes were obviously in error, therefore a typical volume of 800 cc/gm was used.</p>			

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gas volumes shown. The measured volume-to-weight ratio of gas in cc/gm was determined for the noninstrumented capsules. The observed gas molecular weight was used to calculate the weight loss of TNN; however, the average molecular weight of the gas from the noninstrumented capsules of ONT and TNB was obviously in error, so an average value of 28 gm/mol was used.

2. Radiolytic Gas

(CRD) The amount of gas released was calculated for all capsules (Table 6) by measuring the final capsule temperature, pressure, and volume and assuming the perfect gas law applied. The gas volume from the first two ABH samples (DAB-1 and 2) was about half that predicted for complete deflagration. The residue in the capsules appeared to have burned completely; therefore, the low pressures were probably due to a leak in the measuring system that opened up only while the drill was rotating. The system was checked and found to have no leaks before or after perforation, when the drill was not rotating. The high molecular weights calculated for all the noninstrumented capsules except AEO-2 tend to confirm this assumption. Although the same type of seal was used satisfactorily in prior phases, the drill shaft may have been scratched or corroded in the process. All measured gas pressures for Phase I-A noninstrumented capsule appeared to be low except those for AEN-2 and AEO-2. In the case of AEO-2, a small weighing error could account for the low molecular weight observed.

(U) In addition to confirming measured weight loss, gas-release data are needed for the design of sealed explosive devices that will be exposed to nuclear radiation. The design must either be capable of withstanding the pressures produced or have a method of pressure relief. To prevent destructive buildup of gas pressure, the explosive should have some porosity. Pressing pure solid explosives into the devices without a plastic binder will generally result in the desired porosity. A pressed density of 90% of the crystal density can usually be achieved.

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Table 6
Noninstrumented-Capsule Gas-Release Data (U)

Capsule No.	Void Volume (cc)	Final Pressure (mm Hg)	Temp In Cell (°F)	Pressure at 68°F or 20°C (mm Hg)	Loading Pressure (mm Hg)	Loading Temp (°F)	Loading Pressure at 68°F (mm Hg)	Change in Pressure at 68°F (mm Hg)	Wt Loss (gm)	Gas Release at STP (cc)	Measured cc gas/gm gas	Average Molecular Wt of Gas	Assumed Correct cc gas/gm gas	Calculated Wt Loss (gm)	Sample Weight (gm)	Calculated Wt Loss Based on Gas Volume	Remarks
AEN-2	49.03	783.92	78	769.34	759.46	83	738.48	30.86	0.0024 ⁽¹⁾	1.99	829.17	27.01	829	0.0024	1.8122	0.132	OK
AEO-2	46.64	921.43	76	907.67	763.27	79	747.69	159.98	0.0091	9.82	1079.12	20.76	800 ⁽²⁾	0.0123	1.7697	0.695	
AET-2	45.62	947.31	78	929.70	959.46	82	739.84	189.86	0.0224	11.40	508.93	44.01	800 ⁽²⁾	0.01425	1.8090	0.789	(3)
DAB-1	48.66	13797.29	78	13540.80	756.92	80	740.09	12800.71	-	819.58	-	-					Burned
DAB-2	50.75	10808.72	78	10607.79	755.90	82	736.37	9871.42	-	659.18	-	-					Burned
DAB-3	46.04	810.84	78	795.77	761.49	80	744.56	51.21	0.0066	3.10	469.70	47.69					(3)
ADJ-1	47.84	3318.46	78	3256.77	756.92	84	734.65	2522.12	0.2696	158.76	588.87	38.04					(3)
ADJ-2	50.07	1206.78	78	1184.35	756.92	84	734.65	499.70	0.0493	29.63	601.01	37.27					(3)
ADJ-3	46.91	747.3	78	733.41	748.2	78	734.29	0.88	0.0132	(4)	(4)	-					(4)
ADN-1	48.62	1664.20	78	1633.26	761.49	80	744.56	888.70	0.1045	56.85	544.02	41.17					(3)
ADN-2	48.0 (1)	761.33	78	747.18	761.49	78	747.33	0.15	0.0360	(4)	(4)	-					(4)
ADN-3	48.0 (1)	780.39	78	765.88	749.3	78	735.37	30.51	0.0114	1.927	169.04	132.51					(3)
<p>(1) Reported weight loss 0.0014 gm is believed to be due to an error in transcription</p> <p>(2) Equivalent to average gas molecular weight of 28.</p> <p>(3) High indicated molecular weight of gas probably due to a gas leak.</p> <p>(4) Gas volume was too small to measure accurately.</p>																	

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(U) Pressure developed in a uniformly loaded sealed explosive device can be calculated by using the following relationship:

$$P = \frac{0.05 \frac{V}{g} DRT\rho}{1 - R + DR} .$$

where

$\frac{V}{g}$ = gas volume per gram of explosive decomposed, cc/gm (e.g., 784 for DATB),

T = final temperature, °K (e.g., °C + 273 = 473°K),

D = wt fraction decomposed (e.g., 0.05),

R = ratio of loading density to crystal density (e.g., 0.9),

ρ = crystal density, gm/cc (e.g., 1.837),

P = pressure in shell, psia.

(CRD) By using the data given above for DATB and assuming the shell to be loaded at 20°C with explosive pressed to 90% TMD, the pressure developed after 5 wt% of the explosive has decomposed is approximately 10,570 psia. At this pressure, the yield strength of aluminum alloys is approached at 200°C (390°F), and is exceeded at 260°C (500°F). A titanium alloy such as 89% Ti, 7% Al, and 4% Mo is therefore recommended because it has a tensile strength of 118,000 psi at 200°C.

3. Weight Loss

(CRD) Data on weight loss of the explosives tested in Phase I-A, combined with previous data on the same materials, are shown in Figures 18 and 19. The booster explosives NONA, ABH, and HNAB had previously been irradiated to 3.4×10^{10} ergs/gm(c)/hr gamma flux, produced by 30 Mw; therefore, a comparison was made with the effects at 5.6×10^{10} ergs/gm(c)/hr, produced by 50 Mw. On this basis, the new explosives (TNN, ONT, and TNB), which were irradiated to 5.6×10^{10} ergs/gm(c)/hr gamma flux, can be approximately compared with those irradiated at 3.4×10^{10} ergs/gm(c)/hr gamma flux, as shown in Table 7. Most of the increase in decomposition per unit of dose is due to the increase in temperature (gamma heating) between the two irradiations.

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Figure 18 - Weight Loss of Booster Explosives (u)

Figure 19 - Weight Loss of Main-Charge Explosives (u)

Table 7
Weight-Loss Summary (U)

Type	Material	Average Exposure Rates			Integrated Dose to Produce 5% Weight Loss			Maximum Exposure Temp (°C)	Remarks		
		Gamma (ergs/gm(c)/hr) x 10 ¹⁰	Fast (>1 Mev) n/cm ² /sec x 10 ¹²	Neutrons Thermal n/cm ² /sec x 10 ¹²	Gamma (ergs/cm(c)) x 10 ¹⁰	Fast (>1 Mev) n/cm ² x 10 ¹⁶	Thermal n/cm ² x 10 ¹⁷				
Main Charge Explosives	TATB	3.4	7.5	8.32	27.0	21.4	23.9	163	Highest temperature stability		
	TACOT	3.4	7.5	8.32	25.7	20.4	22.7	133			
	DATB	3.4	7.5	8.32	20.6	16.4	18.3	150			
	TNN	3.4	7.5	8.3	20.3	16.1	16.9	-	Estimate		
	TNN	5.4	12.7	14.5	7.4	6.2	7.2	234	High rate		
	ONT	3.4	7.5	8.3	16.0	12.7	14.1	-	Estimate		
	ONT	5.4	12.7	14.5	5.8	4.9	5.6	250	High rate		
	TNB	3.4	7.5	8.3	10.0	7.9	8.8	-	Estimate		
	TNB	5.4	12.7	14.5	3.7	3.1	3.5	~250	High rate		
	TNT	1.0	1.1	1.8	9.8	4.2	6.2	~60	Low rate, estimate		
	HMX**	3.7	8.0	7.1	1.0	2.6	2.9	~170			
Booster Explosives	ABH	3.8	7.5	8.3	15.0	11.9	13.3	183	Burned		
	ABH	5.4	12.7	14.5	-	-	-	~300			
	HNAB	3.4	7.5	8.3	13.4	10.2	11.4	140			
	HNAB	5.4	12.7	14.5	4.6	3.9	4.5	~250	High rate, estimate		
	HNS	3.4	7.5	8.3	12.0	9.5	11.4	140			
	NONA	3.4	7.5	8.3	10.8	8.6	9.6	167			
	NONA	5.4	12.7	14.5	4.2	3.5	4.0	~250	High rate		
	DIPAM	3.5	7.5	8.7	10.5	7.0	7.8	~160			
	HNDS	3.4	7.5	8.3	4.6	3.7	4.1	160			
	Tetryl	3.9	8.1	7.8	3.5	2.6	2.5	~180	Burned		
	PETN	3.7	7.4	6.7	0.96	0.6	0.67	~100			
Primary Explosives	KDNBF	3.8	7.5	8.3	10.2	8.1	9.0	174	Detonated		
	Lead Styphnate	3.8	7.5	8.3	0.1	0.1	0.11	214+			
	NASA 2	3.2	7.5	9.0	0.17	0.14	0.16	~130			
Igniters	Black Powder	3.8	7.5	8.3	33.0	26.2	29.2	~100	Highest radiation stability		
	ALCLO (Al/KC10 ₄)	3.8	7.5	8.3	6.3	5.0	5.6	94			
Propellants**	IB 7158	DATB/PSB	3.8	7.5	8.3	19.4	15.6	17.4	153	Low rate Low rate Low rate Burned at high rate	
	PPLA 3223	DATB/VITON	3.8	7.5	8.3	8.1	6.4	7.1	151		
	HES 6573	KC10 ₄ /Acrylic	3.8	7.5	8.3	5.9	4.7	5.2	~100		
	ANP 3095	AP/Al/PU	3.8	7.5	8.3	6.5	4.6	5.1	~100		
	AK 14	KC10 ₄ /PES	3.8	7.5	8.3	5.5	4.4	4.9	~120		
	IB 7169	KC10 ₄ /PS	3.8	7.5	8.3	4.9	3.9	4.3	~120		
	M-6	NC/DNT	1.0	1.3	2.2	1.4	0.6	0.89	~60		
	T-28	NC/NG	1.0	1.4	2.1	0.8	0.4	0.59	~70		
	T-36	NC/NG/NGU	1.0	1.3	2.2	0.6	0.3	0.44	~80		
	*95% HMX/5% Exon 461										
	**Definitions of propellant abbreviations										
PSB	Polystyrene-butadiene copolymer			PES	Polyester-styrene copolymer						
AP	Ammonium perchlorate			PS	Polystyrene plasticized with dioctylphthalate						
Al	Aluminum			NC	Nitrocellulose						
PU	Polyurethane			NG	Nitroglycerine						
				NGU	Nitroguanadine						

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(CRD) The most-radiation-stable main-charge explosives were TATB and TACOT. All the high-temperature- and radiation-stable explosives contain benzenoid resonances; but, in addition, TATB has additional hydrogen bonding between the nitro and amino groups, and TACOT has azoxy bonding between the azo and nitro groups, as shown in Figure 20. DATB is similar to TATB but, because it lacks one amino group, is only about 80% as stable as TATB. The low stability of the molten explosives TNB and TNT is expected, because the stability imparted by the lattice energy of the crystal is lost when melting occurs (Ref. 28).

(CRD) In the radiolysis of polyphenyls, the C-H bonds break before the C-C bonds and before rupture of the benzene ring. When alkyl benzenes are irradiated, decomposition occurs principally in the side group, which is less stable than the benzene ring; these reactions result in polymer formation (Ref. 31). The effects of radiation on the polyphenyl nitroaromatics are probably similar in nature.

(CRD) The relative radiation stability of the unnitrated aromatics is: naphthalene > biphenyl > m-terphenyl > benzene > quaterphenyl (Ref. 31). The trend is the same in explosives of similar structures: TNN > ABH > NONA. ONT is more stable than NONA because steric hindrance was reduced by removal of the 2' nitro group on the center phenyl ring.

(CRD) The most stable booster explosives, HNAB and ABH, have azoxy bonding similar to that of TACOT, which imparts higher stability to them.

(CRD) ABH has two hexanitro biphenyl groups tied together with an azo linkage, which is apparently stronger than the bonds in the biphenyl group. Because ABH is more stable than NONA and ONT, it has the relative radiation resistance expected of biphenyl.

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HYDROGEN BONDING

AZOXY BONDING

Figure 20 - Resonance Bonding that Imparts Radiation Stability to Explosives (CRD)

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(CRD) These booster explosives were used to make prototypes of radiation-stable EBW detonators. HNAB is preferable for lower-temperature applications where its lower firing energy is an advantage; however, ABH is necessary for maximum temperature stability.

(CRD) The most stable primary explosive was KDNBF, which was about as resistant as HNAB. This stability will permit making radiation-stable hot-wire detonators that can be fired with low-voltage firing systems. The other two primary explosives contained high-atomic-weight metals in their molecules that made them very susceptible to radiation damage. Lead styphnate burned after less than 11×10^8 ergs/gm(c) exposure (2 min at 30 Mw) and also detonated when exposed to approximately the same integrated total dose delivered in a 2-millisecond pulse of radiation when the KIWI-TNT reactor went supercritical (Ref. 5). Although heavy metal salts are commonly used as primary explosives, they should be avoided in designs of ordnance items that will be exposed to nuclear radiation.

(CRD) Black powder, an inorganic mixture of sulfur, KNO_3 , and carbon, was more radiation stable than any of the other materials tested. Although its burning rate is erratic above the melting point of sulfur, its thermal stability up to 260°C is as good as that of the high-temperature-stable explosives. The low stability of ALCLO, a mixture of aluminum and KClO_4 , is believed to be due to the susceptibility of the potassium perchlorate to radiation damage, which likewise appears to be the controlling factor in the radiation stability of high-temperature-stable propellants containing KClO_4 . In contrast, ALCLO retained its thermal stability above 500°C , better than any of the other materials tested.

(CRD) Propellants compounded from high-temperature- and radiation-stable explosives and a plastic binder have good radiation stability if the binder is stable. However, fluorocarbons, such as Viton, degrade the radiation stability of the mixture even though they have good thermal stability. The radiation-stable explosives are deficient in oxygen, so propellants containing

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them have low specific impulses and are hard to burn. Use of KNO_3 as an oxidizer with a polystyrene-butadiene binder should result in a very radiation-stable propellant because of its high radiation stability, as shown by the tests on black powder.

(CRD) Ammonium perchlorate in ANP-3095 propellant has about the same radiation stability as KClO_4 , which indicates that the ClO_4 radical is the controlling factor in both compounds. Although propellants containing NH_4ClO_4 have higher specific impulses than those with KClO_4 , their temperature stabilities are lower. If temperatures do not exceed 150°C , ANP-3095 propellant would provide adequate radiation stability and a high specific impulse. Nitrocellulose, being very susceptible to radiation damage, limits the use of the conventional gun propellants, M-6, T-28, and T-36, to applications involving low temperature and low radiation exposure.

4. Thin-Layer Chromatography

(CRD) Weight loss and gas pressure are measures of only the gaseous products of decomposition. Although reactions that result in loss of energy yield primarily gaseous products, some crosslinking, polymerization, and other reactions also occur that do not lead to gaseous products. On the basis of explosive performance, the solid decomposition products apparently have almost the same explosive performance as the original explosives. This conclusion correlates with the effects produced by thermal decomposition (Ref. 1), indicating that measurements of gas release and weight loss should correlate well with explosive performance, even though the mechanisms involved in radiation damage to explosives are more complex.

(CRD) Some of the explosives from Phase I-C were analyzed by thin-layer chromatography (Ref. 29, 30) after exposure to radiation. The data are summarized in Table 8. The large amount of explosive decomposed relative to the amount of gas produced indicates that polymer formation is the dominant reaction in radiolysis of aromatic explosives, as it is with other aromatic

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Table 8
Thin-Layer-Chromatography Summary (U)

Explosive	Capsule	Weight Loss (%)	Thermal Decompo- sition at 280°C		Radiation Decomposition			
			Heating Time (min)	Explosive Remaining (%)	Irrad Time (min)	Temp Range (°C)	Explosive Remaining (%)	Ratio of Total Decomposition to Wt Loss
DATB	AGW-7	1.18	48	73.2	180	105-115	74.2	5.85
	AGW-8	3.45	80	52.9	300	105-129	55.2	13.0
	AGE-10	9.47	115	45.4	576	105-150	45.0	21.8
HNS	AGV-7	2.21	319	95.5	120	105-126	88.1	5.39
	AGV-8	3.82	462	77.8	180	105-132	73.0	7.06
	AGV-10	5.80	554	58.2	240	105-140	51.8	8.32

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compounds (Ref. 31). This dominance is further shown by the thin-layer chromatography (TLC), since decomposition products were concentrated in a single nonmoving spot.

(CRD) The ratio of total decomposition (gas plus polymer) to the amount of gas produced is also shown in Table 9. This ratio is similar to the 18:1 ratio obtained from the thermal decomposition of benzene and biphenyl at 500°C (Ref. 31). The concentration of the pure explosive decreases and the amount of polymer increases as the exposure to radiation continues. Therefore, the polymerization reactions that do not produce gas appear to predominate with DATB explosive, whereas ring breakage that causes gas appears to be a more important effect of radiation on HNS and the DATB polymers.

(CRD) Table 8 also shows TLC analyses on explosive samples decomposed thermally at 280°C to the same weight loss as for those that were irradiated. The amounts of nonvolatile products, surprisingly, are the same in either case. This result leads to the assumption that the primary mechanisms in radiation damage are similar to those in thermal decomposition, although they occur at lower temperatures. Further study will be needed to confirm this assumption.

(CRD) Once the amount of decomposition was known, it was possible to calculate the G values shown in Table 9, where G is defined as the number of molecules destroyed per 100 ev of energy absorbed. The energy absorption was calculated under the assumption that the energy distribution was the same as calculated in the Phase I report for DATB (Ref. 4). G values for benzene and biphenyl are included for comparison and agree quite well with their explosive analogs.

(CRD) For DATB and HNS, where the total amount of explosive decomposed was known, it was possible to examine the kinetics of the explosive-decomposition reaction. If a first-order reaction is assumed, a plot of the

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Table 9
G Values of Explosives (U)

Explosive	Capsule	G_{gas}	G_T	Approximate Temperature (°C)
DATB	W-10	0.094	0.547	150
	W-7	0.037	0.819	110
HNS	V-10	0.073	0.606	140
	V-7	0.055	0.299	130
Benzene	--	0.051	0.991	30
Biphenyl	--	0.007	0.267	82

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log of concentration vs exposure time (at constant flux and temperature) should be a straight line. Because of the scarcity of data available at this time, results are not very precise. The rate of decomposition of DATB decreased with time and came close to fitting a first-order assumption, whereas HNS decomposed at an increasing rate, possibly because of autocatalytic reactions.

(U) Assuming first order kinetics,

$$-\frac{dc}{dt} = KC.$$

(U) Integrating between the limits C_o at t_o and C_f at t_f :

$$C = e^{-Kt}.$$

(U) Then:

$$K = \frac{2.303}{t_f} \log \frac{C_o}{C_f},$$

where

t = exposure time, hours

C = weight fraction decomposed

ϕ = ergs/gm(c) integrated total gamma dose

(CRD) For DATB at 3.4×10^{10} ergs/gm(c)/hr gamma flux and 150°C ,

$$C \approx e^{-2.48 \times 10^{-12} \phi}.$$

A closer empirical fit to the data for C over the range 1.0 to 0.45 is:

$$C - 0.3 = e^{-4.76 \times 10^{-12} \phi}.$$

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5. Thermal Stability

(CRD) Heat is generated in explosives or propellants exposed to radiation, and most of the heat (86%) is due to gamma heating. The gamma interactions result primarily from Compton scattering of photons (Figure 21), because the reactor gamma flux is in the 1- to 5-Mev energy range. Other sources of heat are elastic collisions of fast neutrons with hydrogen nuclei (6.8%), the N^{14} (n,p) C^{14} reaction with thermal neutrons (6.8%), and, depending on the amount of explosive decomposed, chemical heat of decomposition (0.4% for 5% weight loss from DATB). Radiation heating calculational methods are shown in Appendix C of Reference 4. This heat generation will result in a constantly increasing temperature unless the explosives are cooled. The approximate adiabatic heating rate for typical explosives is given by the following relationship (Ref. 3):

$$\text{Adiabatic heating rate } (^{\circ}\text{C/min}) = 10^{-9} \times \text{gamma flux (ergs/gm(c)/hr)}.$$

When this relationship is applied to the gamma fluxes from the NERVA reactor (Figure 8), thermal stability is seen to be very important. For example, if the reactor were operated continuously for one hour, the explosives were not cooled and maximum gamma flux were 5×10^9 ergs/gm(c)/hr (behind the neutron reflector), a temperature rise of 300°C would occur in the explosives.

(CRD) For this reason, high-temperature-stable materials were evaluated. In general, these materials were also the most radiation-stable materials. A secondary effect is the decrease in thermal stability as the materials sustain radiation damage. The thermal stability and the decrease in thermal stability resulting from radiation were measured by several different methods, because no single test was adequate. These tests were: (1) explosion temperature, using the LASL confinement method (Ref. 33); (2) vacuum stability at 200°C (VTS); (3) differential thermal analysis (DTA); (4) thermogravimetric analysis (TGA); and (5) melting point (MP). The results for Phase I-A are shown in Table 10.

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Figure 21 - Energy Regions over Which the Three Primary Gamma-Absorption Processes Predominate⁽³¹⁾

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Table 10
Thermal-Stability Summary for Phase I-A (U)

Explosive	Sample	Irradiation Time at 50 MW (min)	Differential Thermal Analysis at 20°C/min (°C)			Thermogravimetric Analysis at 20°C/min	Melting Point (°C)	Vacuum Stability at 200°C 2-Hr Exposure (average ml/gm/hr)	Explosion Temperature Test	
			Endotherm	Exotherm		Temperature at 10% Weight Loss (°C)			First Fire (°C)	5-Sec Explosion Temperature (°C)
				Start	Peak					
TNN	AEN-0	0	270 ⁽⁶⁾	350	375	278	(5)	0	343	372
	AEN-1	81	313 ⁽⁶⁾	328	368	287	(5)	6.20	295	325
	AEN-2	40	291 ⁽⁶⁾	333	381	249	(5)	3.04	308	372
ONT	AEO-0	0	--	350	395	338	(5)	0	345	409
	AEO-1	54	355	300	393	335	(5)	2.80	315	352
	AEO-2	30	365	320	393	361	(5)	1.68	335	369
TNB	AET-0	0	353 ⁽¹⁾	--	--	187 ⁽²⁾	123-124	(2)	402 ⁽³⁾	449 ⁽³⁾
	AET-1	40	355 ⁽¹⁾	--	--	198 ⁽²⁾	109-113	(2)	292 ⁽³⁾	400 ⁽³⁾
	AET-2	20	356 ⁽¹⁾	--	--	218 ⁽²⁾	117-120	(2)	475 ⁽³⁾	487 ⁽³⁾
ABH	DAB-0	0	--	333	387	329	(5)	0	340	360
	DAB-1	120 ⁽⁴⁾	--	--	--	--	--	--	--	--
	DAB-2	30 ⁽⁴⁾	--	--	--	--	--	--	--	--
NONA	ADJ-0	0	--	365	392	375	(5)	0.044	380	415
	ADJ-1	120	--	250	361	330	(5)	--	300	329
	ADJ-2	30	--	312	377	360	(5)	--	345	383
HNAB	ADN-0	0	220	313	375	296	221-221.5	0.187	315	355
	ADN-1	60	210	320	365	194	203-206	--	295	341
	ADN-2	30	215	325	365	242	212-215	--	314	333

(1) Boiling point.

(2) High vapor pressure interferred with results.

(3) Boiling interferred with results.

(4) Sample burned.

(5) Exploded before melting.

(6) Endotherm caused by a polymorphic crystalline change.

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a. Differential Thermal Analysis

(U) Since DTA analysis involves heating a small (10-mg) sample at a constant rate (20°C/min), it comes closest to approximating the thermal environment developed by exposure to radiation. The DTA exotherm temperatures were used to establish the temperature limits for all materials shown in Figures 1 through 5.

(CRD) The DTA endotherms on TNN were small, and no melting was observed in the capillary MP test; therefore, these endotherms are believed to be due to a polymorphic phase transition. This transition point was increased in temperature and decreased in amplitude by the crosslinking and polymer formation that occurred during irradiation. ONT developed a new endotherm after irradiation, just before reaching its deflagration temperature, possibly due to a decrease in melting point from dilution of the explosive with its decomposition products. A similar lowering of melting point was produced in HNAB. TNB had two endotherms, one at its melting point, and one at its boiling point. There was no exotherm below its boiling point at atmospheric pressure.

(CRD) The start of the DTA exotherms for all the explosives decreased with exposure, but the peak temperatures first increased and then decreased for TNN and ONT, as did the TGA temperature limits. Exotherm data were not obtained for TNB because it boiled away before it decomposed. No data were obtained for ABH because both samples burned that were exposed to the peak flux of 16×10^{10} ergs/gm(c)/hr produced at the 50-Mw power level, and the detonators exposed to the reduced gamma flux of 0.86×10^{10} ergs/gm(c)/hr were used for detonation tests.

b. Thermogravimetric Analysis

(CRD) The increases in temperature stability shown by the temperatures at which 10% weight loss occurred in TGA analysis of TNN, ONT, and TNB were probably due to the formation of polymers having lower vapor pressures

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than the primary explosives. The low temperatures for TNB were due to its high vapor pressure, so the weight loss indicated was not due to decomposition. In the case of NONA and HNAB, TGA temperature limits decreased as exposure increased.

c. Melting Point

(CRD) Melting points for TNB and HNAB, the two explosives that had distinct melting points, decreased with increasing dosages, as would be expected by the buildup of nonvolatile decomposition products in these explosives.

d. Vacuum Stability

(CRD) Vacuum stability is the best measure of long-term stability (over a 2-hr period). A temperature of 200°C was chosen on the basis of results of prior phases. A limit of 10 ml/gm/hr was established as the maximum gas decomposition rate. On this basis, the two new explosives, TNN and ONT, are expected to be stable up to at least 200°C after exposure to enough radiation to produce a 5% weight loss. The high gas release of TNN (6.2 ml/gm/hr) at 4.6% weight loss indicates that 200°C is close to the maximum safe temperature for these explosives. As expected from prior phases, the vacuum stability of the explosives steadily decreased with increasing dose because of the formation of less-stable by products as a result of radiation damage. Data could not be obtained for TNB because it boiled out of the high-temperature zone at 200°C under vacuum. Data were not obtained on ABH or HNAB because insufficient samples were obtained when the detonators were unloaded; however, these explosives were tested in Phase I-C.

e. Explosion Temperature

(CRD) Explosion temperature involves rapid heating of a 40-mg sample confined in a copper tube. Explosives that melt (HNAB) or boil (TNB) cause erroneous results, but these materials would also cause problems in

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ordnance devices when they melt or boil, so their temperature limits would be established by these temperatures rather than by their explosion temperatures. As in other thermal-stability tests, exposure to radiation caused accumulation of less-stable by-products and therefore lowered the explosion temperatures. Ordnance devices designed for exposure to radiation will have to have these decreases in thermal stability taken into account.

6. Detonators

a. Design

(CRD) Prototypes of one hot-wire and of three EBW detonators were developed and tested for radiation stability by using the most radiation-stable materials found in this program. The hot-wire type used KDNBF, which can be detonated by a 1-amp current from a low-voltage source. Tests on KDNBF detonators were discussed in the Phase I report (Appendix C), and the explosive was tested in Phase I-C (Ref. 2 and 4).

(U) The EBW detonators were developed and irradiated in Phase I-A; the irradiation tests were made on a very small number of detonators. A few nonoptimized detonators were irradiated, and fired with a nonoptimum firing system primarily to determine the feasibility of these designs and to determine the major problem areas and the necessary design changes. This information can then be used to guide the design and development of detonators for large-quantity detonator qualification tests in Phase II.

(1) Hot-Wire Detonator

(CRD) A sketch of the KDNBF prototype loaded detonator is shown in Figure 22. Normally the cavity behind the priming charge would be filled with a pressed booster pellet, but, because this pellet would probably be another explosive, such as NONA, it was omitted to avoid confusing the measurements. These hot-wire-initiated detonators with KDNBF explosive were

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ACTUAL SIZE
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Figure 22 - Hot-Wire-Detonator Prototype (u)

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tested in Phase I and found to have good radiation stability (Ref. 4). This detonator had a 0.0008-in.-dia Tophet C bridgewire, and required about 1 amp at 6 volts to fire reliably. The design could be modified to pass 1 amp or 1 watt without firing by using a thin-film bridge (Ref. 21). However, its temperature stability is limited to 150°C, and safety considerations may make this design less desirable than an EBW detonator. The other primary explosives, lead styphnate and NASA-2, had insufficient radiation stability to be of interest (Ref. 2).

(2) EBW Detonators

(CRD) EBW detonators are normally made with less-sensitive booster explosives, such as PETN. Because the booster explosives from Phase I-C had demonstrated high temperature and radiation stability it was desirable to incorporate them into radiation-stable detonators and to test the assemblies. Preliminary work by Picatinny Arsenal indicated that EBW detonators could not be made with DATB, TATB, DIPAM, or HNS; however, a satisfactory detonator was made by using NONA (Ref. 20). Lockheed developed a detonator using HNAB (Ref. 22), and the Naval Ordnance Lab showed that a detonator could be made by using ABH (Ref. 23). The prototype EBW detonator design shown in Figure 23 was developed for use in the Phase I-A tests. The following unique design requirements were established for this design.

(CRD) Detonators had to be small enough in diameter (0.315 in.) to fit inside the Phase I capsules. To get the 95-mil bridgewire length desired and allow for testing of other lengths down to 35 mils, the pin was located off center. To get a 15-kv stand-off voltage, a glass-bead-type Kovar seal with a 0.2-in. arc length was used. The bridgewire was soldered to the header with 60:40 tin-lead solder with a special aluminum flux. As shown in Figure 24, a low-density powder charge was pressed on the bridgewire and backed up with a booster pellet of the same explosive. This detonator was patterned after the Picatinny Arsenal design of a NONA-loaded detonator, which

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Figure 23 - Prototype-Detonator Components and Assembly

TOTAL ASSEMBLY WEIGHT: 2.63 – 2.75 gm
TOTAL EXPLOSIVE WEIGHT: 0.40 – 0.45 gm

Figure 24 - Prototype Radiation-Stable EBW Detonator

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was their most successful design. The detonator was also similar to the HNAB detonators tested by Lockheed. Aluminum was used wherever possible to minimize absorption of radiation; the bridgewire was aluminum. Previous instrumented-capsule tests had indicated that explosive temperatures did not exceed 180°C when the GETR was operated at 30 Mw. With the increase in GETR power to 50 Mw, it was calculated that explosive temperatures would not exceed 260°C; and it was estimated that the header, because of its good heat transfer, would not exceed 200°C (the melting point of the solder) for any of the detonators.

(U) Before performing the irradiation tests, as many preirradiation tests as possible were performed with the limited quantities of explosives available. These tests, summarized in Appendix D, were used to establish the feasibility of the designs, develop and check out the instrumentation, and determine preirradiation performance. Time and material were insufficient to optimize the detonator designs or accurately determine their performance, so these tests were limited to one standard design that provided relative effects. Parameters of importance that need to be optimized in subsequent detonator designs are: explosive (material, particle size, and density), bridgewire (material, length, and diameter), and explosive train (length, diameter, and confinement).

b. Firing Units

(U) In addition to the detonators, a special high-voltage low-inductance firing unit had to be developed and tested because the high temperature stability of the radiation-stable explosives resulted in more energy being needed to fire them than was available from standard firing units.

(CRD) The first firing unit was adapted from an existing parallel-plate, low-inductance unit, which was modified for current measurement by use of a series shunt containing 100 one-ohm resistors in parallel. Because the feasibility of HNAB and NONA detonators had already been demonstrated

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(Ref. 20 and 22), preliminary tests at AGC were made on ABH. With 7-in. (minimum-length) leads used to minimize inductance, an ABH detonator (DAB-3A) was fired with only 4.6 kv. However, to conform to the ultimate requirements for irradiated detonators, 12-ft leads and a 7-kv firing voltage were used for the remainder of the feasibility tests on detonators DAB-1A through -10A. These tests showed that a detonator could be made and fired by using ABH, but no attempt was made to optimize the design or the firing unit.

(CRD) After selecting HNAB, NONA, and ABH for use in the detonators for Phase I-A tests, a safer, more portable firing unit was built that initially used a Parks coaxial shunt for measurement of detonator current. This shunt was later replaced with a current transformer to reduce RF interference. At the same time, work was started on equipment for measuring firing time and voltage. Because of the limited quantity of ABH (20 gm), this work was done by using NONA and HNAB. The 50-ohm impedance of RG8 cable restricts the flow of current to the detonator, so some tests were made with a lower-impedance triaxial cable, Raychem TPT 20 (19) STIRSTIR 9-2, J-7-10-1-65-6. When the inner and outer shields are used as conductors, this cable has an impedance of 18 ohms. Although this cable worked well at low voltages, its insulation broke down when 15-kv pulses were used. This was the "TRIAX" cable used in the detonator tests in Appendix D.

(U) Because of intermittent shorting of this cable, the currents measured while using it are of questionable accuracy. After the Parks shunt was replaced with a current transformer, the latter was calibrated by using $\frac{di}{dt}$ measurements to calculate peak current, inductance, and effective circuit resistance by the method described in Appendix B. The final firing unit (Figure 25) was used for all tests conducted at GE and for the AGC control tests on DAB-4 and -5 and ADJ-27 through -29, -44 through -47, and -51.

(U) The high currents and short pulses that result when EBW detonators are fired at high voltages are very difficult to measure. RF interference is always present, and inductances, although low, cause loss of power.

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For maximum power delivery, the load impedance should match that of the cable; but the very low resistance of the exploding bridgewire caused a power reflection from the shorted end that interfered with measurements. A suitable system for continuously measuring the voltage across the detonator could not be developed, so only the initial charge on the capacitor was determined.

(U) Function time could only be measured after the cable in the vicinity of the high-current leads was completely shielded by the heavy-steel firing chamber. A pin switch that was closed by the impact of the aluminum disk on the end of the detonator was used to measure transit time. The RC pin-switch circuit is shown in Figure 25. Pin signals were recorded on a Moran raster oscilloscope system. The pin leads were shielded from the high magnetic pulse in the detonator by gluing them in a hole drilled through the aluminum witness block.

c. Effects of Radiation on Detonators

(1) Irradiations at Peak Flux

(CRD) In Phase I-A, the first six capsules of the three EBW detonators containing ABH, HNAB, and NONA were exposed to the peak gamma flux of 5.6×10^{10} ergs/gm(c)/hr produced in the Z-trail cable facility. When ABH was found to have burned after 2 hr of exposure, the exposure time for HNAB was reduced to 1 hr. Weight losses for the first capsules of NONA and HNAB were over 5%, and the capsules could not be detonated with 15 kv; therefore, the exposure time for the next three capsules was reduced to 30 min. ABH detonators still burned, and, although weight loss was less than 3% for HNAB and NONA, the detonators still could not be fired with 15 kv. Unfired detonators were dismantled, and the misfires were found to have been caused by the explosive burning or melting away from the bridgewires (Figure 26).

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N-14

N-16

N-17

N-21

J-33 HEADER

J-36

Figure 26 - Views of Disassembled Detonators after Exposure to Peak Flux (u)

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(CRD) The detonators loaded with HNAB explosive (N-17 and N-16) were exposed to peak flux for $\frac{1}{2}$ hr, and N-14 was exposed for 1 hr. Figure 26 shows that the explosive that was heated to the highest temperature in the center of the detonator decomposed the most. In addition to having the center voids, the explosive was dished out from the bridgewire. The view of detonator N-21, loaded with HNAB, shows an accumulation of explosive on the outside of the detonator, caused when the explosive melted and leaked out around the header threads. The glass-to-metal seals exposed to peak flux were all in good condition, but the solder bead on the center pin appeared to have melted and resolidified as shown in the J-33 header. The bridgewire resistance of the headers that were exposed to peak flux also increased appreciably. After irradiation, the detonators loaded with NONA were similar to J-36, shown in Figure 26. The explosive had not melted but did contain many blackened particles that indicated local overheating had occurred, and the explosive had pulled away from the header, probably because of the high temperature developed at the center pin.

(CRD) No data were obtained on the ABH detonators exposed to peak flux because all had burned. Examination of the capsule bodies after they were opened revealed no signs of a detonation.

(2) Reduced-Flux Irradiations

(CRD) After all detonators failed to withstand the peak flux at the 50-Mw power level, a dummy detonator was loaded with charcoal and a traverse was made to find the position where the temperature of the center pin did not exceed 250°C. As shown in Figure 13, this position was over 32 in. above the bottom of the trail cable tube. Weight losses and plate dents observed with the detonators exposed to reduced flux for 2 hr in capsules DAB-3, ADN-3, and ADJ-3 varied. The additional information shown in Table 11 was obtained on the effect of dose on performance. No significant change in firing time of NONA or ABH detonators resulted from the flux variations, but plate dent, weight loss, and firing time all correlated with the dosage variations.

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Table 11
Effect of Dose Variation on Detonators (U)

Explosive	Capsule	Detonator	Location	Ratio of Dose to Average Fast			Weight Loss (%)	Plate Dent (in.)	Ratio to Average		Detonator Firing Time (μ sec)
				Gamma	Neutrons >0.18 Mev	Thermal Neutrons			Weight Loss	Plate Dent	
ABH	DAB-3	AB-20	Top	0.76	0.59	0.72	0.325	0.088	0.79	0.82	3.5
		AB-19	Upper	0.90	0.81	0.32	0.271	0.072	0.66	1.00	3.5
		AB-18	Lower	1.122	1.09	1.11	0.447	0.058	1.09	1.24	4.2
		AB-17	Bottom	1.32	1.44	1.49	0.598	0.069	1.46	1.04	4.9
		Average					0.410	0.0718			
NONA	ADJ-3	J-24	Top	0.76	0.59	0.72	0.60	0.032	0.78	0.64	15.5
		J-23	Upper	0.90	0.81	0.82	0.58	0.023	0.76	0.89	11.5
		J-22	Lower	1.22	1.09	1.11	0.97	0.013	1.26	1.58	13.7
		J-21	Bottom	1.32	1.44	1.49	0.92	0.014	1.20	1.46	12.3
		Average					0.768	0.0205			
HNAB	ADN-3	N-22	Top	0.76	0.59	0.72	0.56	0.088	0.82	0.87	4.5
		N-21	Upper	0.90	0.81	0.82	0.53	0.085	0.78	0.90	4.7
		N-20	Lower	1.22	1.09	1.11	0.72	0.070	1.06	1.10	4.4
		N-19	Bottom	1.32	1.44	1.49	0.91	0.064	1.34	1.20	4.5
		Average					0.68	0.0768			

Radiation Exposure rates: Fast neutrons 8.9×10^{11} n/cm²/sec, > 1 mev
 Thermal neutrons 1.2×10^{13} n/cm²sec
 Gamma 1.3×10^{10} crg/gm(c)/hr

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(CRD) The plate dents made by the detonators appeared to offer the most accurate means of measuring the extent of radiation damage and the degree of initiation obtained at different voltage levels. These data are plotted in Figures 27, 28, and 29. The ABH detonators had a gradual firing-voltage threshold near 6 kv and were therefore fired at 9 kv after irradiation. HNAB detonators had a sharper threshold of 3 kv and were therefore fired at 6 kv after irradiation. NONA detonators were very erratic, possibly because of the large particle size of the explosive, and were fired at 14 kv after irradiation; they appeared to have a gradual threshold at 6 kv. In all cases, the highest radiation dosages measurably reduced output, whereas the lowest did not; therefore, their damage thresholds were bracketed.

(CRD) The ABH detonators appeared to be affected least by the irradiation, as long as it was below their tolerance limit. HNAB has a lower temperature limit because of its melting point but also has the lowest firing voltage. NONA withstood peak flux and temperature best but requires higher energy to fire. The particular environment to which the detonators will be exposed will determine the ultimate choice, but HNAB appears to provide the best detonator if temperature and exposure can be kept down to the HNAB tolerance limits of 200°C, 1.7×10^{10} ergs/gm(c) gamma, 1.3×10^{15} n/cm² fast neutrons ($E > 0.18$ Mev), and 0.9×10^{17} n/cm² thermal neutrons.

(3) EBW Firing Current

(U) The detonator firing current, bridgewire burst current, and time to wire burst are all functions of the bridgewire material, length, header design, and firing-unit characteristics. The type of explosive used makes little difference in these parameters. Sandia (Ref. 34) has correlated the important bridgewire parameters in the following relationship:

$$I_b = \left[\left(3GL^{-1}V_o \right)^{2/3} - 2.25G^2C^{-1} \left(3GL^{1/2}V_o \right)^{-2/3} - 2RGL^{-1} - 2EwL^{-1} \right]^{1/2}$$

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Figure 27 - ABH Detonator Plate Dents (CRD)

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Figure 28 - HNAB Detonator Plate Dents (CRD)

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Figure 29 - NONA Detonator Plate Dents (CRD)

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Where: I_b = bridgewire burst current, amperes,
 G = gA^2 ,
 A = bridgewire cross section, circular mils
 L = circuit inductance, henrys,
 C = circuit capacity, farads,
 V_o = initial firing voltage, volts,
 R = circuit resistance, ohms
 E_w = $(e) \times (A) \times (l)$,
 l = bridgewire length, mils
 e = $0.028 A^2\text{-sec}/(\text{cir-mil})^2$ for aluminum,
 g = $6 \times 10^{-4} \text{ J/cir-mil/mil}$ for aluminum,

The burst currents calculated for the 2- and 4-mil wires 95 mils long are plotted in Figure 30, along with the observed values. The calculated values for 4-mil wires appear to be in good agreement; however, the change to 2-mil wire did not appreciably affect burst current, although theoretically it should. Since the equation was developed semiempirically, it may be that 2 mils is out of the applicable range, or that some interference in the recording system prevented accurate measurements. Peak currents are shown in Figure 31, but have not been correlated with bridgewire parameters. Some of the scatter in the measurements may be due to variations in the way the bridge-wire was attached to the header, as indicated by variations in the bridgewire resistance before firing.

(4) Revised Detonator Design

(U) In view of the results obtained from the Phase I-A detonator irradiation tests, the following detonator design changes are recommended:

- (1) Replace Kovar with aluminum to reduce gamma heating of the header.

Figure 30 - Burst Current vs Firing Voltage for Exploding Aluminum Wires (u)

Figure 31 - Peak Current vs Firing Voltage for Aluminum Bridgewires (u)

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- (2) Ultrasonically weld the aluminum bridgewire to the header to eliminate solder and thus avoid melting and overheating.
- (3) Monitor detonator temperatures during irradiation and provide better means for cooling when necessary.

A sketch of the proposed design to incorporate these changes is shown in Figure 32. The header is shown assembled by crimping, but radiation-stable adhesives could be used, if they were more stable than the explosive. Compression-type glass-to-metal seals with aluminum are difficult to achieve, and a compression seal cannot be made with the projecting insulator shown in Figure 32. If a larger diameter is used, a compression seal can be made that will withstand the firing voltage; but the number of detonators that can be loaded into a Phase II capsule would be reduced.

D. IRRADIATION PROCEDURES, PHASE I-A

1. Detonator Loading Procedure

(U) Detonator design has been discussed in the section on radiation effects. Detailed assembly procedures are given in Appendix C. The bridgewire type and length were specified on the basis of preliminary firing tests and data from other agencies. Other critical factors in assembly are bridgewire attachment; density, dryness, and particle size of the powder on the bridgewire; and booster-pellet density.

(U) Since a satisfactory ultrasonic bridgewire welding system was not developed in time for Phase I-A, bridgewires were soldered to the headers. The bridgewires were aluminum and were soldered with 60:40 tin-lead solder by using a special flux and the procedure described in Appendix C. Their resistances were 0.02 to 0.06 ohms when soldered, and loaded detonators were rejected if the resistance exceeded one ohm after loading. Because of difficulty in wetting the aluminum wire with solder, the resistances of the

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Figure 32 - Revised Design of Radiation-Stable Detonator

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bridgewires increased when the solder melted during irradiation. The high firing voltages caused arcing over this small gap, and there was very little attenuation since, once ionization occurred, the resistance to current flow was very low. Low resistance before irradiation proved that the bridgewire was not broken during loading.

(CRD) The density of powder on the bridgewire ranged from 0.90 to 0.94 gm/cc. When the density is too low, the energy density will be too low to detonate the booster pellet; when it is too high, the exploding wire cannot initiate a detonation in the powder. Preliminary tests indicated that the booster pellet could not be detonated reliably at powder densities below 0.9 gm/cc on the bridgewire. Although insufficient explosive was available to investigate the particle size of the explosive powder, it also affects the ease of initiation. In general, small particles of approximately 0.5 micron diameter are more sensitive. HNAB and ABH were in this range, but NONA was about 100 microns in diameter and should be investigated in small particle sizes if this explosive is of further interest. All explosives were dried in a vacuum oven at 105°C for at least 1 hr to preclude desensitization by moisture.

(CRD) The density of the booster pellet should be high to produce a high pressure output as demonstrated by plate dents but should be low enough to be sensitive to detonation from the bridgewire powder. Densities ranged from 70 to 85% of maximum crystal density (TMD); NONA was the easiest to press to high density, and ABH was the hardest. At densities below 70% TMD, the pellets were too weak to handle. When more materials are available, the effect of density variations in the booster pellet should be determined.

2. Capsule Loading Procedures

(U) A standard capsule was developed and used for all samples of explosives and propellants irradiated in the program to date. The capsule (Figure 33) has an aluminum body of 2-1/8 in. OD and 9-in. length, with a 0.32-in.-dia 5-in.-long center hole in which the sample is placed. Most samples

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Figure 33 - Components of Noninstrumented Capsule

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were loaded in a 0.25-in.-dia quartz vial which was placed in this center hole. The six outer holes provided for shock attenuation and gas-expansion volume. The webs between the holes provide paths for heat flow from the sample to the cooling water. Assembly details for the capsules are given in the Phase I-A test specification (Ref. 10).

(U) Modifications were made to permit insertion of a copper-constantan thermocouple into the sample to measure internal temperature and pressure during irradiation of selected capsules. These data were recorded during irradiation and were used to determine exposure limits and rates of decomposition based on gas release. A sketch of the modified capsule is shown in Figure 34, and a photograph of the loaded capsules is shown in Figure 35. An X-ray of a loaded, instrumented capsule is shown in Figure 36. The temperature monitors and the nickel flux wire appear as black wires in the X-ray. The aluminum-cobalt flux wire is the same density as the capsule, so is not visible.

(U) When the detonators were irradiated, the quartz tube was not required because the detonators had their own casings. An X-ray of a loaded capsule containing detonators is shown in Figure 37. As shown in Figure 38, capsules were loaded in a helium-filled glove box to prevent reactions with oxygen from increasing sample decomposition.

(U) Loaded capsules were irradiated in the General Electric Test Reactor (GETR), Vallecitos Nuclear Center, Pleasanton, California. The Z-trail cable irradiation facility was used so the samples could be inserted and removed during reactor operation. Details of the general irradiation procedures have been given in the test specifications for this program (Ref. 5 through 9).

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Figure 34 - Instrumented-Capsule Assembly

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Figure 35 - Loaded Capsules

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Figure 36 - X-Ray of Instrumented Capsule

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Figure 37 - X-Ray of Noninstrumented Capsules

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Figure 38 - Capsule Loading in Helium Atmosphere

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3. Phase I-A Irradiation Procedures

a. Objectives

(U) The objectives of the Phase I-A irradiation procedures were:

(U) 1. Irradiation of three instrumented and twelve non-instrumented Aerojet capsules at peak flux positions in the Z-trail cable facility.

(U) 2. Evaluation of the properties of explosives from previously irradiated capsules before irradiating the second or third capsule in the series.

b. Methods

The irradiation methods were as follows:

(U) 1. Each instrumented capsule was irradiated until a pressure of 12 psig or a temperature of 250°C was reached. The time was recorded and the capsule was removed for decay and transfer.

(U) 2. Half of the total time of irradiation for each instrumented capsule was used as the time requirement for the series of non-instrumented explosive capsules (suffixes N-2, O-2, and T-2).

(U) 3. Irradiation procedures are detailed on Pages 14 and 15 of the Phase I-A Data Package (Ref. 10).

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(CRD) 4. The DAB-1 and ADJ-1 noninstrumented capsules were irradiated for a 2-hr period as scheduled. Irradiation periods for subsequent capsules of this series were determined by evaluating the previously irradiated materials. Because excessive damage occurred to DAB-1 and ADJ-1, irradiation of capsule ADN-1 was reduced to 1 hr, and capsules DAB-2, ADJ-2 and ADN-2 were irradiated for 1/2 hr at peak flux. Because 1/2 hr at peak flux still caused misfires, the last three capsules were irradiated for 2 hr at one-tenth the peak rate.

(U) 5. Capsules ADJ-3 and ADN-3 were assembled remotely in the hot cell by using capsule bodies from two previously irradiated instrumented assemblies plus new components. These were noninstrumented capsules and were sent to GETR in a return cask shipment.

c. Irradiation Schedule

(U) The Phase I-A capsules were irradiated in GETR Cycle 81, starting 28 October 1966 and ending 3 November 1966, with the reactor operating at a continuous power level of 50 Mw. There were no reactor scrams during this period. The sample irradiation schedule and exposure times are shown in Table 12. Analyses of samples in the RML were started 31 October 1966 and were completed 4 November 1966. Samples of explosives will be sent to NOL for thin-layer chromatography after their induced radioactivity has decayed.

d. Post Irradiation Procedures

(U) After irradiation, capsules were disassembled remotely in the GE Radiological Materials Laboratory (RML), and then analyzed in a special laboratory set up to handle radioactive explosive materials (Figure 39). This procedure allowed prompt analysis of the samples without waiting for radioactivity to decay. As a result, changes occurring after irradiation were

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Table 12
Phase I-A Irradiation Schedule (U)

Explosive	Capsule	Irradiation Time (min)						Remarks
		10/28/66 Friday	10/29/66 Saturday	10/31/66 Monday	11/1/66 Tuesday	11/2/66 Wednesday	11/3/66 Thursday	
TNN	AEN-1	81						Instrumented
TNN	AEN-2				40			
ONT	AEO-1	54						Instrumented
ONT	AEO-2			30				
TNB	AET-1	40						Instrumented
TNB	AET-2				20			
ABH	DAB-1		120					
ABH	DAB-2			30				
ABH	DAB-3					120*		
NONA	ADJ-1		120					
NONA	ADJ-2			30				
NONA	ADJ-3						120*	
HNAB	ADN-1		60					
HNAB	ADN-2				30			
HNAB	ADN-3						120*	
*Reduced flux, others at peak flux.								

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Figure 39 - RML Explosives Laboratory

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minimized, and data on the analyzed samples could be used to determine the exposures of interest for subsequent samples irradiated in the same series.

(U) Equipment was set up at the GE RML for the following tests:

1. Gas-release volume
2. Weight loss
3. Open ampule and determine condition of temperature monitors
4. Explosion temperature
5. Detonation velocity, $\frac{1}{4}$ -in-dia cylinder and MDF
6. Strand burning rate for propellants
7. Melting point
8. Differential thermal analysis
9. Thermogravimetric analysis
10. Vacuum stability
11. Detonator firing and measurement of
 1. Firing current and voltage
 2. Explosion time
 3. Plate dent
12. Impact sensitivity (PA Machine)

After the induced radioactivity had decayed to less than 200 counts/min, the explosive samples could be shipped and handled as nonradioactive materials. Some samples were sent to Picatinny Arsenal for DTA, m.p., infrared, and X-ray diffraction analyses on the explosives, viscosity in acetone solution, and ultraviolet absorption of propellants. Some samples were also sent to NOL for thin-layer-chromatography analysis.

e. Test Procedures

(U) Test procedures were the same as for prior phases except for the detonator tests. Samples were analyzed before and after irradiation

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for weight loss, gas volume, explosion temperature, melting point, DTA, TGA, and vacuum stability. Gas-release volume was measured for all capsules before they were opened. Weight loss and bridgewire resistance were measured for all detonators; then they were fired and the firing voltage, current, function time, and plate dent were determined.

(U) Because of their high levels of induced radioactivity, the detonators were weighed and fired by using remote manipulators in the RML hot cell. The detonator firing fixture shown in Figure 40 was used for the test firing to confine the blast and fragments. The steel case also confined the RF interference caused by the high-voltage high-current firing pulse so function time could be measured. The equipment outside the cell is shown in Figure 41. Detailed procedures are given in Appendix C.

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Figure 40 - Detonator Firing Fixture

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Figure 41 - Detonator Firing Apparatus

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E. QUALITY CONTROL

(U) To satisfy contractual requirements and ensure the required end results, an effective quality-control program was established and maintained throughout the fabrication, loading, and testing of irradiation capsule assemblies.

(U) To the extent specified, the quality-control requirements followed AGC corporate Quality Control Standard No. H-3-2, which defines quality program administration requirements for compliance with NASA Quality Publication NPC 200-2, Quality Program Provisions for Space Contractors.

(U) All purchased raw materials required physical and chemical test reports, as applicable. Formal Inspection Instruction Sheets (IIS, Ref. Appendix F) requiring 100% inspection were used for all purchased and AGC-manufactured items, as well as for the loading and assembly functions.

(U) Minor discrepancies or nonconformities in manufactured hardware were handled by formal Material Review Forms (Engineering Review).

(U) Objective evidence of acceptance was maintained on all parts and operations, and records of inspections and acceptance tests were maintained for review.

(U) All assembled units were X-rayed for verification of proper assembly, and the results, as well as the Inspection Instruction Sheets for the assembly portion, were forwarded to GE for final review.

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F. PLANS FOR FURTHER WORK

(U) The Countermeasures Radiation Effects Program was divided into four major phases. The first phase, which has been completed and is the subject of this report, involved irradiation and testing of 1.8- and 3.6-gm samples to determine which materials were most radiation stable, what the effects of radiation were, and what the approximate exposure limits were for the best materials. The remaining three phases involve testing of larger quantities of explosives and propellants; therefore, a capsule capable of safely containing 80 gm of explosive was developed by Picatinny Arsenal with technical assistance from AGC. This capsule will be used in Phase II to determine the combined effects of heat and radiation on larger bulk samples of the best explosives and propellants and to make available larger samples of irradiated propellants and detonators for more accurate determination of the effects of radiation on their performance. (Phase III will be similar to Phase II except that the irradiated materials will be cooled to permit separation of temperature effects from radiation effects.) Phase IV will be used to test components and mockups of critical parts of the final destruct-system design and will simulate as closely as possible the environment to which these parts will be exposed during flights of a NERVA vehicle.

(U) Data on radiation-stable propellants and explosives have been obtained for preliminary countermeasure designs. Development of adequate countermeasures systems should start as soon as possible, and these design data should be used to determine the prototype radiation-effects tests needed in Phase IV. Basic material performance information from Phases II and III should be obtained before establishing the final system design, because the results of these phases will probably have a pronounced influence on the final design requirements.

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G. REFERENCES

1. Kamlet, M. J., Perspectives and Prospects for Research in High Energy Chemistry in 1966-1975. I. Heat Resistant Explosives (U), NOLTR 65-220, Naval Ordnance Lab, Silver Spring, Md., 24 May 1966. (C)
2. Final Test Report for Phase I-C, Countermeasures Radiation Effects Program (U), AGC REON Report RN-S-0280, March 1966. (CRD)
3. Final Test Report for Phase I-B, Countermeasures Radiation Effects Program (U), AGC REON Report RN-S-0217, April 1965. (CRD)
4. Final Test Report for Phase I, Countermeasures Radiation Effects Program (U), AGC REON Report RN-S-0210, April 1965. (CRD)
5. Final Test Report for Phase I-D, Countermeasures Radiation Effects Program (U), AGC REON Report RN-S-0268, November 1965. (CRD)
6. Final Test Specifications for Phase I of the Countermeasures Radiation Effects Program (U), Addendum to REON Report No. 2510, December 1963. (U)
7. Final Test Specifications for Phase I-B of the Countermeasures Radiation Effects Program (U), Addendum No. 2 to REON Report No. 2510, September 1964. (CRD)
8. Final Test Specifications for Transient Nuclear Test (KIWI-TNT) of the Countermeasures Radiation Effects Program (U), Addendum No. 3 to REON Report No. 2510, December 1964. (U)
9. Final Test Specifications for Phase I-C of the Countermeasures Radiation Effects Program (U), REON Report No. RN-S-0235, Addendum No. 4 to Report No. 2510, July 1965. Vol I (U), Vol II (CRD)
10. Final Test Specifications for Phase I-A of the Countermeasures Radiation Effects Program (U), AGC REON Report No. RN-S-0324, September 1966. Vol I (U), Vol II (CRD)
11. Loftus, J. J. and Gross, D., Thermal and Self-Ignition Properties of Six Explosives, NBS Report No. 6548, September 1959. (U)
12. Fedoroff, B. T., and Sheffield, O. E., Encyclopedia of Explosives and Related Items, PATR 2700, Vol. 2, pp B48 and pp B292, Picatinny Arsenal, Dover, N.J. (1962). (U)
13. Andrew, K. K., et al, Theory of Explosives, Machine Translation from Russian, FTD MT 63-254, AD 605-706, January 1964. (U)
14. Velicky, R. W., Botteo, L. A., Thermal Conductivity and Heat of Reaction of DATB (U), PA TR 65-VG4-8, November 1965. (C)

UNCLASSIFIED

15. Murphy, M. F. and Coleburn, N. L., Preliminary Evaluation of TACOT, a New Heat Resistance Explosive (U), NOLTR 61-155, November 1961. (C)
16. Kury, J. W., Lawrence Radiation Lab, Private communication.
17. Mader, C. L., Detonation Properties of Condensed Explosives Computed Using the BKW Equation of State, LASL Report LA 2900, July 1963. (U)
18. Jaklevick, J. F., Countermeasures Radiation Effects Program, Phase I-B Summary and Final Report (U), GEIC-1011, March 1965. (C)
19. Taylor, F. and Oesterling, R. E., Heat Resistant Explosives XX Preparation of HNS II, NOLTR 65-142, August 1965. (C)
20. Sadlon, P., Rover Flight Safety Program - Preliminary Review, Volume III Part B Post Operational Destruct System, PATM 1746, December 1965. (CRD)
21. Kenworthy, H., Pulse Sensitive Electro-Explosive Devices, AGC Report 0689-01 (10)FP, June 1963.
22. Morgan, W. C., Synthesis, Processing, and Evaluation of HNAB for EBW Detonator Explosive and Other Applications II, LMSCR 72026, July 1964.
23. Dare, J. A., "Data on ABH", Letter to W. Voreck, #D2502, December 1965. (C)
24. Leopold, H. S., "Initiation of Explosives by Exploding Wires", NOLTR 65-127, November 1965. (C)
25. Visnov, M., PAD Propellants for Use at High Temperatures, Frankford Arsenal Report R-1773 Part I, AD 366-853, September 1965.
26. Simmons, R. L., Dev. of High Temp-Resistant Propellants, Hercules Powder Co., FA Report R-1703, AD 430-591, January 1964.
27. Zimmerman, G., Development of Solid Composite Propellants for High Temperature Operation, Aerojet-General Corp. Report 0110-01-SR1, July 1958. (C)
28. Rosen, J. M., and Dacons, J. C., Relationship of Thermal Stability with Structure of Organic High Explosives, I, Trinitrophenyl Derivatives with an Alpha C-H Linkage, NOLTR 62-192, November 1962. (C)
29. Hoffsommer, J. C., Analysis of Complex Explosive Mixtures by Means of Thin Layer Chromatography (U), NOLTR 65-207, November 1965. (C)
30. Hoffsommer, J. C., NOL, Silver Spring, Md., letter to W. Voreck, 1/18/67.
31. Bolt, R. L., and Carroll, J. G., Radiation Effects on Organic Materials, Academic Press, N.Y., 1963.

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32. Kircher, J. F. and Bowman, R. E., Effects of Radiation on Materials and Components, Reinhold Pub. Co., N.Y. (1964).
33. Rogers, R. N., Thermal Initiation of Explosives, Ind. and Eng. Chem., Prod. Research & Dev., Vol 1, p. 169, 1962.
34. Chance, W. G. and Moore, H. K., Exploding Wires, Vol. III, Plenum Press, N.Y. (1964).

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APPENDIX A

PHASE I-A RADIATION EXPOSURES

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Table 13
Phase I-A Thermal-Neutral Flux Analysis (U)

Phase IA Thermal Neutron Flux Analysis
(<0.17 ev)

Capsule No.	$\frac{\text{dps Co-60}}{\text{gm Co}}$ 11-9-66	Flux Rate (n/cm ² sec)	Integrated Total Dose (n/cm ²)
HIGH RATE			
AEN-1	1.05×10^9	1.54×10^{14}	7.48×10^{17}
ADJ-1	1.46×10^9	1.40×10^{14}	10.1×10^{17}
AEO-1	6.83×10^8	1.47×10^{14}	4.76×10^{17}
ADN-1	6.93×10^8	1.34×10^{14}	4.83×10^{17}
AET-1	5.22×10^8	1.51×10^{14}	3.63×10^{17}
AEO-2	4.05×10^8	1.56×10^{14}	2.81×10^{17}
ADJ-2	3.48×10^8	1.34×10^{14}	2.42×10^{17}
ADN-2	3.54×10^8	1.37×10^{14}	2.47×10^{17}
AEN-2	5.13×10^8	1.49×10^{14}	3.57×10^{17}
AET-2	2.53×10^8	1.47×10^{14}	1.76×10^{17}
Average High Rate		1.45×10^{14}	
LOW RATE			
DAB-3	1.09×10^8	1.06×10^{13}	7.60×10^{16}
ADN-3	1.34×10^8	1.30×10^{13}	9.38×10^{16}
ADJ-3	1.32×10^8	1.28×10^{13}	9.18×10^{16}
Average Reduced Rate		1.21×10^{13}	

Table 14
Phase I-A Fast-Neutron Flux Analysis (U)

Phase IA Fast Neutron Flux Analysis
(>0.18 Mev).

Capsule No.	<u>dps Co-58</u> gm Co 11-10-66	Flux Rate (n/cm ² sec)	Integrated Total Dose (n/cm ² sec)
HIGH RATE			
AEN-1	7.59×10^6	2.50×10^{13}	1.22×10^{17}
ADJ-1	1.09×10^7	2.36×10^{13}	1.70×10^{17}
AEO-1	4.63×10^6	2.20×10^{12}	7.12×10^{16}
ADN-1	5.20×10^6	2.22×10^{13}	8.00×10^{16}
AET-1	3.76×10^6	2.40×10^{13}	5.77×10^{16}
AEO-2	2.94×10^6	2.45×10^{13}	4.42×10^{16}
ADJ-2	2.75×10^6	2.29×10^{13}	4.12×10^{16}
ADN-2	2.65×10^6	2.20×10^{13}	3.95×10^{16}
AEN-2	3.75×10^6	2.35×10^{13}	5.64×10^{16}
AET-2	1.79×10^6	2.23×10^{13}	2.68×10^{16}
Average Peak Rate		2.32×10^{13}	
LOW RATE			
DAB-3	7.00×10^5	1.43×10^{12}	1.03×10^{16}
ADN-3	9.00×10^5	1.83×10^{12}	1.32×10^{16}
ADJ-3	7.78×10^5	1.58×10^{12}	1.14×10^{16}
Average Reduced Rate		1.61×10^{12}	
Notes: Multiply by 0.553 to get n/cm ² /sec >1.0 Mev. Multiply by 1.47 to get n/cm ² /sec between 0.17 ev and 0.18 Mev. Multiply by 0.6 to get n/cm ² /sec >0.9 Mev.			

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Table 15
Phase I-A Gamma Exposures (U)

Capsule No.	Exposure Time (min)	Integrated Total Dose	
		ergs/gm(c) x 10 ¹⁰	R x 10 ⁸
AT PEAK FLUX			
AEN-1	81	7.2	8.2
DAB-1	120	10.9	12.4
ADJ-1	120	10.9	12.4
AEO-1	54	4.9	5.6
ADN-1	60	5.4	6.2
AET-1	40	3.6	4.1
AEO-2	30	2.7	3.1
DAB-2	30	2.7	3.1
ADJ-2	30	2.7	3.1
ADN-2	30	2.7	3.1
AEN-2	40	3.6	4.1
AET-2	20	1.8	2.1
AT REDUCED FLUX			
ADN-3	120	2.6	3.0
ADJ-3	120	2.6	3.0
DAB-3	120	2.6	3.0
Average peak flux		6.2 x 10 ⁸ R/hr, or 5.44 x 10 ¹⁰ ergs/gm(c)/hr	
Average reduced flux		1.5 x 10 ⁸ R/hr, or 1.31 x 10 ¹⁰ ergs/gm(c)/hr	

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APPENDIX B

CALIBRATION OF EBW CURRENT TRANSFORMER

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APPENDIX B

I. INSTRUMENTATION SYSTEM

(U) A substantial part of the experimental phase of the detonator program involved development of a multioscilloscope instrumentation system that would yield reliable data. The two major instrumentation problems were interference caused by electromagnetic radiation from the capacitor-bank system and ground loops in the interconnected electronic equipment.

(U) The high current through the exploding wire was measured by means of a current transformer in the firing circuit. Since $\phi = Li$, the rate of change in the magnetic flux, $d\phi/dt$, is proportional to di/dt ; thus a transformer can be calibrated to indicate di/dt by using an amplifier (Tektronix Type-G) and an oscilloscope (Tektronix 555). The current, i , was readily obtained by electronically integrating di/dt with a Tektronix Type-0 operational amplifier having $Z_i = 10,000$ ohms and $Z_f = 100 \mu\mu f$ so that $RC = 1 \mu\text{sec}$.

II. DERIVATION OF R, L, AND $di/dt|_{t=0}$

(U) The transformer output has a high-frequency oscillation (caused by the spark gap in the switch) superimposed on the first portion of the di/dt wave form, which makes it impossible to determine the exact value of I_0 or $di/dt|_{t=0}$ directly from the oscilloscope trace.

(U) The capacitor-bank discharge into the inductive firing system (cables, switch, and detonator) appears as a highly damped oscillating wave form. Because the discharge oscillations are highly damped, the experimental measurement of circuit resistance, inductance, and current is made more difficult.

(U) The terms used are defined as follows (also see Figure 42):

$$\omega_n = \frac{1}{\sqrt{LC}}, \text{ the undamped natural angular velocity.}$$

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Figure 42 - Oscilloscope Record Indicating Parameters Used in Obtaining R, L, and I

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$$\omega = \omega_n \sqrt{1 - \zeta^2} ; \text{ the actual angular velocity } = \sqrt{\frac{1}{LC} - \frac{R^2}{4L^2}} .$$

$$\zeta = \frac{R}{2} \sqrt{\frac{C}{L}} , \text{ the damping ratio.}$$

$$\zeta \omega_n = \text{ the attenuation factor.}$$

$$t_1 = \text{ time at which first minimum occurs.}$$

$$t_2 = \text{ time at which second minimum occurs.}$$

$$T = t_2 - t_1, \text{ the period of oscillation between the first two minima.}$$

$$V_C = \text{ initial capacitor-bank voltage.}$$

$$L = \text{ total circuit inductance.}$$

$$R = \text{ total circuit resistance.}$$

$$C = \text{ the total circuit capacitance. (In practice, the capacitance of the calibrated capacitor bank constitutes approximately 99.995\% of the total circuit capacitance; thus, all other capacitance may be neglected.)}$$

The equation for the discharge current is that of the classic RLC circuit:

$$i = \frac{V_c}{\omega_n L \sqrt{1 - \zeta^2}} e^{-\zeta \omega_n t} \sin (\omega_n \sqrt{1 - \zeta^2} t) \quad (1)$$

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Taking the first derivative gives

$$\frac{di}{dt} = \frac{V_c}{\omega_n L \sqrt{1 - \zeta^2}} e^{-\zeta \omega_n t} \left[\omega_n \sqrt{1 - \zeta^2} \cos (\omega_n \sqrt{1 - \zeta^2} t) - \zeta \omega_n \sin (\omega_n \sqrt{1 - \zeta^2} t) \right]. \quad (2)$$

Taking the second derivative and setting the resulting equation equal to zero gives the conditions for maximum and minimum values of di/dt :

$$\omega t = \tan^{-1} \frac{2\zeta \sqrt{1 - \zeta^2}}{2\zeta^2 - 1} + n\pi \quad (n = 0, 1, 2, 3, \dots). \quad (3)$$

The first two minima are:

$$\omega t_1 = \tan^{-1} \frac{2\zeta \sqrt{1 - \zeta^2}}{2\zeta^2 - 1}; \quad (4)$$

$$\omega t_2 = \tan^{-1} \frac{2\zeta \sqrt{1 - \zeta^2}}{2\zeta^2 - 1} + 2\pi. \quad (5)$$

The amplitudes of the first two di/dt minima are:

$$\left. \frac{di}{dt} \right|_{t=t_1} = \frac{V_c}{\omega_n L \sqrt{1 - \zeta^2}} e^{-\zeta \omega_n t_1} \left[\omega_n \sqrt{1 - \zeta^2} \cos \left(\tan^{-1} \frac{2\zeta \sqrt{1 - \zeta^2}}{2\zeta^2 - 1} \right) - \zeta \omega_n \sin \left(\tan^{-1} \frac{2\zeta \sqrt{1 - \zeta^2}}{2\zeta^2 - 1} \right) \right] \quad (6)$$

and

$$\left. \frac{di}{dt} \right|_{t=t_2} = \frac{V_c}{\omega_n L \sqrt{1 - \zeta^2}} e^{-\zeta \omega_n t_2} \cdot \left[\omega_n \sqrt{1 - \zeta^2} \cos \left(\tan^{-1} \frac{2\zeta \sqrt{1 - \zeta^2}}{2\zeta^2 - 1} + 2\pi \right) - \zeta \omega_n \sin \left(\tan^{-1} \frac{2\zeta \sqrt{1 - \zeta^2}}{2\zeta^2 - 1} + 2\pi \right) \right]. \quad (7)$$

Dividing Equation 6 by Equation 7 and simplifying gives:

$$\frac{\left. \frac{di}{dt} \right|_{t=t_1}}{\left. \frac{di}{dt} \right|_{t=t_2}} = e^{\zeta \omega_n (t_2 - t_1)} \quad (8)$$

$$\text{or } \zeta \omega_n = \frac{\ln \left(\frac{\left. \frac{di}{dt} \right|_{t=t_1}}{\left. \frac{di}{dt} \right|_{t=t_2}} \right)}{t_2 - t_1} \quad (9)$$

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Using the definition of terms and the basic equation $T = \frac{2\pi}{\omega}$ relating period and angular velocity gives

$$T = \frac{2\pi}{\sqrt{\frac{1}{LC} - \frac{R^2}{4L^2}}} \quad (10)$$

Solving Equation 10 for L gives

$$L = \frac{T^2}{C \sqrt{4\pi^2 + \frac{R^2 T^2}{4L^2}}} \quad (11)$$

However,

$$\frac{R}{2L} = \zeta \omega_n = \frac{\ln \left(\frac{\frac{di}{dt} \big|_{t=t_1}}{\frac{di}{dt} \big|_{t=t_2}} \right)}{t_2 - t_1} \quad (\text{Equation 9}).$$

Thus, the equation for L becomes

$$L = \frac{(t_2 - t_1)^2}{C \left[4\pi^2 + \left(\ln \frac{\frac{di}{dt} \big|_{t=t_1}}{\frac{di}{dt} \big|_{t=t_2}} \right)^2 \right]} \quad (12)$$

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An equation for R can be obtained by substituting Equation 12 into Equation 9 and solving for R:

$$R = \frac{2(t_2 - t_1) \ln \left(\frac{\frac{di}{dt} \big|_{t=t_1}}{\frac{di}{dt} \big|_{t=t_2}} \right)}{C \left[4\pi^2 + \ln \left(\frac{\frac{di}{dt} \big|_{t=t_1}}{\frac{di}{dt} \big|_{t=t_2}} \right) \right]} \quad (13)$$

A current transformer has a voltage output given by $V_s = M \frac{di}{dt}$, where M is the mutual inductance of the transformer used. Thus, the voltage outputs of a transformer at three instants of time are given by:

$$A_o = M \frac{di}{dt} \bigg|_{t=0}; \quad (14)$$

$$A_1 = M \frac{di}{dt} \bigg|_{t=t_1}; \quad (15)$$

$$A_2 = M \frac{di}{dt} \bigg|_{t=t_2}; \quad (16)$$

Since $\frac{di}{dt} \bigg|_{t=0} = \frac{V_c}{L}$, Equation 14 becomes

$$A_o = \frac{MV_c}{L} \quad (17)$$

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By substituting Equations 15 and 16 into Equation 12, a new equation for L is derived that uses the transformer output wave form as recorded by an oscilloscope:

$$L = \frac{(t_2 - t_1)^2}{C \left[4\pi^2 + \left(\ln \frac{A_1}{A_2} \right)^2 \right]} \quad (18)$$

Also the equation for R becomes

$$R = \frac{2(t_2 - t_1) \ln \frac{A_1}{A_2}}{C \left[4\pi^2 + \left(\ln \frac{A_1}{A_2} \right)^2 \right]} \quad (19)$$

Since

$$\omega_n = \frac{1}{\sqrt{LC}},$$

$$\omega = \omega_n \sqrt{1 - \zeta^2} = 2\pi f;$$

and

$$\zeta = \frac{R}{2} \sqrt{\frac{C}{L}};$$

$$\zeta \omega_n = \frac{R}{2L}.$$

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Substituting the results in Equation 1 gives

$$i = \frac{V_c}{\omega L} e^{-\frac{Rt}{2L}} \sin \omega t \quad (20)$$

Since peak current ($i_{\max}$) occurs at the first quarter-cycle when $\sin \omega t = 1$,

$$i_{\max} = \frac{V_c}{2\pi f L} e^{-\frac{R}{8Lf}}. \quad (21)$$

The output of the current transformer was the rate of change of current with time, $\frac{di}{dt}$. This output was amplified by a Tektronix Type-G, wide-band, dc amplifier and was recorded by the Tektronix 555 oscilloscope, as shown by the trace that starts at a high level in Figure 42. The $\frac{di}{dt}$ trace was integrated to display current vs time by a Tektronix Type-0 operational amplifier ($Z_i = 10,000$ ohms, $Z_f = 100$ μ mf). The RG-58 cable connecting the oscilloscope to the transformer was terminated with a 52-ohm resistor to prevent reflections. The integrated trace starts at zero in Figure 42. Because of the integration, less RF interference occurred on the current trace; thus, in many detonator tests, this trace was more accurate than the $\frac{di}{dt}$ measurement.

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APPENDIX C

DETAILED PHASE I-A PROCEDURES

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APPENDIX C

I. INTRODUCTION

(U) Phase I-A involved fabrication of detonators, loading of capsules, irradiation of the capsules, and testing of the irradiated and nonirradiated materials. These procedures are discussed in the following sections as they were actually performed. Some of the proposed procedures described in the Phase I-A test specifications (Ref. 10) had to be modified.

II. PROCEDURES

A. DETONATOR FABRICATION

1. General

(U) Detonators were assembled at the AGC Ordnance Test Laboratory in Downey, California. Headers were purchased in accordance with the specifications shown on AGC Drawing 520203 (Figure 43). The aluminum bridgewires were soldered to the headers; the booster pellets were pressed, and the detonators were then assembled by the following procedures.

2. Soldering of Bridgewire to Header Assembly (PN 520428)

- a. Clean parts thoroughly with alcohol and dry at 150°F for 15 min.
- b. Use 90 v on regulator to control temperature of soldering tip.
- c. Stretch wire across face of header by crossing through center of pin and edge of case. Use United No. 150 low-temperature aluminum flux on wire at solder points.

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Figure 43 - Detonator Header

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- d. Pick up a minute particle of solder on tip and apply to edge of case. Pick up a little larger particle of solder on tip and apply to pin. Avoid getting solder on wire between connections.
- e. Neutralize parts in ammonia water.
- f. Clean thoroughly with alcohol and dry at 150°F for 15 min.
- g. Check bridgewire resistance from pin to case. Bridgewire resistance shall be: 0.03 ± 0.01 ohm for 520428-1, 0.05 ± 0.01 ohm for 520428-2.

B. DETONATOR LOADING (PN 520419)

1. Booster-Pellet Pressing

(U) The explosive pellets are formed by pressing the specified explosive in a pellet die. A predetermined amount of explosive is weighed and poured into the die and pressed at 18,000 psi for a dwell period of 1 min. The predetermined amount of explosive is calculated to produce a pellet length of 0.250 ± 0.010 in. Each pellet is identified after ejection from the die. The pellet length and diameter are measured with a micrometer and recorded. Each pellet is also weighed, and its density is computed and recorded.

2. Detonator Assembly

(U) The bridged header and body are assembled with a small amount of Eastman No. 910 compound on the threads and are tightened securely. This assembly is identified and weighed, and the depth of the charge holder is determined by micrometer measurement. A pellet is selected and the amount of explosive to be loaded is determined from the density desired and the charge-holder and pellet measurements. An amount of explosive that allows for loading losses is weighed and pressed into the charge holder to a stop point. To allow for variations in pellet lengths, shims of appropriate thickness are used to

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control the pressing-ram stop point. The low-density-explosive pressing allows several thousandths of an inch for compression after insertion of the pellet in order to ensure contact of the low-density explosive and the higher-density pellet. The aluminum closure disk is weighed, placed over the pellet, and pressed against the shoulder of the charge holder; and the charge holder is then crimped to complete the assembly. The assembled unit is weighed, and, with the previously recorded measurements, the density of the low-density load is computed and recorded.

(U) Copies of typical detonator inspection instructions and reports are shown in Appendix F.

C. IRRADIATION PROCEDURES

1. Noninstrumented Capsules

(U) Irradiation procedures for the noninstrumented capsules are described in Paragraph IV,B of Reference 4, pages 17 and 18.

2. Instrumented Capsules

(U) Irradiation procedures for the instrumented capsules are basically the same as described in Reference 4, but experience has shown minor changes to be desirable; therefore, the revised procedures are shown below:

a. Exercise caution when handling the instrumented capsules. Do not twist the aluminum tubing in relation to capsule or use it to support the capsule.

b. Connect the capsule to the pressure panel. Check to see that valves A, B, D, and E are closed. Make sure the valve from the capsule and valve C are open.

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c. Check the resistance of the thermocouple and the insulation resistance. Attach the thermocouple wires to the terminal strip on the panel.

d. Check to see that the steel cable and the tubing fittings are properly connected and are tight. Turn on the recorder.

e. Slowly open valve A and pressurize the panel and connection as far as the capsule valve (Hoke Valve, Figure 34) with helium to 50 psi. Shut off the helium valve and check to see that pressure does not decrease over a 5-min period. Check connections with a soap solution and tighten if necessary to stop leaks. Check the recorder against the indicator on the pressure gage.

f. Release the pressure in 10-psi increments by opening valve B, and mark the location of the recorder needle when the pressure gage shows 50, 40, 30, 20 and 10 psi, respectively. Bleed off pressure to zero and close valve B.

g. Open the capsule valve and then slowly open valve A to bleed helium into the capsule, or open valve B to remove helium, until zero pressure is indicated.

h. Carefully lower capsule into location of peak flux in Z-trail cable facility.

i. Record initial time, temperature, and pressure, plus the same data as recorded for noninstrumented capsules.

j. Check pressure gage against recorder readings and mark the chart periodically with gage readings and time.

k. Watch the temperature and pressure recordings; stop irradiation if pressure exceeds 12 psi or if temperature exceeds 250°C.

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1. Discontinue radiation after 5 hr (if not stopped sooner) by withdrawing the capsule from the irradiation zone and recording data as before.

m. Open valve D to the vent tank to reduce pressure to below atmospheric. Close valves and disconnect the tubing and thermocouples from the panel.

n. Transfer the capsule to the reactor canal.

o. After samples have cooled in the canal, withdraw the capsule and place it in the transfer cask; coil up the aluminum tube in the process.

3. Postirradiation Procedures

(U) Irradiated capsules will be allowed to cool in the reactor pool until 6 a.m. and will then be transferred to the RML by 7:30 a.m.

(U) The procedure for transferring irradiated capsules from the test reactor (GETR) to the Radiological Materials Laboratory (RML), as well as for RML (hot cell) operations such as gas-release measurement and capsule disassembly, will be the same as described in Paragraph D of Reference 4 (pages 19 through 28).

D. TESTING PROCEDURES

1. Explosive Testing

(U) Pressure will be measured in the three noninstrumented explosive capsules (AEN-2, AEO-2, and AET-2). The noninstrumented capsules will then be opened by using a lathe to cut the tops of the capsules off near the retainer disk. Instrumented capsules will be opened by removing the 12 cap

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screws and the cap. Thermocouples will be removed from the three instrumented capsules (AEN-1, AEO-1, and AET-1), and the quartz vials from the six capsules containing explosives (AEN-1 and -2, AEW-1 and -2, and AET-1 and -2) will be transferred to the RML basement laboratory for analysis, as in Phase I-C.

(U) Tests will include:

- a. Weight loss
- b. DTA
- c. TGA
- d. Explosion temperature
- e. Vacuum stability
- f. Melting point (on AET-1 and AET-2 only)

Excess material will be saved and sent to the Naval Ordnance Laboratory for thin-layer chromatography. Control tests will be made on these explosives and on the explosives used in the detonators. Procedures for these tests are the same as reported in References 2 and 4.

(U) Flux wires will be removed and sent to the GE chemistry laboratory for counting. Temperature monitors will be removed, and the temperature ranges of the samples will be reported. No propellant samples will be tested in this series. Samples from capsules AET-1 and AET-2 will have melted during irradiation, and the quartz vials will have to be crushed to remove them, as was done with the melted samples in Phase I.

2. Detonator Testing

(U) A total of four detonators, two temperature monitors, and two flux wires will be loaded into each of six capsules (ADN-1, ADN-2, ADJ-1, ADJ-2, DAB-1 and DAB-2). Although the internal explosives will vary, all units will use the same outer case and assembly.

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(U) Two capsules of each type of detonator will be irradiated. The first capsule will be irradiated for a length of time approaching its threshold, as determined from the prior phases. After testing, the dosage of the second capsule of the same detonator will be established in an attempt to bracket the exposure dosage at which significant performance changes occur.

(U) After irradiation, the capsules will be transported to the RML for opening and analysis. The capsules will be opened in the standard manner, either by removal of the 12 cap screws or by cutting off the top at the inner end of the blast cup. Enough clearance has been allowed (0.006 to 0.013 in.) to allow the detonators to slide out of the center hole of the capsule. However, if necessary, the bottom of the capsule could be cut off about 1 in. above the bottom to allow the detonators to be pushed out. The X-ray of the capsule will be measured to determine the exact location of the cut.

(U) After removal from the capsule, the temperature monitors should be transferred to the basement laboratory for examination and the flux wires to the chemistry laboratory for counting. The induced radioactivity of the detonators will be high enough so that it will be preferable to test fire them in the RML hot cell. They will be loaded into the firing chamber and fired. A firing rack, a Moran 101 raster oscilloscope, and a Tektronix 555 dual-beam oscilloscope will be located outside the cell.

(U) The loading and firing procedure for detonators will be as follows:

- a. Weigh individual detonators on an analytical balance.
- b. Measure resistance of the bridgewire by inserting it in the bridgewire test fixture connected to the Kelvin bridge.

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- c. Open firing box and clean inside. Save witness block from prior test; discard rest of residue.
- d. Check bridgewire resistance on Kelvin bridge.
- e. Check firing-cable resistance.
- f. Put steel support washer around glass-to-metal seal of detonator to be tested.
- g. Plug detonator pin into insulated socket, place this subassembly in the firing chamber, and attach firing lead.
- h. Put confining sleeve and contact spring around detonator.
- i. Put witness block on top of detonator face, and connect pin wires to clip leads.
- j. Check witness-block connections.
- k. Put cover on firing chamber.
- l. Check continuity of firing circuit and bridgewire with an ohmmeter.
- m. Set oscilloscope voltage gain (2 v/cm if below 10 kv, 5 v/cm if above 10 kv).
- n. Check Tektronix oscilloscope:
 - (1) Trigger level
 - (2) Intensity
 - (3) Film in camera
 - (4) Reset trigger

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- o. Check rasterscope:
 - (1) High voltage on
 - (2) Raster appearance (switch in 1 NT)
 - (3) Close viewing ports on windows
 - (4) Check film in cameras
 - (5) Battery connected
 - (6) Turn raster switch to fire
 - (7) Trigger-reset light on
- p. Connect firing cable to panel.
- q. Charge high-voltage capacitor.
- r. Disconnect high-voltage power supply.
- s. Open shutters.
- t. Fire detonator.
- u. Develop film and identify.
- v. Disconnect battery.
- w. Remove plate and measure dent.
- x. Clean shot can.

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APPENDIX D

DETONATOR DATA

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APPENDIX D

I. ASSEMBLY

(U) Detailed detonator assembly and testing data are tabulated in this section. Loading data are given in Tables 16 and 17. Critical items are: density of powder on bridgewire, resistance of bridgewire, and booster-pellet density.

(U) The values of bridgewire resistance shown are those measured after loading and after irradiation. Before loading, bridgewire resistance was 0.02 to 0.06 ohms.

II. FIRING DATA

(U) Detailed data obtained from test-firing the 122 prototype detonators are given in Tables 18 and 19. Development of the firing unit and diagnostic procedures was performed at the same time that the prototype detonators were being tested at Aerojet; therefore, data were not always obtained during this period, and the accuracy of some measurements is questionable. Some tests were made by using steel witness blocks (marked St1), but dents were so small that accurate measurement was difficult. The remainder of the tests were made with 1/2-in.-thick 6061-T6 aluminum witness blocks.

(CRD) Many of the tests were made with TRIAX cable because of its low impedance. However, its insulation resistance was too low, and arcing occurred during firing, although resistance was high when checked at lower voltages. The accuracy of data obtained while using TRIAX cable are therefore questionable, particularly the abnormally high currents measured while firing ADJ detonators at Aerojet. After the TRIAX was replaced with RG-8 cable for the final tests at Aerojet and those at GE, no further arcing was apparent.

(U) The time of wire burst was indicated by a momentary drop in firing current. High-frequency interference made it difficult to obtain consistently accurate measurements of this time on the oscilloscope traces.

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Table 16

Loading Data for Prototype Detonators Tested at GE (U)

Sheet 1 of 2

Detonator No.	Explosive	Bridgewire			Bridgewire Charge		Booster Pellet			Total Detonator Weight** (gm)
		Length (in.)	Diameter (in.)	Resistance (ohms)	Weight (gm)	Density (gm/cc)	Weight (gm)	Length (in.)	Density (gm/cc)	
ADN-23*	HNAB	0.095	0.002	0.095	0.1777	0.925	0.2465	0.245	1.490	2.6638
-24*	↑	↑	↑	0.045	0.1717	0.921	0.2570	0.252	1.510	2.7024
-25*				0.088	0.1656	0.922	0.2620	0.257	1.510	2.7185
-26*				0.091	0.1661	0.928	0.2560	0.256	1.482	2.7262
-11				0.065/2.3 K	0.1560	0.927	0.2547	0.252	1.497	2.7028
-12				0.060/15 K	0.1700	0.918	0.2517	0.248	1.500	2.6756
-13				0.060/1 K	0.1667	0.908	0.2548	0.253	1.489	2.7062
-14				0.080/1.15K	0.1644	0.923	0.2475	0.249	1.470	2.7029
-15				0.035/1.5	0.1613	0.913	0.2550	0.265	1.424	2.6705
-16				0.040/35 K	0.1675	0.902	0.2350	0.245	1.420	2.6807
-17				0.070/7.0	0.1625	0.908	0.2510	0.247	1.502	2.7194
-18				0.030/3.13	0.1697	0.920	0.2573	0.252	1.511	2.7345
-19				0.415/0.61	0.1735	0.923	0.2536	0.250	1.498	2.7099
-20				0.025/0.087	0.1681	0.920	0.2567	0.255	1.491	2.6798
-21				0.045/0.103	0.1537	0.905	0.2630	0.260	1.497	2.6560
-22	HNAB	0.095	0.002	0.930/00	0.1708	0.923	0.2590	0.253	1.512	2.7238
DAB-1*	ABH	0.095	0.004	0.0160	0.1700	0.912	0.2370	0.252	1.405	2.7067
-2*	↑	↑	↑	0.0171	0.1728	0.938	0.2440	0.258	1.390	2.7430
-8*				0.0180	0.1734	0.896	0.2365	0.245	1.425	2.6953
-9*				0.0151	0.1762	0.925	0.2381	0.249	1.420	2.6993
-3				0.0242	0.1650	0.900	0.2400	0.260	1.363	2.6830
-6				0.0198	0.1622	0.900	0.2394	0.264	1.340	2.7172
-11				0.0745	0.1640	0.902	0.2460	0.256	1.419	2.6744
-12				0.0332	0.1679	0.900	0.2270	0.242	1.386	2.6553
-13				0.0310	0.1690	0.900	0.2210	0.245	1.332	2.6780
-14				0.0370	0.1654	0.914	0.2313	0.241	1.420	2.6326
-15				0.0237	0.1521	0.917	0.2501	0.275	1.345	2.6804
-16				0.0396	0.1578	0.911	0.2423	0.268	1.343	2.6735
-17				0.0442/0.53	0.1608	0.907	0.2425	0.257	1.400	2.6724
-18				0.0240/0.096	0.1608	0.910	0.2425	0.259	1.387	2.7133
-19				0.0368/0.072	0.1670	0.913	0.2395	0.254	1.395	2.7325
-20	ABH	0.095	0.004	0.0210/0.051	0.1780	0.928	0.2236	0.240	1.380	2.6725

*Control

**Before irradiation

Table 16

Loading Data for Prototype Detonators Tested at GE (U)

Sheet 2 of 2

Detonator No.	Explosive	Bridgewire			Bridgewire Charge		Booster Pellet			Total Detonator Weight** (gm)
		Length (in.)	Diameter (in.)	Resistance (ohms)	Weight (gm)	Density (gm/cc)	Weight (gm)	Length (in.)	Density (gm/cc)	
ADJ-30*	NONA ↑ ↑ ↑ ↑ ↑ ↑ ↑ ↑ ↑ ↑ ↓ ↓ ↓ ↓	0.095	0.004	0.055	0.1516	0.922	0.2693	0.248	1.603	2.7022
-40*				0.035	0.1599	0.903	0.2720	0.253	1.588	2.7042
-41*				0.190	0.1735	0.910	0.2715	0.249	1.600	2.7331
-42*				0.025	0.1646	0.918	0.2732	0.253	1.597	2.7317
-31				0.043/200 K	0.1690	0.915	0.2710	0.253	1.583	2.7138
-32				0.021/90 K	0.1555	0.916	0.2810	0.259	1.600	2.7342
-33				0.035/150 K	0.1632	0.913	0.2800	0.257	1.610	2.7482
-34				0.020/27.5K	0.1603	0.918	0.2725	0.250	1.610	2.6645
-35				0.025/5 M	0.1589	0.915	0.2731	0.250	1.610	2.6827
-36				0.015/7 K	0.1643	0.917	0.2733	0.251	1.610	2.7512
-38				0.022/2.3	0.1668	0.912	0.2712	0.250	1.604	2.6883
-39				0.010/12.5K	0.1657	0.916	0.2723	0.251	1.603	2.7308
-21				0.021/0.046	0.1666	0.924	0.2663	0.246	1.605	2.7168
-22				0.024/1.92	0.1490	0.905	0.2757	0.254	1.607	2.6658
-23	0.018/0.085	0.1552	0.918	0.2756	0.255	1.600	2.7050			
-24	NONA	0.095	0.004	0.018/0.070	0.1646	0.907	0.2718	0.251	1.602	2.7045
*Control **Before irradiation										

Table 17

Loading Data for Development Detonators Tested at AGC (U)

Sheet 1 of 2

Detonator No.	Explosive	Bridgewire			Bridgewire Charge		Booster Pellet			Total Detonator Weight (gm)
		Length (in.)	Diameter (in.)	Resistance (ohms)	Weight (gm)	Density (gm/cc)	Weight (gm)	Length (in.)	Density (gm/cc)	
ADN-1	HNAB	0.040	0.002	0.068	0.187	0.950	0.245	0.238	1.51	2.6865
-2	↑	↑	↑	0.083	0.173	0.950	0.264	0.257	1.51	2.6941
-3				0.045	0.182	0.950	0.253	0.246	1.53	2.7341
-4				0.030	0.183	0.960	0.257	0.247	1.54	2.7375
-5				0.057	0.179	0.960	0.262	0.253	1.54	2.7775
-6				0.046	0.180	0.975	0.263	0.256	1.52	2.6999
-7				0.033	0.181	0.960	0.260	0.249	1.55	2.7100
-8				0.048	0.179	0.970	0.260	0.252	1.54	2.7229
-9				0.098	0.181	0.970	0.261	0.253	1.52	2.7138
-10				0.047	0.185	0.985	0.261	0.254	1.52	2.7612
-1NS		0.040	0.004	0.045	0.160	0.890	0.259	0.253	1.52	2.7279
-2NS	↓	↓	↓	0.020	0.168	0.940	0.246	0.241	1.51	2.6813
-3NS				0.030	0.165	0.900	0.251	0.250	1.48	2.7075
-4NS				0.022	0.160	0.910	0.259	0.259	1.48	2.7250
-5NS		0.040	0.004	0.100	0.159	0.923	0.258	0.259	1.48	2.7069
-1NL		0.095	0.002	0.059	0.156	0.905	0.251	0.249	1.49	2.6422
-2NL		↓	↓	0.068	0.161	0.910	0.243	0.245	1.47	2.7375
-3NL				0.064	0.156	0.906	0.249	0.249	1.48	2.6661
-4NL				0.057	0.159	0.924	0.250	0.252	1.47	2.6455
-5NL				0.058	0.165	0.900	0.236	0.252	1.39	2.6582
-6NL				0.020	0.163	0.920	0.260	0.256	1.50	2.6694
-7NL				0.025	0.161	0.900	0.258	0.253	1.51	2.7420
-8NL				0.015	0.157	0.913	0.259	0.257	1.50	2.7185
-9NL		0.095	0.002	0.030	0.162	0.904	0.255	0.254	1.49	2.6681
-27	↑	0.095	0.004	0.045	0.172	0.903	0.250	0.240	1.53	2.7153
-28		↑	↑	0.085	0.161	0.918	0.247	0.244	1.49	2.6942
-29				0.055	0.157	0.908	0.259	0.262	1.47	2.6308
-30				0.065	0.168	0.919	0.260	0.257	1.50	2.6983
-31			0.004	0.035	0.169	0.918	0.254	0.255	1.48	2.7080
-32			0.002	0.025	0.162	0.935	0.259	0.253	1.52	2.6258
-33			↑	0.020	0.155	0.904	0.257	0.259	1.47	2.6455
-34				0.015	0.163	0.914	0.262	0.257	1.51	2.7263
-35	HNAB	0.095	0.002	0.010	0.167	0.913	0.263	0.255	1.52	2.6964

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Table 17

Loading Data for Development Detonators Tested at AGC (U)

Sheet 2 of 2

Detonator No.	Explosive	Bridgewire			Bridgewire Charge		Booster Pellet			Total Detonator Weight (gm)
		Length (in.)	Diameter (in.)	Resistance (ohms)	Weight (gm)	Density (gm/cc)	Weight (gm)	Length (in.)	Density (gm/cc)	
DAB-1A	ABH	0.095	0.004	0.17	0.138	0.82	0.229	0.252	1.36	2.6624
-2A				-	0.155	0.897	0.234	0.257	1.36	2.6971
-3A				0.09	0.142	0.82	0.222	0.241	1.365	2.6839
-4A				0.07	0.140	0.80	0.221	0.240	1.365	2.7212
-5A				0.07	0.136	0.765	0.228	0.246	1.37	2.7305
-6A				0.08	0.144	0.82	0.224	0.241	1.37	2.6800
-7A				0.17	0.141	0.84	0.241	0.261	1.37	2.7159
-8A				0.17	0.126	0.725	0.226	0.250	1.34	2.6859
-9A				0.08	0.146	0.83	0.229	0.246	1.37	2.6573
-10A				0.15	0.143	0.805	0.208	0.246	1.25	2.6595
-4				0.017	0.161	0.897	0.253	0.265	1.41	2.7340
-5	ABH			0.022	0.163	0.895	0.248	0.261	1.40	2.7100
ADJ-1	NONA			0.0250	0.1721	0.903	0.2708	0.250	1.610	2.7444
-2				0.0151	0.1755	0.913	0.2681	0.247	1.605	2.7675
-3				0.0207	0.1733	0.910	0.2707	0.250	1.605	2.7731
-4				0.0103	0.1720	0.903	0.2716	0.250	1.605	2.7651
-5				0.0147	0.1717	0.900	0.2710	0.249	1.607	2.7161
-6				0.0131	0.1731	0.909	0.2713	0.251	1.605	2.7700
-7				0.0109	0.1726	0.906	0.2705	0.252	1.610	2.7466
-8				0.0086	0.1731	0.909	0.2728	0.252	1.605	2.7597
-9				0.0109	0.1726	0.906	0.2729	0.252	1.605	2.7198
-10				0.0166	0.1717	0.900	0.2728	0.252	1.605	2.7415
-11				0.203	0.170	0.988	0.274	0.252	1.61	2.713
-12				0.115	0.168	0.917	0.272	0.249	1.61	2.730
-13				0.021	0.167	0.915	0.272	0.250	1.61	2.687
-14				0.018	0.168	0.898	0.272	0.250	1.61	2.713
-15				0.023	0.169	0.927	0.273	0.251	1.61	2.718
-16				0.023	0.169	0.900	0.270	0.248	1.61	2.741
-17				0.017	0.152	0.897	0.275	0.251	1.62	2.652
-18				0.020	0.168	0.978	0.275	0.251	1.62	2.668
-19				0.014	0.160	0.945	0.274	0.252	1.61	2.697
-37				0.215	0.157	0.908	0.271	0.252	1.59	2.696
-43				0.030	0.158	0.914	0.275	0.253	1.60	2.707
-51				0.020	0.168	0.909	0.266	0.243	1.62	2.710
-46				0.015	0.162	0.922	0.275	0.254	1.60	2.730
-47				0.015	0.178	0.920	0.241	0.223	1.60	2.639
-27				0.02	0.154	0.902	0.272	0.251	1.60	2.648
-28				0.03	0.167	0.913	0.271	0.251	1.60	2.698
-29				0.27	0.167	0.912	0.271	0.250	1.60	2.717
-44				0.02	0.169	0.913	0.276	0.251	1.63	2.703
-45	NONA	0.095	0.004	0.02	0.160	0.914	0.275	0.250	1.62	2.679

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Table 18
Firing Data for Prototype Detonators Tested at GE (U)

Sheet 1 of 3

Detonator No.	Firing Unit		Firing Cable		Firing Voltage (kv)	Bridgewire			Detonator Firing Time (μsec)	Plate Dent (in.)
	Inductance (μ H)	Resistance (ohms)	Length (ft)	Type		Peak Current (amp)	Burst Current (amp)	Wire Burst Time (μsec)		
ADJ-30*	1.63	0.375	9.5	RG8	12	--	--	--	8.8	0.025
ADJ-40*	1.63	0.375	9.5	RG8	15	4305	3675	2.4	11.7	0.051
ADJ-41*	1.63	0.375	9.5	RG8	14	3990	1470	3.7	17.0	0.025
ADJ-42*	1.63	0.375	9.5	RG8	13	3780	--	4.2?	11.2	0.038
ADJ-31	1.63	0.375	9.5	RG8	**	--	--	--	--	--
ADJ-32	1.63	0.375	9.5	RG8	**	--	--	--	--	--
ADJ-33	1.63	0.375	9.5	RG8	**	--	--	--	--	--
ADJ-34	1.63	0.375	9.5	RG8	15	4200	--	--	13.2?	0
ADJ-35	1.63	0.375	9.5	RG8	**	--	--	--	--	--
ADJ-36	1.63	0.375	9.5	RG8	**	--	--	--	--	--
ADJ-38	1.63	0.375	9.5	RG8	15	7350	7350	2.0	4.4	0
ADJ-39	1.63	0.375	9.5	RG8	**	--	--	--	--	--
ADJ-21	1.63	0.375	9.5	RG8	14	7350	4200	0.8	12.3	0.014
ADJ-22	1.63	0.375	9.5	RG8	14	7350	6300	1.2	13.7	0.013
ADJ-23	1.63	0.375	9.5	RG8	14	7350	?	2.2	11.5	0.023
ADJ-24	1.63	0.375	9.5	RG8	14	7350	3675	0.8	15.5	0.032
*Control **Detonators disassembled to determine cause of misfiring.										

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Table 18
Firing Data for Prototype Detonators Tested at GE (U)

Sheet 2 of 3

Detonator No.	Firing Unit		Firing Cable		Firing Voltage (kv)	Bridgewire			Detonator Firing Time (μsec)	Plate Dent (in.)
	Inductance (μ H)	Resistance (ohms)	Length (ft)	Type		Peak Current (amp)	Burst Current (amp)	Wire Burst Time (μsec)		
ADN-23*	1.63	0.375	9.5	RG8	7	--	--	--	10.0	0.095
ADN-24*	1.63	0.375	9.5	RG8	6	--	--	--	--	0.088
ADN-25*	1.63	0.375	9.5	RG8	Broken in cell	--	--	--	--	0.091
ADN-26*	1.63	0.375	9.5	RG8		5	--	--	--	
ADN-11	1.63	0.375	9.5	RG8	15†	4410	--	4.0	--	0
ADN-12	1.63	0.375	9.5	RG8	**					
ADN-13	1.63	0.375	9.5	RG8	**					
ADN-14	1.63	0.375	9.5	RG8	**					
ADN-15	1.63	0.375	9.5	RG8	15†	Burned only				0
ADN-16	1.63	0.375	9.5	RG8	**					
ADN-17	1.63	0.375	9.5	RG8	**					
ADN-18	1.63	0.375	9.5	RG8	15†	Burned only				0
ADN-19	1.63	0.375	9.5	RG8	6	2835	2730	1.2	4.5	0.085
ADN-20	1.63	0.375	9.5	RG8	6	2940	2887	1.2	4.4	0.070
ADN-21	1.63	0.375	9.5	RG8	6	2940	2940	1.2	4.7	0.064
ADN-22	1.63	0.375	9.5	RG8	6	2887	2835	1.2	4.5	0.088

*Control.

**Detonators dissassembled to determine cause of misfiring.

†Solder melted on bridgewire.

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Table 18
Firing Data for Prototype Detonators Tested at GE (U)
Sheet 3 of 3

Detonator No.	Firing Unit		Firing Cable		Firing Voltage (kv)	Bridgewire			Detonator Firing Time (μsec)	Plate Dent (in.)
	Inductance (μ H)	Resistance (ohms)	Length (ft)	Type		Peak Current (amp)	Burst Current (amp)	Wire Burst Time (μsec)		
DAB-1*	1.63	0.375	9.5	RG8	8	2100	1890	2.7?	4.4	0
DAB-2*	1.63	0.375	9.5	RG8	6	1470	--	2.6?	--	0
DAB-8*	1.63	0.375	9.5	RG8	7	3360	3150	1.2	4.1	0.064
DAB-9*	1.63	0.375	9.5	RG8	9	2310	--	2.0?	3.7	0.075
DAB-3	1.63	0.375	9.5	RG8		**				
DAB-6	1.63	0.375	9.5	RG8		**				
DAB-11	1.63	0.375	9.5	RG8		**				
DAB-12	1.63	0.375	9.5	RG8		**				
DAB-13	1.63	0.375	9.5	RG8		**				
DAB-14	1.63	0.375	9.5	RG8		**				
DAB-15	1.63	0.375	9.5	RG8		**				
DAB-16	1.63	0.375	9.5	RG8		**				
DAB-17	1.63	0.375	9.5	RG8	9	4410	3360	1.0?	4.9	0.069
DAB-18	1.63	0.375	9.5	RG8	9	3990	3675	2.0	4.2	0.058
DAB-19	1.63	0.375	9.5	RG8	9	4200	3150	0.8	3.5	0.072
DAB-20	1.63	0.375	9.5	RG8	9	4410	3360	1.0?	3.5	0.088
*Control. **Burned in capsule.										

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Table 19
Firing Data for Development Detonators Tested at AGC (U)
Sheet 1 of 2

Detonator No.	Firing Unit		Firing Cable		Firing Voltage (kv)	Bridgewire			Detonator Firing Time (μsec)	Aluminum Plate Dent (in.)
	Inductance (μ H)	Resistance (ohms)	Length (ft)	Type		Peak Current (amp)	Burst Current (amp)	Wire Burst Time (μsec)		
ADN-1	1.41	0.304	6	RG8	2	No Data	No Data	-	-	0
-2	-	-	8	TRIAx	4	↑	↑	1.6	5.7	0
-3	-	-	8	TRIAx	8			1.8	3.5	0
-4	1.33	0.220	4	RG8	8			2.5	-	0
-5	1.33	0.220	4	RG8	15			0.8	-	0.064
-6	-	-	8	TRIAx	15			1.2	-	0.054
-7	-	-	8	↑	10			1.0	-	0
-8	-	-	↑		12.5			1.5	-	0
-9	-	-	↑		13.5			0.6	-	0.057
-10	-	-	↑		13.5			1.2	-	0.058
-1NS	1.30	0.406	↑	↑	10			↓	↓	No Data
-2NS	↑	↑			5	↑	↑			0
-3NS					7.5	0.061				
-4NS					7	0				
-5NS					8	0.061				
-1NL	↓	↓	↓	↓	10	0.062				
-2NL					5	0				
-3NL					5	0				
-4NL					8	0				
-5NL					8	-				
-6NL					8	0.017 (Steel)				
-7NL					5	0.065				
-8NL					3	0				
-9NL					4	No Data	No Data	No Data	No Data	~0.06
-27	↓	↓	↓	↓	5.5	2966	2781	1.5	3.8	0.070
-28					6.5	3708	2781	1.0	1.6	0.090
-29					8	4635	-	-	3.2	0.021 (Steel)
-30					4	2410	1854	1.5	3.2	0
-31					6	3708	-	-	2.8	0
-32					5	3059	~2966	1.5	2.4	0.086
-33					4	2596+	-	-	5.4	0.052
-34					4	2503	2410	1.7	2.8-3.8	0
-35	1.30	0.406	8	TRIAx	3	-	-	-	0	

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Table 19
Firing Data for Development Detonators Tested at AGC (U)

Sheet 2 of 2

Detonator No.	Firing Unit		Firing Cable		Firing Voltage (kv)	Bridewire			Detonator Firing Time (μsec)	Aluminum Plate Dent (in.)
	Inductance (μ H)	Resistance (ohms)	Length (ft)	Type		Peak Current (amp)	Burst Current (amp)	Wire Burst Time (μsec)		
DAB-1A	1.23	0.38	12	RG8	4.6	1435	1190	4.0	N/A	0
-2A	1.23	0.38	12	RG8	7	1485	1890	1.75	N/A	0.044
-3A	< 1.23	< 0.38	*	-	4.6	No trigger				0.033
-4A	1.23	0.38	12	RG8	7	-	1090	2.4	N/A	0.042
-5A	↑	↑	12	↑	7	1485	692	2.0	N/A	0
-6A	↑	↑	12	↑	7	2770	1632	2.8	N/A	0.049
-7A	↑	↑	12	↑	7	No trigger				0.041
-8A	↓	↓	12	↓	7	2430	1583	2.0	N/A	0
-9A	↓	↓	12	↓	7	1090	445	2.5	N/A	0
-10A	1.23	0.38	12	↓	7	2430	1583	2.1	N/A	0
-4	1.47	0.315	6	↓	8	4125	3708	1.0	3.9	0.060
-5	1.47	0.315	6	↓	10	6480	2318	1.1	3.9	0.089
ADJ-1	1.41	0.304	↑	↑	4.6	-	-	1.7	N/A	0
-2	↑	↑	↑	↑	7	-	-	1.5	N/A	0.021
-3	↑	↑	↑	↑	7	-	-	1.3	N/A	0.013
-4	↑	↑	↑	↑	7	-	-	-	N/A	0.015
-5	↑	↑	↑	↑	7	-	-	1.8	N/A	0.005
-6	↑	↑	↑	↑	12.75	-	-	-	N/A	0.047
-7	↑	↑	↑	↑	10	-	-	-	N/A	0.008
-8	↑	↑	↑	↑	13.75	-	-	-	N/A	0.053
-9	↑	↑	↑	↑	7	-	-	-	N/A	0.002
-10	1.41	0.304	6	RG8	10	-	-	-	N/A	0.010
-11	1.30	0.406	8	TRIAX	13	8820	7840	1.5	15	0 (Steel)
-12	↑	↑	↑	↑	15	10290	5880	6.0	-	0.002 (Steel)
-13	↑	↑	↑	↑	13	8330	4900	0.3	-	0.015
-14	↑	↑	↑	↑	15	10780	5390	0.2	~2	0.015
-15	↑	↑	↑	↑	15	11760	-	-	1.5	0
-16	↑	↑	↑	↑	15	11760	9898	1.6	-	0
-17	↑	↑	↑	↑	15	11760	9800	1.6	3	0
-18	↑	↑	↑	↑	15	10780	9800	1.5	4	0
-19	↑	↑	↑	↑	16	-	-	-	7	0
-37	↑	↑	↑	↑	16	-	-	-	-	0
-43	1.30	0.406	8	TRIAX	16	-	-	-	-	0
-51	1.47	0.315	6	RG8	16	-	-	-	-	0.051
-46	↑	↑	↑	↑	14	8343	5562	0.8	14.4	0.057
-47	↑	↑	↑	↑	12	6952	4635	0.9	-	0.012
-27	↑	↑	↑	↑	11	No picture				0.018
-28	↑	↑	↑	↑	10	5562	3708	0.5	7.8	0.015
-29	↑	↑	↑	↑	9	~4635	-	-	12.8	0.029
-44	↑	↑	↑	↑	8	2596	1947	0.4	13.0	0.010
-45	1.47	0.315	6	RG8	7	4079	3708	1.2	13.5	0.017

*7 in. leads

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APPENDIX E

PRESSURE AND TEMPERATURE MEASUREMENT IN
INSTRUMENTED CAPSULES

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APPENDIX E

(U) A dual-pen Leeds and Northrup 0- to 10-mv strip-chart recorder was used to record both temperature and pressure inside the instrumented capsules. Chart speed was set at 5 min/in. Pressure was measured and indicated by a Heise 0- to 100-psig test gage accurate to ± 0.1 psi. This pressure was transmitted to the recorder by use of the dc excitation circuit shown in Figure 44 and a 5000-ohm Giannini 8511 Microtorque precision potentiometer accurate to $\pm 0.1\%$ of full scale. Before each irradiation, the recorder was recalibrated with the test gage at 10-psig intervals for a range of 0 to 50 psig on the chart (blue pen).

(U) The volume of the system must be known for calculating gas volume. Although the other parts of the capsule and pressure-measurement system had a constant volume, the internal volume of the gage increased with pressure. This change in volume was measured, and the appropriate volume corrections from Figure 45 were used to determine the total system volume.

(U) Temperature of the explosive sample was measured by a 28-gage, glass-fiber-insulated, welded copper-constantan thermocouple embedded in the center of the explosive powder. The explosive was compacted as much as possible by hand pressure, and small-diameter wires were used to get as accurate a temperature measurement as possible. To convert to a millivolt signal and increase the sensitivity of the measurement in the range of interest, a heated cold junction at 63°C was used. This temperature was held constant to an accuracy of $\pm 0.1^{\circ}\text{C}$ by a Pace (BRJ 13A-12TP-1074) thermocouple reference junction oven. The temperature-calibration curve for the recorder is shown in Figure 46.

Figure 44 - Pressure-Measurement Schematic

Figure 45 - Pressure-Panel Calibration

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Figure 46 - Temperature-Recorder Calibration

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APPENDIX F

INSPECTION INSTRUCTIONS
FOR DETONATORS

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APPENDIX F

INSPECTION INSTRUCTIONS

Typical inspection instructions for detonator assembly and capsule loading are given on the following four pages. Inspection instructions for the other capsules were given in the Phase I-A Test Specifications.⁽¹⁰⁾

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Aerojet-General

REF ID: A66484

INSPECTION INSTRUCTION

FORM AGC 912 33 01

B P NO 520419		PART NO	
CHG LTR N/C EOS		520419-1	
PROJECT/MODEL		PLANNING OPER NO	
		DETONATOR ASSY.	
LOT SIZE	UNIT SERIAL/	ISSUE DATE	REV DATE
16	AJD-100-1	9-14-66	9-19-66
		REV NO	REVISED BY
		01	KOK

CHAR ITEM NO	REF CAT	INSP OPER CHAR LOC	CHARACTERISTIC	TYPE OF GAGE OR INSPECTION EQUIPMENT	SEQ NO	RECORD VALUE	INSP FRM ALL	INSP STR UD
1			Record Shop Order No. 110300 Verify evidence of previous AGC inspection and acceptance of component parts. 520428-1 Header Assy. Lot 520343-1 Body, Det. Lot 520347 Cover, Det. Lot PELLET PRESSING					
2			Verify density of pellets per Detonator Pellet Data Sheet Expl. "J" Lot x -570					
3			Verify Eastman 910 adhesive applied to underside of the shoulder of the header assy.	Visual				
4			Verify information required per Detonator Data Sheet					
5			Inspect for proper crimping	Visual				
6			Inspection Complete					

PART NO

PLANNING OPER NO

PREPARED BY

REMARKS

APPROVED BY

(*) RECORD VALUES
CODED THUS *
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B P NO 520418		INSPECTION INSTRUCTION <small>FORM AGC 9 2 33 01</small>		PAGE 1		PART NO 520418		
CHG LTR N/C EOS				OF 2		PLANNING OPER NO -		
PROJECT/MODEL				PART NAME IRRADIATION CAPSULE ASSY.				
LOT SIZE 7	UNIT SERIAL/ LOT NO AJD-100-1			ISSUE DATE 9-8-66	REV DATE 9-22-66	REV NO 01	REVISED BY KDK	
CHAR ITEM NO	REF CAT	INSP OPER CHAR LOC	CHARACTERISTIC	TYPE OF GAGE OR INSPECTION EQUIPMENT	SEQ NO	* RECORD VALUE	INSP FREQ AGL	INSP STATUS
1			Record Shop Order No. <u>110048</u> Verify evidence of previous AGC inspection and acceptance of component parts. 513585-7 Body (1) Lot 513584-1 Cap (1) Lot 520419-1 Det. Assy. (4) Lot 515268-7 Spring Comp. (1) P/O R4-25B Seal (Com. Prod.) (1) P/O .25-20UNC + 1.75 Sch. Hd. Cap Screw (12) P/O MS 35649-41 Nut (1) P/O AN 515-4-8 Screw (1) P/O 515266-3 Temp. Ind. Assy. (1) S/O 515266-1 Temp. Ind. Assy. (1) S/O 515265-3 Flux Indicator Assy. (1) S/O 515265-1 Flux Indicator Assy. (1) S/O 515262-1 Bracket (1) S/O 513645-1 Ring (1) S/O 513643-1 Retainer Disk (1) S/O 513642-1 Cup (1) S/O					
2			Record detonator weight, on attached form.				100%	
3			Verify by witnessing the assy. operation that the assy. procedures are carefully followed.				100%	
PREPARED BY _____			REMARKS			(**) RECORD VALUE CODED THUS * U		
APPROVED BY _____								

 PART NO
 PLANNING OPER NO

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B P NO 520418		INSPECTION INSTRUCTION <small>FORM AGC 912 33 01</small>	PART NO 520418	
CHG LTR N/C EOS			PAGE 2	PLANNING OPER NO -
PROJECT/MODEL			OF 2	PART NAME
LOT SIZE 7	UNIT SERIAL/ LOT NO AJD-100-1		ISSUE DATE 9-8-66	REV DATE REV NO REVISED BY

CHAR ITEM NO	REF CAT	INSP OPER CHAR LOC	CHARACTERISTIC	TYPE OF GAGE OR INSPECTION EQUIPMENT	SEQ NO	* RECORD VALUE	INSP FREQ AGL	INSP STATUS
4			Inspect torque (12 bolts) a. Tighten across 180 in lbs. b. Tighten around 200 in lbs. PRIOR TO LEAK TEST				100% 100%	
5			Verify the weight of the assembled capsule to accuracy of 0.1 gram and record on attached record form.				100%	
6			After leak test verify weight of capsule accurate to 0.1 gram. Record on attached record form. NOTE: The difference between the before and after weights must not exceed 9 grams. Record difference in appropriate block on attached record form. If the weight differential exceeds 9 grams, the unit is to be disassembled and reloaded and releak tested.				100% 100%	
7			X-ray capsule to confirm that all parts are properly assembled.					
8			Parts identified and tagged with P/N and S/N per ASD 5215M.				100%	
9			Inspection Complete				100%	

PART NO

PLANNING OPER NO

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REMARKS

(*) RECORD VALUE CODED THUS *

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DOWNEY CALIFORNIA

LOT NO. AJD-100-1	TEST DATA RECORDING SHEET	MODEL/PROJECT
DATE STARTED: 9-28-66	PART NUMBER: 520418	TEST ENGINEER: E. Lindberg
DATE COMPLETED: 9-30-66	PART NAME: IRRADIATION CAPSULE ASSY.	TEST PERFORMED BY: Lubbock/Drake
	TEST PERFORMED: AS NOTED	WITNESS AND/OR APPROVED (INSPECTION DEPT.)

DETONATOR WEIGHT					LEAK TEST			
REF. A-4 ASSY. PROCEDURES (9-1-66)					REF. A-6 ASSY. PROCEDURES (9-1-66)			
UNIT	DETONATOR S/N				S/N	WEIGHT "Grams"		
S/N	1	2	3	4		Before	After	Diff.
DAB-1	AB-3	AB-6	AB-11	AB-12	DAB-1	1,450.65	1,450.9	+0.25
	2.6830	2.7172	2.6744	2.6553				
	Total explosive weight 1.6115 gm							
DAB-2	AB-13	AB-14	AB-15	AB-16	DAB-2	1,449.25	1,457.05	+7.80
	2.6780	2.6326	2.6804	2.6735				
	Total explosive weight 1.5890 gm							
DAB-3	AB-17	AB-18	AB-19	AB-20	DAB-3	1,446.1	1,446.1	-0-
	2.6724	2.7133	2.7325	2.6725				
	Total explosive weight 1.6147 gm							
ADJ-1	J-31	J-32	J-33	J-34	ADJ-1	1,451.45	1,451.66	+0.15
	2.7138	2.7342	2.7482	2.6645				
	Total explosive weight 1.7625 gm							
ADJ-2	J-35	J-36	J-38	J-39	ADJ-2	1,450.40	1,450.5	+0.1
	2.6827	2.7512	2.6883	2.7308				
	Total explosive weight 1.7456 gm							
ADN-1	N-11	N-12	N-13	N-14	ADN-1	1,446.9	1,447.1	+0.2
	2.7028	2.6756	2.7062	2.7029				
	Total explosive weight 1.6658 gm							
ADN-2	N-15	N-16	N-17	N-18	ADN-2	1,450.1	1,450.5	+0.4
	2.6705	2.6807	2.7194	2.7345				
	Total explosive weight 1.6599 gm							

CALIBRATION DATES & GAGE NAMES					
NAME	DUE DATE	NAME	DUE DATE	NAME	DUE DATE
501-26		550-21		711-33	11-2-66
Analytical- Balance	10-26-66	Vacuum Gage	10-14-66	Torque Wrench	9-28-66
501-31					
Triple Beam Balance	10-10-66				

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APPENDIX G

WEIGHTS OF CAPSULE COMPONENTS

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TABLE 20

Weights of Capsule Components

<u>Noninstrumented Capsule Component</u>	<u>Weight, gm</u>
Washer	23.5561
Seal	6.2531
Glass ball	0.5241
Disk closure	1.0485
Quartz wool	0.5
Spring	0.4276
Quartz tube	3.1 - 3.3
Bolt and nut	1.113
Two temperature-monitor assemblies	0.4 - 0.5
Cup	16.6290
Two flux-wire assemblies	0.3 - 0.4
Bracket	9.4547
Bolts (12 ea)	135.4927
Cap	95.1347
Body	1150.0
TOTAL WEIGHT	1145

Additional Instrumented Capsule Components

Locking bracket	7.9605
Clamping bar (2 ea)	39.8765
Tube support (Spring)	10.4989
Clamp bracket	23.5688
Screw and nut (2 ea)	3.2480
Seal ring	0.3925
Clip (Modified)	15.6805
Cap (Modified)	93.3891
Protection disk (Al)	0.07
Copper-constantan thermocouple wire	0.336

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