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Impact and Thermal Sensitivity of Commercial Detonators

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IMPACT AND THERMAL SENSITIVITY OF COMMERCIAL DETONATORS

by

Karl R. Becker,[1] John C. Cooper,[2] and Richard W. Watson[3]

ABSTRACT

A variety of commercial detonators (fuse type and electric instantaneous and delay types) were subjected to impact and thermal stimuli to determine initiation stimulus levels and the dominant parameters in resistance to initiation.

In the impact trials the detonators were impacted along their length to find the most sensitive region; threshold initiation limits obtained for these regions ranged from 3.47 to 20.82 joules (2.6 to 15.4 ft-lb). The friction sensitivity of the explosive component was an important parameter in determining sensitivity; various construction features of nonexplosive components played a role as well.

In the thermal sensitivity trials, the detonators were heated from ambient to 100° C at an average rate of about 1.0° C/min, and thereafter at 0.5° C/min until they exploded; the explosion temperatures observed ranged from 121° to 188° C. These temperatures correlated quite well with the reaction temperatures of certain characteristic explosive components used by different manufacturers. The data also indicated an effect of confinement on explosion temperatures of detonators.

INTRODUCTION

As part of its continuing research in mining safety, the Federal Bureau of Mines conducted a series of impact and thermal experiments on detonators. The main purpose of this work was to gather information in the interest of safety and not to grade detonators manufactured by the various companies. In view of this, and the proprietary information on explosives composition discussed in this report, the trade and/or company designations of the products have been omitted. Although detonator manufacturers perform a variety of tests on their products (including tests on impact and thermal hazards), the results are used for comparison with standards established within each company, and are not generally published.

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[1]Research physicist.
[2]Research chemist.
[3]Research supervisor.

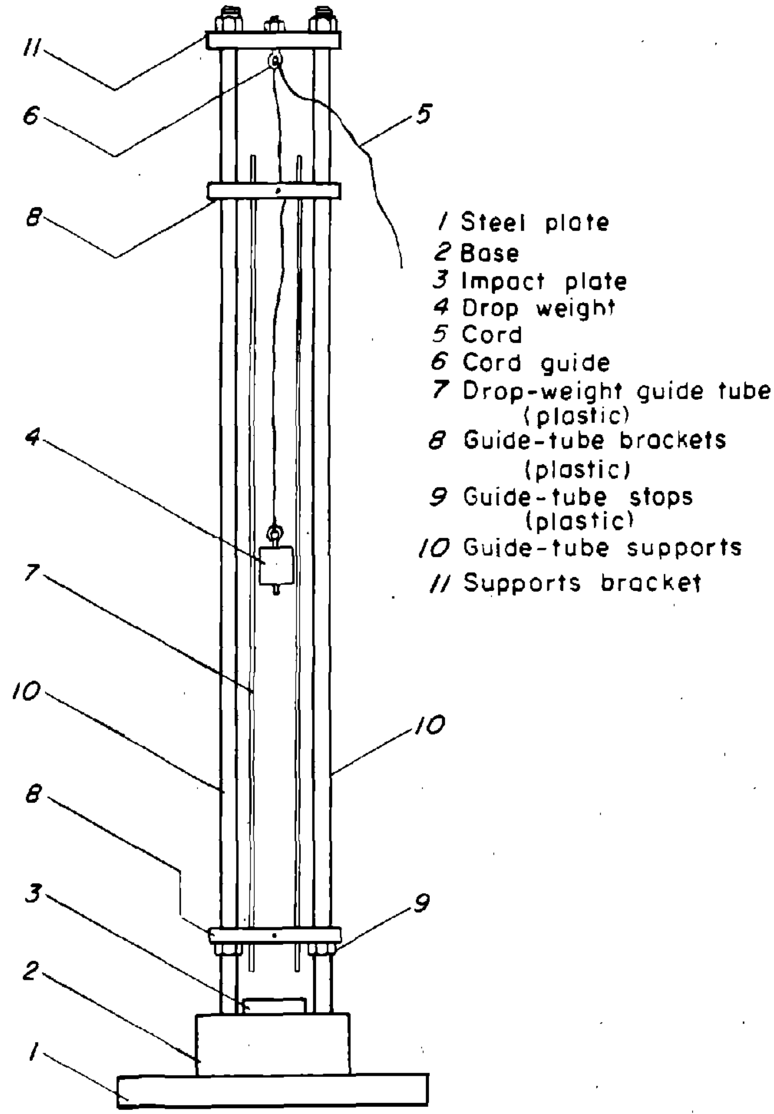

FIGURE 1. - Schematic diagram of drop-weight tester.

ACKNOWLEDGMENTS

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EXPERIMENTAL TECHNIQUES

Impact Sensitivity Studies

The drop-weight test apparatus (fig. 1) utilized a steel drop weight, 6.35 cm in diam by 9.7 cm long, with a mass of 2.36 kg. The falling weight was guided inside a plastic tube, 6.35 cm in diam by 1.25 m long, with a 0.65-cm wall; the tube was supported in a vertical position by two steel rods anchored in a steel base plate 25 cm in diam by 10 cm thick. Three types of impact tests were conducted: (1) horizontal broad-surface impact, where the detonators were impacted lying flat by the flat-bottom surface of the drop weight; (2) a vertical broad-surface impact, where the detonators were placed upright and were struck by the flat-bottom surface of the drop weight; and (3) a localized impact, in which a 0.635-cm-diam by 3.8-cm-long cylindrical steel pin was inserted in the bottom face of the drop weight for impacts on selected regions along the length of the detonator. The localized-impact tests were conducted to determine the most sensitive spot--ignitor, delay element, primary- or base-charge region. The impact surfaces of the drop weight (pins and base disks) were expendable and could be easily replaced.

For a test, the detonator was placed on a 10- by 10- by 2.54-cm-thick steel plate (also expendable) that rested upon the large steel base. The weight was raised remotely by a calibrated, waxed cord. Drop heights were precise to within 1.0 cm, and the impact velocities were found to be within 5 pct (less) of the theoretical drop velocities.

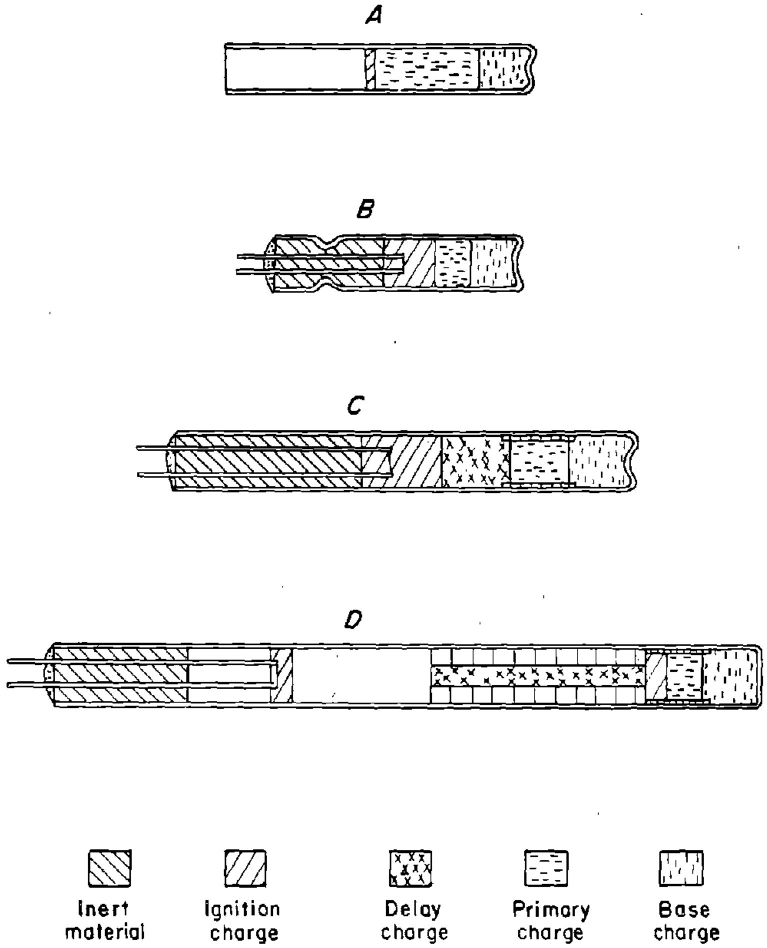

FIGURE 2. - Representative detonators tested in impact and thermal studies. *A*, FBC; *B*, instantaneous EBC; *C*, delay EBC (four active elements); *D*, delay EBC (five active elements).

Sketches of several representative detonator types are shown in figure 2. These sketches and the brief discussion that follows are not intended to elucidate all the intricacies of detonator designs; rather, they simply show the basic elements of a fuse-type blasting cap (FBC) and electric blasting caps (EBC). An instantaneous EBC and two slightly different designs for delay EBC's are shown.

As shown in figure 2A, the upstream end of the FBC has an open well that accepts the fuse. In a downstream direction are the ignition, primary, and base explosive elements.

A representative instantaneous EBC is shown in figure 2B. It is similar to the FBC except that the ignition charge is ignited by an electrically heated bridge wire or other device; the upstream end contains leg wires held in place by rubber or plastic plugs.

The chemical composition of the ignition, primary, and delay elements are many and varied; however, ignitor components in general are relatively heat sensitive, and primary explosives are sensitive to a variety of stimuli including heat, friction, and impact. The base charges are secondary explosives and with few exceptions are either PETN or PETN-graphite.

The main features of a delay EBC are shown in figure 2C. It has four active components; the fourth component is the delay element, which is always located immediately downstream from the ignition charge. The delay period for members of a given delay series is varied by changing the length, loading pressure, and composition of the delay element.

Figure 2D illustrates a delay EBC with five active components. The fifth component is a second ignition element situated between the delay and primary components. It is utilized when the delay element is not a good ignitor for the primary charge. Some FBC's and instantaneous EBC's utilize only two explosive components--a combination ignition-primary component and a base component.

Thermal Sensitivity Studies

For the thermal sensitivity determinations, the detonators were placed in a sand-filled pipe (2.0 inches ID by 5.5 inches long) capped at both ends. The heating unit was Nichrome[4] heating ribbon wrapped spirally around the exterior of the pipe; the heating rate was controlled manually by a variable transformer. A No. 28 Chromel-Alumel thermocouple was attached to the exterior of the detonator, and the temperature was monitored on a chart recorder. In several preliminary trials, it was verified that no temperature gradient existed between the interior and exterior of the detonator at the heating rates used. The detonators were heated from ambient temperature to 100° C at an average rate of 1.0° C/min, and therefore at a uniform rate of 0.5° C/min until they initiated. At this instant, the recorder chart trace exhibited a marked discontinuity and the observer was able to detect a loud report. Some traces exhibited an exotherm shortly before the explosion. The start of these exotherms, when evident, were not very reproducible between repeat trials; they usually occurred several degrees earlier than the explosion temperatures, which were quite reproducible. Three repeat trials were made for each of 20 detonator types; they were the same detonator types used in the localized-impact trials.

RESULTS AND DISCUSSION

Impact Sensitivity Studies

Broad-Surface Impacts

Horizontal and vertical broad-surface impact trials were conducted primarily for screening purposes and to compare the extent of damage to various detonators under constant impact energy. A secondary objective was to gain some insight as to the amount of deformation that detonators could sustain without initiating. Twenty-seven different detonators from eight different manufacturers were impacted by flat-bottom weight at a 100-cm drop height. The detonators tested were FBC's and EBC's, both instantaneous and delay.

Five repeat trials of the horizontal and vertical tests were made on the detonators; in both types of tests, the leg wires were removed prior to impact. Preliminary trials conducted in the vertical impact mode with the drop weight striking the upper (leg wire or fuse) end of the detonator or the lower (base charge) end indicated that ignition was independent of the orientation. In the screening tests, three trials were conducted with the drop weight striking the upper end, and two trials with the weight striking the lower end.

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[4]Reference to specific trade names is made for information only and does not imply endorsement by the Bureau of Mines.

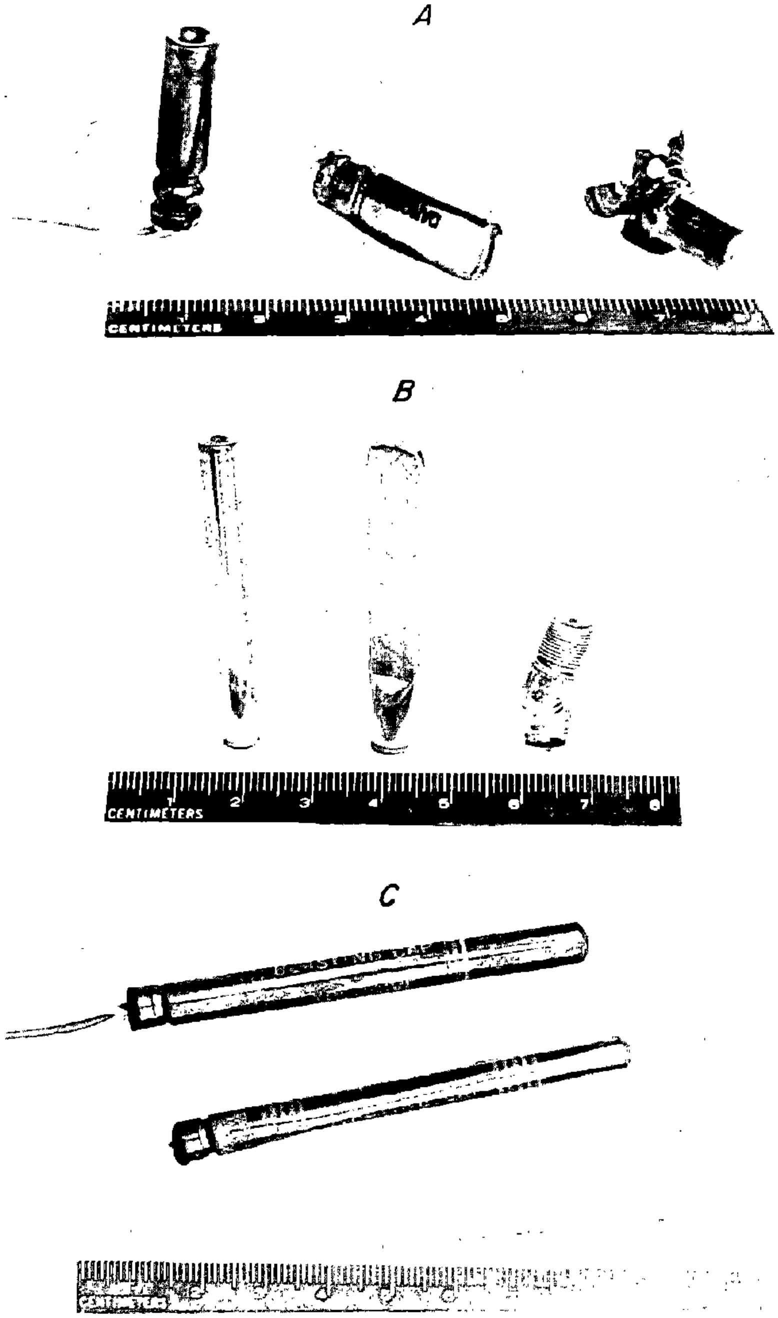

FIGURE 3. - Detonators deformed in horizontal and vertical impacts. *A*, Instantaneous EBC (from left to right) before deformation, after horizontal deformation, and after vertical deformation; *B*, FBC (from left to right) before deformation, after horizontal deformation, and after vertical deformation; and *C*, delay EBC (top) before deformation and (bottom) after horizontal deformation.

Several different detonators that were deformed in the broad-surface impact trials are shown in figure 3. Figure 3A, from left to right, shows an instantaneous EBC before impact and two others after impact in the horizontal and vertical modes. The degree of deformation, that is, the flattening in the horizontal impact and axial compression and rupture in the vertical impact, is moderately severe and is fairly typical for most detonators. However, for a variety of reasons, including detonator size, case strength, and inner component construction, or a combination of these and other features, the amount of deformation varied somewhat. Figure 3B shows an FBC with an aluminum case that sustained very severe deformations in both vertical and horizontal modes; figure 3C is a delay EBC that sustained only slight deformation in the horizontal mode.

Results of the broad-surface impacts are summarized in table 1. As will be noted, ignitions occurred in only 4 of the 27 detonators tested. Of these, two are no longer in production; one was an outdated foreign product, and the other was a relatively small-size military item. The significant observations in these screening trials were that all the modern detonators tested and in use at the present time could sustain quite severe deformations under this type of impact without initiating.

TABLE 1. - Results of broad-surface impact tests from 100-cm drop height

Detonator	Mfr.	Description[1]	Horizontal impact	Vertical impact
		FBC's		
1	1	No. 6, aluminum case..........	5 nonignitions..	5 nonignitions.
2	2	No. 6........................	.....do.........	Do.
3	2	No. 8, aluminum case..........	.....do.........	Do.
4	2	-	.....do.........	Do.
5	3	No. 6........................	.....do.........	Do.
6	3	No. 8........................	.....do.........	Do.
7	5	No. 6, obsolete...............	4 ignitions, 1 nonignition.	5 ignitions.
8	5	No. 8, obsolete...............	3 ignitions, 2 nonignitions.	Do.
9	8	Foreign product...............	1 ignition, 4 nonignitions.	5 nonignitions.
		INSTANTANEOUS EBC's		
10	1	No. 6........................	5 nonignitions..	5 nonignitions.
12	1	No. 8........................	.....do.........	Do.
13	2	No. 6........................	.....do.........	Do.
14	3	-	.....do.........	Do.
15	4	No. 6, plastic case...........	.....do.........	Do.
16	5	No. 6........................	.....do.........	Do.
17	6	Military item, aluminum case..	1 ignition, 4 nonignitions.	4 ignitions, 1 nonignition.
18	7	Foreign product..............	5 nonignitions..	5 nonignitions.
		DELAY EBC's		
19	1	100-msec delay time...........	5 nonignitions.	5 nonignitions.
20	1	500-msec delay time...........	.....do........	Do.
21	2	No. 8, 25-msec delay time.....	.....do........	Do.
23	2	135-msec delay time...........	.....do........	Do.
24	2	No. 8, 500-msec delay time....	.....do........	Do.
25	2	No. 8, 2.9-sec delay time.....	.....do........	Do.
26	3	175-msec delay time...........	.....do........	Do.
28	3	500-msec delay time...........	.....do........	Do.
30	4	No. 6, period 3, aluminum case	.....do........	Do.
31	7	No. 6, 80-msec delay time, foreign product.	.....do........	Do.

[1]Numbers in this column indicate the relative strength of the detonators. Outer-case material is copper or copper alloy unless otherwise indicated.

Localized Impacts

Twenty different detonators made by seven different manufacturers were subjected to localized impacts. Again, FBC's, instantaneous EBC's, and delay EBC's were tested. The locations of given explosive components within the detonator were determined from radiographs, company sketches, and measurements obtained from detonators that were disassembled at the Bureau.

The location of the impacts was varied along the length of the detonators to find the most sensitive region--ignitor, delay element, primary, or base charge. The force of impact was transmitted to a specific area of the detonator by the 0.635-cm-diam steel pin previously described. The pin was rigidly recessed into the base of the drop weight. The drop-height interval used was 5 cm; total drop heights were accurate to ±1 cm.

Results from the localized impacts are presented in table 2 in terms of the threshold initiation limit (TIL), which is the highest drop-height interval at which five successive failures occurred from impacts in the most sensitive region. The detonators exhibited a relatively wide range of impact sensitivities yielding TIL values ranging from 15 to 90 cm, with corresponding impact energies of 3.47 and 20.82 joules (2.6 and 15.4 ft-lb). In certain cases (detonators 1, 5, and 7), the ignition charge and primary charge were in such close proximity that they were both influenced by the striking pin during a single impact and, consequently, the specific component leading to observed TIL could not be identified. In another case (detonator 13), the ignition and primary mixtures were combined into a single component. In general, the primary or "ignition-primary" charges were associated with the most sensitive impact regions. However, there were important exceptions. The most sensitive regions of detonators 12, 14, 18, 24-26, 28, and 31 contained the ignition charge. In fact, detonator 26 exhibited the highest sensitivity (lowest TIL value) of any of these tested. In still another case (detonator 21), the most sensitive region was associated with the delay train.

TABLE 2. - Results of localized-impact tests

Detonator	Mfr.	Description[1]	Most sensitive region	TIL value, cm
		FBC's		
1	1	No. 6, aluminum case	Ignition-primary[2]	40
2	2	No. 6	Primary	50
5	3	No. 6	Ignition-primary[3]	50
7	5	No. 6, obsolete	do.[2]	25
		INSTANTANEOUS EBC's		
10	1	No. 6	Primary	35
12	1	No. 8	Ignition	40
13	2	No. 6	Ignition-primary[3]	45
14	3	-	Ignition	25
15	4	No. 6, plastic case	Primary	45
17	6	Military item, aluminum case	do	35
18	7	No. 6, foreign product	Ignition	25
		DELAY EBC's		
19	1	100-msec delay time	Primary	45
20	1	500-msec delay time, aluminum case	do	90
21	2	No. 8, 100-msec delay time	Delay train	45
24	2	No. 8, 500-msec delay time	Ignition	50
25	2	No. 8, 2.9-sec delay time	do	50
26	3	175-msec delay time	Ignition	15
28	3	500-msec delay time	do	35
30	4	No. 6, aluminum case	Primary	60
31	7	Foreign product, 80-msec delay time	Ignition	25

[1] Numbers in this column indicate the relative strength of the detonators. Outer-case material is copper or copper alloy unless otherwise indicated.

[2] Separate ignition and primary charges were in such close proximity that both were impacted simultaneously.

[3] Ignition and primary mixtures were combined into a single component.

Before elaborating on these results, it should be pointed out that the conceivable parameters affecting resistance to ignition by impact are numerous. Among them are the inherent sensitivity of the explosive used, the thickness and strength of the outer case, the protection offered by inner shells or sleeves surrounding the explosive components, and suspension points immediately outside the impact area of interest. Without detailed knowledge or precise control of these parameters, the relative standings of all the TIL values obtained cannot be accounted for in precise fashion. In an effort to gain additional insight into the factors influencing the impact sensitivity, selected detonators were disassembled and sensitivity tests were run on the various explosive components. In addition, a careful examination was made of the physical characteristics of the detonators that might affect sensitivity.

Effect of Explosive Sensitivity

Friction-sensitivity tests were conducted on the various active components extracted from disassembled detonators. The tests were run on a friction tester developed by the German Federal Institute for Materials Testing (Bundesanstalt für Materialprüfungen, BAM).[5] With this apparatus, small samples of the material under investigation are placed between a stationary porcelain pin and a moving porcelain plate that both have a standard roughness. The pin is rounded at each end and is mounted on a lever arm upon which any 1 of 9 weights may be placed in 6 possible positions, thus providing a total of 54 load increments ranging from 0.5 to 36.0 kg. For a test, a switch is thrown, and the anvil upon which the porcelain plate is mounted reciprocates once to and fro and automatically shuts off. The relative sensitivities of the explosives are ranked in terms of a TIL, which is the maximum load in kilograms resulting in no reactions in five trials.

Despite precautions, the samples of the active components extracted from detonators did contain very small amounts of contaminants from adjacent components. It was possible, however, through painstaking efforts, to remove foreign particles from the test samples. This resulted in reproducible test results that were in essential agreement with extant data when comparisons were available. The friction test results are summarized in table 3, along with the TIL values at the most sensitive region, taken from table 2.

The most important feature of the data in table 3 is the fact that in every case the most sensitive region of a given detonator was associated with the component (or components) having the greatest friction sensitivity. Thus, the inherent sensitivity of the most sensitive material plays a dominant role in determining the impact sensitivity of a given detonator. However, for the various items tested there was no apparent correlation between the TIL values observed in the impact tests on detonators and the friction tests of the explosive components. This observation indicates the importance of the external and internal construction features of detonators in determining impact sensitivity. The excellent correlation between the most sensitive region and

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[5]Koenen, H., and K. H. Ide. Uber die Prüfung explosives Staffe. 1. Ermittlung der Reibempfundlichkeit (Testing of Explosives--Determination of Frictional Sensitivity). Explosivstoffe, No. 5/6, 1955, pp. 57-65; No. 7, 1955, pp. 89-93.

the friction sensitivity of the material contained in that region indicates that friction is an important initiation mechanism for detonators exposed to mechanical impact. This is not too surprising since large frictional forces with attendant localized heating must occur during the massive deformation process.

TABLE 3. - Friction sensitivities for active components of detonators

Detonator	Description[1]	Component	Friction sensitivity,[2] kg
		FBC's	
5	No. 6	Ignition	0.5 } (50 cm)
		Primary	2.0 }
		Base	6.0
7	No. 6	Ignition	0.5 } (25 cm)
		Primary	<.5 }
		Base	24
		INSTANTANEOUS EBC's	
10	No. 6	Ignition	1.0
		Primary	<.5 (35 cm)
		Base	2.0
13	No. 6	Ignition-primary	<.5 (45 cm)
		Base	4.0
17	Military item, aluminum case.	Ignition	<.5
		Primary	<.5 (35 cm)
		Base	4.0
		DELAY EBC's	
20	500-msec delay time, aluminum case.	Ignition	8.0
		Delay	>36.5
		Primary	<.5 (90 cm)
		Base	4.0
21	No. 6, 100-msec delay time.	Ignition	6.0
		Delay	1.0 (45 cm)
		Primary	1.0
		Base	4.0
26	175-msec delay time.	Ignition 1	.5 (15 cm)
		Delay	>36.0
		Ignition 2	.5
		Primary	1.0
		Base	4.0
28	500-msec delay time.	Ignition 1	<.5 (35 cm)
		Delay	-
		Ignition 2	-
		Primary	-
		Base	2.0

[1] Numbers in this column indicate the relative strength of the detonators. Outer case material is copper or copper alloy unless otherwise indicated.
[2] Numbers in parentheses indicate TIL for impacts on detonator at most sensitive region (taken from table 2).

Effect of Outer Case

The resistance to deformation of the outer case of the detonator should have an effect on its resistance to initiation by impact. This effect is

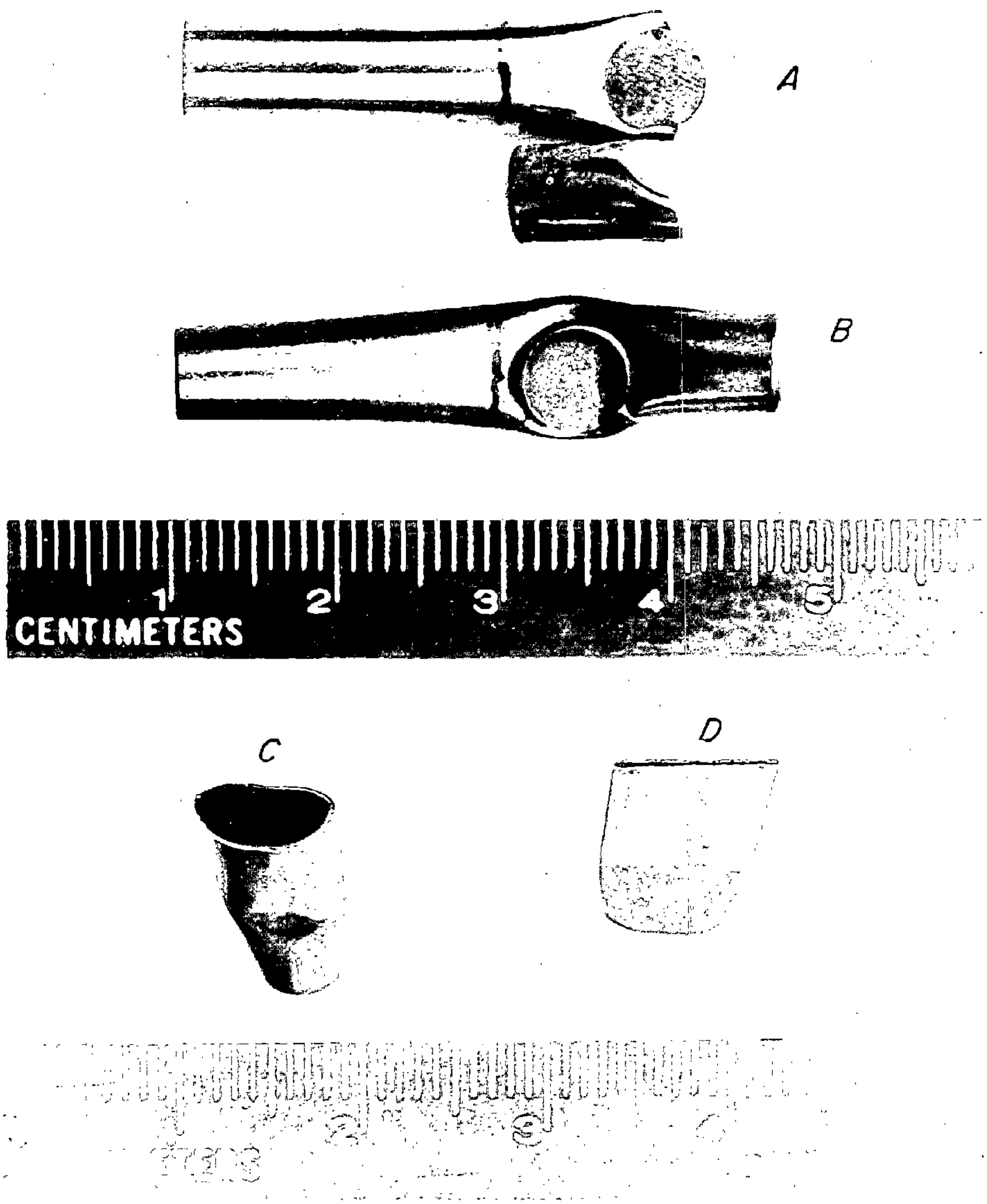

FIGURE 4. - Effect of outer case strength demonstrated by localized impacts on two different live detonators (top) and broad-surface impacts on their empty cases (bottom). *A*, Detonator 7, case thickness of 7 mils; *B*, detonator 5, case thickness of 9 mils; *C*, detonator 5; and *D*, detonator 7.

demonstrated by the data for two FBC's shown in the following tabulation:

Detonator No.	Friction sensitivity, kg	Outer case thickness, mils	TIL for impact on detonator, cm
5	0.5	9	50
7	.5	7	25

These FBC's were chosen for the comparison because their construction is simple and free of possible effects from bridge wires and supports in or near the vicinity of impact. The data clearly show a correlation between the outer-case thickness and resistance to initiation by impact for constant explosive sensitivity. This is further illustrated in figure 4, which shows the effects of localized and broad-surface impacts on the two detonators. Detonator 7, with the 7-mil-thick case, suffered much more serious deformation in both instances.

Effect of Internal Construction Features

Protection offered by inner shells was quite marked in some instances. The additional resistance to deformation offered by inner shells is demonstrated by detonator 21, a delay EBC with a delay time of 100 msec. The basic features of this detonator are the same as those depicted in figure 2C. The sketch shows a bridge-wire element immersed in an ignition charge; downstream from this region is a delay element, a primary charge surrounded by an inner shell, and a base explosive charge. Pertinent data illustrating the inner-case effect for detonator 21 are given in the following tabulation:

Explosive component	Friction sensitivity, kg	TIL for impact on detonator, cm
Primary................	1.0	90
Delay..................	1.0	45

The results were obtained from localized impacts on the areas containing the primary and delay elements. The friction sensitivities of the primary and delay elements were the same. However, the area of the detonator containing the primary charge was significantly less sensitive to impact because of the additional protection offered by the inner case. Figure 5 shows impacts, at constant drop height, upon the outer case (5A) and upon the outer case and inner shell together (5B) of detonator 21; the explosives had been removed for the demonstration. The additional resistance to deformation provided by the inner shell is significant.

In other instances, detonator 26 for example (fig. 2D), an inner shell surrounding one component will provide protection to other unprotected explosive components if the impacting surface is large, as was the case in the broad-surface impacts. In particular, this detonator had a very sturdy inner brass cylinder surrounding a relatively insensitive delay explosive component (friction sensitivity=36 kg or greater); this cylinder, together with the end plug, provided protection for a very sensitive (friction sensitivity=0.5 kg)

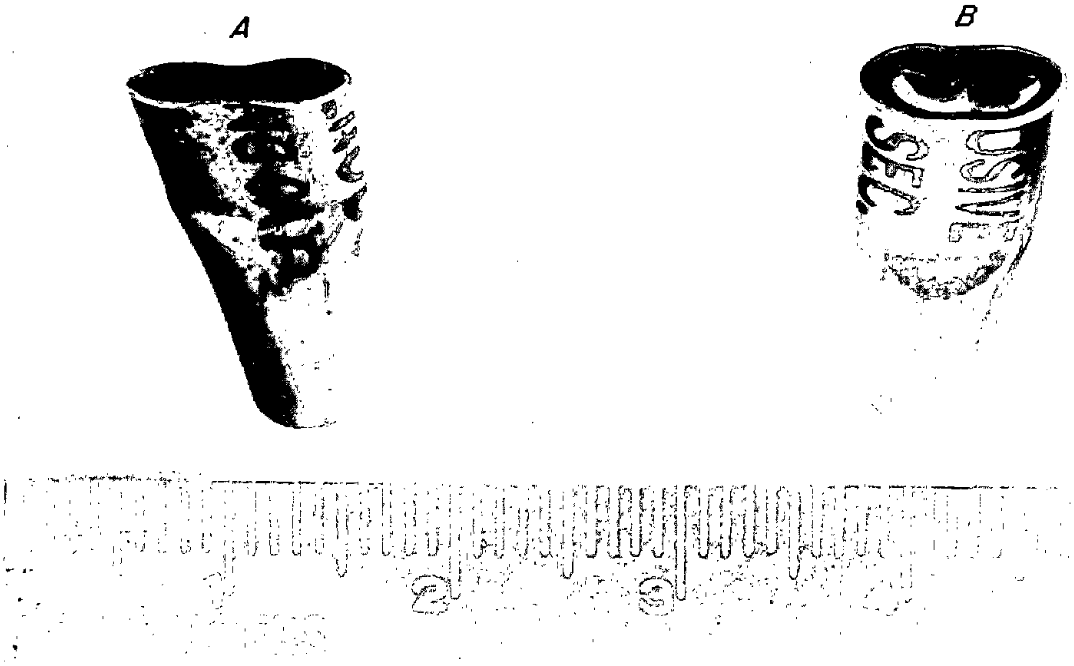

FIGURE 5. - Results of impacts on metal case of detonator 21. *A*, Inner shell removed and *B*, inner shell intact.

composition used in this case as an ignition element. In the broad-surface impacts, this detonator sustained relatively little deformation (fig. 3C), yet localized-impact trials on the ignition region produced the lowest TIL value (15 cm) of any region in any detonator tested.

It is instructive to examine some of the features of this detonator and another one, detonator 28, in the same delay series. Data pertinent to the discussion are shown in the following tabulation:

Detonator	Most sensitive area	Friction sensitivity, kg	TIL for impact on detonator, cm
26 (175-msec delay time)	Ignition charge...	0.5	15
28 (500-msec delay time)	.....do..........	<.5	35

The friction sensitivities of the ignition elements are believed to be about the same, since in five trials with a 0.5-kg load, no ignitions were observed for detonator 26 and only one ignition was observed for detonator 28. Their construction features from the upstream end down to their delay components appear to be identical; that is, their case thicknesses are the same (9 mils), and the ignition elements in both detonators are situated in a long air cavity and are the same distance from the upstream end of the detonators. In both cases, the ignition elements were contained in inner sleeves. For detonator 26, it was a cardboard sleeve, 13/16 inch long with a wall thickness of about 13 mils; for detonator 28, the sleeve appeared to be polyethylene, about 15/16 inch long with a wall thickness of about 16 mils. Quite probably, the added protection provided by the thicker plastic sleeve was the main factor responsible for the significant difference in the impact TIL values.

Lastly, it would be instructive to discuss briefly some of the pertinent features of the detonator that was least sensitive to initiation in the localized impacts. Detonator 20 was a delay EBC, 500 msec, and had four active elements: ignition, delay, primary, and base charges. The friction sensitivity data in table 3 show sensitivity values for ignition, delay, primary, and base charges of 8, >36, <0.5, and 4 kg, respectively, for those components. Except for the primary explosive, the elements were relatively insensitive. Strictly on this basis, one would not expect the regions of the detonator containing these insensitive components to be very sensitive to impact; this was the case. The most sensitive region, the primary region, was in itself insensitive, considering that it contained such a sensitive explosive; the TIL value for impacts on this region was 90 cm. This is a good example of a case in which there was limited access to a sensitive explosive. One could not impact the primary explosive in a localized impact without engaging the delay element immediately upstream (which was surrounded by a sturdy inner cylinder), or the base charge immediately downstream, or both. It was observed that the primary region was most vulnerbale to impacts centered so that all the tool overlap was upon the base charge and none upon the inner metal cylinder around the delay charge. Even so, it is quite conceivable that the metal cylinder, although immediately outside the area of impact, lent some support against deformation of the outer case, since it represented a close support or suspension point for impacts in that immediate neighborhood.

Thermal Sensitivity Studies

Data previously obtained at the Bureau[6] gave explosion temperatures ranging from 260° to 300° F (127°-149° C). The data in this report confirm and extend the earlier data.

Results of the thermal sensitivity trials are given in table 4. The average explosion temperatures for 19 different detonators ranged from 121° to 188° C; one FBC made by manufacturer 3 (detonator 5) did not explode at the maximum attainable temperature of 240° C. The average spread in repeat trials was about 3° C. It should be pointed out that the explosion temperatures obtained are "test sensitive"; that is, at other heating rates, a different set of explosion temperatures may be expected. To demonstrate the point, several additional tests were performed in which detonators from 3 manufacturers were heated at 5.0° C/min, 10 times the rate used in this study. The results given in table 5 show that the detonators exploded at correspondingly higher (7° to 15° C) temperatures than when heated at the lower rate. On this basis, one would not expect a very significant difference in results if the rate were varied by a factor of two. Thus, the exploding temperatures given in table 4 do not necessarily give indications of "safe temperature limits." For the most part, however, it is believed that the test, as performed, provides a useful index of the relative sensitivities of the detonators to thermal stimuli.

[6]Forshey, D. R., T. C. Ruhe, and C. M. Mason. The Reactivity of Ammonium Nitrate-Fuel Oil With Pyrite-Bearing Ores. BuMines RI 7187, 1968, 10 pp.

TABLE 4. - Explosion temperatures of various detonators[1]

Detonator	Description[2]	Average explosion temperature, ° C	Variation, n=3 spread, ° C
	MANUFACTURER 1		
1	FBC, No. 6, aluminum case	160	4
11	Instantaneous EBC, No. 6	150	3
12	Instantaneous EBC, No. 8	150	2
19	Delay EBC, 100-msec delay time	143	4
20	Delay EBC, 500-msec delay time, aluminum case	151	8
	MANUFACTURER 2		
2	FBC, No. 6	136	3
13	Instantaneous EBC, No. 6	133	1
22	Delay EBC, 100-msec delay time, No. 8	134	2
24	Delay EBC, 500-msec delay time, No. 8	134	2
25	Delay EBC, 2.9-sec delay time, No. 8	137	4
	MANUFACTURER 3		
5	FBC, No. 6	No explosion up to 240° C[3]	-
14	Instantaneous EBC	121	1
27	Delay EBC, 175-msec delay time	122	0
28	Delay EBC, 500-msec delay time	130	3
	MANUFACTURER 4		
15	Instantaneous EBC, No. 6, plastic case	139	4
29	Delay EBC, No. 6, period 4 delay time, aluminum case.	188	1
	MANUFACTURER 5		
7	FBC, No. 6, obsolete	132	1
	MANUFACTURER 6		
17	Instantaneous EBC, aluminum case, military item.	149	2
	MANUFACTURER 7		
18	Instantaneous EBC, No. 6, foreign product	156	4
31	Delay, EBC, 80-msec delay time, foreign product.	151	3

[1]Detonators were heated at constant rate of 0.5° C per minute.
[2]Numbers in this column indicate the relative strength of the detonators. Outer-case material is copper or copper alloy unless otherwise indicated.
[3]Decomposed active elements flowed out of fuse cavity.

TABLE 5. - Comparison of explosion temperatures of three instantaneous EBC's obtained under different heating rates[1]

Detonator	Manufacturer	0.5° C/min[2]	5.0° C/min
11	1	150	165
13	2	133	140
14	3	121	134

[1]Outer-case material is copper or copper alloy; No. 6 strength.
[2]Taken from table 4.

The data in table 4 exhibit a remarkable degree of orderliness; that is, the explosion temperatures can be ordered according to certain characteristic explosives they contain. The reaction temperatures of these characteristic explosives found in the literature correlate with the explosion temperatures given in table 4. This is demonstrated in table 6 which, for simplicity sake, presents only the data for detonators made by manufacturers 1, 2, and 3. First, it is quite apparent that, depending on the manufacturer, the data divide into three distinct temperature ranges of 143°-160°, 133°-137°, and 121°-130° C for manufacturers 1, 2, and 3, respectively. Despite the unavailability of information on some proprietary explosives used in these detonators, the temperature ranges can be uniquely associated with certain explosives (mainly the priming elements) characteristically used by the manufacturers. For example, it is known that PETN is utilized as a base charge in all these detonators. It is also known that manufacturer 3 utilized Mannitol Hexanitrate (HNM) in all detonators, whereas the other two manufacturers did not. Manufacturers 2 and 3 utilized Diazodinitrophenol (DDNP), whereas manufacturer 1 utilized lead azide consistently (lead styphnate was used as well in some detonators) and in no case utilized either DDNP or HNM. The last column in table 6 shows reaction temperatures for lead azide, PENT, HNM, and DDNP obtained by another technique[7] in which these explosives were loaded in an empty No. 8 FBC case and dipped in a Woods metal bath at a temperature that produced a reaction in 5 sec. These data show that, among the explosives considered, HNM reacted at the lowest temperature; DDNP, PETN, and lead azide reacted at successively higher temperatures. Thus, the explosion temperatures obtained for the detonators can be divided into three distinct groups on the basis of several criteria--manufacturer, characteristic explosive used, and reaction temperature of the explosive as determined in the Woods metal test.

TABLE 6. - Selected thermal sensitivity results

Manufacturer	FBC results,[1] ° C	Explosion temperature range, ° C	Characteristic explosives used	Results of Woods metal test, ° C
1	160	143-160	PETN	225
			Lead styphnate	282
			Lead azide	340
2	136	133-137	DDNP	180
			PETN	225
3	>240 126 confined	121-130	HNM	165
			DDNP	180
			PETN	225

[1]Taken from table 4.

When explosion temperature data for the remaining six different detonators made by manufacturers 4, 5, and 7 are considered on a basis similar to that used on data for manufacturers 1, 2, and 3, they also show a similar orderliness. For example, an obsolete detonator made by manufacturer 5 (detonator 7) contained mercury fulminate and tetryl. This detonator exploded at 132° C;

[7]U.S. Army Material Command. Engineering Design Handbook (Explosives). AMC Pamphlet No. 706-177, March 1967, 394 pp.

the Woods metal test result for mercury fulminate was 210° C (that for tetryl is higher). Hence this detonator would fit in an appropriate place among those containing HNM and DDNP. All five remaining detonators did not contain HNM, DDNP, or mercury fulminate. Rather, like those for manufacturer 1, they contained lead azide and lead styphnate and, in several cases, utilized RDX as a base charge. Based upon the Woods metal tests results found in the literature and the fact that all of these detonators exploded at temperatures higher than any that contained HNM, DDBP, or mercury-fulminate, they would be placed in proper order among those made by manufacturer 1.

The role of the delay component in delay detonators was ignored in the discussion. However, except for the delay charge, for the most part they contained explosive components similar to that used in their instantaneous and fuse-type counterparts. Since they exploded in the same temperature range as the FBC's and instantaneous EBC's, it appears reasonable to assume that the role of the delay charge was unimportant.

The possible role of matchhead ignitors was also ignored. Manufacturers 3 and 7 both incorporated matchhead ignitors in their electric detonators. However, manufacturer 3 utilized HNM and DDNP in all detonators and they exploded in the temperature range of 121° and 13° C. Detonators made by manufacturer 7 did not contain HNM or DDNP and they exploded in the temperature range 151° to 156° C. Hence, matchheads did not apparently play an important role.

One other interesting qualitative feature of the data in table 6 is that the FBC's in each group exploded at higher temperatures than that observed for instantaneous and delay EBC's. In fact, the FBC made by manufacturer 3 did not explode at the maximum attainable temperature of 240° C; the partially decomposed explosives flowed out of the open fuse well. In a special test, the open fuse well was crimped shut, and under these conditions this detonator exploded at 126° C, in the same temperature range as others in the group containing HNM. Thus, an effect of confinement is indicated.

SUMMARY AND CONCLUSIONS

Impact Sensitivity Studies

Results of the earlier screening trials where forces of impact were distributed over wide areas of detonators showed that most detonators could sustain severe deformations without initiating. The amount of deformation at constant impact energy varied markedly, depending upon various construction features of the detonators.

In localized impacts, it was found that the most sensitive region of the detonator corresponded to the area containing the element exhibiting the highest friction sensitivity. This indicated that the impact sensitivity of those detonators that were disassembled was dictated by the inherent sensitivity of the most sensitive components, regardless of construction features.

Widely different values of impact sensitivity, however, were observed with different detonators containing explosives having the same friction sensitivity, indicating that construction details played an important role in determining impact sensitivity.

Although it is doubtful that the inherent sensitivity of the active materials used in detonators can be significantly altered, the avoidance of large air spaces and the use of protective sleeves and more rigid outer cases are measures that could be easily taken and would result in detonators less prone to impact initiation.

Thermal Sensitivity Studies

Ten detonators that utilized HNM, DDNP or mercury fulminate as components exploded in a rather narrow temperature range of 121° to 137° C. Ten other detonators containing lead azide and/or lead styphnate exploded in a distinctly higher but broader temperature range of 139° to 188° C. These temperatures correlate quite well with the reaction temperatures found in the literature for the explosives utilized. The spread in explosion temperatures for detonators in the first group was only 16° C; yet it was feasible to subdivide this group into two distinct groups on the basis of whether or not they contained HNM. Those containing HNM exploded at the lowest temperatures. Again, this is consistent with data found in the literature. The spread in the explosion temperatures for detonators containing lead azide or lead styphnate was 49° C. It was not feasible on the basis of available knowledge to account for any differences in explosion temperatures for detonators in this group.

Although it was not within the scope of this work to establish minimum explosion temperatures at which the various detonators would explode (given sufficient time), the data obtained should provide insight into the relative sensitivities of various detonators to thermal stimuli. The study also relates explosion temperatures obtained with characteristic explosives utilized.

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