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THE GROWTH TO DETONATION OF LOW DENSITY EXPLOSIVE MIXTURES

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UNITED STATES NAVAL ORDNANCE LABORATORY, WHITE OAK, MARYLAND

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THE GROWTH TO DETONATION OF LOW DENSITY EXPLOSIVE MIXTURES

Prepared by:

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ABSTRACT: The growth to detonation of normal lead styphnate-lead azide, normal lead styphnate-silver azide, normal lead styphnate-PETN, silver azide-PETN, and normal lead styphnate-flake aluminum mixtures was observed using a rotating mirror smear camera. Normal lead styphnate-lead azide mixtures (75/25 to 25/75 proportions) retain the hot wire sensitivity of the normal lead styphnate and develop a terminal detonation velocity characteristic of the lead azide. Normal lead styphnate-PETN mixtures propagate slower than normal lead styphnate alone. Silver azide-PETN mixtures develop a terminal detonation velocity characteristic of PETN.

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This report describes the results of an investigation on the growth to detonation of low density explosive mixtures. The investigation was performed under WepTask RUME-3-E-000/212 1/F008-10-004, P. A. 016.

This report describes laboratory results which should be of interest to personnel engaged in electric initiator design. The data and conclusions are for information only and are not intended as a basis for action.

The identification of commercial materials implies no criticism or indorsement of these products by the Naval Ordnance Laboratory.

R. E. ODENING
Captain, USN
Commander

C. J. Aronson

C. J. ARONSON
By direction

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THE GROWTH TO DETONATION OF LOW DENSITY EXPLOSIVE MIXTURES

Introduction

1. Many detonators contain three charges; the first or ignition charge provides the desired sensitivity, the second or intermediate charge builds rapidly from burning to detonation and provides the power needed to initiate the less sensitive but more powerful third or base charge. In present U. S. military detonators the ignition charge is usually (but not always) lead styphnate or a lead styphnate base composition. The intermediate charge is frequently lead azide, and the base charge one of the more sensitive high explosives such as PETN, RDX, or tetryl. Lead styphnate is easily ignited but is difficult to bring to detonation making necessary the intermediate charge of lead azide. Lead azide is less sensitive than lead styphnate, but rapidly goes into detonation even from extremely weak initiation. When stringent sensitivity requirements do not exist, lead azide can be used as both the ignition and intermediate charges.

2. The properties of lead azide and lead styphnate apparently complement each other and combinations of these two explosives have been employed in detonators. British patent 138,083 filed in 1920 tells of a detonator primed with lead azide to which had been added lead styphnate to serve as a kindling material for increasing the ignitibility of the lead azide (1). Marshall tells of the use by the Rheinisch-Westfölische Sprengstoffe A. G. in 1925 of an ignition charge of 40% lead azide and 60% lead styphnate in detonators (2). Grant and Tiffany in 1945 reported that the order of efficiency of selected ignition mixtures as determined by minimum initiating charges was as follows (3):

a. 80% lead azide - 20% lead styphnate

b. 60% lead azide - 40% lead styphnate

c. 100% lead azide

d. 40% lead azide - 60% lead styphnate

e. 20% lead azide - 80% lead styphnate

f. 100% lead styphnate

Although the properties of lead azide and lead styphnate apparently complement each other, mixtures of the two found little use in this country until Langdon and Fisher in 1960 used the reported optimum mixture of 80% lead azide - 20% lead styphnate as the ignition material in a symmetrical radial output detonator (4).

3. Little is known about the manner in which primary explosive mixtures burn and grow to detonation. As the lead azide - lead styphnate mixtures show promise for increased use in ordnance items, it was considered worthwhile to investigate the manner in which this mixture and other initiating explosive combinations burn and grow to detonation.

Experimental Arrangement

4. The build-up to detonation of the explosive mixtures was observed in a fixture as shown in Figure 1. The fixture was made by drilling two 0.050-inch diameter holes in a plexiglas plate and force fitting two 0.052-inch diameter brass contact pins into the holes. A 0.001-inch diameter Tophet-C* bridgewire was then soldered across the contact pins flush with the surface of the plexiglas plate. The bridge resistance was 2 to 4 ohms. A linen base phenolic ring 0.080-inch deep was glued to the plexiglas plate so that the bridgewire was located in the center of the ring. The test explosive mixture was loaded into this ring and the fixture was completed by gluing a solid plexiglas plate on the top of the ring to contain the explosive.

5. The loaded fixture was then mounted in a firing chamber. The transparent plexiglas backing permitted camera observation of the bridgewire between the two contact pins. The slit of a rotating mirror smear camera was aligned perpendicularly to the bridgewire as shown in Figure 2. The smear camera record would thus show the growth to detonation along the surface of the test explosive mixture in contact with the plexiglas square. The 0.800-inch I.D. of the ring would permit the build-up to be observed for 0.400 inch to each side of the bridgewire resulting in a symmetrical pattern as shown in Figure 2.

6. A one-microfarad condenser charged to 500 volts was used as the firing source throughout the investigation. The firing circuit was of conventional design with a 5C22 hydrogen thyratron used as the switching device. The charge voltage used was chosen because the effect of this voltage on single initiating explosives was known from a previous phase of the investigation and it was known that the 5C22 thyratron would fire reliably at this voltage.

*60% nickel, 16% chromium, 24% iron

7. The bridgewire exploded at the 500 volt level and Figure 3a shows a smear camera picture of the wire exploding into the ambient atmosphere. A parabola test plot of $(2R)^2$ vs. T (where R = radius of luminous boundry and T = time) from the smear record gave a straight line showing the explosion closely followed a parabolic trajectory for times greater than one microsecond. (See Figure 3b.) Parabolic explosion is indicative of a strong shock. Figure 3c is a voltage and current oscillogram which is typical of exploding bridgewires. It shows that the wire exploded about 2 microseconds after the start of the current flow.

Experimental Results

8. Four initiating explosives; dextrinated lead azide (milled and unmilled), normal lead styphnate (NLS), silver azide, and PETN, and flake aluminum were used to make the binary mixtures investigated. Photomicrographs of these materials are shown in Figure 4.

9. The binary mixture of greatest interest (lead azide and lead styphnate) was the first combination investigated. Three mixtures were prepared:

75% lead azide - 25% normal lead styphnate

50% lead azide - 50% normal lead styphnate

25% lead azide - 75% normal lead styphnate.

Two particle sizes of lead azide were used. The first set of mixtures was made with dextrinated lead azide as received and the second set was made with dextrinated lead azide which had been milled in ethanol for twenty four hours. The mixtures were prepared by hand tumbling until they appeared homogeneous under a microscope.

10. Bruceton tests were run to determine the mean firing energy of 100% lead styphnate, 100% dextrinated lead azide, and the mixtures. The tests were run using initiator plugs bridged with a 0.001 inch-diameter Tophet C wire. The resistance range was 2 to 4 ohms. Fifty shots were used for each test with the capacitance held constant at one microfarad and the voltage varied. The samples for the Bruceton test were loaded at 10,000 psi, which is higher than the loading pressure in the test fixture used to observe the growth to detonation. Figure 5 shows the Bruceton test results with the unmilled lead azide. The unmilled lead azide had a distinctly higher firing energy and larger standard deviation than did the mixtures. The mixtures retained the sensitivity of the lead styphnate. Figure 6 shows the Bruceton test results with the milled lead azide. Milling increased the

sensitivity of the lead azide and decreased the standard deviation. The mixtures showed only a slight increase in the mean firing energy over that of the normal lead styphnate.

11. The mixtures were loaded at a pressure of 2900 to 3000 psi in the test fixture previously described. Build-up to detonation traces were obtained using a rotating mirror smear camera. See Figure 7 for typical smear camera records. A comparison of the build-up to detonation traces (time-distance curves) is shown in Figure 8 for unmilled lead azide, normal lead styphnate, and the three mixtures. Zero time corresponds to explosion of the bridgewire. The 75/25 lead azide/lead styphnate mixture took about 0.8 microsecond longer for the detonation to develop than did the lead azide alone. The 50/50 lead azide/lead styphnate mixture had a longer burning period before attaining a constant velocity. The constant velocity occurred at a distance of 2.5 mm from the bridgewire. The 25/75 lead azide/lead styphnate mixture had a still longer deflagration period changing abruptly to a constant velocity at 5.5 mm from the bridgewire. Lead styphnate alone burned a distance of only 1.6 mm in the same length of time required for the complete consumption of the 25/75 lead azide/ lead styphnate mixture.

12. The build-up to detonation traces of the milled lead azide and mixtures containing it were obtained using the same loading pressure as with the unmilled form. (See Figure 9.) The milled lead azide went immediately into stable detonation whereas the unmilled lead azide accelerated from a lower velocity to its stable detonation velocity. The 75/25 and 50/50 milled lead azide/lead styphnate mixtures developed a stable velocity faster than the corresponding mixtures containing unmilled lead azide. The 25/75 milled lead azide/lead styphnate mixture exhibited a long deflagration period before attaining a constant velocity.

13. The results with the lead azide/lead styphnate mixtures showed that within the concentration limits tested, the sensitivity of the mixtures remained close to that of the lead styphnate. The final detonation velocities, however, were characteristic of the lead azide with a slight decrease in terminal velocity noted with increasing concentrations of lead styphnate. No evidence of an optimum mixture was found at the loading pressure used. However, detonation commences sooner in the mixtures with higher lead azide concentration.

14. The build-up to detonation of mixtures of silver azide and lead styphnate in the same proportions as the lead azide/lead styphnate mixtures was observed. The most important difference noted was that the silver azide dominated the reaction to a greater extent than did the dextrinated lead azide. (See Figure 10.) Increasing percentages of lead styphnate had only a slight effect on the observed initial and terminal velocities.

15. The build-up to detonation of mixtures of lead styphnate and PETN was observed. (See Figure 11.) Increasing amounts of PETN slowed the burning rate markedly. With 75% PETN in the mixture, the terminal velocity was only 110 meters/second; the PETN acted almost as an inert diluent. It is probable that the results would be much different at higher voltage levels.

16. The build-up to detonation of mixtures of silver azide and PETN was observed. (See Figure 12.) PETN entered into the reaction as evidenced by the detonation velocity. The mixture which contained 75% PETN had a detonation velocity of 5,680 meters/second typical of PETN alone at the density used. Increasing amounts of PETN delayed the appearance of the detonation trace. It is interesting to note that PETN entered into the reaction when mixed with the silver azide whereas it did not do so when mixed with lead styphnate.

17. Burning lead styphnate alone was found to be insufficiently luminous to give a readable photographic trace with the smear camera used. Therefore, a small amount of flake aluminum (0.1%) was added to the styphnate to increase the emitted light. Tests were run to determine the effect of the addition of 0.1% and larger amounts of flake aluminum on the burning of lead styphnate. 0.1, 3.0, and 10 percent flake aluminum mixtures with lead styphnate were prepared and their photographic traces compared to that part of the all lead styphnate trace which could be measured. (See Figure 13.) Increasing amounts of flake aluminum decreased the reaction velocity. Aluminum is classified as a fuel and since lead styphnate is an oxygen negative explosive, the observed decrease in velocity was expected.

Discussion

18. Many sensitive explosive mixtures are used as the ignition charge to set off higher explosives. Although the compositions are many and varied, they are very likely to contain at least one of the explosives investigated here. Possible practical applications are suggested by the results of this investigation. The lead azide-lead styphnate mixtures retain the hot wire sensitivity of the lead styphnate and develop a detonation velocity characteristic of the lead azide. Such mixtures might be used for the development of two component detonators containing the mixture and a base charge of PETN or RDX instead of a three component detonator containing individual increments of lead styphnate, lead azide, and PETN or RDX. A decrease in the number of explosive charges would lessen the probability of loading errors. Other possibilities are a one component primer containing only the normal lead styphnate-lead azide mixture and a one component detonator containing only silver azide-PETN mixture. This latter combination

might retain the hot wire sensitivity of the azide and develop the higher detonation velocity characteristic of the PETN. Highly pressed columns of lead styphnate have been used for delays in the 0.005 to 0.015 second range. This investigation suggests the possible substitution of a slower burning lead styphnate-PETN mixture to increase the delay range without an increase in the size of the device.

Conclusions

19. 25/75, 50/50, and 75/25 mixtures of normal lead styphnate and lead azide retain the hot wire sensitivity of the normal lead styphnate and develop a stable detonation velocity characteristic of the lead azide. The higher the normal lead styphnate content of the mixture, the longer it takes for the stable detonation velocity to develop.

20. The build-up to detonation of 25/75, 50/50, and 75/25 mixtures of normal lead styphnate and silver azide is more characteristic of the silver azide.

21. In the build-up to detonation of 25/75, 50/50, and 75/25 mixtures of normal lead styphnate and PETN, the PETN acts almost as an inert diluent at the input energy employed in the experiments reported herein.

22. In the build-up to detonation of 25/75, 50/50, and 75/25 mixtures of silver azide and PETN the terminal detonation velocity is characteristic of the PETN.

23. The addition of flake aluminum between the limits of 0.1 and 10 percent to normal lead styphnate causes a decrease in the burning rate of the lead styphnate.

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(3) Grant, R. L. and Tiffany, J. E., "Factors Affecting Initiating Efficiency of Detonators", Industrial and Engineering Chemistry 37, 661-666 (1945)

(4) Langdon, P. J. and Fisher, H. J., "Design of a High Reliability Detonator with a Symmetrical Radial Output", Proceedings of Electric Initiator Symposium, 1960 (Confidential)

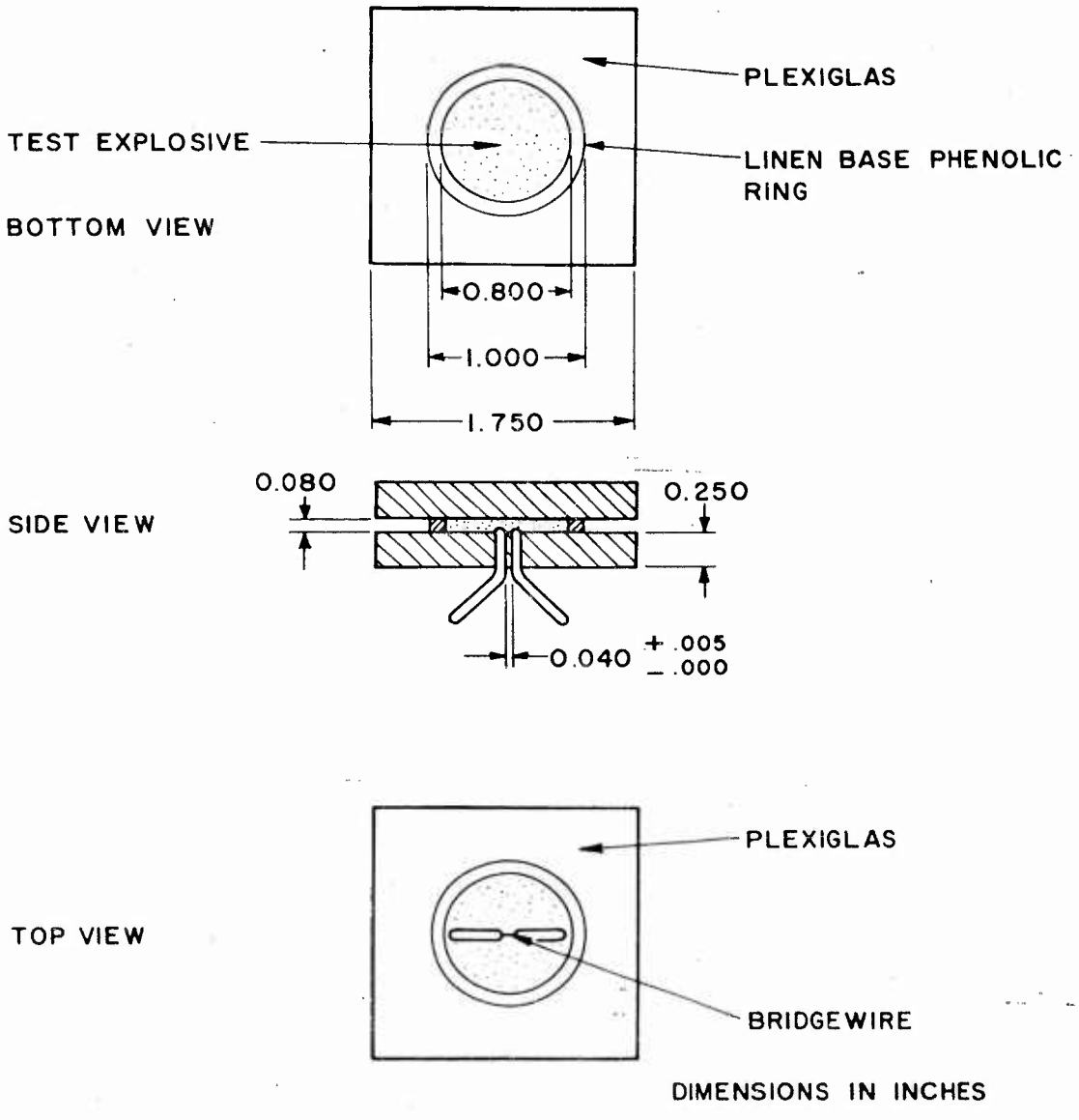


FIG. 1 TEST FIXTURE ASSEMBLY

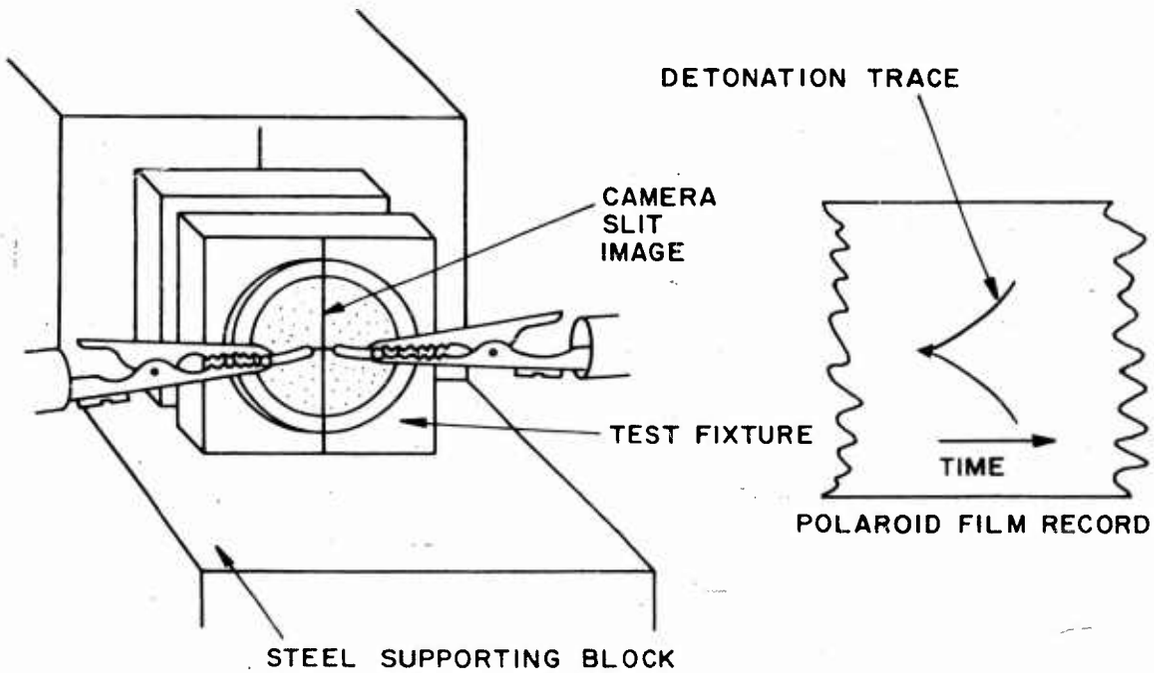
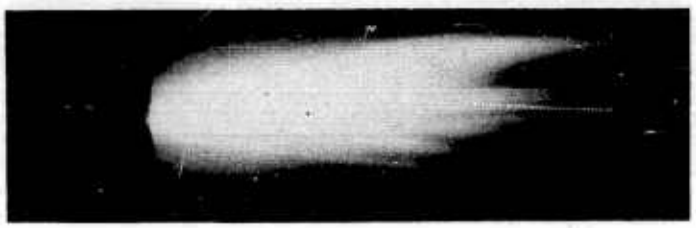
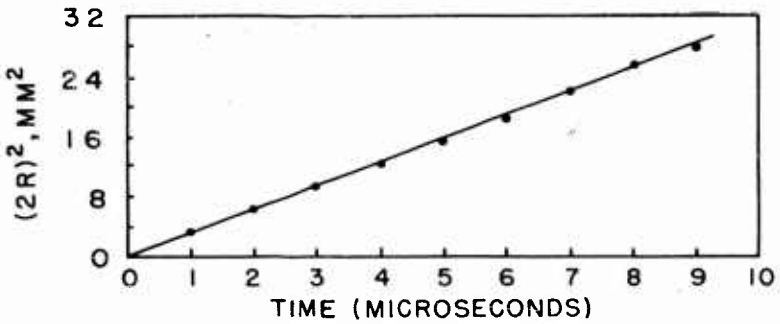


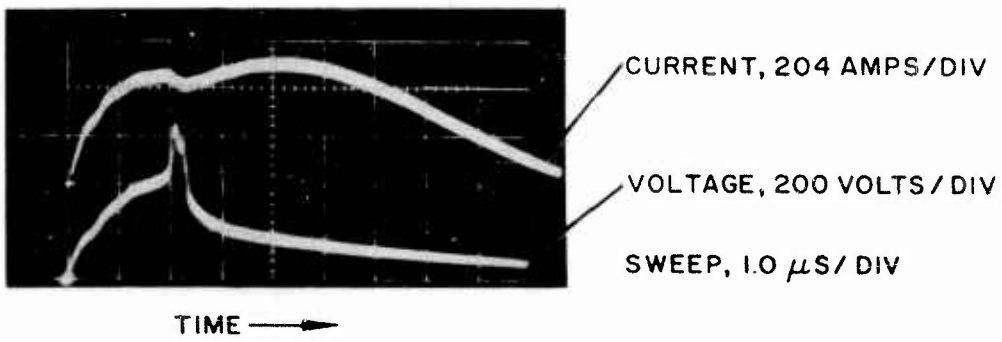
FIG. 2 EXPERIMENTAL ARRANGEMENT AND TYPE OF SMEAR CAMERA RECORD



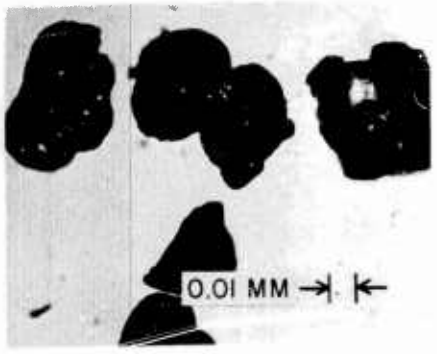
3a SMEAR CAMERA RECORD OF EXPLODING NICHROME WIRE



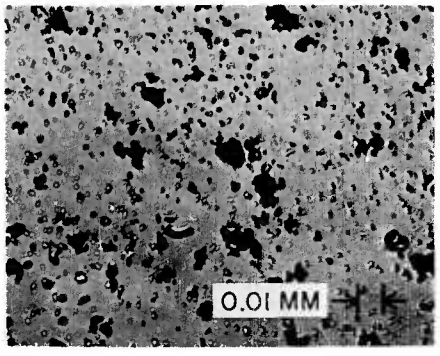
3b PARABOLA TEST PLOT OF EXPLODING NICHROME WIRE



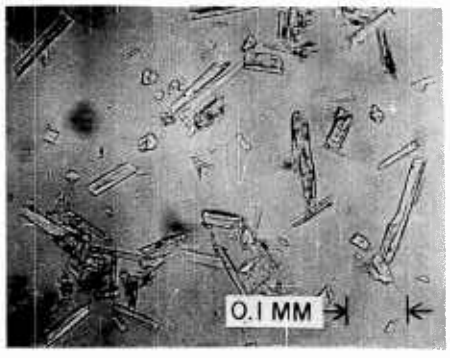
3c TYPICAL OSCILLOGRAM OF EXPLODING NICHROME WIRE



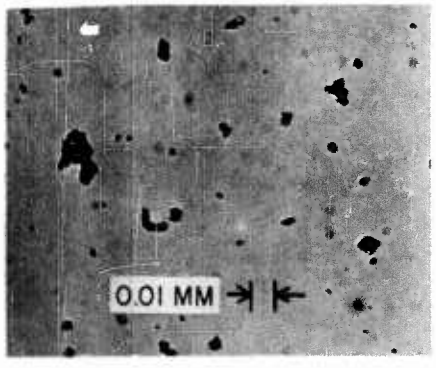
DEXTRINATED LEAD AZIDE



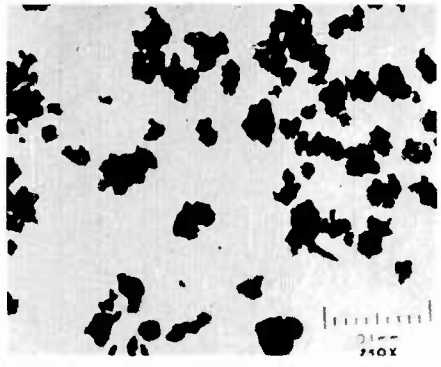
MILLED DEXTRINATED LEAD AZIDE



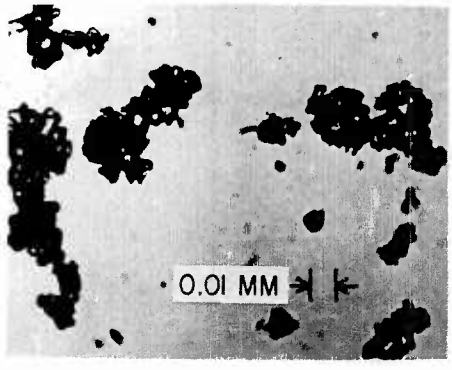
PETN



MILLED NORMAL LEAD STYPHNATE



FLAKE ALUMINUM



SILVER AZIDE

FIG. 4 PHOTOMICROGRAPHS OF TEST MATERIALS

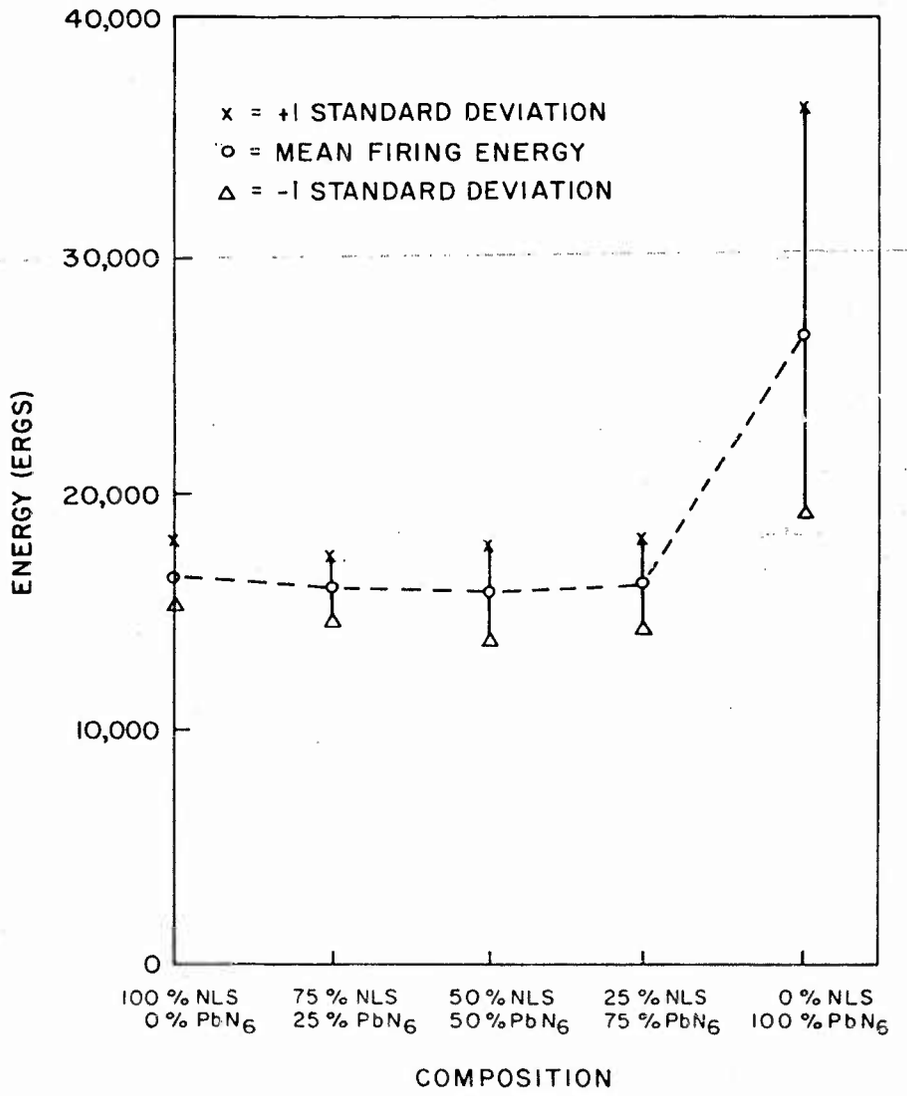


FIG.5 MEAN FIRING ENERGIES FOR MILLED NORMAL LEAD STYPHNATE AND UNMILLED LEAD AZIDE MIXTURES

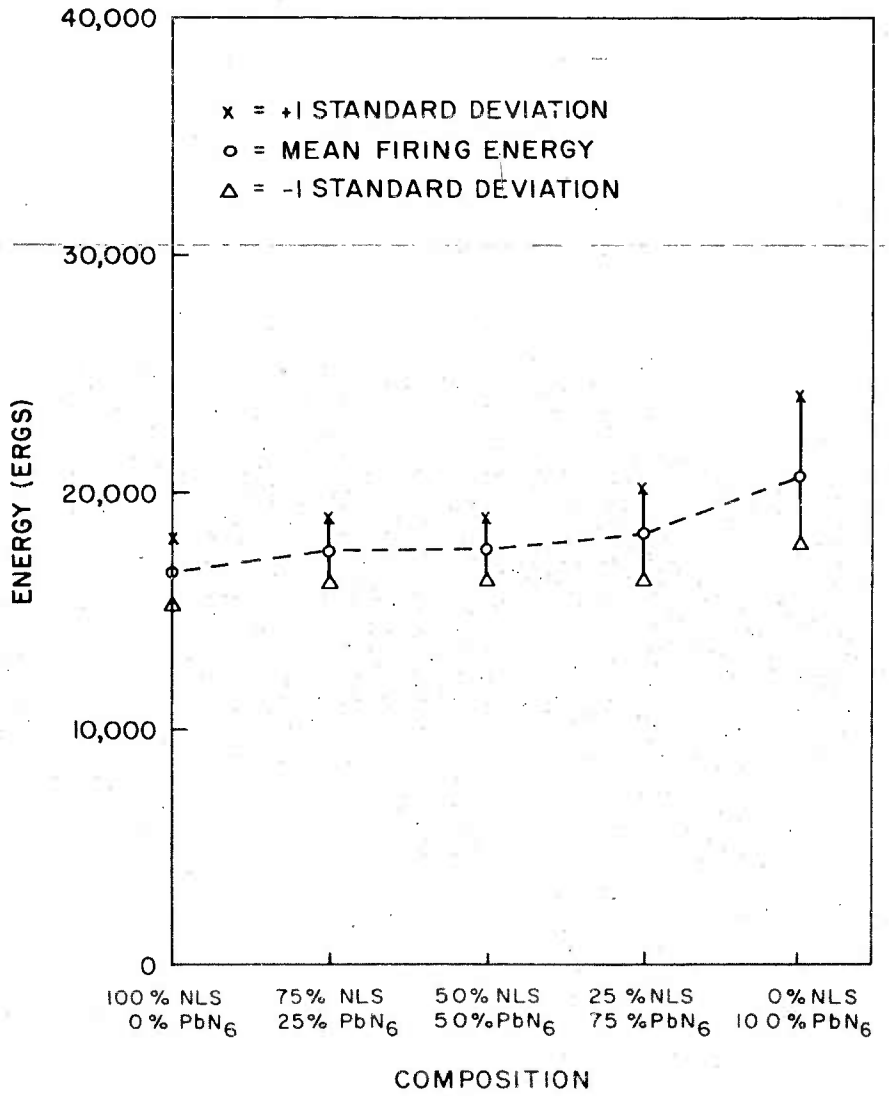
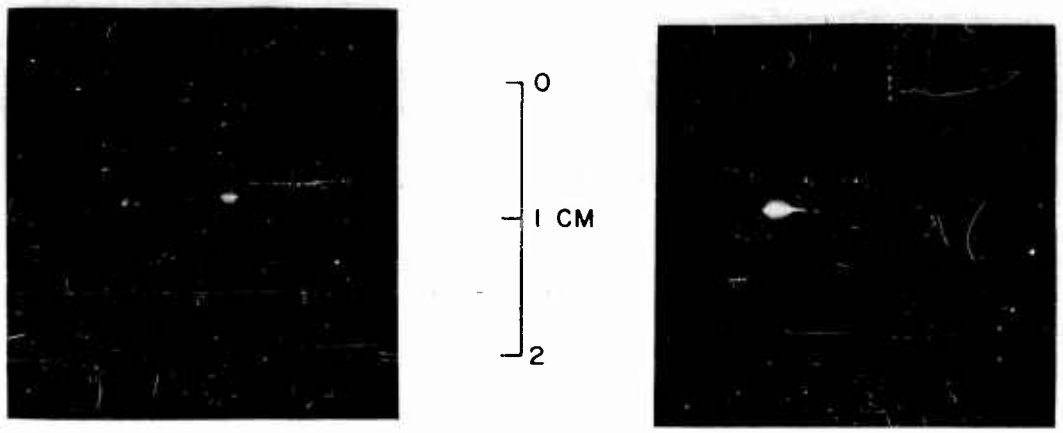
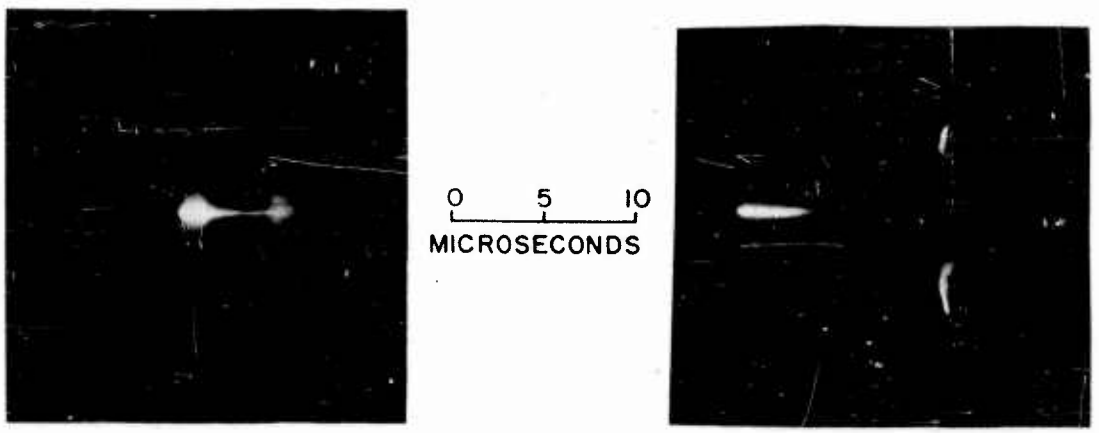


FIG. 6 MEAN FIRING ENERGIES FOR MILLED NORMAL LEAD STYPHNATE AND MILLED LEAD AZIDE MIXTURES



100 % UNMILLED LEAD AZIDE

75% UNMILLED LEAD AZIDE
25% NORMAL LEAD STYPHNATE



50% UNMILLED LEAD AZIDE
50% NORMAL LEAD STYPHNATE

25% UNMILLED LEAD AZIDE
75% NORMAL LEAD STYPHNATE

FIG. 7 SMEAR CAMERA RECORDS

	NORMAL LEAD STYPHNATE(%)	LEAD AZIDE (%)	DENSITY (g/CM^3)
A	0	100	2.45
B	25	75	2.32
C	50	50	2.20
D	75	25	2.10
E	100	0	2.00

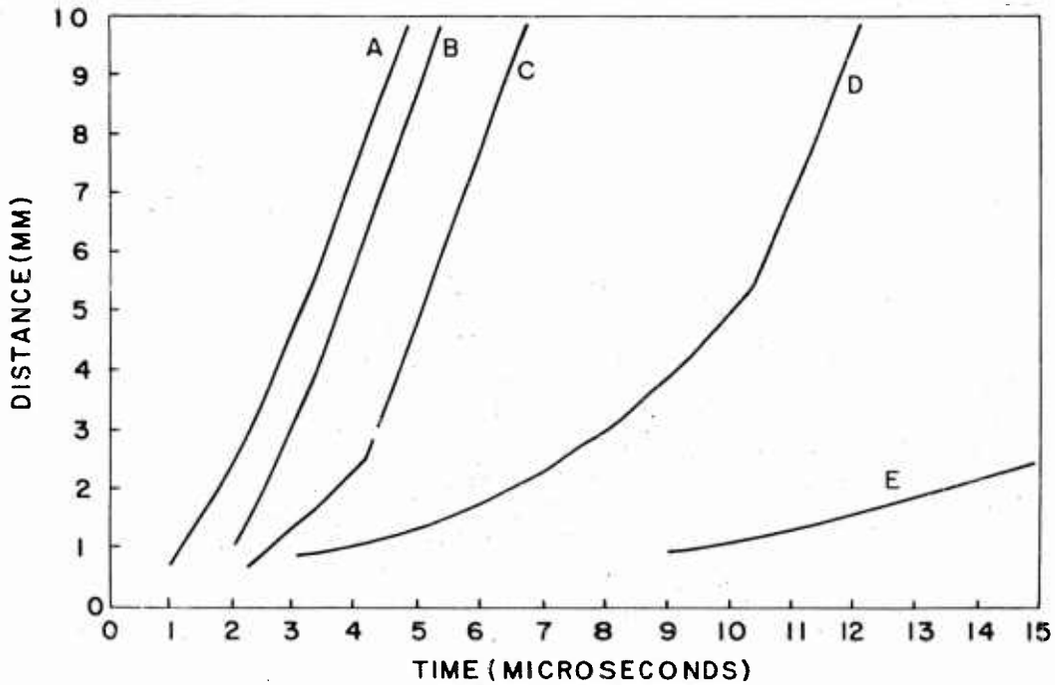


FIG.8 THE BUILD-UP TO DETONATION OF MILLED NORMAL LEAD STYPHNATE AND UNMILLED LEAD AZIDE MIXTURES

	NORMAL LEAD STYPHNATE(%)	LEAD AZIDE (%)	DENSITY (g/CM^3)
A	0	100	2.45
B	25	75	2.32
C	50	50	2.20
D	75	25	2.10
E	100	0	2.00

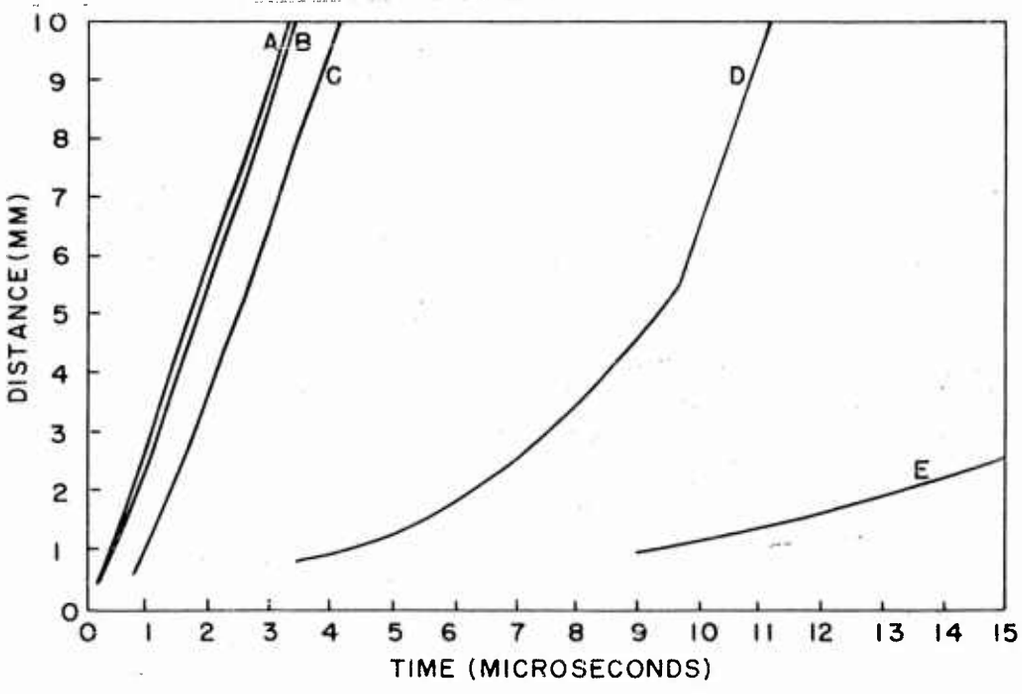


FIG. 9 THE BUILD-UP TO DETONATION OF MILLED NORMAL LEAD STYPHNATE AND MILLED LEAD AZIDE MIXTURES

	NORMAL LEAD STYPHNATE(%)	SILVER AZIDE (%)	DENSITY (g/CM^3)
A	0	100	2.50
B	25	75	2.22
C	50	50	2.22
D	75	25	2.22
E	100	0	2.00

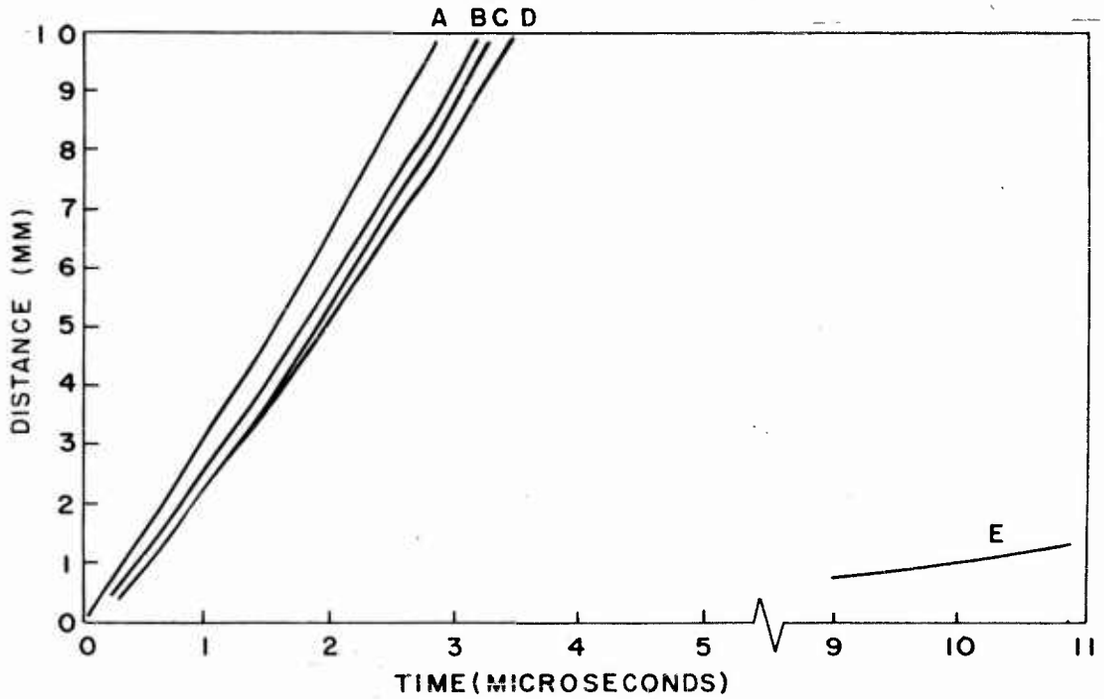


FIG. 10 THE BUILD-UP TO DETONATION OF MILLED NORMAL LEAD STYPHNATE AND SILVER AZIDE MIXTURES

	NORMAL LEAD STYPHNATE (%)	PETN (%)	DENSITY (g/CM^3)
A	100	0	2.00
B	75	25	2.00
C	50	50	1.52
D	25	75	1.52

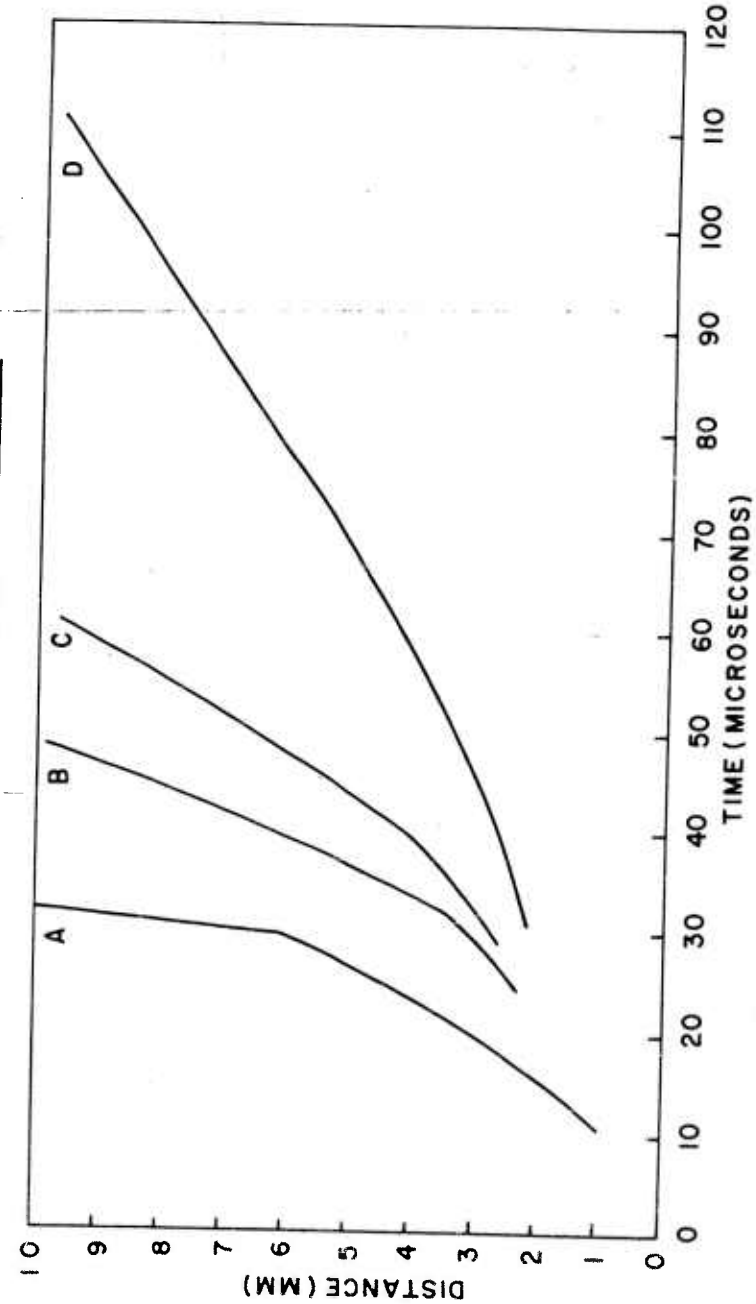


FIG. 11 THE BUILD-UP TO DETONATION OF MILLED NORMAL LEAD STYPHNATE AND PETN MIXTURES

	SILVER AZIDE (%)	PETN (%)	DENSITY (g/CM^3)
A	75	25	1.00
B	50	50	1.00
C	25	75	1.00

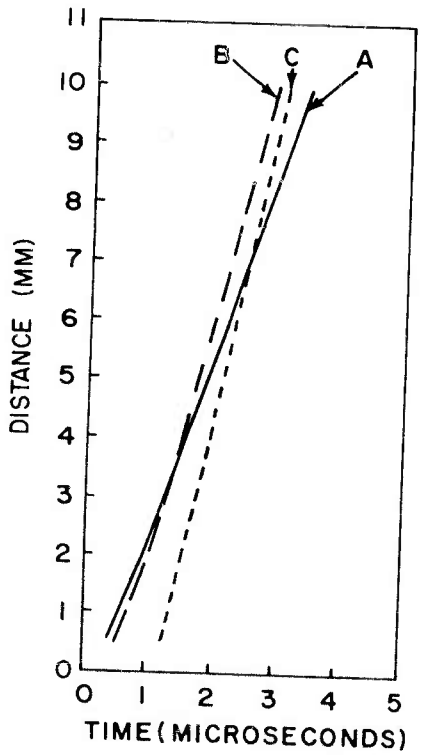


FIG. 12 THE BUILD-UP TO DETONATION OF SILVER AZIDE AND PETN MIXTURES

	NORMAL LEAD STYPHNATE(%)	ALUMINUM (%)	DENSITY (g/CM^3)
A	100	0	2.00
B	99.9	0.1	2.00
C	97.0	3.0	1.31
D	90.0	10.0	1.31

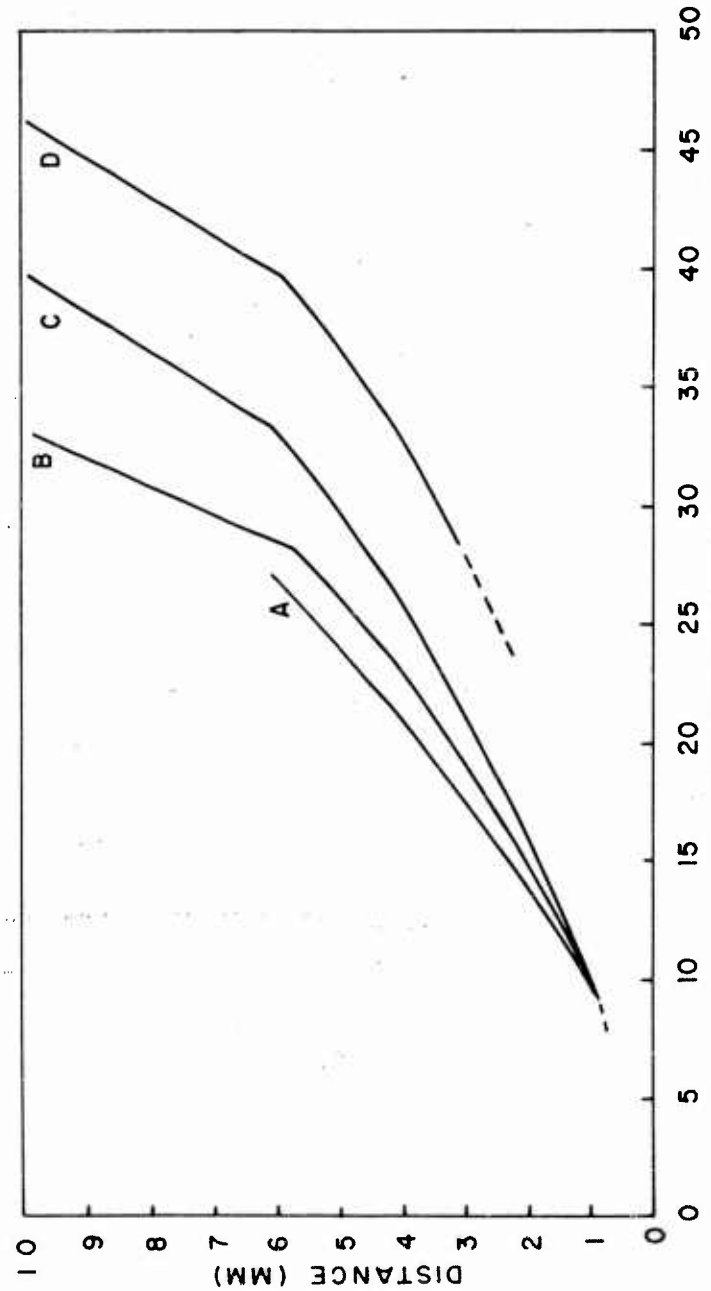


FIG. 13 THE BUILD-UP TO DETONATION OF MILLED NORMAL LEAD STYPHNATE AND FLAKE ALUMINUM MIXTURES

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SUBJECT ANALYSIS OF REPORT

DESCRIPTORS	CODES	DESCRIPTORS	CODES	DESCRIPTORS	CODES
Growth	GROW	Tetra	TERA	Propagation	PROO
Detonation	DETO	Nitrate	NITT		
Low density	LOWY	Flake	FLKE		
Explosive	EXPL	Aluminum	ALUM		
Mixtures	MIXT	Rotating	ROTA		
Explosions	EXPS	Mirror	MIRR		
Lead	LEAD	Smear	SMEA		
Styphnate	STYP	Camera	CAME		
Azide	AZID	Hot-wire	HOTW		
Silver	SILV	Sensitivity	SENV		
Penta	PENA	Terminal	TERI		
Erythritol	ERYT	Velocity	VELC		

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Naval Ordnance Laboratory, White Oak, Md.
(NOL technical report 62-89)
THE GROWTH TO DETONATION OF LOW DENSITY EXPLOSIVE MIXTURES, by Howard S. Leopold. 26 July 1962. 20p. illus., diagr. Task RUME-3-E-000/212 1/F008-10-004. UNCLASSIFIED

The growth to detonation of normal lead styphnate-lead azide, normal lead styphnate-silver azide, normal lead styphnate-PETN, silver azide-PETN, and normal lead styphnate-flake aluminum mixtures was observed using a rotating mirror smear camera. Normal lead styphnate-lead azide mixtures (75/25 to 25/75 proportions) retain the hot wire sensitivity of the normal lead styphnate and develop a terminal detonation velocity characteristic of the lead azide. Normal lead styphnate-PETN mixtures develop a terminal detonation velocity characteristic of PETN.

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3. Explosions - Velocity
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