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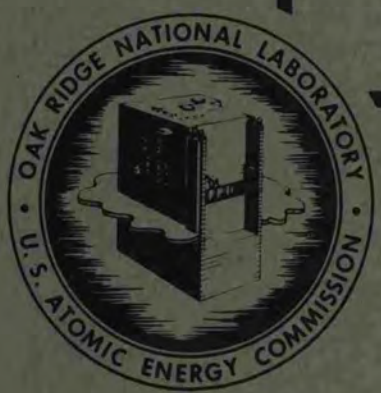
EFFECTS OF GAMMA RADIATION ON EXPLOSIVES

Final and Summary Report on Army Ordnance Project TA3-5003R

Stability and Reactions of Explosives

Written by
H. Rosenwasser



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Stability and Reactions of Explosives

Written by
H. Rosenwasser

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EFFECTS OF GAMMA RADIATION ON EXPLOSIVES

ABSTRACT

This is the final report on the joint investigation of the effects of gamma radiation on explosives by the Oak Ridge National Laboratory and the Picatinny Arsenal. The data obtained by subjecting different explosives at various temperatures to the influence of an intense gamma-radiation field are presented. The work showed that the different explosives exhibited varied resistances to the treatment and gave an indication of the direction future work should follow. Explanation is required for the sensitization of the primers and detonators used, as well as the peculiar characteristic of gas formation by some of the explosives following irradiation. More generally, however, a need for a study of the radiation chemistry of explosives is indicated. It is hoped that provision will be made for such a study.

INTRODUCTION

A preliminary investigation of the effects of gamma radiation on explosive materials was carried out jointly between the Los Alamos Scientific Laboratory and the Oak Ridge National Laboratory in 1948.[1] Representative 5-g samples of RDX, tetryl, TNT, and Composition B in airtight glass tubes were placed in a nest of activated uranium slugs. The radiation received by the specimens was of relatively low intensity; during a ten-day exposure the total dosage per sample was only 8.6×10^6 r. No visible change in the samples could be detected, gas evolution was slight, and melting-point changes were negligible.

An analogous study was conducted at Aberdeen Proving Ground,[1] where specimens of TNT, Pentolite, Composition B, Tetrytol, tetryl, lead azide, black powder, and the propellants M1, M8, and M15 were exposed to 1-Mev x rays for 1 hr at a dosage of 12 r/sec. No rise in temperature was observed, and no significant changes in sensitivity were noted.

It was requested[2] that the Ordnance Department conduct a more extensive investigation at ORNL on the effects of radiation on the sensitivity and stability of explosives. The proposed gamma-radiation exposures were to be equivalent to the exposure obtained from 1 megacurie of radioactive tantalum at a distance of 2 ft for a period of 90 days. The sensitivities of explosives to shock and to friction were to be determined during and after irradiation. Sensitivity changes caused by temperature variation in the range from –65 to 180°F, as well as decomposition or physical deterioration from the irradiation, were to be noted.

[1] Joint NME-AEC Panel on Radiological Warfare, *Radiological Warfare Report*, TID-204, p 59 (Aug. 29, 1948).

[2] Enclosure 2 on 0.0.000.91/182 RD (A)–S (Jan. 14, 1949).

EXPERIMENTAL PROCEDURE

The sample of explosive was transferred to the tube of the vacuum-stability apparatus (Fig. 1). The connecting capillary tube was calibrated by measuring the length of a mercury slug of known mass, as outlined elsewhere.[3] The sample tube was coupled to the glass capillary by the ground-glass joint and sealed with 1 ml of mercury. Seven milliliters of mercury was placed in the cup at the lower end of the capillary tube, and the system was evacuated to a pressure of about 5 mm Hg. When the vacuum pump was disconnected, the external atmospheric pressure raised the mercury meniscus in the vertical capillary tube to a near-barometric height above the mercury level in the cup. After sufficient time had been allowed for possible leakage in the glass system to be detected, an iron-constantan thermocouple was inserted in the well at the bottom end of the sample tube and the thermocouple leads were secured to the sides of the tube with cellulose tape. The assembly was placed in the source shield (Fig. 2) so that the vertical section of the manometer rested against the face of the meter stick, and the sample tube was placed in the shield cavity 2 in. below the surface. About 2 ml of silicone oil was added to the surface of the mercury seal at the upper end of the sample tube to prevent evaporation of the mercury and subsequent alloying with the radioactive-gold sources.

When the glass assembly was placed in position in the source shield, the horizontal section of glass capillary that contained two 60-deg bends rested in a slot in the lead wall. After the thermocouple leads had been brought out through the slot and the ends of the leads had been connected to an electronic temperature recorder, the slot was filled with a plastic gasketing compound. The shield lid (suspended by a chain hoist, Fig. 2) was then carefully lowered into place.

The gold sources (Fig. 3) consisted of gold-lined magnesium cylinders (4¼ in. in length), which contained 250 g of gold. Each source was 3 in. long, 1 in. in inside diameter, and 2 mm in annular thickness and was nickel-plated for protection against mercury vapor. Reactor irradiation of stable $_{79}Au^{197}$ produces the unstable $_{79}Au^{198}$ isotope with a half life of 2.69 days.

[3] Picatinny Arsenal Technical Report 1401 (March 18, 1944).

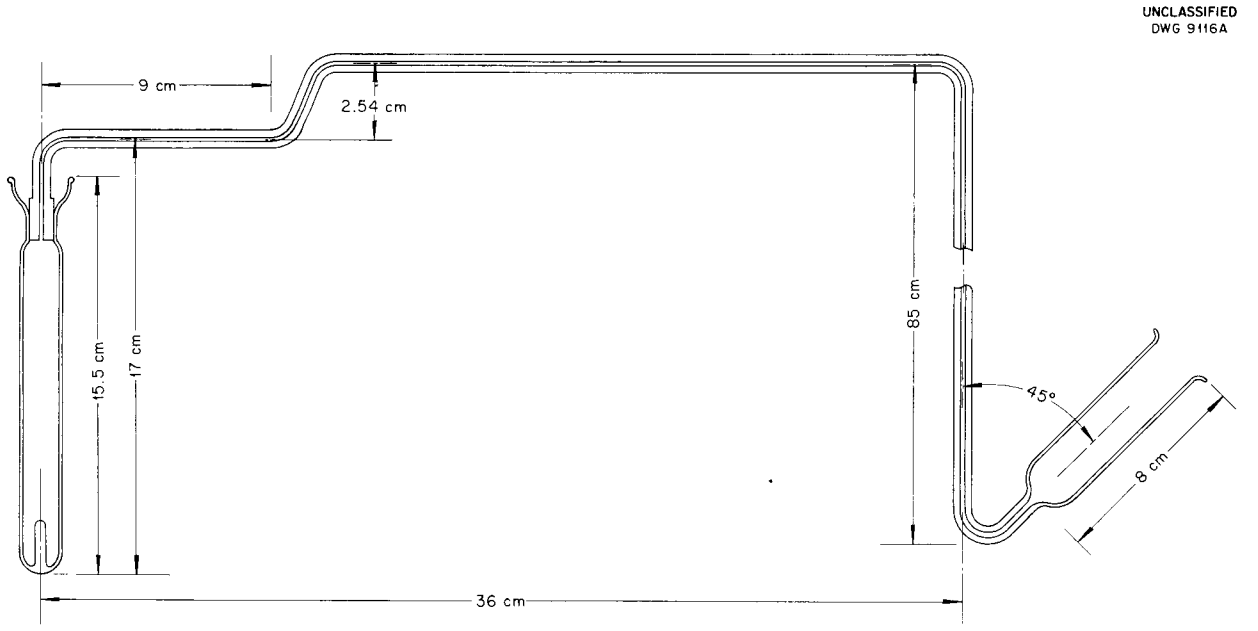

Fig. 1. Vacuum-Stability Test Apparatus.

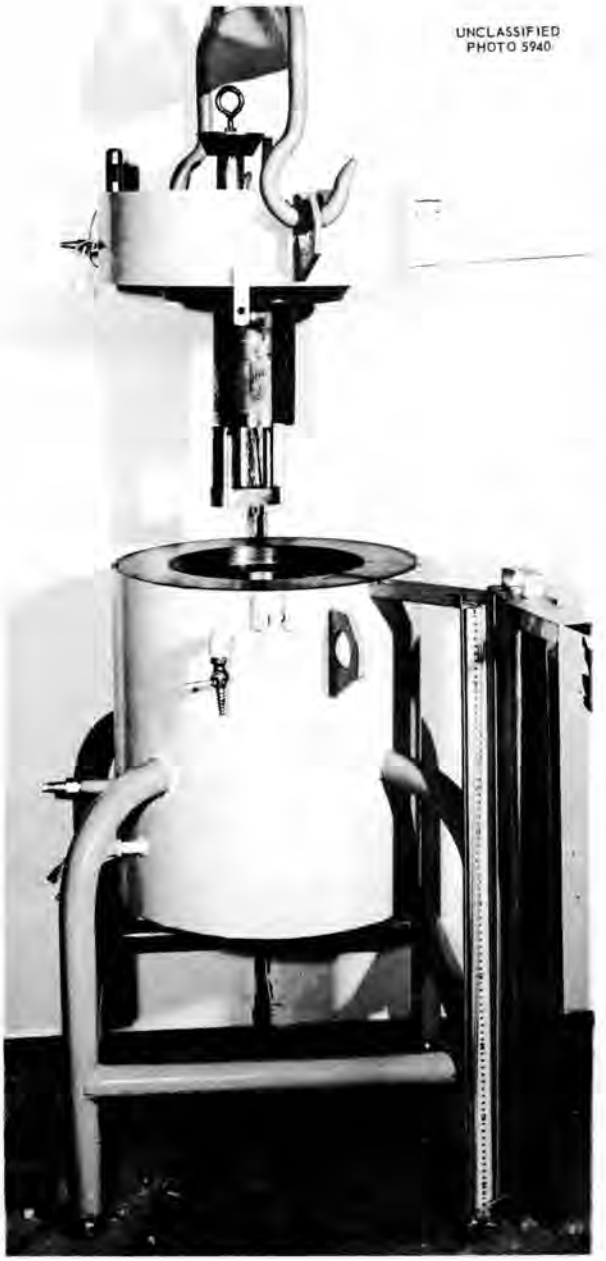

Fig. 2. Source Shield.

During decay the $_{79}Au^{198}$ emits a beta particle of 0.96 Mev and a gamma quantum of 0.41 and becomes transformed to $_{80}Hg^{198}$.

In Fig. 4 the source shield (H) is shown in position under the pneumatic tube apparatus, in which a lift truck (G) is used to force the source shield tightly against the magazine which contains the gold-source receiving chambers (D). As a gold source emerged from the reactor, its open end was in a downward position, and the source had to be inverted before it was dropped into a source shield. To accomplish this inversion, the gold cylinder was allowed to fall from the receiving chambers into the breach plug (I). The breach plug was then rotated 180 deg, and the gold source was dropped into the source shield. Two microswitches (E) indicated the position of a source when it was ready to drop into the source shield or ready to be blown back into the reactor for reactivation, by flashing a light on the control panel (F). Additional lights were provided on the control panel to indicate the locations of from one to six gold sources in the reactor. The receiving chambers were rotated by the index plate (J) so that each source, upon removal from the reactor, was located in a separate compartment.

The source shield was moved on the lift truck to a convenient place near the temperature recorder (not shown), and the lead plug (Fig. 2) with its ring handle was inserted into the hole in the shield lid. Inside the source shield, the gold cylinder was held in a cup mounted on one end of a revolving arm which rotated about a vertical rod. The vertical rod passed out through the lid and served as a manual control for rotating the gold source in place within the shield and raising it up around the sample of explosive.

The gold sources were removed once a week from the samples of explosive and replaced with freshly activated sources. Each gold cylinder that had been used for seven days was reintroduced into the reactor by reversing the procedure described for bringing the source to the explosive. Air pressure of 100 psi was supplied to the apparatus from a tank (K), and the air flow was controlled through solenoid valves by push buttons on the control panel.

For the irradiation of explosives, it was decided to screen out the beta component of the total gold radiation. Geiger-counter measurements of an irradiated gold foil placed in a vacuum-stability tube showed that the glass wall absorbed nearly all the beta radiation. Weekly readings with a Q842 ionization chamber indicated that there was an average output of 10^5 r/hr from each gold source, essentially equivalent to that from the specified megacurie tantalum source.[4]

[4] O. Sisman, *Interim Report on Equipment for Subjecting Explosives to Gamma Radiation*, ORNL CF-50-2-8 (Feb. 2, 1950).

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Fig. 3. Gold Source.

The progress of the decomposition of the explosives was followed by measuring the amount of gas formed in the capillary manometer tubes. These measurements took into account the density of the explosive, the temperature, and the barometric pressure. The gas volumes were reduced to 0°C and 760 mm Hg for purposes of illustration. Gas analysis was conducted in a scaled-down version of the standard Hempel buret and in absorption bulbs with traps. Gas samples were withdrawn from the vacuum-stability tube by a mercury piston which operated like a Toepler pump. The following absorption reagents were used: 10% H_2SO_4 for NH_3, concentrated $FeSO_4$ solution for NO and NO_2, KOH (300 g/liter) for CO_2, alkaline pyrogallate solution for O_2, acid CuCl for CO, and combustion over palladium black for H_2. Any remaining gas was assumed to be N_2.

Melting points were determined in the conventional manner by use of an electrically heated, stirred oil bath. A temperature-rise rate of 0.4°C per minute was obtained in the neighborhood of the melting point in every case, and the usual stem corrections were made. The treated and untreated materials were accurately compared by determining their melting points simultaneously.

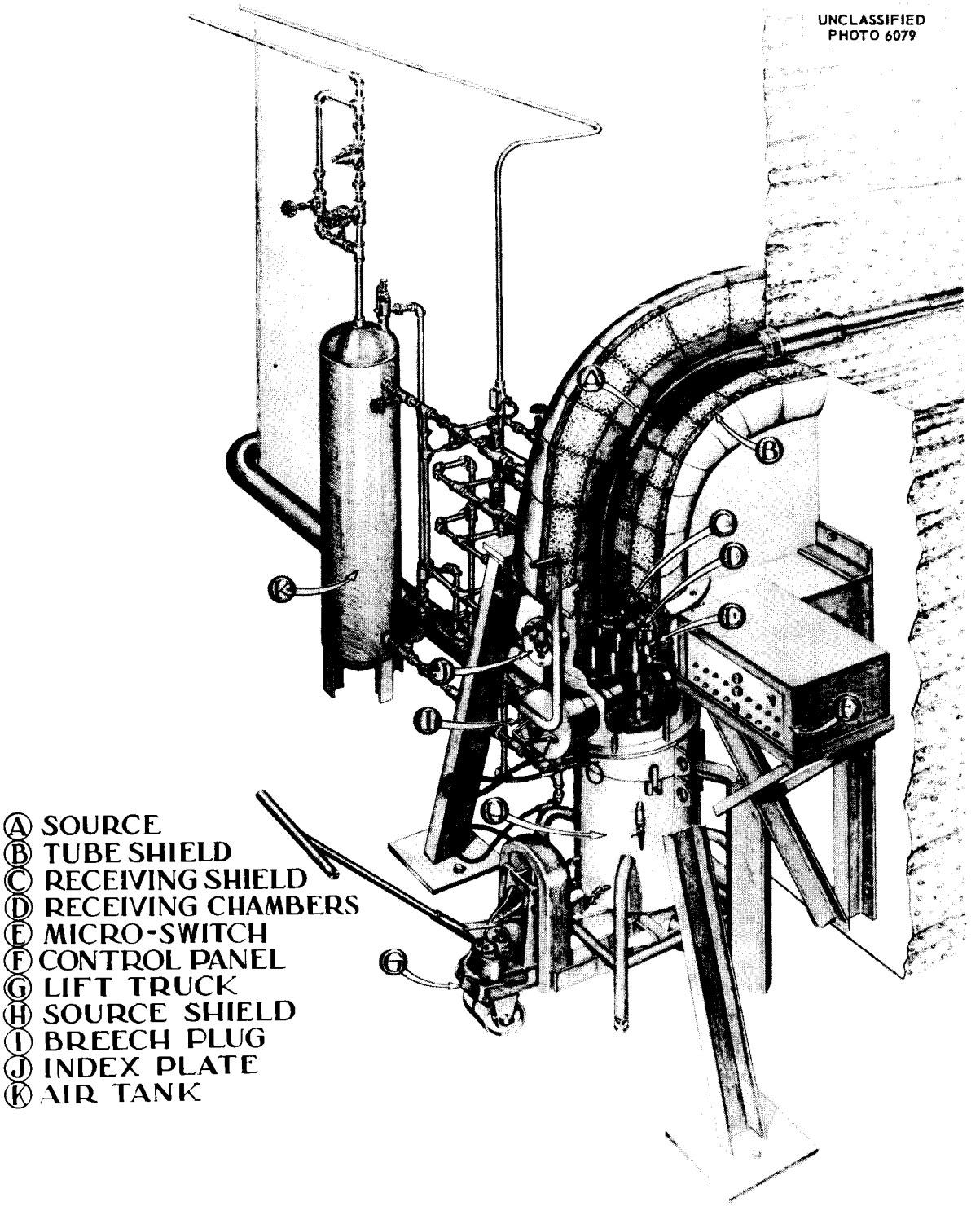

Fig. 4. Pneumatic Tube Apparatus.

Sensitivity to impact was measured at the Picatinny Arsenal with two pieces of standardized equipment, the Bureau of Mines machine and the Picatinny Arsenal machine. Twenty-milligram samples of explosives were used in the Bureau of Mines impact-test machine. The sample of explosive was placed on a hardened-steel anvil, and a steel cylinder, 1 cm in diameter at its lowest tip, was allowed to rest on the sample, which was maintained at a uniform thickness. A 2.0-kg weight was permitted to fall from a desired height and strike the cylinder resting on the explosive. The recorded test value was that height, in centimeters, at which at least one explosion was obtained (as indicated by fire, smoke, or noise) in ten trials and that height 1 cm below which the falling weight caused no explosion in ten tests. A fresh sample was used in each trial, and the metal parts were cleaned thoroughly after each impact.

Considerably more confinement for the test sample was provided by the Picatinny Arsenal impact-test machine than was obtained between two parallel steel surfaces in the Bureau of Mines machine. A small steel cup (0.220 in. in diameter) was filled with explosive, covered with a tightly fitted brass cover, and placed on a steel anvil. A vented plug of high-carbon steel (0.200 in. in diameter), hardened to Rockwell number C 62–C 63, was centered on the brass cover, and a 2.0-kg weight was dropped on the assembly from a desired height. The falling weight caused the plug to shear through the brass cover and impinge directly onto the explosive in the cup underneath. The test value recorded was that height, in inches, from which the falling weight caused at least one explosion in ten trials, and that height 1 in. below which the falling weight caused no explosion in ten tests. New plugs, cups, and samples of explosive were used in each trial.

Comparative determinations of the brisance or shattering power of irradiated and unirradiated explosives were made with the sand test. Briefly, the method consisted in detonating 0.40 g of explosive which was confined in a gilding-metal blasting cap and immersed in a bed of standard Ottawa sand in a bomb of prescribed dimensions. For primary explosives a black-powder fuse was used for initiation; boosters required an added increment of standard lead azide, and high explosives required added increments of standard lead azide plus standard tetryl. The sand, originally 20 to 30 mesh (U.S. Standard Sieve Series), was then sifted, to separate it from the sand crushed finer than 30 mesh by the detonation wave, and weighed.

In order to maintain samples at 71°C, a separate heater was fabricated for each of the three shields. Compressed air was passed through the heaters, over thermoswitches which monitored the temperature, and then through the lead shields and around the samples of explosives and the gold cylinder. A record of the temperature was kept on a Brown recorder. For the tests at –40°C, air was forced by two compressors through coils surrounded by a dry ice–trichlorethylene cooling bath. After five days the cold air was stopped and the gold cylinder was removed from around the sample. The equipment was then allowed to reach room temperature before a cylinder was replaced.

Inasmuch as the results for the gas-volume readings were supposed to be accurate to only about 20%, an average daily radiation-intensity value in roentgens was considered adequate. The radiation values, measured with an ionization chamber built and calibrated especially for this work, are as follows:

Days	Total Exposure (10^6 r)
1.0	2.0
2.0	3.6
3.0	4.8
4.0	5.7
5.0	6.4
6.0	7.0
7.0	7.4

Thus 27% of the irradiation was emitted during the first day, 22% the second, 16% the third, and only 5% the seventh.

DISCUSSION

PRIMARY EXPLOSIVES

Lead Azide. – Irradiation of a 2-g sample of lead azide (PbN_6) was permitted to continue for 52 days, and during this time 11.02 ml of gas was formed; an additional 5.5 ml of gas developed while the sample remained under normal room conditions for the following 36 days. The gaseous decomposition product of dextrinated lead azide appeared to be practically pure nitrogen, inasmuch as no absorption could be observed during gas analysis; tests for O_2 and CO_2 were negative.

An accurate method for the determination of the azide radical in lead azide[5] – the technique of liberating nitrogen by oxidation with ceric ammonium nitrate – was used in sample analysis. Determinations made before irradiation indicated that the purity of the lead azide was 93.08%, whereas after irradiation, while the sample remained under normal conditions, the purity, from duplicate determinations, averaged 89.04% – a loss in azide content of 4.04%. This loss agrees closely with the percentage of lead azide decomposed as computed from the quantity of gas released in the stability tube. Volumes of gas evolved by PbN_6 were as follows:

Irradiation Time	Gas Evolved (ml)
First 10 days	1.11
Second 10 days	0.80
Third 10 days	0.99
Fourth 10 days	1.02
Fifth 10 days	1.38

At the end of the 52-day period of irradiation, gas continued to evolve but at a reduced rate (Table 1, Fig. 5). The rate of gas formation slowed to 0.36 ml/g during the last ten-day period following irradiation. The total volume of nitrogen obtained (16.5 ml) corresponded stoichiometrically to 0.0735 g of lead, or 3.95% of the sample, when allowance was made for the 7% of dextrin present.

The irradiation of additional lead azide at ambient conditions served as a check on the reproducibility of the curve for gas evolution (Fig. 5). A comparison of the rates of evolution of nitrogen for the first and second samples, for which exposures for 52 days produced gas at rates of 5.6 and 4.7 ml/g, respectively, is shown in Fig. 6. The two curves are practically identical for the first 25 days and then become inflected, with the first curve (2-g sample) rising more sharply than the second (5-g sample). The 5-g sample was re-evaluated on the twenty-fifth day of irradiation by reducing the gas pressure above the sample from 621 to 44 mm Hg. This operation may have tended to alter the shape of the curve. Observations for gas formed after irradiation

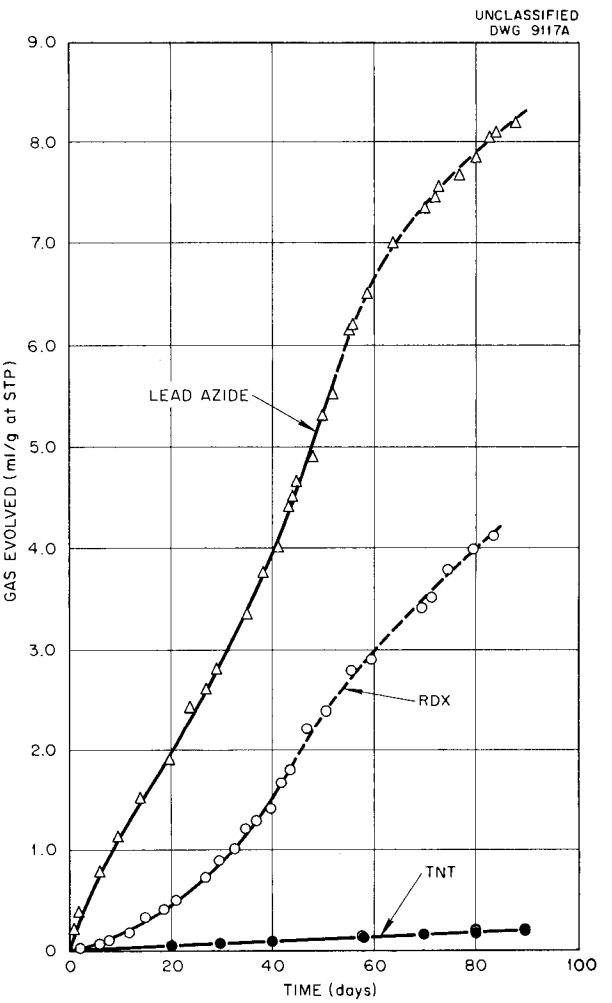

Fig. 5. Volumes of Gas Evolved by Lead Azide, RDX, and TNT During Irradiation with 0.41-Mev Gamma at 10^5 r/hr (Solid Lines) and After Irradiation (Broken Lines).

[5] Lead azide; Military Specification MIL-L-3055, par. 4.4.3.1 (Sept. 30, 1949).

TABLE 1. SUMMARY OF DATA OBTAINED FROM ALL EXPLOSIVES AFTER EXPOSURE TO GAMMA RADIATION AT AMBIENT TEMPERATURE

Explosive	Weight of Sample (g)	Gas Produced During Irradiation (ml/g)							Gas Produced After Irradiation (Periods Noted) (ml/g)			
		10 Days	20 Days	30 Days	40 Days	50 Days	60 Days	90 Days				
Lead styphnate	2.00	0.02	0.04	0.05	0.07	0.09	0.10	0.15				
TNT No. 1	5.00	0.03	0.05	0.07	0.09	0.11	0.12	0.22				
TNT No. 2	5.00	0.04	0.07	0.08	0.10	0.12	0.14					
Tritonal	5.00	0.03	0.06	0.09								
Standard baratol	5.00	0.04	0.07	0.11							35 days, 0.01	
Tetryl No. 1	5.00	0.10	0.21	0.34	0.49	0.66	0.83	1.39	10 days, 0.11			
Tetryl No. 2	5.00	0.05	0.12	0.19	0.30	0.44	0.60					
Tetrytol	5.00	0.07	0.19	0.34					10 days, 0.01	20 days, 0.03	30 days, 0.04	
Pentolite	5.00	0.09	0.16	0.33							28 days, 1.29	
RDX	5.00	0.16	0.44	0.87	1.49	44 days, 1.79			10 days, 0.88	20 days, 1.5	30 days, 2.1	40 days, 2.5
Composition B	5.00	0.20	0.46	0.92					10 days, 0.11		35 days, 0.28	84 days, 0.67
M15 propellant	4.34	0.24	0.62	1.15	1.82	2.55	3.35					
PETN	5.00	0.18	0.51	1.27	2.42							
Ballistite	5.00	0.10	0.25	0.80	38 days, 2.8							
JPN propellant	5.00	0.38	1.08	2.15					7 days, 0.27			
Lead azide No. 1	2.00	1.11	1.91	2.90	3.92	5.30	52 days, 5.51		10 days, 1.32	20 days, 1.92	30 days, 2.43	40 days, 2.79
Lead azide No. 2	5.00	1.11	1.91	2.81	3.50	4.38						
DDNP	2.00	0.25	1.35	3.25	5.6	45 days, 7.2						
Nitroglycerin	1.073	1.6	5.0	7.7	9.0	10.1	56 days, 11.5					
Mercury fulminate	5.00	0.17	0.57	29 days, 2.97					10 days, 2.0	20 days, 3.2		

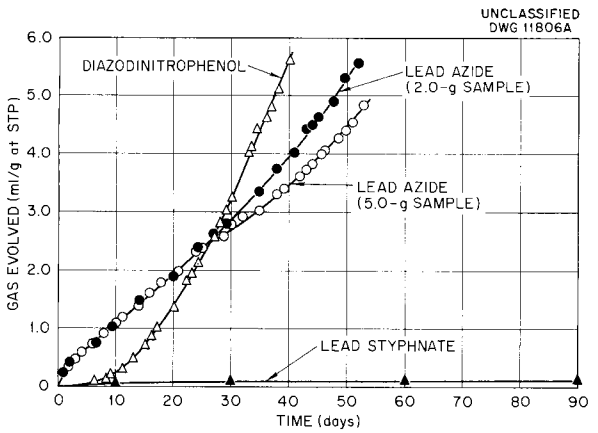

Fig. 6. Volumes of Gas Evolved by Lead Azide, DDNP, and Lead Styphnate During Irradiation with 0.41-Mev Gamma at 10^5 r/hr.

stopped were not made for the 5-g sample.

As indicated by tests with the Bureau of Mines machine, the sensitivity to impact was lowered slightly by exposure to radiation; a value of 75 cm was obtained for the irradiated lead azide and 65 cm was obtained for the unirradiated material. The corresponding values observed on the Picatinny Arsenal machine were 3 in. for both samples; that is, there were no observable differences in sensitivity.

When individual 0.40-g samples of irradiated and unirradiated lead azide were detonated in the sand test by a black-powder fuse, the weight of crushed sand resulting from the explosion amounted to 18.7 and 20.5 g, respectively.

It was originally suggested that an investigation be made of the sensitivity change in explosives caused by temperature variation in the range from –54 to 82°C. However, the upper limit was changed to 71°C, because the suggested maximum is near the melting point of grade I TNT (82.1°C) and because the upper temperature requirement for the performance of ammunition and other material, as fixed by the Ordnance Committee in 1948,[6] is 71°C.

Unirradiated lead azide, when maintained at a temperature of 71°C in the glass stability equipment for a period of 30 days, evolved 0.29 ml of gas per gram of sample. The data for gas evolution are listed in Table 2 and graphically presented in Fig. 7. Most of the gas was formed during the first day. The evolution for the remainder of the 30-day period amounted to only 0.06 ml/g. Before the azide sample was subjected to gamma radiation at 71°C, it was maintained at this temperature for six days, during which time it evolved 0.38 ml of gas per gram of sample. This volume was considered as the base line, and corrections were made in all future readings for this amount of gas formation from thermal instability at 71°C. Thus the corrected value for a period of 27.9 days of irradiation is 5.41 ml/g. When irradiated at ambient temperatures, lead azide evolved 2.67 ml of gas per gram of sample after being exposed for 27.9 days. Therefore at 71°C the amount of gas evolved was 2.03 times that at normal temperature.

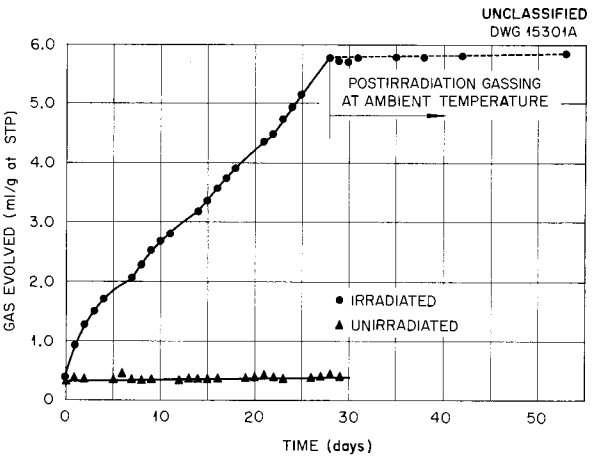

Fig. 7. Volumes of Gas Evolved by Lead Azide During and After Irradiation at 71°C with 0.41-Mev Gamma at 10^5 r/hr.

The irradiation curve (Fig. 7) was begun at a point where gas formation caused by thermal instability appeared to level off, and these points should be regarded as the base line for radiation damage to the explosives at 71°C (Table 2). For accurate results, the slope of the lower curve should be subtracted from that of the upper one.

Another irradiation at 71°C for 29.5 days, an exposure of 29.9×10^6 r, caused the evolution of 6.53 ml of gas per gram of sample. The cumulative data for this gas formation are summarized in Table 2 and shown graphically in Figs. 8 and 9.

Irradiation at –40°C for intermittent periods totaling 25 days, an exposure of 32×10^6 r,

[6]Ordnance Committee Item 32242 (April 15, 1948).

TABLE 2. SUMMARY OF DATA ON GAS EVOLUTION FROM EXPLOSIVES

	Lead Azide	Tetryl	TNT	Lead Styphnate
After Exposure to Gamma Radiation at 71°C				
Weight of sample, g	5.00	5.00	5.00	5.00
Total irradiation time, days	29.5	29.9	29.8	35.5
Average volume* of gas produced at 71°C, without irradiation, ml/g				
After 9 days	0.23	0.047	0.042	0.049
After 20 days	0.25	0.051	0.047	0.060
After 29 days	0.29	0.059	0.056	0.065
Total time at 71°C before irradiation, days	4	2	2	4
Base-line volume* at start of irradiation, ml/g	0.06	0.03	0.02	0.09
Total volume* of gas evolved, ml/g	6.53	1.14	0.33	0.09
Volume* of gas produced, ml/g, after following exposures				
7.4×10^6 r	1.84	0.22	0.08	0.02
14.8×10^6 r	3.07	0.41	0.12	0.03
22.2×10^6 r	4.51	0.69	0.22	0.05
29.6×10^6 r	6.42	0.99	0.31	0.07
37.0×10^6 r				0.09
Total gamma exposure, in 10^6 r	29.9	33.1	32.7	37.6
After Exposure to Gamma Radiation at −40°C				
Weight of sample, g	5.00	5.00	5.00	5.00
Total irradiation time, days	25	21.0	26.0	21.1
Total gamma exposure, in 10^6 r	32.1	28.2	35.6	30.4
Volume* of gas produced, ml/g, after following exposures				
6.4×10^6 r	0.43	0.01	0.015	0.005
12.8×10^6 r	0.81	0.03	0.025	0.010
19.2×10^6 r	1.25	0.07	0.03	0.015
25.6×10^6 r	1.66	0.115	0.035	0.020
32.0×10^6 r	2.15	0.16**	0.04	0.025**
Total volume* of gas evolved, ml/g	2.16	0.12	0.04	0.02

*Corrected to STP.

**These values were extrapolated.

TABLE 2. (continued)

	Lead Azide		Tetryl		TNT		Lead Styphnate
	No. 1	No. 2	No. 1	No. 2	No. 1	No. 2	
After Exposure to Gamma Radiation at Ambient Temperature							
Weight of sample, g	2.00	5.00	5.00	5.00	5.00	5.00	2.00
Total irradiation time, days	52	53.1	97.9	58	90	80	87
Total volume* of gas evolved, ml/g	5.51	4.83	1.63	0.58	0.22	0.03	0.01
Volume* of gas produced, ml/g, after following exposures							
7.4×10^6 r	0.65	0.78	0.05	0.02	0.02	0.03	0.01
14.8×10^6 r	1.30	1.37	0.14	0.08	0.04	0.06	0.02
22.2×10^6 r	1.95	1.98	0.21	0.12	0.05	0.07	0.04
29.6×10^6 r	2.63	2.65	0.30	0.17	0.07	0.08	0.05
37.0×10^6 r	3.19	3.06	0.39	0.28	0.08	0.09	0.06
44.4×10^6 r	4.08	3.60	0.49	0.33	0.10	0.11	0.07
51.8×10^6 r	4.92	4.25	0.64	0.42	0.11	0.12	0.08
59.2×10^6 r	5.78**	4.96**	0.75	0.51	0.12	0.13	0.10
66.6×10^6 r			0.88	0.61**	0.12	0.15	0.11
74.0×10^6 r			1.01		0.14	0.17	0.12
81.4×10^6 r			1.19		0.16	0.18	0.13
88.8×10^6 r			1.35		0.20	0.20*	0.14*
96.2×10^6 r			1.55		0.22		
Total gamma exposure, in 10^6 r	56.9	57.7	97.4	62.8	95.6	86.2	87.7

*Corrected to STP.

**These values were extrapolated.

yielded 2.16 ml of gas per gram of explosive (Table 2, Fig. 8).

The amount of gas formed, therefore, increases for equivalent exposures as the temperature increases from –40 to 71°C. After exposures of 30×10^6 r, the gas formation at ambient temperatures is 1.35 times that at –40°C, whereas at 71°C it is 3 times that at –40°C (Table 3).

An unexpected phenomenon was observed with lead azide and other explosives which exhibited postirradiation gas formation. When samples being irradiated at 71°C were removed from the gamma source and brought to ambient temperatures, no postirradiation gas formation occurred. However, when other samples were maintained at 70°C after being irradiated for suitable periods, postirradiation gas formation did occur. In all cases, more gas was evolved than could have resulted from thermal instability alone.

Mercury Fulminate. – A 5-g sample of vacuum-dried mercury fulminate was irradiated for 29 days at ambient conditions in the vacuum-stability apparatus. The rate of gas formation from this explosive was comparatively rapid (2.97 ml/g in 29 days) and increased exponentially with the time of exposure; the slope of the curve (Fig. 10)

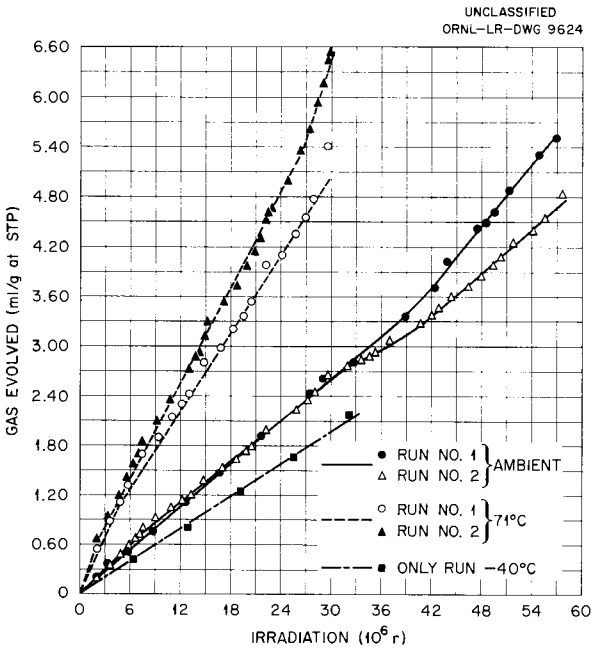

Fig. 8. Volumes of Gas Evolved by Lead Azide During Irradiation (10^6 r) at Different Temperatures.

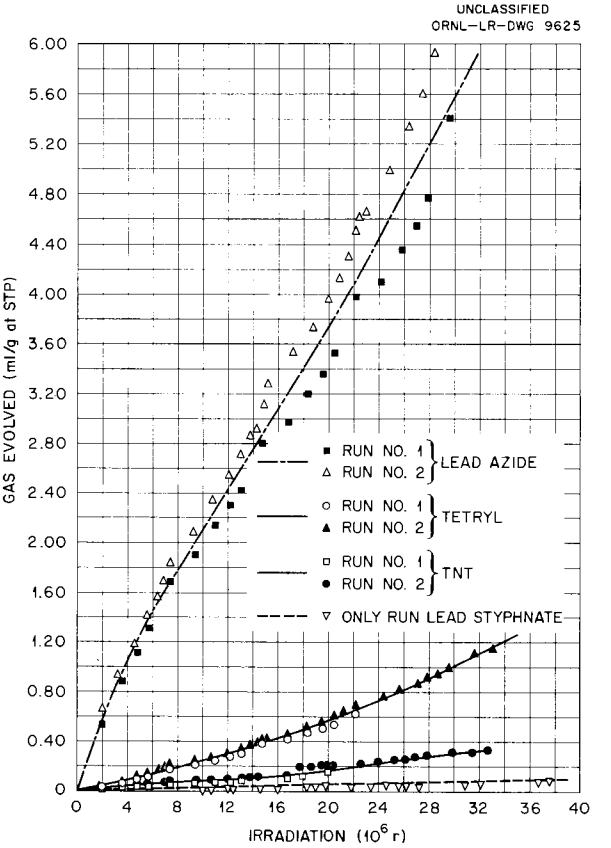

Fig. 9. Volumes of Gas Evolved by Lead Azide, Lead Styphnate, TNT, and Tetryl During Irradiation (10^6 r) at 71°C.

was slight during the first 15 days of irradiation but subsequently increased very rapidly to a maximum at 29 days. Gas formation continued after irradiation but gradually decreased in volume. Gas formation following irradiation was also noted with lead azide and may be an indication of further deterioration of the explosive subsequent to photon bombardment. Chemical analysis showed that the gas produced by mercury fulminate during irradiation consisted of CO_2 (71%) and N_2 (19%). Tests for NO, NO_2, and CO were negative.

Fifty days after irradiation a weighed sample of the black residue was analyzed by allowing it to react to completion with excess sodium thiosulfate and titrating the liberated alkali with standard HCl. The deteriorated specimen assayed only 65.5% mercury fulminate, whereas its original purity was 97.5%.

Determinations of the sensitivity to impact and the sand-test value of the residue were made 35 days after it had been analyzed for purity. The sensitivity to impact approximated that of the original material, the minimum heights of fall of the 2.0-kg weight being 5 and 7 cm, respectively.

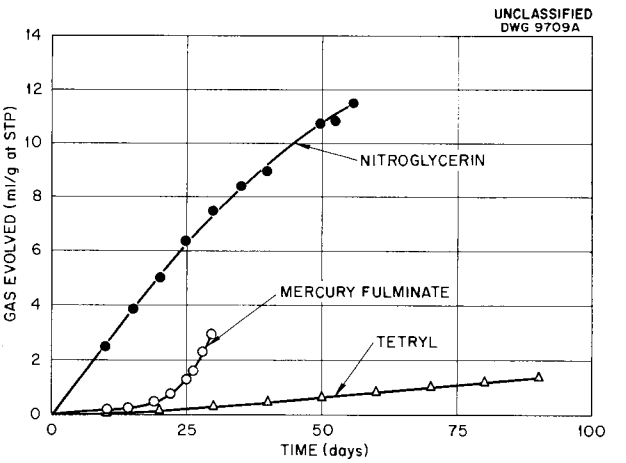

Fig. 10. Volumes of Gas Evolved by Mercury Fulminate, Tetryl, and Nitroglycerin During Irradiation with 0.41-Mev Gamma at 10^5 r/hr.

TABLE 3. SUMMARY OF GAS-EVOLUTION DATA OBTAINED FROM EXPLOSIVES AFTER COMPARABLE EXPOSURES TO GAMMA RADIATION AT VARIOUS TEMPERATURES

Explosive	Exposure Temperature (°C)	Volume of Gas Produced, ml/g, After Following Exposures			
		7.4×10^6 r	14.8×10^6 r	22.2×10^6 r	29.6×10^6 r
Lead styphnate	−40	0.005	0.01	0.015	0.02
	Ambient	0.01	0.02	0.04	0.05
	71	0.02	0.03	0.05	0.07
TNT	−40	0.02	0.03	0.03	0.04
	Ambient	0.02	0.05	0.06	0.07
	71	0.06	0.11	0.20	0.30
Tetryl	−40	0.01	0.04	0.09	0.14
	Ambient	0.04	0.10	0.16	0.23
	71	0.20	0.39	0.66	0.99
Lead azide	−40	0.48	0.93	1.44	1.96
	Ambient	0.71	1.33	1.96	2.64
	71	1.76	2.94	4.24	5.91

The irradiated sample failed to explode when ignited by a black-powder fuse but burned readily, without violence, under its confinement in the No. 6 blasting cap. No sand was crushed in the sand test when the fulminate was tested alone. However, it was found that the irradiated mercury fulminate contained some potential energy which could be released as a detonation wave. When initiated with lead azide, the fulminate crushed about half the quantity of sand (13.1 g) that is characteristic of a normal specimen (25.7 g).

According to these data (Table 4), intense gamma radiation is effective in nullifying the basic function of mercury fulminate as an initiating agent.

Lead Styphnate. – Lead styphnate was dried by gentle heating in a vacuum for 5 hr. Such heating does not remove the water of crystallization from normal specification-grade material. A 2-g sample was irradiated at ambient conditions, and only 0.12 ml of gas per gram was formed during the 90-day irradiation period, indicating that lead styphnate was comparatively stable. The average amount of gas evolved during 10 days of irradiation was 0.055 ml/g. The average increased to 0.09 ml/g in 30 days, to 0.12 ml/g in 60 days, and remained at that level for the rest of the 90-day period (Figs. 6 and 11).

Similar values for sensitivity to impact were obtained for samples before and after exposure to gamma radiation when tested with the Bureau of Mines (20 and 22 cm, respectively) and Picatinny Arsenal (6 and 6 in., respectively) machines. Similar samples crushed 14.1 and 14.3 g of sand in the sand test (within the limits of experimental error). Thus the sensitivity to impact and the brisance of lead styphnate were essentially unaltered by irradiation (Table 5).

When the lead styphnate was irradiated at a temperature of 71°C for 33.5 days, an exposure of 37.6×10^6 r, the amount of gas produced was 0.09 ml/g (Table 3, Figs. 9 and 11). When the sample was irradiated at −40°C for intermittent periods totaling 21.1 days (30.4×10^6 r), only 0.02 ml of gas evolved from each gram of explosive (Table 3, Figs. 11 and 12). Lead styphnate produced the smallest volumes of gas of any of the explosives tested.

Diazodinitrophenol (DDNP). – The amount of dried commercial DDNP irradiated was limited

TABLE 4. SUMMARY OF DATA OBTAINED FROM EXPLOSIVES AFTER EXPOSURE TO GAMMA RADIATION

	TNT	Tetryl	RDX	Lead Azide	Mercury Fulminate	Nitroglycerin
Weight of sample, g	5	5	5	2	5	1.0
Volume of gas produced, ml/g, in the following times						
10 days	0.02	0.10	0.16	1.10	0.17	2.5
20 days	0.04	0.20	0.44	1.95	0.57	5.0
30 days	0.06	0.35	0.87	2.90	2.96[a]	7.5
40 days	0.08	0.48	1.49	3.95		9.0
50 days	0.11	0.66		5.30		10.8
90 days	0.20	1.40				
Total irradiation time, days	90	90	44	52	29	56
Purity of sample, by chemical analysis, %						
Original material				93.08	97.5	
Irradiated material				89.04	65.5	
Melting points, corrected, °C						
Original material	82.1	128.8	204.8			
Irradiated material	80.9	127.8	204.8			
Sensitivity to impact, Picatinny Arsenal machine, in.[b]						
Original material	13		9	*c*		
Irradiated material	12		8	*c*		
Sensitivity to impact, Bureau of Mines machine, cm[b]						
Original material	95	25	40	*c*	7	
Irradiated material	95	26	25	*c*	5[d]	
Sand test, 200-g bomb, grams of sand crushed when sample was ignited by black-powder fuse only						
Original material				*c*	21.5	
Irradiated material				*c*	0.0[d]	
Sand test, 200-g bomb, grams of sand crushed when sample was initiated by 0.30 g of lead azide						
Original material	48.9	56.4	61.7	*c*	25.7	
Irradiated material	50.1	56.0	62.0	*c*	13.1[d]	

[a]Volume of gas evolved from sample in 29 days.

[b]Minimum height of fall of 2.0-kg weight to produce at least one explosion in ten trials.

[c]These tests will be conducted at a later date when more irradiated lead azide becomes available.

[d]Sensitivity-to-impact tests and sand tests were performed 35 days *after* chemical analysis.

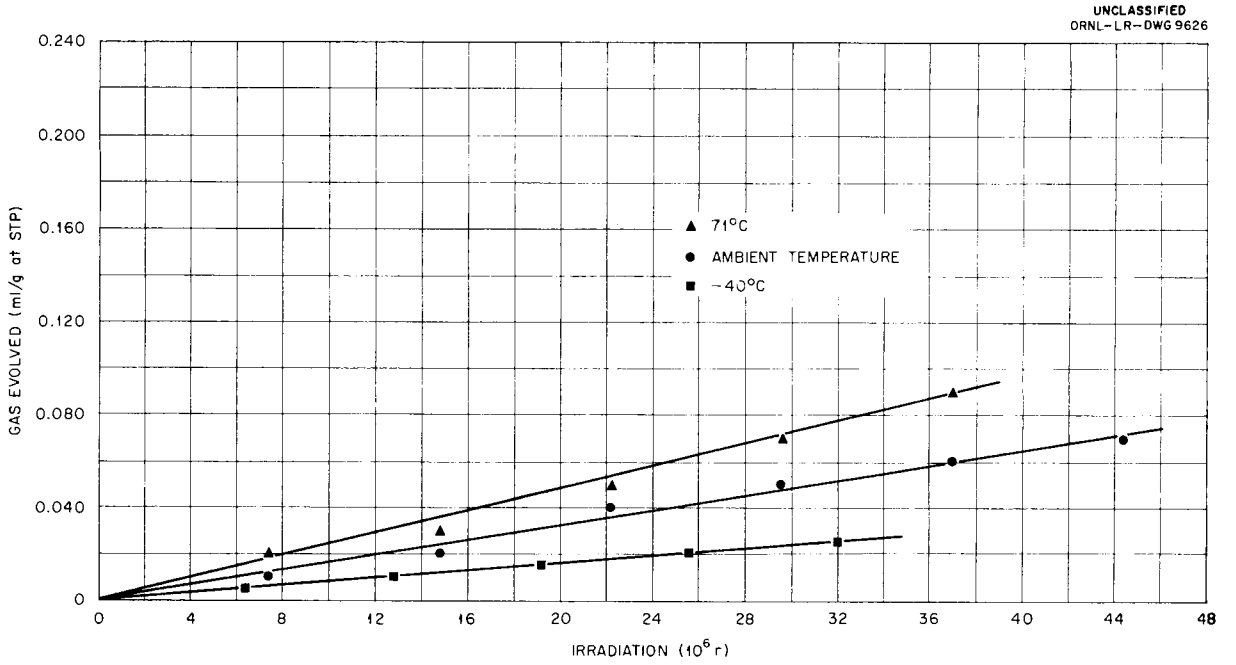

Fig. 11. Volumes of Gas Evolved by Lead Styphnate During Irradiation (10^6 r) at Different Temperatures.

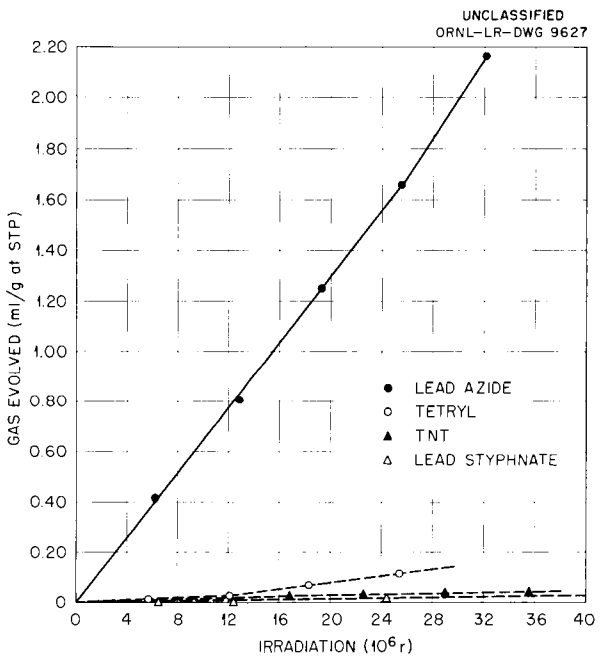

Fig. 12. Volumes of Gas Evolved by Lead Azide, Lead Styphnate, TNT, and Tetryl During Irradiation (10^6 r) at -40°C.

to 2 g because of its extremely low apparent density. Irradiation at ambient conditions brought about the evolution of quantities of gas of the same order of magnitude as those evolved by lead azide (Fig. 6), although the slopes of the curves are quite different. Each gram of DDNP evolved 0.25 ml of gas during the first ten days of irradiation, 1.10 ml during the second ten days, 1.90 ml the third, and 2.35 the fourth. At the end of 45 days, a total of 7.2 ml/g had been produced. The exponential rate of gas formation resembled that of mercury fulminate under irradiation.

Duplicate impact tests yielded values for unirradiated and irradiated DDNP, respectively, of 2 and 2 in. for the Picatinny Arsenal machine and 4 and 3 cm for the Bureau of Mines machine. The difference for the latter test is not considered significant. Five trials of the irradiated material in the sand test yielded amounts of pulverized sand which ranged from 7.2 to 21.0 g, with an average of 14.1 g. Unirradiated DDNP consistently yielded 22.1 g of crushed sand (Table 5). Therefore high-level radiation for periods of about

TABLE 5. SUMMARY OF DATA OBTAINED FROM INITIATING-TYPE EXPLOSIVES DURING AND AFTER EXPOSURE TO GAMMA RADIATION

	Lead Azide	Lead Styphnate	Mercury Fulminate	Diazodinitrophenol
Weight of initiating explosive irradiated, g	5	5	5	2
Volume of gas produced,[a] ml/g, in the following times				
10 days	1.10	0.05	0.17	0.25
20 days	1.95	0.07	0.57	1.35
30 days	2.90	0.09	2.96[b]	3.25
40 days	3.95			5.60
45 days	4.65			7.2
50 days	5.30			
60 days		0.10		
90 days		0.12		
Total irradiation time, days	52	90	29	45
Sensitivity-to-impact tests[c]				
Picatinny Arsenal machine, in.				
Original material	3	6		2
Irradiated material	3	6		2
Bureau of Mines machine, cm				
Original material	65	20	7	4
Irradiated material	75	22	5	3
Sand tests, 200-g bomb, weight of sand crushed when sample was				
Ignited by the spit of black-powder fuse, g				
Original material	20.5	14.1	21.5	22.1
Irradiated material	18.7	14.3	0.0	14.1 ± 6.9[d]
Initiated by 0.30 g of lead azide, g				
Original material			25.7	
Irradiated material			13.1	

[a]Portions of the gassing data were taken from K. S. Warren, *Effects of Nuclear Radiation on Explosives*, ORNL CF-50-4-103 (April 1950), ORNL CF-50-8-54 (August 1950), and ORNL CF-50-12-109 (December 1950).

[b]Volume of gas evolved from sample in 29 days.

[c]Minimum height of fall of 2.0-kg weight to produce at least one explosion in ten trials.

[d]Erratic sand-test values resulted in a range of 13.9 g of crushed sand over five trials.

45 days is sufficient to render this explosive unreliable for use as an initiator.

HIGH EXPLOSIVES

TNT. – During a 90-day period of irradiation at ambient conditions, 5 g of TNT, previously dried under vacuum, evolved 1.0 ml of gas at a relatively constant rate (Fig. 5). These data indicate that TNT is comparatively stable under gamma radiation, and a microdetermination of the gaseous composition did not seem warranted. It seems likely that the stability of TNT can be attributed

to the aromatic ring. The photochemical reaction, in which the original light straw color turned to a medium brown, was probably chiefly due to isomerization or molecular rearrangement. The decomposition products and the TNT probably possessed molecular weights of the same order of magnitude. A melting-point depression of 1.2°C (Table 4) indicates the presence of about 2 wt % of impurity formed as a result of irradiation. It is of interest to note that, whereas exposure of a bottle of TNT to the ultraviolet rays of sunlight will cause darkening of a very thin layer of explosive immediately adjacent to the glass, the greater penetrating power of gamma radiation caused homogeneous discoloration of the TNT.

A second 60-day exposure was made as a check (Fig. 13). During this period, TNT liberated 0.14 ml of gas per gram; the same amount was liberated during the first 60 days of the original TNT irradiation. The melting point of the second sample of TNT after a 60-day exposure was 1.0°C lower than that of the explosive before exposure (Table 6), and after 90 days the depression was 1.2°C.

The impact-sensitivity values determined on the Picatinny Arsenal machine (13 and 12 in.) and the Bureau of Mines machine (95 and 95 cm) were found to be approximately the same before and after exposure to radiation. Sand-test values were also similar before and after irradiation

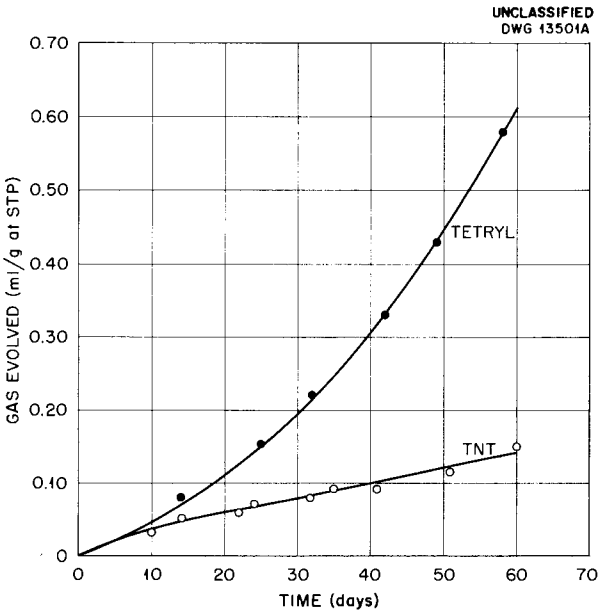

Fig. 13. Volumes of Gas Evolved by TNT and Tetryl During Irradiation with 0.41-Mev Gamma at 10^5 r/hr.

TABLE 6. SUMMARY OF DATA OBTAINED FROM EXPLOSIVES AFTER EXPOSURE TO GAMMA RADIATION

	TNT	Tetryl	PETN	Ballistite Propellant	Nitroguanidine Propellant
Weight of sample, g	5.0	5.0	5.0	5.0	4.34
Total irradiation time, days	60	60	42	37	60
Volume of gas produced, ml/g, during irradiation periods as follows					
10 days	0.03	0.05	0.10	0.10	0.24
20 days	0.06	0.11	0.43	0.25	0.62
30 days	0.08	0.20	1.04	0.80	1.15
40 days	0.10	0.31	2.33		1.82
50 days	0.12	0.45			2.55
60 days	0.14	0.62			3.35
First 60 days of previous irradiation*	0.14	0.84			
Melting points, corrected, °C					
Original material	82.1	128.8	140.8		
Irradiated material	81.1	128.5	137.0		

*Data on gas evolution by TNT and tetryl during previous irradiations were taken from K. S. Warren, *Effects of Nuclear Radiation on Explosives*, ORNL CF-50-4-103 (April 1950) and ORNL CF-50-8-54 (August 1950).

(48.9 and 50.1 g, respectively, Table 4). Unirradiated TNT, when held at 71°C for 30 days, evolved 0.56 ml of gas per gram of sample for the entire period. The greatest amount of gas was formed during the first day. As indicated by the slope of the curve (Fig. 14), only about 0.010 ml/g was formed during the remainder of the period (Table 2). Before irradiation this sample of TNT evolved 0.06 ml/g. The corrected value for the total gas formation of TNT irradiated for 19.0 days is 0.15 ml/g, an increase of 2.6 times over the average amount evolved by two samples observed at room temperature.

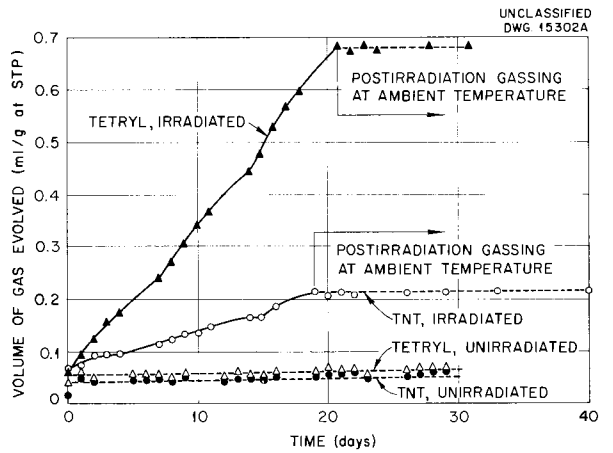

Fig. 14. Volumes of Gas Evolved by TNT and Tetryl During and After Irradiation at 71°C with 0.41-Mev Gamma at 10^5 r/hr.

In another irradiation at 71°C for 29.8 days, an exposure of 32.7×10^6 r, a sample of TNT evolved 0.33 ml of gas per gram of sample (Table 2, Fig. 15). The –40°C exposure for 26.0 days (35.6×10^6 r) yielded 0.04 ml/g (Table 2, Figs. 12 and 15). The gas formation of this explosive was almost linear in time, although at –40 and 71°C more gas appeared during the earlier periods of exposure than appeared later on. At ambient temperature (~21°C) the ratio of gas formation was 1.75 times that at –40°C, whereas at 71°C the ratio increased to 7.5 times that at –40°C (Table 3).

Tetryl. – Tetryl evolved gas at a linear rate with respect to time during exposure to gamma radiation under ambient conditions, as shown in Fig. 10. By the end of 90 days of continuous

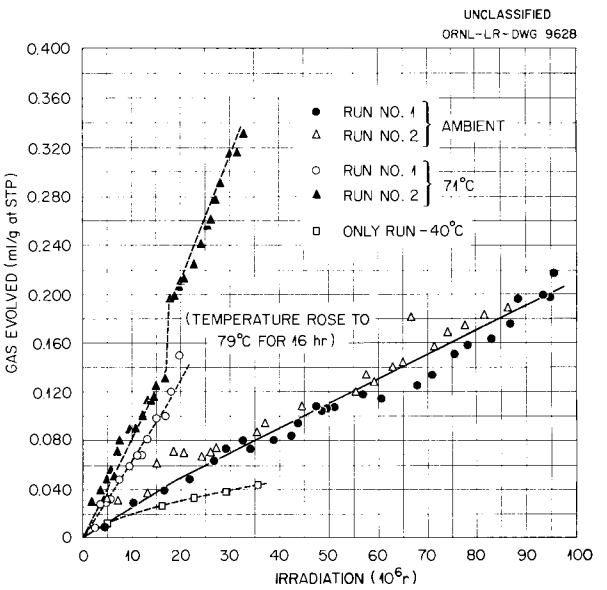

Fig. 15. Volumes of Gas Evolved by TNT During Irradiation (10^6 r) at Different Temperatures.

irradiation, 1.4 ml of gas per gram of explosive had accumulated in the stability tube, about six times that for TNT. Tetryl, nevertheless, exhibited a resistance considerably greater than that shown by RDX, lead azide, mercury fulminate, and nitroglycerin. The lowering of the melting point of tetryl by 1.0°C indicates that a small amount of a tetryl-soluble substance was formed by photolysis (Table 4). The impurity thus formed was not sufficient to affect the sensitivity-to-impact value of samples before and after irradiation (26 and 25 cm, respectively) or the sand-test value, since the value after irradiation (56.0 g) agreed within experimental error with the values of the original sample (56.4 g, Table 4). Since a pulverized or melted portion of the irradiated sample possessed the same darkened appearance as did the remainder in the granular state, it was evident that the discoloration of the tetryl was not confined to the external surface of the grains but that it existed throughout the mass of the explosive.

During the second run (60-day irradiation), 0.62 ml of gas was evolved per gram, as compared with 0.84 ml/g for the first run, and the melting-point depression was only 0.3°C (Fig. 13).

Unirradiated tetryl evolved 0.059 ml of gas per gram of sample when heated at 71°C for 30 days (Table 2). As with lead azide and TNT, the

highest rate of gas formation occurred during the first day (Fig. 14). The base-line volume was 0.06 ml/g when the sample was kept at 71°C for six days prior to irradiation. The gas formed by irradiating tetryl for 20.9 days at 71°C amounted to 0.62 ml per gram of sample exposed, an increase of 3.7 times over the average value for two samples previously tested at room temperature.

When again subjected to gamma photons at 71°C for a period of 29.9 days (33.1×10^6 r), tetryl evolved 1.14 ml of gas per gram (Figs. 9 and 16). After tetryl was irradiated at an exposure of 28.2×10^6 r at temperatures which averaged −40°C for intermittent periods totaling 21 days, 0.12 ml of gas per gram of sample was produced (Figs. 12 and 16).

Tetryl, which is structurally similar to TNT, formed more gas than did TNT after equivalent exposures at the three experimental temperatures.

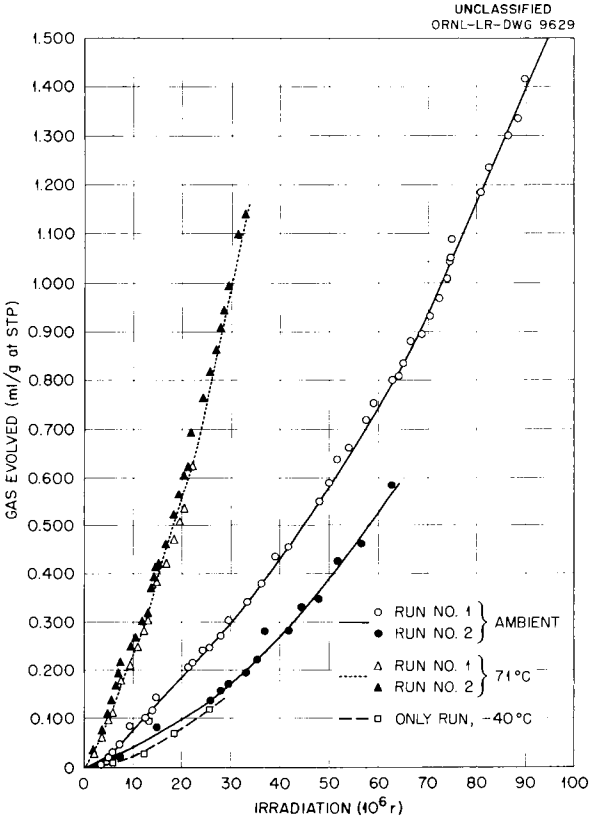

Fig. 16. Volumes of Gas Evolved by Tetryl During Irradiation (10^6 r) at Different Temperatures.

The ratios of the gas formation between these two compounds were fairly constant (3.5 at −40°C, 3.3 at ~21°C, and 3.3 at 71°C) over the entire temperature range (Table 3).

RDX (cyclo-trimethylenetrinitramine). – During 44 days of irradiation at ambient temperatures, 5 g of RDX produced 8.95 ml of gas. On the forty-fourth day, irradiation was discontinued because of the increase in the rate of gas formation. Decomposition continued after irradiation, with the production of an additional 12.5 ml of gas during the next 40 days (Table 1). The colorless gas evolved was a mixture of N_2, CO_2, and a small percentage of H_2. The tests for ammonia, nitrogen oxides, oxygen, and carbon monoxide were negative. The generation of gas by RDX during irradiation followed a substantially parabolic curve (Fig. 5); when gas volume was plotted against time squared, a straight line resulted. This exponential behavior may also be pointed up by a consideration of the following data. Each gram of RDX evolved 0.16 ml of gas during the first ten days of irradiation, 0.28 ml during the second ten-day period, 0.43 ml during the third, and 0.62 ml during the fourth.

The color and melting point of RDX were unchanged by the exposure. Considerable decomposition accompanied the melting phenomena and possibly masked the detection of the presence of impurities.

Sensitivity-to-impact tests with the Bureau of Mines machine yielded, for the untreated material, a detonation at a minimum fall of 40 cm for a 2-kg hammer, whereas the corresponding value for the irradiated specimen was 25 cm. More nearly identical results were obtained with the Picatinny Arsenal impact-test machine; a 9-in. minimum drop caused detonation of the unirradiated sample, and only an 8-in. drop was required for the irradiated sample. Sand-test values were 61.7 g crushed before exposure and 62.0 g crushed after exposure (Table 4).

PETN (pentaerythritol tetranitrate). – PETN is regarded as one of the most stable organic esters of nitric acid and has a high velocity of detonation. During 42 days of gamma irradiation at ambient conditions, 2.7 ml of gas per gram of PETN was formed. Therefore the rate of gas evolution from PETN is much lower than that from another organic nitrate, nitroglycerin, which evolved the same amount of gas in about ten days.

On this basis of comparison, PETN is more resistant to radiation damage than are lead azide, mercury fulminate, and diazodinitrophenol but much less resistant than is TNT or tetryl. An important characteristic of the gas-evolution curve for PETN (Fig. 17, Table 1) is the sharp upward trend after the first 10 or 15 days, which resembles that of RDX and ballistite. Further evidence of damage to PETN was obtained from a comparison of its melting point before (140.8°C) and after (137.0°C) exposure to irradiation (Table 6). The difference of 3.8°C represents the melting-point depression caused by the presence of a radiation-produced decomposition product which is soluble in molten PETN. Since the melting-point depression of tetryl was only 1°C, that explosive is preferable to PETN as a booster under conditions involving intense gamma fields.

Nitroglycerin. – The nitroglycerin, dissolved in absolute ethanol for shipment, was evaporated in a vacuum desiccator at room temperature to constant rate of weight loss, and 1 g of the pure explosive was then transferred to a stability tube for evacuation and measurement. Nitroglycerin decomposed under the influence of gamma radiation at ambient conditions and produced 11.5 ml of gas in 56 days (Fig. 10). These decomposition gases corroded mercury upon direct contact, an action which had not been observed in the other explosives tested. The residue was a thick, very viscous liquid, which evolved fumes of nitrogen dioxide, and upon standing 50 additional days at room temperature it had become practically solidified. Because nitroglycerin underwent such a severe deterioration during and subsequent to radiation exposure, further physical testing did not seem warranted.

BINARY EXPLOSIVES

Tetrytol. – A 5-g sample of tetrytol (65% tetryl, 35% TNT), when irradiated for 33.7 days under ambient conditions for a total exposure of 34.8×10^6 r, evolved 0.37 ml of gas per gram of sample (Fig. 18). The pattern of gas formation simulated that of the first tetryl sample. Following irradiation, 0.04 ml of gas per gram of sample was evolved in 30 days (Tables 1 and 7).

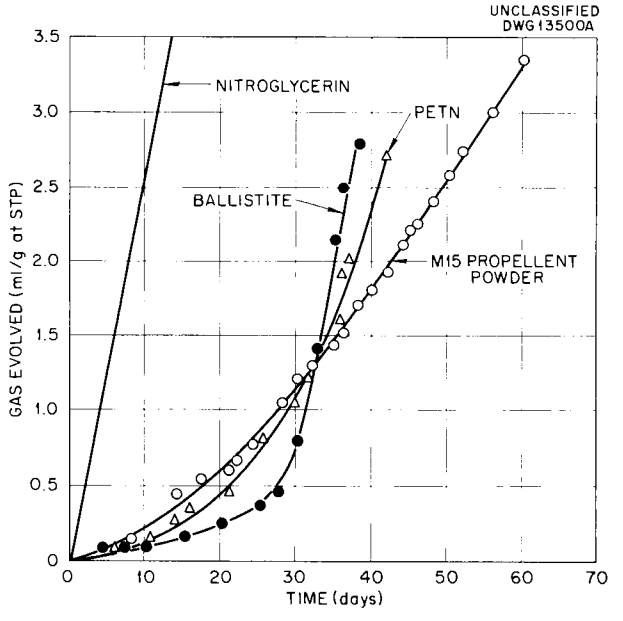

Fig. 17. Volumes of Gas Evolved by PETN, Nitroglycerin, Ballistite, and M15 Propellant Powder During Irradiation with 0.41-Mev Gamma at 10^5 r/hr.

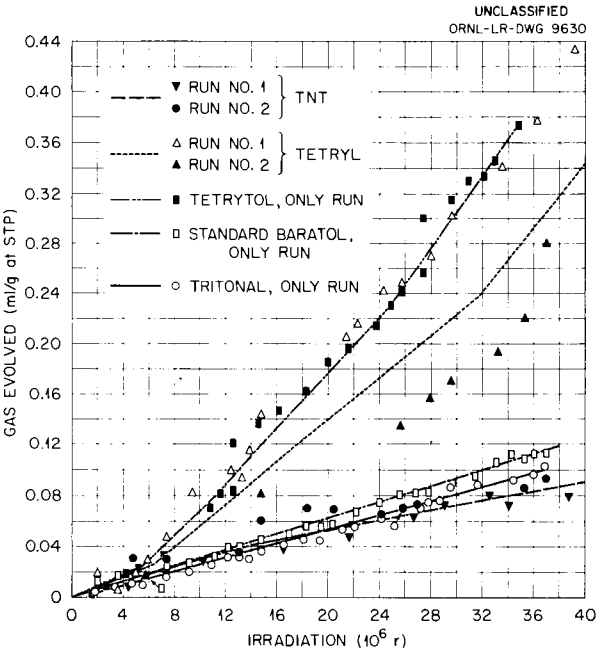

Fig. 18. Volumes of Gas Evolved by Tetrytol, TNT, Tetryl, Standard Baratol, and Tritonal During Irradiation (10^6 r) at Ambient Temperatures.

TABLE 7. SUMMARY OF DATA OBTAINED FROM BINARY EXPLOSIVES AFTER EXPOSURE TO GAMMA RADIATION AT AMBIENT TEMPERATURE

	Binary Explosive							
	Tetrytol (Tetryl 65%, TNT 35%)	Standard Baratol ($Ba(NO_3)_2$, 67%, TNT 33%)	Composition B (RDX 60%, TNT 40%	Tritonal (TNT 80%, Al 20%)	Pentolite (PETN 50%, TNT 50%)	JPN Propellant	RDX	PETN
Weight of sample, g	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
Total irradiation time, days	33.7	35.0	26.9	34.7	33.8	35	43.9	42
Total gamma exposure, in 10^6 r	34.8	37.0	27.5	36.9	36.5	37	46.5	44.4
Total volume* of gas evolved, ml/g	0.37	0.11	0.72	0.10	0.45	2.73	1.79	2.71
Volume* of gas produced, ml/g, after following exposures								
7.4×10^6 r	0.03	0.03	0.15	0.02	0.08	0.22	0.08	0.09
14.8×10^6 r	0.14	0.05	0.29	0.04	0.10	0.53	0.29	0.26
22.2×10^6 r	0.20	0.07	0.50	0.06	0.15	1.17	0.49	0.55
29.6×10^6 r	0.32	0.09	0.83**	0.09	0.24	1.86	0.76	1.04
37.0×10^6 r	0.40**	0.11		0.10	0.47**	2.73	1.21	1.63
44.4×10^6 r							1.66	2.71

*Corrected to STP.

**These values were extrapolated.

Standard Baratol. – This binary explosive, containing 33% TNT and 67% $Ba(NO_3)_2$, was irradiated for 35 days under ambient conditions for a total exposure of 37×10^6 r. A 5-g sample evolved 0.11 ml of gas per gram, an action similar to that of TNT under like conditions of irradiation (Fig. 18). Gas formation following irradiation amounted to only 0.01 ml (Tables 1 and 7).

Composition B. – Irradiation of this mixture of 60% RDX and 40% TNT for 26.9 days under ambient conditions for a total exposure of 27.5×10^6 r resulted in the evolution of 0.72 ml of gas per gram of sample (Fig. 19) – a rate almost identical to that of RDX over a similar irradiation period. During an 84-day period following irradiation, a 5-g sample evolved 0.67 ml of gas per gram (Tables 1 and 7).

Tritonal. – Tritonal (80% TNT, 20% Al) behaved like TNT when irradiated for 34.7 days under ambient conditions for a total exposure of 36.9×10^6 r. The amount of gas evolved by a 5-g sample was 0.10 ml/g (Fig. 18, Tables 1 and 7).

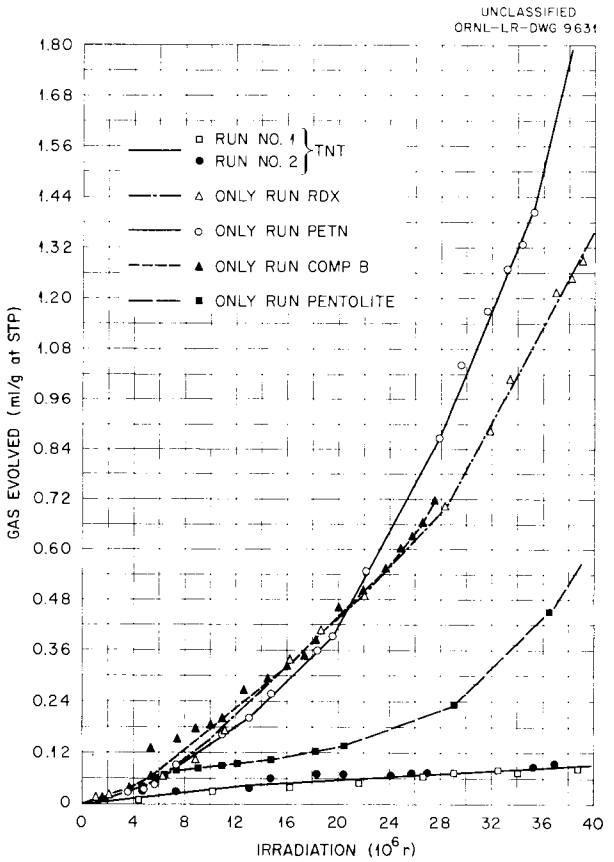

Fig. 19. Volumes of Gas Evolved by Composition B, TNT, RDX, PETN, and Pentolite During Irradiation (10^6 r) at Ambient Temperatures.

Pentolite. – Pentolite (50% PETN, 50% TNT) did not react under irradiation like the other binary explosives. In tests on the other binary explosives, the volume of gas formed corresponded closely to the volume formed, under similar conditions, by the major gas-producing component. For the first exposure of pentolite, to 7.4×10^6 r under ambient conditions, the curve for PETN was followed, but the slope then changed abruptly and followed that for TNT. After two exposure periods of 7.4×10^6 r, a slope parallel to that for PETN was again followed (Fig. 19). Pentolite evolved 1.29 ml of gas per gram while standing for 28 days following irradiation, whereas during the 30-day irradiation period 0.33 ml/g was evolved (Tables 1 and 7).

PROPELLANTS

Ballistite. – Double-base propellants, in a variety of grain and sheet forms and containing various percentages of nitroglycerin, have been used in small-arms, trench-mortar, and artillery ammunition. Ballistite is one of the oldest of the double-base compositions, and the only sample available was the remainder of a master sample of graphited flake ballistite manufactured in 1918. The composition of this powder is nitrocellulose, 69.25%; nitroglycerin, 30.50%; diphenylamine, 0.25%; and a graphite coat. This material had not undergone severe deterioration during continued storage for more than 25 years.

When a sample of ballistite was subjected to the usual irradiation for 38 days at ambient conditions, about 2.80 ml of gas was evolved per gram of sample. The slope of the decomposition curve increased very rapidly with exposure time, so that the rate of gas generation was about 0.28 ml/g/day near the end of the exposure (Fig. 17). Results obtained from the irradiation of nitroglycerin are included in Fig. 17 for purposes of comparison, because that compound probably contributes greatly to the poor radiation stability of ballistite.

M15 Propellant. – This double-base propellant consists of nitroguanidine, 54.7%; nitrocellulose, 20.0%; nitroglycerin, 19.0%; ethyl centralite, 6.0%; and cryolite, 0.3%. A sample in granular

form was irradiated for 60 days at ambient conditions and produced 3.35 ml of gas per gram of explosive (Fig. 17). The rate of gas formation did not change so rapidly as with ballistite, but the gas undoubtedly originated in the nitroglycerin.

M26 Primers. – The primers were dried in a desiccator overnight prior to irradiation. Since the amount of gas evolved could not be measured, brass tubes which permitted the simultaneous exposure of 100 M26 primers within the desired flux of the radioactive-gold cylinder were used as containers.

The M26 primer consists of a gilding-metal cup and closing disk of carefully controlled dimensions (Fig. 20) that contains a pressed mixture of PA 100 primer composition, which consists of the following: potassium chlorate (oxidizing agent), 53%; antimony sulfide (fuel), 17%; lead thiocyanate (sensitizer), 25%; and lead azide (blast agent), 5%. Experience has shown that the relatively high sensitivity to stab action of the M26 primer is chiefly attributable to the intimate contact of the potassium chlorate and lead thiocyanate.

Four groups of irradiated M26 primers, together with an equal number of nonirradiated primers, were subjected to the standard test for sensitivity to stab action. The unexposed primers complied with the specification requirements for sensitivity; all functioned normally under the impact of a standard 3.95-oz steel ball dropped from a height of 1½ in. on the prescribed firing pin. The three groups of primers which had been exposed to the gamma source for 15, 30, and 60 days, respectively, also functioned normally under the stab-action testing. Of the fourth group of 100 primers, irradiated for 90 days, 98 functioned normally, and two burned but failed to explode (Fig. 21).

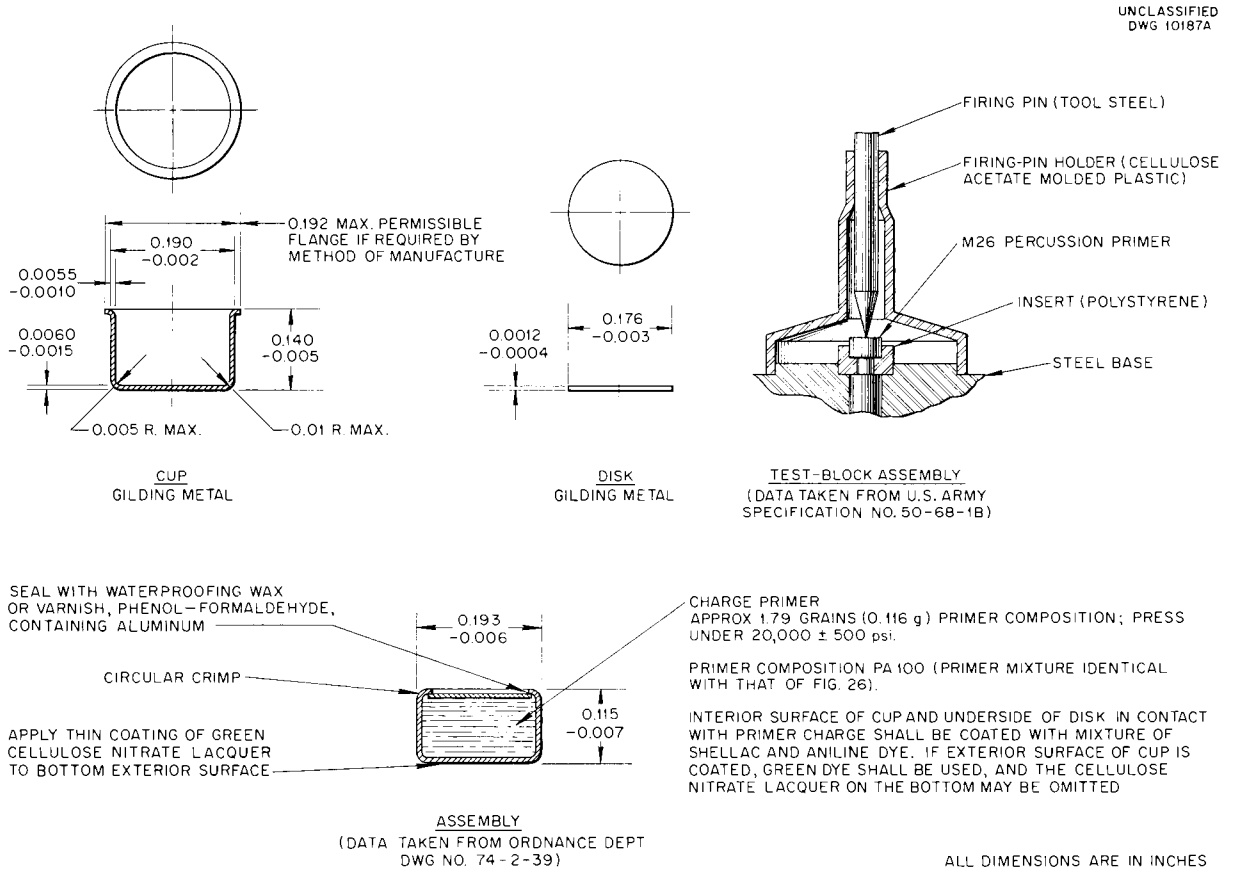

Fig. 20. Detailed Diagram of M26 Primer and Test-Block Assembly.

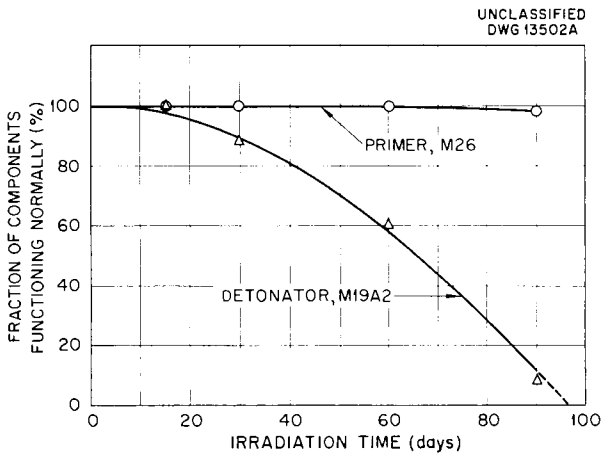

Fig. 21. Apparent Radiation Damage to Standard Loaded Components After Irradiation with 0.41-Mev Gamma at 10^5 r/hr.

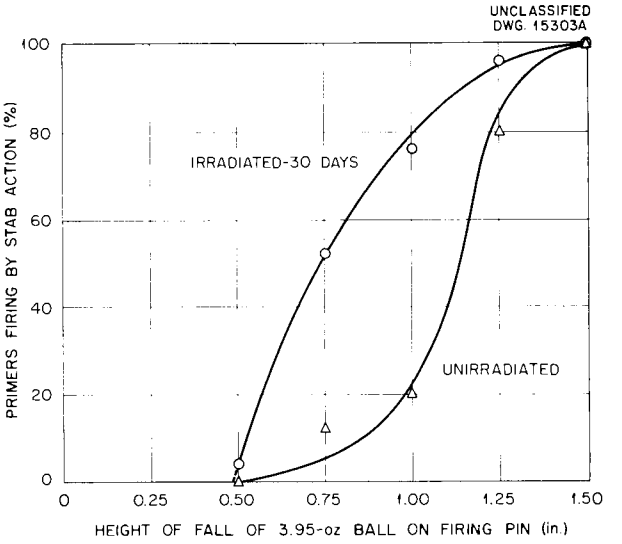

Fig. 22. Sensitivity to Stab Action of M26 Primers Before and After Irradiation at Ambient Temperatures.

These data indicate that the sensitivity of the primer mixture PA 100 is not increased by exposure to radiation for as long as 60 days. In addition, the polystyrene inserts employed in holding each primer during stab-action testing (Fig. 20) were consistently fragmented; this indicates that the lead azide had not deteriorated significantly during the 15-, 30-, and 60-day exposures. However, 2% of the primers did not detonate properly after an exposure of 90 days – an indication of perceptible radiation damage for the longer exposure time.

Run-down tests on sensitivity to stab action were performed on unirradiated M26 primers and on M26 primers that had been exposed to radiation for 30 days. Twenty-five primers of each type were used at each 0.25-in. step as the fall height of the steel ball was reduced from 1.75 to 0.50 in. Sensitivity to stab action is apparently increased by irradiation, as shown graphically by the test data (Fig. 22). The two curves nearly intersect in the region of the 0.5-in. height of fall. Functioning of primer charges depends upon penetration, however slight, of the cover disk by the firing pin. At 0.5-in. drops of the steel ball, the resistance to indentation of the cover disk protects the primer composition from this slight percussive action and prevents detonation. This preventive action "forces" the curves to almost intersect as shown (Fig. 22).

When 50 primers were irradiated at 71 ± 2°C for 30 days, a total exposure of 33.2×10^6 r, they produced 100% high-order detonations. The same number of unirradiated primers stored for the same length of time at 70 ± 2°C produced 98% high-order detonations when tested for standard functioning.

M26 primers irradiated at –40°C at an average rate of 4.6×10^4 r/hr for total exposures of 31.2×10^6 r, as well as 65×10^6 r, also produced 100% high-order detonations. The run-down test, however, shows that sensitivity was increased by irradiation. The data are listed in Table 8 and presented graphically in Fig. 23. There was very little difference between the results obtained for primers stored at the low temperature and the results for primers stored at ambient conditions.

M19A2 Detonator. – A series of radiation exposures similar to the exposure for the M26 primer was conducted on the M19A2 detonator. The lead disks employed, along with typical changes that resulted from the tests, are illustrated in Fig. 24. A detectable bulge in the cover disks of 12 detonators was noted. Gas pressure within the hermetically sealed detonator cup probably caused the bulges (Fig. 25). The test-block assembly is shown in Fig. 26. A detonator is slid into the upper cavity of a plastic firing-pin holder, and the lead disk is fitted into the open bell. This assembly is placed in the

TABLE 8. RUN-DOWN SENSITIVITY TESTS ON LOADED M26 PRIMERS STORED AT −40°C FOR 30 DAYS

(Twelve primers tested at each height of fall of a 3.95-oz ball)

Height of Fall of Ball (in.)	Number of Unirradiated Primers			Number of Irradiated Primers		
	Exploded	Burned Out[a]	Failed to Fire[b]	Exploded	Burned Out[a]	Failed to Fire[b]
1.25	12	0	0	12	0	0
1.00	4	0	8	11	0	1
0.75	0	0	12	3	0	9
0.50	0	0	12	0	0	12

[a]Burned out, with no fragmentation of the plastic insert holding the primer.

[b]Component failed to fire upon being stabbed by firing pin; there was no burning or no explosion.

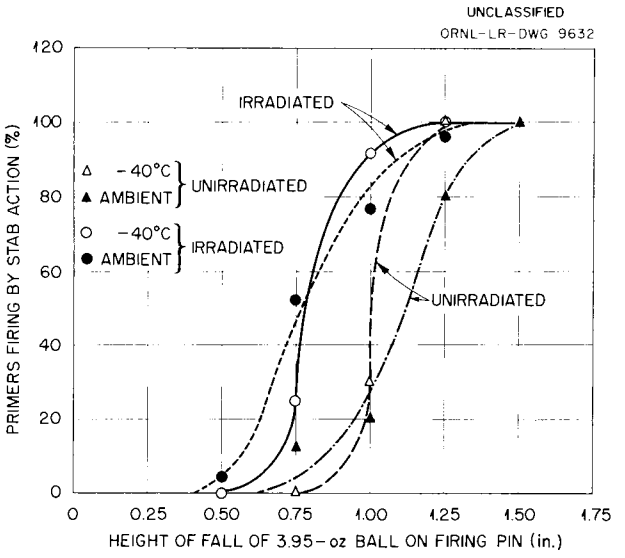

Fig. 23. Sensitivity to Stab Action of M26 Primers Before and After Irradiation at −40°C and at Ambient Temperatures.

proper position on the steel base of the test block, and a firing pin is carefully inserted in its holder so that the point is in contact with the sensitive end of the detonator. The steel ball which falls on the firing pin is released by an electromagnet. New firing pins, holders, and lead disks were used for each test.

The degree of radiation damage to this detonator was significant, as seen from an inspection of Fig. 21. A 15-day exposure to gamma radiation produced no change in functioning characteristics that could be detected by sensitivity lead-plate-puncture tests on the small number (50) of detonators which could be irradiated at one time. Longer exposures of 30, 60, and 90 days resulted in malfunctions of 12, 60, and 92%, respectively. The observed malfunctioning consisted in incomplete detonation, in which the lead plate was merely dented by the primer rather than punctured by the initiation of the tetryl as prescribed by the applicable specification. It is important to note, however, that all the samples tested, whether irradiated or not, were adequately stab-sensitive under the standard firing pin and that the primer mixture consistently fired under the required 3-in. fall of a 3.95-oz ball.

The PA 100 primer mixture, employed as the upper charge in the M19A2 detonator, was used as the entire charge of the M26 primer. The observation that the stab sensitivity of the detonator was not materially impaired by a 60-day exposure substantiates the corresponding observation with the primer. Adjacent to the PA 100 composition in the detonator was a lead azide increment, which was used to initiate the lower charge of tetryl (Fig. 26). Malfunctioning in the irradiated M19A2 detonators is attributable to failure of the deteriorated lead azide to consistently initiate the tetryl, which possesses normal brisance and impact sensitivity upon irradiation for 90 days. Spot tests for tetryl indicate that it is present on the B-type disk but not on the C-type disk. There was no intermediate

(a) LEAD DISKS BEFORE USING TEST BLOCK ASSEMBLY (SEE FIG 26)

(b) INDENTED LEAD DISKS RESULTING FROM MALFUNCTIONING M19A2 DETONATORS (SEE TEXT)

(c) PUNCTURED LEAD DISKS PRODUCED BY NORMALLY FUNCTIONING M19A2 DETONATORS

Fig. 24. Illustration of Typical Results from Normally and Abnormally Functioning M19A2 Detonators on Lead Disks Used in Puncture Tests.

Fig. 25. Detonator Cups Used in Stab Tests of M19A2 Detonators, with a Comparison of the Appearance of a Normal Detonator (Right) and One After 90 Days of Exposure to Radiation (Left). The cover disk in the left picture is bulged outward as a result of internal pressure.

stage of damage; all irradiated detonators which produced a hole $\frac{3}{8}$ in. or greater in diameter, instead of a dent, left holes with diameters equal to those produced by unirradiated detonators.

The results of run-down sensitivity tests on 20 detonators are shown in Fig. 27, where the height of fall is plotted against the fraction of detonators fired. As with the M26 primers, although sensitivity was increased, the use of the detonators after a 30-day exposure is not considered to be unduly hazardous.

After irradiation at 71 ± 2°C for 36.5 days, an exposure of 39.8×10^6 r, only 38% of the 50 detonators tested produced high-order detonations; 4% blew a hole less than $\frac{3}{8}$ in. in diameter, and 58% fired but failed to initiate the tetryl charge. Equivalent damage was sustained after a 60-day exposure. After storage at 70 ± 2°C for the same period without irradiation, all 50 detonators produced high-order detonations. At this temperature the 39.8×10^6 r exposure did as much damage as 64.9×10^6 r at normal temperature.

At –40°C, exposures up to 32×10^6 r did not affect the functioning of the M19A2 detonators. As with the primers, sensitivity is increased but to a lesser extent (Table 9, Fig. 28).

HISTORY OF SAMPLES OF EXPLOSIVES

1. TNT – Lot WLD-179 of January 1943; Batch No. 12271, PA Rep. No. 125965, Spec. JAN-T-248 Granular, grade III (Sept. 29, 1945).

2. RDX – Wabash Lot E-20; PA Rep. No. 125903, Spec. JAN-R-398 (type A, class A) (Sept. 25, 1946).

3. Lead azide – Lot KNK-1008; PA Rep. No. 126157, Army Spec. No. 50-13-12B with Amendment 3 (July 13, 1948).

4. Tetryl – Lot PA-82; PA Rep. No. 125903, Spec. JAN-T-339 (grade I, class A) (May 1946).

5. Mercury fulminate – Lot AP-1 (1945) Atlas Powder Co.; PA Rep. No. 126678, Spec. JAN-M-219 (May 30, 1945).

6. Nitroglycerin – Hercules Powder Co., transported as 10% nitroglycerin in 90% absolute alcohol; PA Rep. No. 126572, Spec. JAN-N-246 (July 31, 1945).

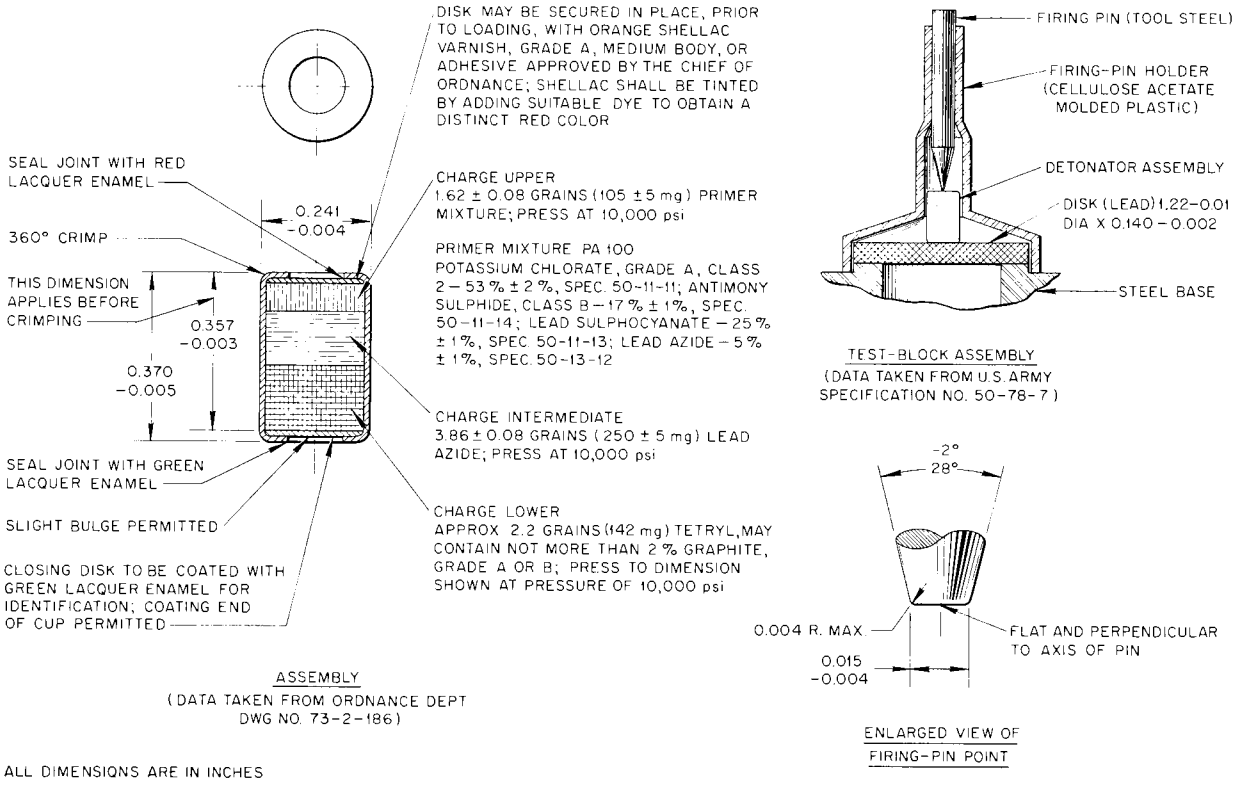

Fig. 26. Detailed Diagram of M19A2 Detonator and Test-Block Assembly.

TABLE 9. RUN-DOWN SENSITIVITY TESTS ON LOADED M19A2 DETONATORS STORED AT –40°C FOR 30 DAYS

(Ten detonators tested at each height of fall of a 3.95-oz ball)

Height of Fall of Ball (in.)	Number of Unirradiated Detonators				Number of Irradiated Detonators			
	Exploded	3/8 in.[a]	Dents[b]	Failed to Fire[b]	Exploded	3/8 in.[a]	Dents[b]	Failed to Fire[b]
2.00	10	10	0	0				
1.75	8	8	0	2	10	10	0	0
1.50	4	4	0	6	10	10	0	0
1.25	2	2	0	8	8	8	0	2
1.00	0	0	0	10	2	2	0	8
0.75					0	0	0	10

[a]Detonators produced a normal 3/8-in. hole in the standard lead disk during functioning.

[b]No puncture was produced in the lead disk during functioning of the detonator; only a dent was produced, of the same diameter as the detonator.

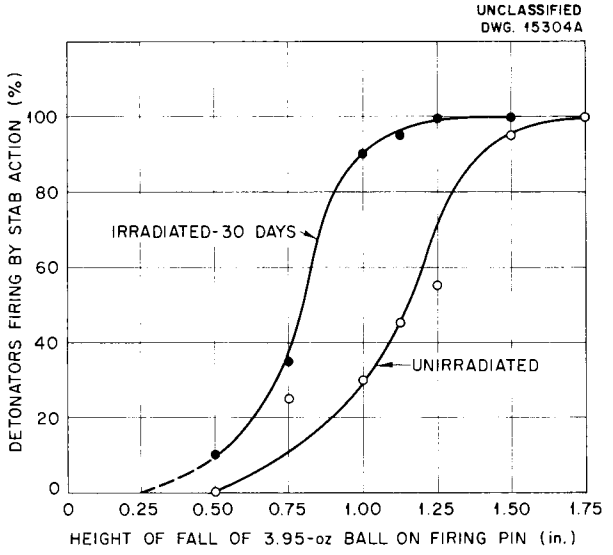

Fig. 27. Sensitivity to Stab Action of M19A2 Detonators Before and After Irradiation at Ambient Temperatures.

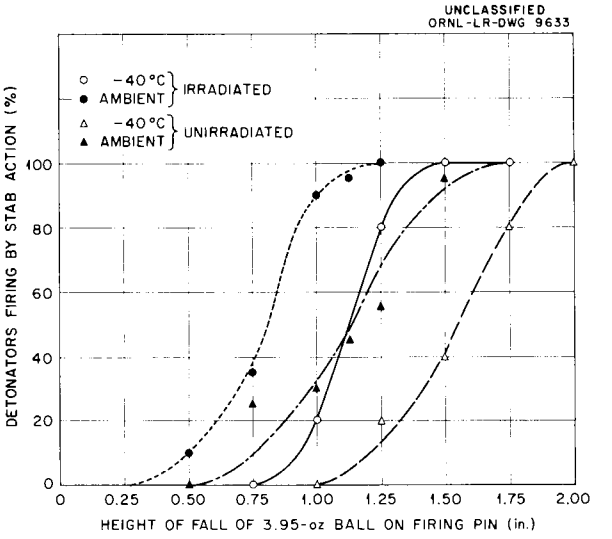

Fig. 28. Sensitivity to Stab Action of M19A2 Detonators Before and After Irradiation at –40°C and at Ambient Temperatures.

7. Lead styphnate – Remington Arms Co., Sample No. 226; PA Rep. No. 125509, Spec. JAN-L-757 (April 13, 1949).

8. Diazodinitrophenol – Hercules Powder Co.

9. M26 Primer – PA Lot No. 26-120, Army Spec. No. 50-68-1B (Dec. 4, 1946).

10. M19A2 Detonator – AOP-1-63, Army Spec. No. 50-78-7 (Nov. 7, 1946).

11. PETN – Trojan Powder Co.; PA Rep. No. 126453, Spec. JAN-P-387 (Aug. 29, 1946).

12. Ballistite – DP Lot 317 of 1918 (Army Lot 25); PA Rep. Nos. 1384 and 127052.

13. M15 Propellant – DPCP Lot Ex. A-6284; PA Rep. Nos. 126409 and 124852, Army Spec. AXS-1720 (March 6, 1946).

14. Tetrytol 65/35 – Lot PA laboratory preparation.

15. Standard Baratol – Plant grade.

16. Composition B – Holston No. 2-4.

17. Tritonal 80/20 – Lot PA laboratory preparation.

18. Pentolite 50/50 – Lot RAD 914.