Factors Affecting Initiating Efficiency of Detonators

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The influence of the following factors upon the initiating efficiency of detonators was studied: base charge, priming charge, reinforcing capsule, and outside diameter of shell. The initiating efficiencies of laboratory-prepared detonators were determined by the miniature-cartridge test (7). Results indicated that the initiating efficiency increased in this order for the following base charges: 80 mercury fulminate–20 potassium chlorate mixture, tetryl, PETN, hexogen. The efficiency of priming compositions, as determined by minimum initiating charges, was as follows: (1) 80 lead azide–20 lead styphnate; (2) 80 lead azide–18 lead styphnate–0.5 aluminum–1.5 potassium chlorate and 60 lead azide–40 lead styphnate; (3) 100% lead azide, 80 lead azide–17 lead styphnate–3 aluminum, 40 lead azide–60 lead styphnate, and 75 DDNP–25 potassium chlorate; (4) 20 lead azide–80 lead styphnate and 80 mercury fulminate–20 potassium chlorate; (5) 100% lead styphnate. The use of a copper reinforcing capsule to enclose the priming charge increased the initiating efficiency of a detonator from one to three grades. As the outside diameter of a detonator was increased, the initiating efficiency of the detonator decreased as an approximate inverse straight-line function. Tests with the lead-plate test produced results in substantially opposite order to those of the miniature-cartridge test when the diameter of the detonator was varied. The initiating efficiency of the various kinds of detonators was calculated in terms of unit weight of explosive charge in the detonator and then systematically tabulated; detonators were thus classified according to initiating characteristics. This classification, along with selected curves, revealed that hexogen-base detonators are uniformly more efficient than detonators with other base charges. These curves also disclosed that both quantity and quality of the explosive charge in a detonator must be considered in relation to the initiating efficiency of that detonator.

THE question of what constitutes an efficient detonator is of critical importance to designers and manufacturers of detonators and to all who test and use explosives. The behavior of detonators is not clear because knowledge of the initiating characteristics of detonators is incomplete. This report studies the following four factors and their effects on the initiating efficiency of detonators: base charge, priming charge, reinforcing capsule, and diameter of detonator shell. The influence of each factor was ascertained by measuring the initiating efficiency of laboratory-prepared detonators by the routine procedure of the miniature-cartridge test (*7*). The testing of detonators has been reported in previous publications (*5, 6, 11, 26, 27*). Another purpose of this article is to present the initiating characteristics of a series of hexogen-base detonators which, although patented by Herz in 1920 (*12*), have not been described in the literature or used in practice. By the miniature-cartridge test these detonators are consistently superior to detonators containing other base charges.

The terms adopted by *Chemical Abstracts* are, for the most part, employed here for the various explosives tested. However, the common name or designation, when this is widely accepted, is also used.

The term "tetryl" is employed for the explosive chemically known as trinitrophenylmethylnitramine.

Pentaerythritol tetranitrate is commonly known in this country as PETN. This compound is variously listed in the literature as tetranitropentaerythritol, tetranitropentaerythrite, pentrite, penthrit, and niperyth.

"Hexogen" is the term used by *Chemical Abstracts* for cyclotrimethylenetrinitramine. In common usage in this country it is frequently called "cyclonite".

Lead styphnate is known chemically as normal lead trinitroresorcinate or the lead salt of styphnic acid.

DDNP refers to diazodinitrophenol. It is occasionally called dinol; *Chemical Abstracts* lists it under both "DDNP" and "benzoxdiazole, 4,6-dinitro-".

The weights of the explosive charges in the detonators described are designated by centigrams (0.01 gram). Convenient whole numbers, rather than decimal fractions, result; and weighings of the charges in the laboratory-prepared detonators are accurate to a centigram. A tendency has been noted in this country, especially in specifications, to use grains; although they provide whole numbers, "grains" are cumbersome and confusing.

The initiating efficiencies of the detonators studied were determined by the routine miniature-cartridge test (*7*). The screens used in the previous work were retained for the tests described here in order to ensure intercomparison of results.

EFFECT OF BASE CHARGE

Modern detonators are compound detonators loaded with a base charge, a priming charge, and sometimes an ignition charge (*5, 16*). The relative efficiencies of the following four base charges were studied: 80 mercury fulminate–20 potassium chlorate mixture, tetryl, PETN, and hexogen. The first was selected because it constitutes the charge of standard detonators in this country and mercury fulminate is the oldest of detonator charges. The common base charges in use today are tetryl (*17, 32*) and PETN (*3*); the latter has been introduced within the past decade. Hexogen was chosen because its high rate of detonation (approximately 8400 meters per second) indicated that it might be an effective base charge. Herz patented this compound in 1920 (*12*) and suggested it as a detonator charge (*13*). It has not been used in practical detonators, however. Its preparation and properties have been studied and described by Desvergnes (*4*), Somlo (*23*), Tonegutti (*31*), Guastalla and Raccin (*10*), Sollazo (*22*), and Stettbacher (*24*).

EXPERIMENTAL. Gilding-metal shells, of outside diameter 0.69 cm. and with the usual depressed bottoms, were used. The shells were identical to those on the market, and this particular diameter represents the most common detonator.

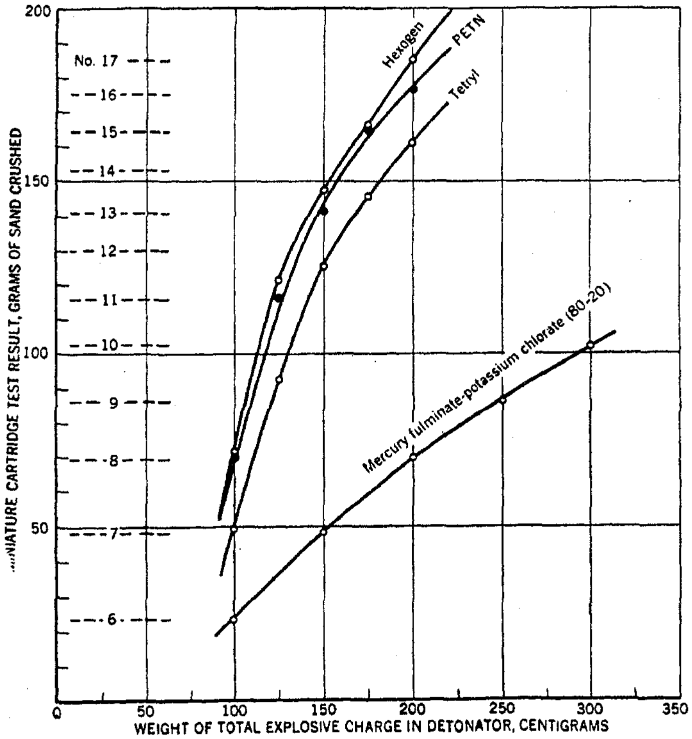


Figure 1. Effect of Base Charge on Initiating Efficiency of Detonators

For the first series of detonators containing 80–20 fulminate-chlorate, the base charge was loaded in increments of 50 cg. (0.5 gram) at a pressure of 63 kg. per sq. cm. (900 pounds per square inch). The priming charge was also 80–20 fulminate-chlorate, weighed 50 cg. for each detonator, and was pressed at 49 kg. per sq. cm. (700 pounds per square inch).

For the next three series of detonators containing tetryl, PETN, and hexogen as base charges, detonators were prepared having 25, 50, 75, 100, and 125 cg. of each base charge pressed at 98 kg. per sq. cm. (1400 pounds per square inch). The priming charge for all of these detonators was 75 cg. of 80–20 fulminate-chlorate, loaded singly and pressed at 49 kg. per sq. cm.

Figure 1 shows the results of the initiating efficiencies of the four series of detonators as determined by the routine miniature-cartridge test. Since each point represents six trials (two each for the 80–20 and 70–30 TNT–iron oxide mixtures and two for the detonator blank), the set of four curves includes a total of one hundred twenty trials.

Conclusions and Discussion. Figure 1 indicates that the order of increasing initiating efficiency for the base charges studied is: 80 mercury fulminate–20 potassium chlorate mixture, tetryl, PETN, hexogen. Furthermore, reference to tables of detonation rates reveals that the results are in the same approximate relative order as the respective rates of detonation of the base charges.

Various relations are derivable from Figure 1—for example, the relative initiating efficiencies of detonators having equal weights of total charges. By entering the graph along the 100-cg. vertical ordinate, it is found that a detonator containing, for example, 25 cg. of tetryl and 75 cg. of 80–20 fulminate-chlorate priming charge is equivalent to a No. 7 fulminate-chlorate reference detonator.

Haid and Koenen (*11*) reported results for fulminate-chlorate, tetryl-base, and PETN-base detonators that are in close agreement with those of Figure 1. They suggested that the initiating efficiency of an explosive may be expressed in terms of its brisance value, B, which they calculated from the following formula:

$$B = \Delta \times D \times T/273 \times V_0$$

where Δ = density
D = rate of detonation
T = absolute explosion temperature
V_0 = gas volume produced by explosive

EFFECT OF PRIMING CHARGE

The chief function of a priming charge in a detonator is to transmit full detonation to the less sensitive but usually more powerful base charge. Because the priming charge is generally a sensitive and expensive explosive, a relatively small quantity is desirable.

The common priming charges studied in this section have been selected from those used in detonators in the United Stat s and in Europe, especially Great Britain and Germany. They include 80 mercury fulminate–20 potassium chlorate mixture, lead azide (*15*, *32*), lead styphnate (*15*, *28*), lead azide–lead styphnate mixtures (*15*, *18*), and 75 DDNP–25 potassium chlorate mixture (*1*, *3*). In addition, the effect of aluminum, alone and with potassium chlorate, when mixed with lead azide and lead styphnate, was tested.

Determination of Minimum Initiating Charge. Among the important properties of a priming composition is the minimum charge required to detonate the base explosive in the detonator. For determining this characteristic the well-known procedure of Taylor and Cope (*29*) was followed. Some details differ, however, and are noted in the following outline of the procedure used in this study.

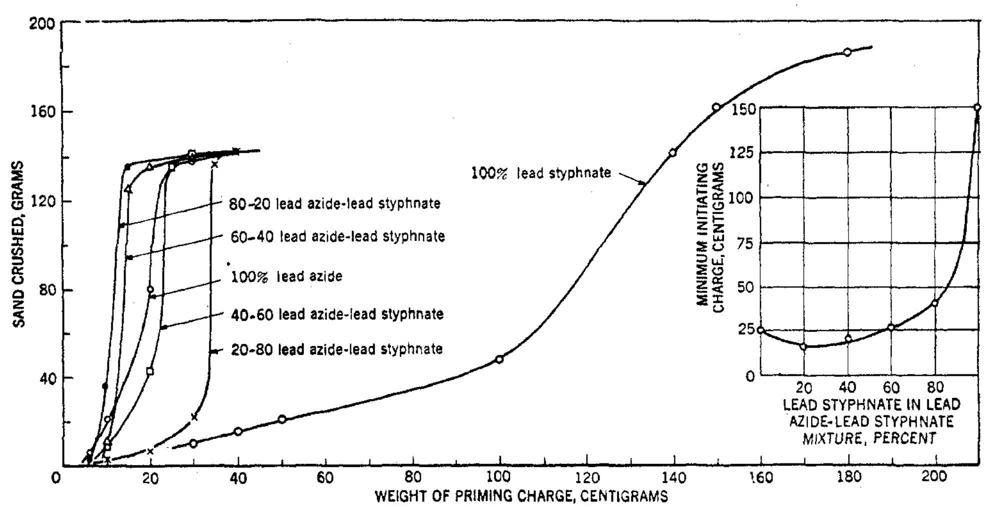


Figure 2. Determination of Minimum Initiating Charges of Lead Azide, Lead Styphnate, and Their Mixtures for 125 Cg. of Tetryl

A charge of 125 cg. was loaded in five 25-cg. increments into a gilding-metal shell having an outside diameter of 0.69 cm. Each increment was pressed at 98 kg. per sq. cm. The 125-cg. charge represents the maximum weight of base charge studied in these experiments. Varying weights of priming charge, in 5-cg. increments, were then inserted as a single charge on top of the base charge and pressed at 49 kg. per sq. cm. For these experiments no reinforcing capsule was employed. An electric match head of the copper acetylide type, obtained from Atlas Powder Company, was inserted into the detonator and the shell carefully crimped at the top. The detonator was placed in the center of 350 grams of Ottawa standard sand, introduced in portions of 100 plus 250 grams into Bureau of Mines bomb No. 2 having an inside diameter of 2 inches (*19*). The bomb was closed and fastened securely, and the detonator fired. The weight of sand crushed served as a criterion of whether the base charge detonated; it was determined by screening through a No. 30 U. S. Standard series screen (opening, 0.059 cm. or 0.0232 inch). The weight of priming charge, to the nearest 5 cg., which produced three complete detonations, without partial or incomplete detonations, was taken as the minimum initiating charge.

Table I gives the minimum initiating charges of the various priming compositions for base charges of tetryl, PETN, and hexogen. The general conclusion from these results is that hexogen is more sensitive to detonation than PETN which, in turn, is more sensitive than tetryl. If other factors are equal, a greater sensitivity to detonation is a desirable property in a base charge. The order of efficacy of the priming compositions, with the best listed first, follows:

1. 80 lead azide–20 lead styphnate
2. 80 lead azide–18 lead styphnate–0.5 aluminum–1.5 potassium chlorate and 60 lead azide–40 lead styphnate
3. 100% lead azide, 80 lead azide–17 lead styphnate–3 aluminum, 40 lead azide–60 lead styphnate, and 75 DDNP–25 potassium chlorate
4. 20 lead azide–80 lead styphnate and 80 mercury fulminate–20 potassium chlorate
5. 100% lead styphnate

TABLE I. MINIMUM CHARGES OF PRIMING COMPOSITIONS (TO NEAREST 5 CG.) REQUIRED TO DETONATE 125 CG. OF BASE CHARGE

Priming Composition	Tetryl	PETN	Hexogen
Without Reinforcing Capsule			
80 mercury fulminate–20 potassium chlorate	40	35	35
Lead azide	25	10	5
80 lead azide–20 lead styphnate	15	5	5
60 lead azide–40 lead styphnate	20	..	..
40 lead azide–60 lead styphnate	25	..	..
20 lead azide–80 lead styphnate	40	..	..
Lead styphnate[a]	150	..	..
75 DDNP–25 potassium chlorate	25	20	15
18 lead azide–17 lead styphnate–3 aluminum	25	..	..
80 lead azide–18 lead styphnate–0.5 aluminum–1.5 potassium chlorate	20	..	..
With Reinforcing Capsule			
80 mercury fulminate–20 potassium chlorate	20	15	15
80 lead azide–20 lead styphnate[b]	5	5	5

[a] Result is approximate.
[b] Small hole (diameter 0.15 cm.) in inner copper capsule; priming charge pressed under capsule at 98 kg. per sq. cm.

LEAD AZIDE–LEAD STYPHNATE MIXTURES. Mixtures of lead azide and lead styphnate have long been used as priming charges for detonators (*9*, *14*, *18*) and have been employed in foreign detonators, especially those of Great Britain and Germany (*25*, *30*). These mixtures, however, are not found in detonators marketed in the United States. Properties of the two constituents evidently complement each other; the low ignition temperature of lead styphnate compensates for the higher ignition temperature of lead azide, while the high initiating power of lead azide amends the low power of lead styphnate (*18*, *27*).

Of the various lead azide–lead styphnate mixtures, the 80–20 is the best according to the results of Table I. It is superior to either lead azide or lead styphnate alone. As little as 5 cg. of this mixture completely detonates 125 cg. of either PETN or hexogen, whereas 35 cg. of the fulminate-chlorate mixture are required. The priming composition used by Rheinish-Westfaelische Sprengstoffe was reported to be the 40–60 lead azide–lead styphnate mixture (*21*). Figure 2 presents the relative initiating values of the lead azide–lead styphnate mixtures.

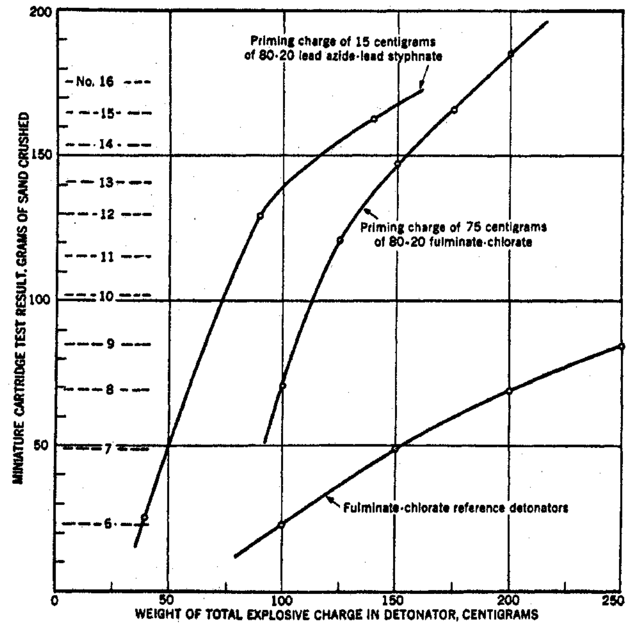


Figure 3. Effect of Priming Charge on Initiating Efficiency of Detonators

INITIATING EFFICIENCY TESTS. The relative initiating efficiencies of various detonators prepared with the three base charges (tetryl, PETN, and hexogen) and the several priming compositions were determined by the routine procedure of the miniature-cartridge test. At this point the following arbitrary rule, which provided a safety factor of 2 to 3, was established and used for all subsequent detonators tested: The weight of priming charge for use in a detonator is taken as between two and three times the minimum initiating charge. These detonators were prepared like those described in the section on "Effect of Base Charge", in which the base charges were pressed at 98 kg. per sq. cm. and the priming charges at 49 kg.

Figure 3 shows two curves for hexogen-base detonators that compare the most effective priming charge with one that is relatively ineffective. The priming charges selected are the 80–20 lead azide–lead styphnate and the 80–20 mercury fulminate–potassium chlorate mixtures, respectively. Curves for the other priming charges (except for lead styphnate) will, in general, fall between these two curves, provided the same weight of the same base charge is used. Table II gives the make-up of the various detonators tested and their relative initiating efficiencies.

EFFECT OF REINFORCING CAPSULE

It is generally conceded that the use of a reinforcing or inner capsule to enclose the priming charge has the effect of producing a lower minimum charge necessary to detonate the base composition (*26*, *27*). This is attributed to the additional confinement and to a focusing of the shock wave from the priming charge in the direction of the base charge. Another advantage of a reinforcing capsule is that it provides additional mechanical protection around the usually sensitive priming composition and thus improves the safety features of the detonator.

The experiments of this section consisted of obtaining the initiating efficiencies of two series of detonators made similarly,

Table II. Initiating Efficiency of Various Detonators

Priming Composition	Tetryl Base: Wt., Cg. Priming	Tetryl Base: Wt., Cg. Base	Tetryl Base: Miniature-cartridge result[a], g.	PETN Base: Wt., Cg. Priming	PETN Base: Wt., Cg. Base	PETN Base: Miniature-cartridge result[a], g.	Hexogen Base: Wt., Cg. Priming	Hexogen Base: Wt., Cg. Base	Hexogen Base: Miniature-cartridge result[a], g.
Without Reinforcing Capsule									
80 mercury fulminate–20 potassium chlorate	75	75	125	75	75	141	75	75	147
Lead azide	50	75	121	25	75	130	15	75	130
80 lead azide–20 lead styphnate	30	75	116	15	75	127	15	75	129
75 DDNP–25 potassium chlorate	50	75	129	40	75	138	30	75	134
80 lead azide–17 lead styphnate–3 aluminum	50	75	123	..	..	...	..	..	...
80 lead azide–18 lead styphnate–0.5 aluminum–1.5 potassium chlorate	40	75	128	..	..	...	..	..	...
With Reinforcing Capsule									
80 mercury fulminate–20 potassium chlorate[b]	50	75	126	50	75	138	50	75	146
80 lead azide–20 lead styphnate[c]	15	75	111	15	75	134	15	75	140

[a] Represents average grams of sand crushed by 80–20 and 70–30 TNT–iron oxide mixtures after subtraction of blank.
[b] Reinforcing capsule 0.64 cm. long, 0.64 cm. o.d., with hole having 0.25-cm. diameter; priming charge pressed at 49 kg. per sq. cm.
[c] Reinforcing capsule as given in [b] except hole has 0.15-cm. diameter; priming charge pressed at 98 kg. per sq. cm.

except that one series contained a reinforcing capsule while the other did not. The shells were the same as those described in the preceding sections. The reinforcing copper capsules were 0.64 cm. (0.25 inch) in length and 0.64 cm. in outside diameter. For the 80–20 fulminate-chlorate composition the diameter of the hole in the capsule was 0.25 cm. (0.1 inch); for the 80 lead azide–20 lead styphnate composition this diameter was 0.15 cm. (0.06 inch). The pressure for the former was 49 kg. per sq. cm., for the latter, 98 kg. It was found that a smaller hole and higher pressure were necessary to retain the lead azide–lead styphnate priming charge in the detonator.

The results of these experiments are given at the bottom of Table II and plotted as curves representing four series of detonators in Figure 4. The conclusion indicated by these results is that, in general, the use of a reinforcing capsule increases the initiating efficiency of a detonator one to three grades. The extent of the increase depends upon the degree to which the reinforcing capsule decreases the minimum initiating charge of the priming composition. From the curves of Figure 4 it is possible to determine detonators equivalent in initiating efficiency.

EFFECT OF SHELL DIAMETER

Miniature-Cartridge Test. Detonators with gilding-metal shells having the following different outside diameters were studied: 0.59 cm. (0.23 inch), 0.69 cm. (0.27 inch), and 0.79 cm. (0.31 inch). These three diameters represent a majority of the detonators marketed today in the United States in the nominal No. 6 and No. 8 grades. The shell having a diameter of 0.69 cm. was identical with those described in preceding sections and is the common diameter used for commercial electric detonators. The shells of all diameters had the usual depressions in their bottoms and were manufactured similarly by the usual shell-drawing machines. The wall thickness of all shells was the same, approximately 0.022 cm. (0.009 inch), as was the thickness of their bottoms, 0.064 cm. (0.025 inch). In loading the explosive charges, the same pressures were used as for detonators previously studied.

The results of the routine miniature-cartridge test are given in Figures 5 and 6; the initiating efficiency is seen to increase markedly as the diameter is decreased. For example, detonators containing a total weight of 90 cg. (75 of hexogen and 15 of 80–20 lead azide–lead styphnate) for the diameters of 0.79, 0.69, and 0.59 cm. are Nos. 9, 12, and 14 grades, respectively (Figure 5). In Figure 6 the outside diameter is plotted against the result obtained with the miniature-cartridge test; it is reasonable to conclude that the initiating efficiency is approximately an inverse straight-line function of the diameter of the shell for the range of diameters tested. The top curve is the result of a confirmatory experiment in which 5 grams of TNT were loaded in a miniature cartridge of 1/2 inch inside diameter at a density of 0.94 gram per cc. The four lower curves represent the results of the routine miniature-cartridge test. A possible explanation of the effect of the diameter, based upon geometrical considerations, is that for a given weight (and hence a given volume) of explosive charge the surface of the cylindrical column increases with a decrease in diameter.

Tests with Small Lead Plates. The significant effect of the diameter of the detonator on its initiating efficiency, as measured by the miniature-cartridge test, prompted experiments with the lead plate test commonly used for control work (8). The detonators tested were prepared exactly as in the experiments

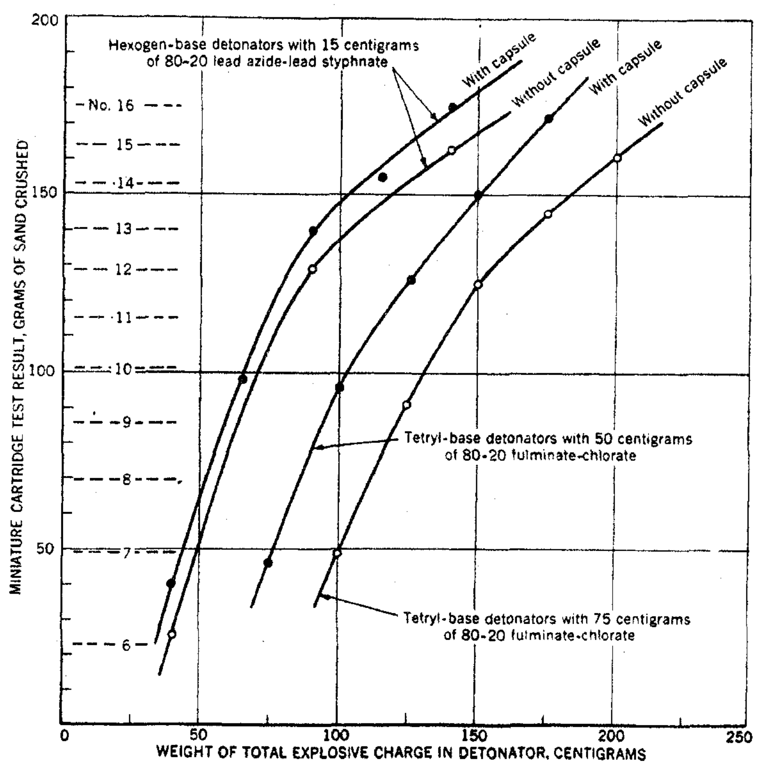


Figure 4. Effect of Reinforcing Capsule on Initiating Efficiency of Detonators

with the miniature-cartridge test and fired in the center of a 3.75 × 3.75 × 0.3 cm. ($1^1/_2 \times 1^1/_2 \times ^1/_8$ inch) lead plate in the usual manner. The diameter of the hole produced was taken as the criterion of the detonator strength in accordance with the well known procedure. In addition, the weight of lead displaced by the explosion of the detonator was also determined. Table III gives the results obtained.

If the values in Table III for detonators of decreasing diameter are compared with the corresponding results plotted in Figure 5, it is evident that the order of results of the lead-plate test and those of the miniature-cartridge test are opposite. For the miniature-cartridge test the smallest diameter (0.59 cm.) produced the greatest initiating efficiency; this diameter gave the smallest efficiency by the lead-plate test. If it is assumed that the miniature-cartridge test is substantially satisfactory, the above experiments permit the conclusion that the lead-plate test produces erroneous results when detonators of different diameters are compared.

Table III. Results of Lead Plate Test for Detonators of Different Outside Diameters

Weights, Cg.			Diam. of Hole, in Cm., Produced in Lead Plates with Detonators Having O.D. of:			Grams of Lead Displaced by Explosion of Detonators Having O.D. of:		
Base charge[a]	Priming charge[b]	Total charge	0.79 cm.	0.69 cm.	0.59 cm.	0.79 cm.	0.69 cm.	0.59 cm.
25	15	40	1.0	1.05	0.95	0.55	0.68	0.64
50	15	65	1.25	1.2	1.05	1.20	0.97	0.68
75	15	90	1.3	1.2	1.05	1.37	0.98	0.73

[a] Hexogen.
[b] 80 lead azide–20 lead styphnate.

Table IV. Initiating Efficiencies of Various Detonators with Results of Miniature-Cartridge Test Expressed as Grams of Sand Crushed per Gram of Explosive Charge in Detonator

Priming Charge[a]	O.D. of Shell, Cm.	Reinforcing Capsule	Initiating Efficiency of Detonator Containing 75 Cg. of Base Charge of: Tetryl	PETN	Hexogen
80 mercury fulminate–20 potassium chlorate	0.69	Without	83	94	98
Lead azide	0.69	Without	97	130	145
80 lead azide–20 lead styphnate	0.69	Without	110	141	143
75 DDNP–25 potassium chlorate	0.69	Without	103	120	127
80 lead azide–17 lead styphnate–3 aluminum	0.69	Without	98	...	...
80 lead azide–18 lead styphnate–0.5 aluminum–1.5 potassium chlorate	0.69	Without	111	...	...
80 mercury fulminate–20 potassium chlorate	0.69	With	101	110	117
80 lead azide–20 lead styphnate	0.69	With	123	149	156
80 lead azide–20 lead styphnate	0.79	Without	...	...	96
80 lead azide–20 lead styphnate	0.59	Without	...	...	175
80 lead azide–20 lead styphnate	0.59	With	...	...	180

[a] Weights of priming charges are given in Table II.

EFFICIENCY EXPRESSED AS UNIT WEIGHT OF CHARGE

The data obtained in the experiments are made more instructive by calculating the initiating efficiency per unit weight of explosive charge in the detonator. This is accomplished by dividing the result of the miniature-cartridge test (average grams of sand crushed by the 80–20 and 70–30 TNT–iron oxide mixtures, after subtraction of the detonator blank) by the total weight of explosive charge in the detonator in grams. As an example, for a detonator containing a total explosive charge of 150 cg. (1.50 grams), the miniature-cartridge test result was 125 grams of sand crushed. The "sand crushed per unit weight of explosive charge in detonator" is 125/1.50, or 83 grams.

Table IV gives data derived in this manner from the data of the experiments. For all detonators represented in this table, the base charge weighed 75 cg., loaded in three equal increments as already described.

Figure 7 gives plots of eleven series of detonators selected from Figures 1, 3, 4, and 5, and recalculated to express the efficiency per unit weight of explosive charge. Each curve represents a series of detonators with a range of base charge from 25 to either 100 or 125 cg., with the exception of curve 1 which depicts a series

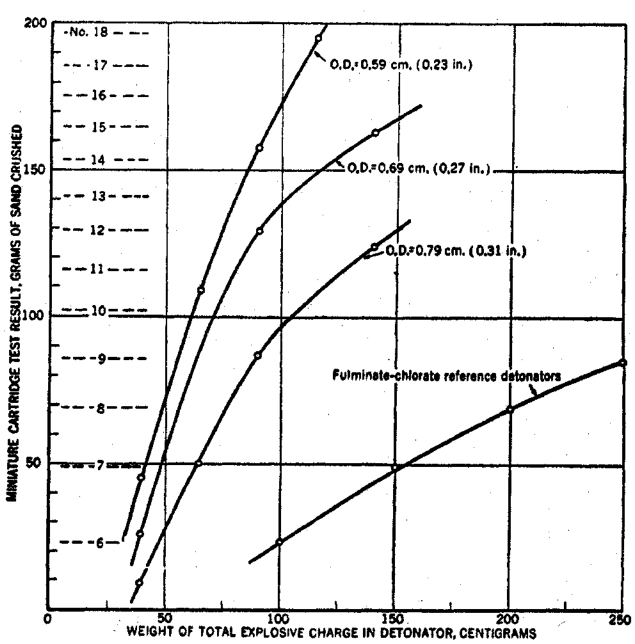


Figure 5. Effect of Diameter of Shell on Initiating Efficiency

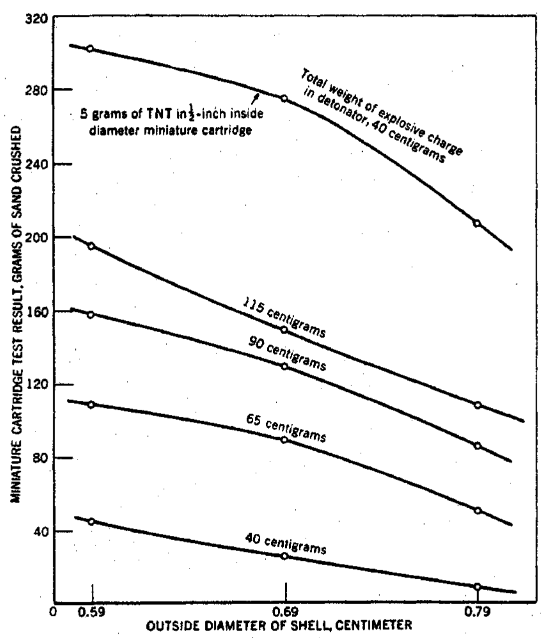
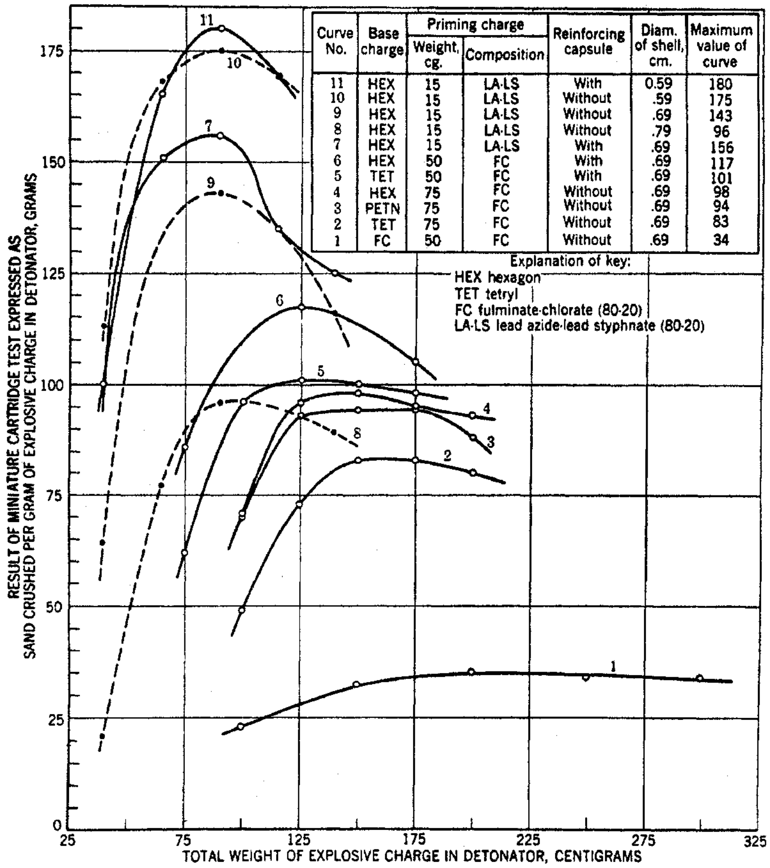


Figure 6. Effect of Diameter of Detonator Shell on Initiating Efficiency



Curve No.	Base charge	Priming charge: Weight, cg.	Priming charge: Composition	Reinforcing capsule	Diam. of shell, cm.	Maximum value of curve
11	HEX	15	LA-LS	With	0.59	180
10	HEX	15	LA-LS	Without	.59	175
9	HEX	15	LA-LS	Without	.69	143
8	HEX	15	LA-LS	Without	.79	96
7	HEX	15	LA-LS	With	.69	156
6	HEX	50	FC	With	.69	117
5	TET	50	FC	With	.69	101
4	HEX	75	FC	Without	.69	98
3	PETN	75	FC	Without	.69	94
2	TET	75	FC	Without	.69	83
1	FC	50	FC	Without	.69	34

Figure 7. Initiating Efficiencies of Eleven Series of Detonators Expressed as Unit Weight of Explosive Charge in Detonator

of standard fulminate-chlorate detonators. The curves were selected for Figure 7 to illustrate the influence of the factors studied in this report. The relations of the various factors affecting initiating efficiency are sharply depicted by these curves: base charge, curves 1, 2, 3, and 4; reinforcing capsule, curves 2 and 5; priming charge, curves 6 and 7; and diameter, curves 8, 9, and 10.

Curve 11 represents a high-efficiency detonator combining all the advantageous features of the previous detonators. It possesses the following characteristics: The base charge is hexogen, and the priming charge is 80–20 lead azide–lead styphnate pressed under a copper reinforcing capsule. The shell is gilding metal having an outside diameter of 0.59 cm. Its initiating efficiency, as indicated by the maxima of the curves of Figure 7, is of the order of five and a half times that of a fulminate-chlorate detonator on an equal-weight-of-explosive-charge basis. Further investigation of other factors would probably reveal detonators of greater efficiency. Of these factors, the effect of the magnitude of the pressure on the detonator charges is no doubt important. An investigation of these and other factors is contemplated.

Detonator designers have been cautious about containing lead azide in copper capsules or shells because of the possibility of formation of dangerously sensitive copper azide, especially if moisture may be present (*18*, *20*). One method of circumventing this difficulty has been to use aluminum shells. Another has been to seal the detonator positively, as in electric detonators, to exclude the entrance of moisture (*2*). Still another method has been to enclose the lead azide completely in a cavity in the base charge. The detonators studied in this report were fired generally the same day they were made, thus minimizing the possibility of copper azide formation.

The maxima in the curves of Figure 7 result from the mathematical operation of subtracting the detonator blank from the total sand crushed. Curves showing the total sand crushed by the TNT–iron oxide mixture and the detonator rise to maxima and level off. The curves for the detonator blanks are essentially straight lines. Subtraction of the latter from the former produces curves with maxima as in Figure 7.

A study of Figure 7 reveals the significant fact that the initiating efficiency of a detonator depends upon both the quantity and quality of its explosive charge, and that both must be considered. Increasing the weight of charge in a mercury fulminate detonator, for example, is not nearly so effective as substituting a composition having a higher rate of detonation, such as PETN or hexogen. Another way of stating this is the generalization that a given force applied to a given area is more likely to produce initiation of an explosive than the same force applied to a larger area. Increasing the weight of charge in a detonator will increase the total force, but substituting an explosive having a higher rate of detonation will increase the force per unit area.

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