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ATL-TR-65-92

EXPLODING BRIDGEWIRE INITIATION OF CAST EXPLOSIVES (U)

December 1965

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EXPLODING BRIDGEWIRE INITIATION OF CAST EXPLOSIVES (U)

FOREWORD

This is the final report prepared on Project 2511, Task 251103, under Contract AF 08(635)-4181, "Exploding Bridge Wire Initiation of Cast Explosives".

The work was administered under the direction of Mr. Carl Kyselka, Directorate of Armament Development, Research and Technology Division, Weapons Division (ATWR), Air Force Systems Command, United States Air Force, Eglin Air Force Base, Florida 32542, Purchase Authorization ASQWR 64-429, issued by APGC (PGKK), Eglin AFB, Florida; initiator Lt. Cobb; negotiator, Lt. Hefferman.

The research program was conducted from March 16, 1964 to March 16, 1965 by The Franklin Institute Research Laboratories, Philadelphia, Pennsylvania 19103. Key personnel who conducted the research are E.E. Hannum, Manager, Applied Physics Laboratory; R. G. Amicone, Group Leader; D.W. Mayer, Project Leader; and V.W. Goldie, contributor.

This document, except the title, is classified CONFIDENTIAL because of the potential military application of the research performed.

This technical report has been prepared and marked in accordance with the DOD Industrial Security Manual by the contractor.

This technical report has been reviewed and is approved.

DAVID K. DEAN
Colonel, USAF
Chief, Weapons Division

UNCLASSIFIED ABSTRACT

Good progress has been made in the development of a system to initiate relatively insensitive explosives like TNT without the use of primary explosive. The initiation is triggered by the use of an exploding bridgewire and the reaction in the surrounding high explosive is enhanced by confinement by a barrier whose rupture adds to the build up of detonation in the main column of high explosive. The results show that high order detonations are achievable with this system. Seventeen shots were made all of which resulted in high order judged by dent in steel block or the condition of the damage to the confinement. Further studies are recommended to optimize practical designs.

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1. INTRODUCTION

The purpose of this study is to develop a means of initiating a new family of high temperature resistant fluorinated high explosives. The initiating system should be as insensitive to high temperature, shock, and vibration, as the new high explosive themselves. These stringent environmental requirements for a high explosive initiating system result from space, missile and hypersonic flight applications.

This project is a continuation of a previous contract AF 08(635)3237, on which we studied methods to meet the environmental requirements mentioned above.

On this previous contract (Ref. 1) we conducted a literature survey directed toward finding the most promising system to initiate high explosives. As result of this study three schemes were considered to have the most likely possibilities; wire bridge ignition, conductive mix ignition and the application of high energy laser source. In the preliminary study we were successful in initiating high order detonation in cast DFTNB with the wire bridge scheme. No work was done on the other methods suggested.

The proposed initiation system can use cast explosives obviating dependency upon powdered high explosive of a definite particle size which could not be relied upon if the temperature cycles it experiences can go above and below the melting point of the explosives.

Our present task and the objective of this contract was the further development of the selected method of initiation. This initiation method consists of application of electrical energy at a high rate, directly to the new material, without introduction of other sensitive explosives. TNT was used as our experimental high explosive since it resembles the new explosives in sensitivity.

We have conducted a study which is chiefly experimental to improve this scheme to initiate high explosives. This study has been broken down into the following objectives.

1. Input: Improvement of the source of firing energy, which is directly dependent on the initiator element.

2. Initiator Element (bridge): Improvement of initiator element design.

3. Initiator Section (or booster section): Improvement of physical design to best suit the initiator element and to achieve best output for transfer to the high explosive.

4. Main Charge: Study of the best method of conversion from deflagration to detonation by confinement and barrier or air gap etc.

5. Output: Measurement of the relative output of all design variations listed above.

During this contract we stressed the input system and initiating element for several reasons. First, it is essential that the highest order of ignition be obtained at the initiation element; this would serve to initiate the high explosive most reliably and to reduce the confinement and the dependence upon barrier, air gaps etc. which would otherwise be needed to obtain high order detonation. Second, the input energy requirements found necessary during the previous contract would require a large initiation package, which is undesirable and reduces the maximum payload of any weapons system.

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2. DESCRIPTION OF INITIATOR SYSTEM

As developed, the initiator system is made up of an initiator section and a heavy confinement. The initiator section can also be used with a smaller output test confinement for the purpose of evaluating the output of the initiator section alone. The following discussion describes these parts and the method of measuring their performance.

2.1 Initiator Section and Test Confinement

Since the initiator section is used for two purposes, its description will be given first. Figure 1 shows the initiator section in the test confinement, and Figure 2 shows it in the heavy confinement.

The basic initiator section is a threaded part made of high strength steel with a small hole drilled through the middle for an insulated conductor which connects the center conductor of a General Radio coaxial connector on one end to the initiator element at the other end. The initiator element is soft soldered between the inner conductor and the outside of the initiator section wall.

The initiator element (or bridge) is in a 0.62 cc cavity at the output end, into which is cast the high explosive. This cavity will contain about 0.97 grams of cast TNT. The initiator section is designed to provide a high pressure seal to prevent gases from escaping between it and the confinement and down the lead wire. This pressure is higher than 100,000 psi for a short duration but varies with the barrier used. The initiator section must also pass an acceptance breakdown test of 5 KV for one minute between the inner connector and the body, hence, the conductor is insulated with Teflon tubing and Silastic castable silicone rubber.

After the initiator element has been soldered in place, the explosive is cast into this cavity and a barrier is placed over the output end. The assembly is screwed into either the test confinement or the heavy confinement according to the nature of the test to be performed. In the case of the test using the initiator section confinement the initiator section can be reused many times. In tests requiring the heavy confinement, both it and the initiator section are destroyed.

The test confinement shown in Figure 1 is similar to the heavy confinement, except that its output end is 3/16 of an inch long with no explosive; the heavy confinement is 10 inches long and filled with high explosive. In order to obtain a measure of the quality of initiation of the explosive confined behind the barrier, a sintered brass or an aluminum alloy dent block is placed at the end of the 3/16 inch long bore. When initiation takes place the barrier is sheared free and strikes the witness block producing a dent. There are many factors affecting the depth of dent, such as the mass of sheared barrier part and the time-pressure conditions within the confinement; but for our purposes, the depth of dent was used as a measure of degree of initiation. Other factors which were used to estimate order of initiation are included.

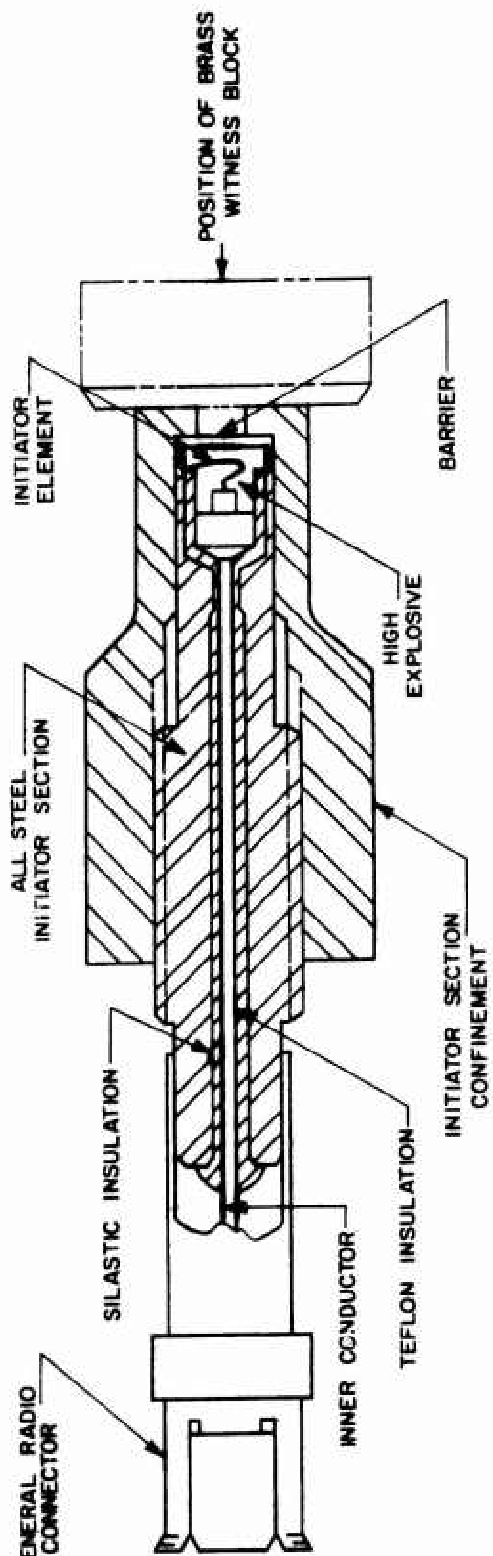

FIG.1 ALL STEEL INITIATOR SECTION WITH OUTPUT TEST CONFINEMENT

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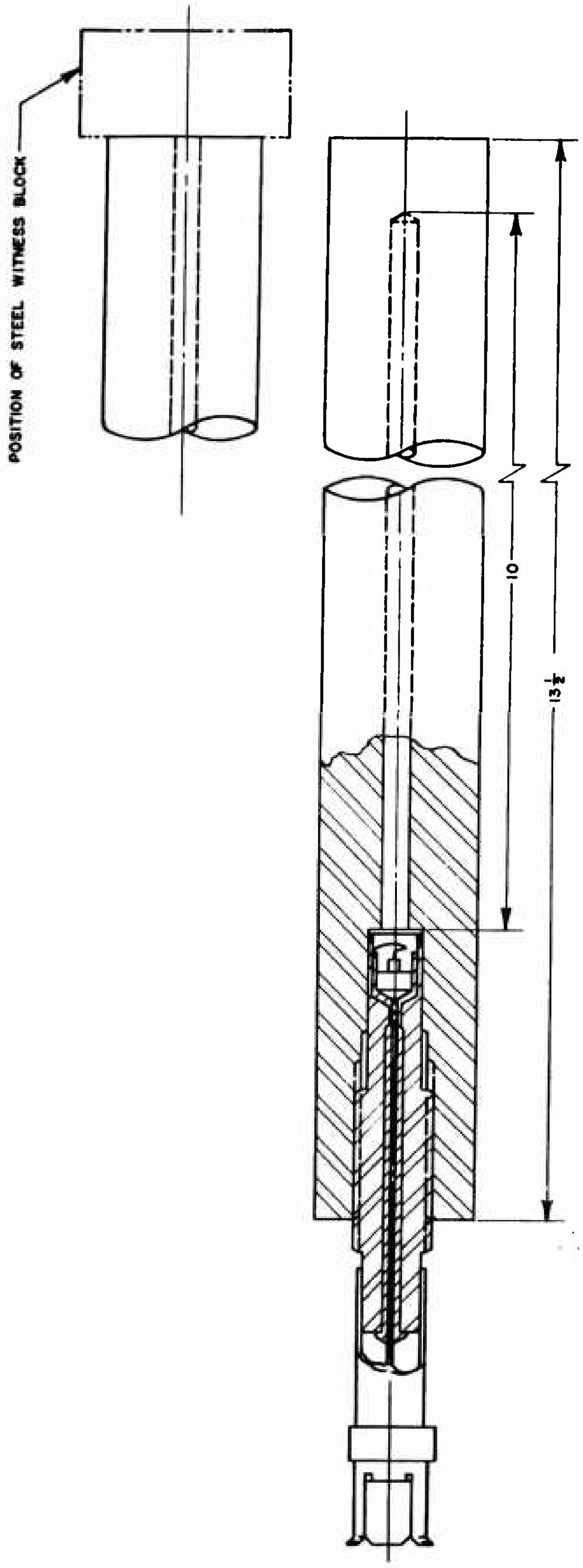


FIG.2. HEAVY CONFINEMENT SHOWING CLOSED (LOWER) AND OPEN TYPE

The amount of high explosive consumed, and the general condition of the inner conductor and the hardware after the shot were also taken into consideration in estimating output. These tests were usually made in groups of three shots under the same test conditions, to indicate the degree of variability.

The initiator section tests served as the basis for final evaluation of the work done in the development of the initiator element and the input system. These tests were run without variations in the barriers. Another series of tests was made with fixed input and initiation element, to evaluate the effects of barrier variations.

2.2 Heavy Confinement

The initiator section, as described above is also used in the heavy confinement tests. The heavy confinement is 1-1/2 inches in diameter made from Elastuf type A2 steel and is 13 inches in length. It is shown in Figure 2. A 10-inch hole, 1/4 inch in diameter, is cast full of explosive. It holds about 13.5 grams of TNT. There are two models of the confinement, one with a closed end, the 1/4-inch hole not drilled through, and one with an open end. Only the first two shots were made with closed confinement. With the open-end confinement we used a cold-rolled steel dent block to measure the output of the high explosive. Prior to the use of the open tube we used the condition of the confinement after the test to indicate how close we were to high order initiation. Note was taken of the number of parts into which the confinement was divided, and of the dilation and general condition of the 1/4 inch hole which contained the high explosive. In general if the confinement remained unfractured, the detonation was considered not to have attained full high order. Because of the length required to reach detonation it is possible to trace the growth of detonation by noting the increase in the diameter of the hole toward the output end of the confinement. Also at this end the confinement would be split into two or three segments, or, in the case of open end heavy confinement, expanded into a bell-mouth.

For a reference we used the results of a test performed during the previous contract, in which we detonated a column of cast TNT in the heavy confinement, using a M-6 blasting cap as shown in Figure 5. This resulted in a large diameter hole the full length of the confinement, and also split the confinement in half.

With the open-end heavy confinement we use both of these observations and also the depth of dent in a steel block, from which we can obtain an estimate of the detonation velocity using the curve of Figure 3, which was taken from Reference 2.

Functioning time was recorded for 10 tests of the heavy confinement for TNT and for 4 tests with the fluorinated explosives. Functioning time is defined as the interval between application of the firing pulse to the initiating element and the subsequent output of explosive products of the filled cylinder. The output of the explosive products was detected by the resulting ionization of the air,

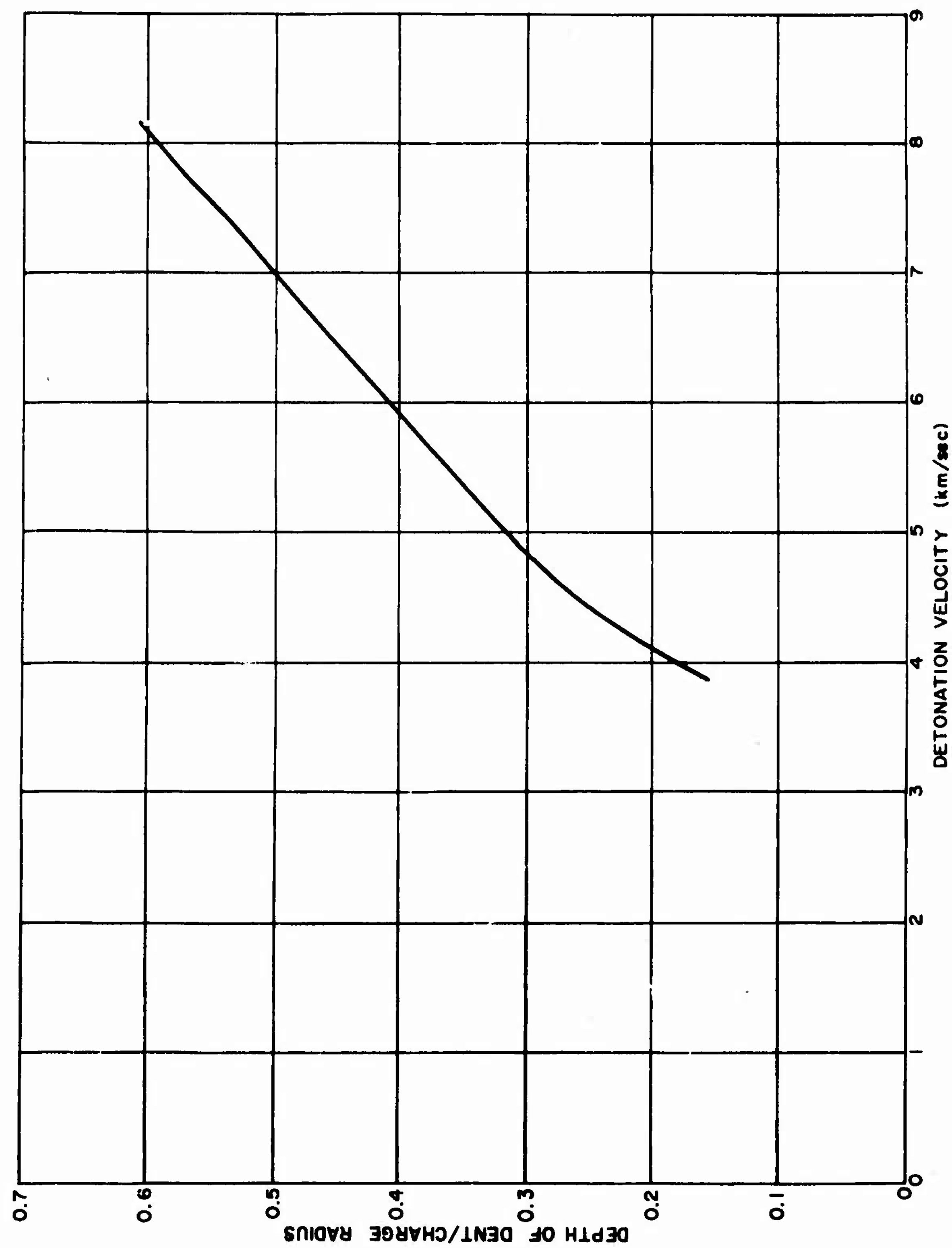


FIG.3. DEPTH OF DENT DIVIDED BY THE RADIUS vs. DETONATION VELOCITY FOR 0.250 DIAMETER CHARGED OF PRESSED TNT FROM REF 2

and was recorded as function of time on the screen of an oscilloscope. Figure 4 depicts the circuit diagram used for these measurements.

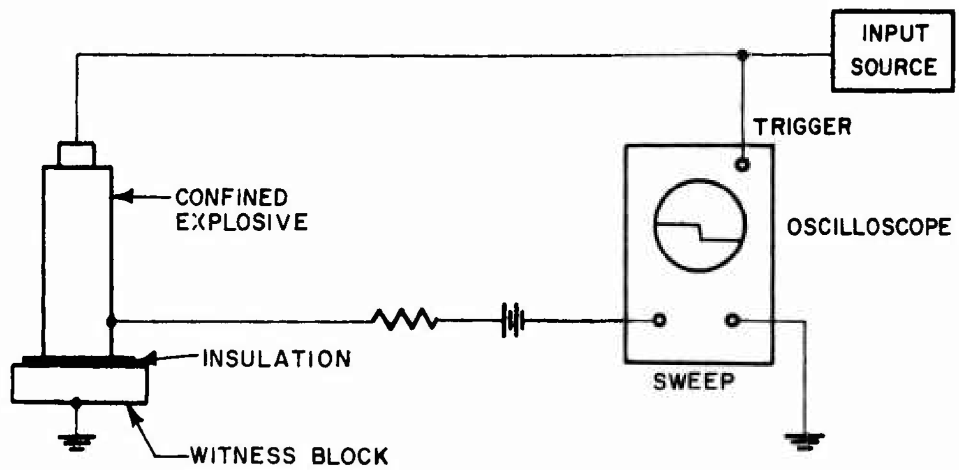


FIG.4. FUNCTIONING TIME MEASUREMENT CIRCUIT

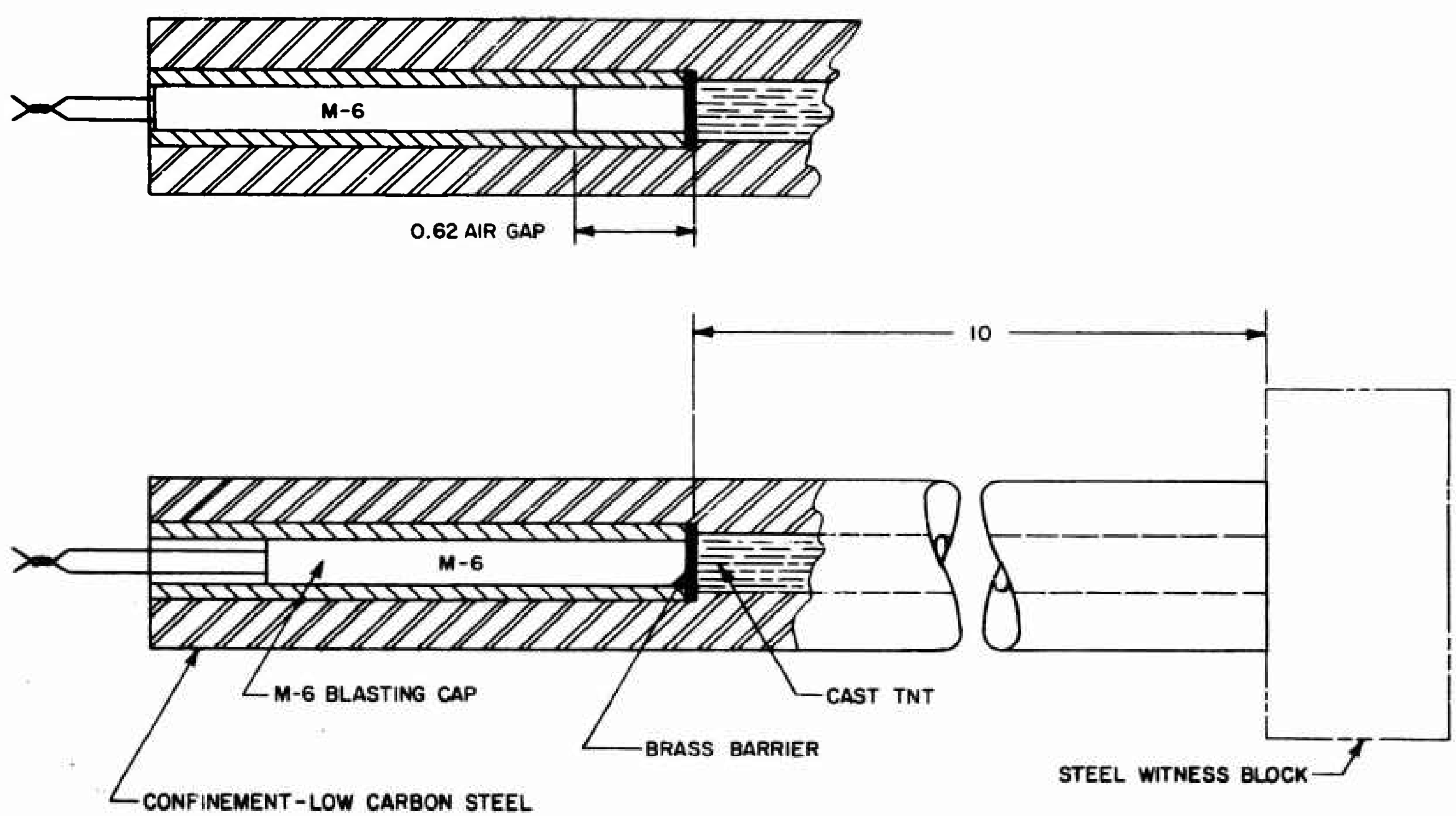


FIG. 5. BARRIER GAP TEST ARRANGEMENT TOP DETAIL SHOWS AIR GAP TEST

3. DISCUSSION OF EXPERIMENTAL PROCEDURES AND RESULTS

3.1 Pulse Forming Network Energy Source

The use of a rectangular pulse for delivering energy to the initiating element was considered. The concept being that a rectangular pulse input would sustain a high input power for a longer period of time than does a capacitor discharge, thus creating a condition where acceleration of the element material would continue as long as energy is being supplied.

A pulse forming network, designed to deliver a 3 microsecond rectangular pulse, was tried in the firing system described in Appendix I, in place of the capacitor. This network, capable of being charged to 5 kv, was used to deliver a burst of energy to specific initiating elements. It proved much less efficient than the capacitor since instead of exploding the elements it merely caused them to glow. Very probably a good bit of the stored energy was being dissipated in the inductive element of the PFN sections.

3.2 Development of Initiating Element

3.2.1 Stainless Steel Tubes

Relatively short lengths (0.5 inch) of stainless steel tubes were considered for use as initiating elements in the manner of exploding bridgewires. It was hoped that by filling the tube with TNT the EBW action of the tube would initiate the filling and thus add to the overall output of the element. This phase of the study was designed to find the advantage, if any, of having the tube filled with explosives. Silicone rubber (Silastic 601) witness blocks were used to measure relative output of filled and empty initiating tube elements. The tubes used in this program were commercially available stainless steel hypodermic needles, #304. Table 1 lists the parameters of the tubes used as initiating elements. Table 2 is a summary of test conditions. The firing source was the energy stored on a 10 μf capacitor which was discharged into the tube element.

For measuring the output of these tubes and other initiating elements (wire bridge) we needed a material for our witness block which would respond to the output; the usual steel or brass was too rigid. Materials such as styrofoam and putty were tried with no success; but a silicone rubber material, known as Silastic 601 met our requirements. Initiating elements exploded at varying distances from the Silastic left signatures in the form of striations in the material. The pattern and quantity of these striations differed for varying distances from the element. For initiating elements exploded against the Silastic, readable signatures were produced.

Based on output indicated in the Silastic blocks, little, if any, advantage is to be had by filling the tube with explosives. The relative output of empty #26 and #27 tubes is as good as when these tubes are filled with either TNT or DFTNB; in fact a wax filling produces the same overall results as an explosive filling. Filling the tube with either wax or explosive does result in some flaring of the Silastic material; but this flaring is also noted in

Table 1

INITIATING TUBE PARAMETERS

Tube (Gage)	O.D (cm)	I.D (cm)	Steel* Volume (cm^3)	Steel* Weight (mg)	TNT Filling* Volume (cm^3)	TNT Filling* Weight (mg)
29	0.0330	0.0178	0.00087	6.7	—	—
28	0.0356	0.0178	0.00109	8.4	—	—
27	0.0406	0.0178	0.00152	11.8	0.000361	0.56
26	0.0470	0.0203	0.00205	15.9	0.000469	0.73
25	0.0508	0.0228	0.00235	18.2	0.000592	0.92
24	0.0559	0.0254	0.00282	21.9	0.000735	1.15
Special	0.0813	0.0647	0.00276	21.4	0.004767	7.4

*Density stainless steel = 7.75 gm/c.c.
Density (cast) TNT = 1.57 gm/c.c.

Table 2

OUTPUT TESTS ON INITIATING TUBE ELEMENTS
(Input = 10µf @ 5KV Except (*) Fired at 4KV)

No. Tested	Element	Length	Contents	Remarks (Observations of Silastic Blocks)
3	special	1.45 cm.	Empty	poor output - charring noted
5	special	1.45 cm.	TNT	poor putput - charring noted
3	special	1.45 cm.	DFTNB	poor output - charring noted
5	special	0.72 cm.	Empty	poor output - charring noted
2	#24	1.45 cm.	Empty	poor output - charring noted
2	#24	1.45 cm.	TNT	poor output - charring noted
3	#25	1.45 cm.	Empty	poor output - charring
2	#25	1.45 cm.	DFTNB	poor output - charring
5	#25	0.72 cm.	Empty	fair output - not reproducible
8	#26	1.45 cm.	Empty	good output - reproducible
5	#26	1.45 cm.	TNT	good output - reproducible
3	#26	1.45 cm.	DFTNB	good output - reproducible
4	#26	0.72 cm.	Empty	good output - reproducible
11	#27	1.45 cm.	Empty	good output - flaring
7	#27	1.45 cm.	TNT	good output - flaring
4	#27	1.45 cm.	Wax	good output - flaring
3	#27	1.45 cm.	DFTNB	fair output
4(*)	#27	1.45 cm.	Empty	fair output - marginal
4	#27	0.72 cm.	Empty	good output - flaring
6	#28	1.45 cm.	Empty	good output - some flaring
6	#29	1.45 cm.	Empty	good output - some flaring
4	0.015Dia	1.45 cm.	S.S.wire	good output - flaring

empty #28 and #29 tubes. A special tube capable of holding approximately 7 times the volume of explosive as the #26 tube produced little displacement of the Silastic; but much charring, indicating burning rather than explosive output. If the input energy was reduced by decreasing the capacitor voltage from 5 kv to 4 kv then the output of #27 tubes was noticeably decreased, indicating that the input energy (5 kv at 10 µf) was probably marginal. Based on these results we have concluded that there is no advantage in using explosive-filled tubes over that of empty tubes of the same dimensions. Since there is no advantage in an explosive filling, then there is really no need to use a tube at all. Stainless steel wires of 0.015 inch diameter, having a cross sectional area approximately equal to that of a #27 tube, were tested. The resulting output signature was as good as that obtained with #27 tubes, empty or filled. Figures 6, 7, and 8 respectively, show output signatures in Silastic witness blocks, a sequence of high speed photographs of an exploding tube, and output signatures comparing empty tubes with TNT and wax-filled #27 tubes accompanied by photos of the exploding tubes.

Photographic techniques were used to study the initiating element under dynamic conditions. This system consisted of the high speed camera Abtronics Model 5-2R, with auxiliary equipment. This camera is a two-frame self-contained electronic camera with exposure times of 0.005, 0.01, 0.1, and 1.0 microseconds. The camera may be synchronized with practically any system, and an internal delay generator is incorporated within the camera to permit observation of phenomena up to 100 microseconds after start of initiation. This model is capable of taking two pictures of a continuing event at a controlled time interval between pictures.

3.2.2 Study of Wires as Initiating Elements

The merit of solid wires of small cross sectional area for initiating elements as opposed to the tubes, was investigated. Although empty #27 tubes were satisfactory, there were advantages in going to a fine solid wire. Good initiation of #27 tubes required an excessively large input stimulus (10 µf at 5 kv). Use of a fine wire resulted in a higher resistance termination for the firing line, and hence better efficiency of the firing system. Furthermore, the current densities required to obtain EBW action should be reached more rapidly, and the required input reduced.

3.2.3 Output Response of Initiating Elements

The response characteristics of initiating elements were investigated by observing oscilloscope records of the voltage and current wave-forms during application of the initiating pulse in order to provide quantitative information pertaining to current density and response time of the element for specific input conditions. The information is needed to determine the least firing energy which will reliably cause initiation.

A dual beam Tektronix model 551 oscilloscope was used in the study. The current was measured indirectly by recording the voltage drop across a calibrated 0.05 ohm resistance in series with the test element. Voltage was observed across a resistive network in parallel with the element. Current

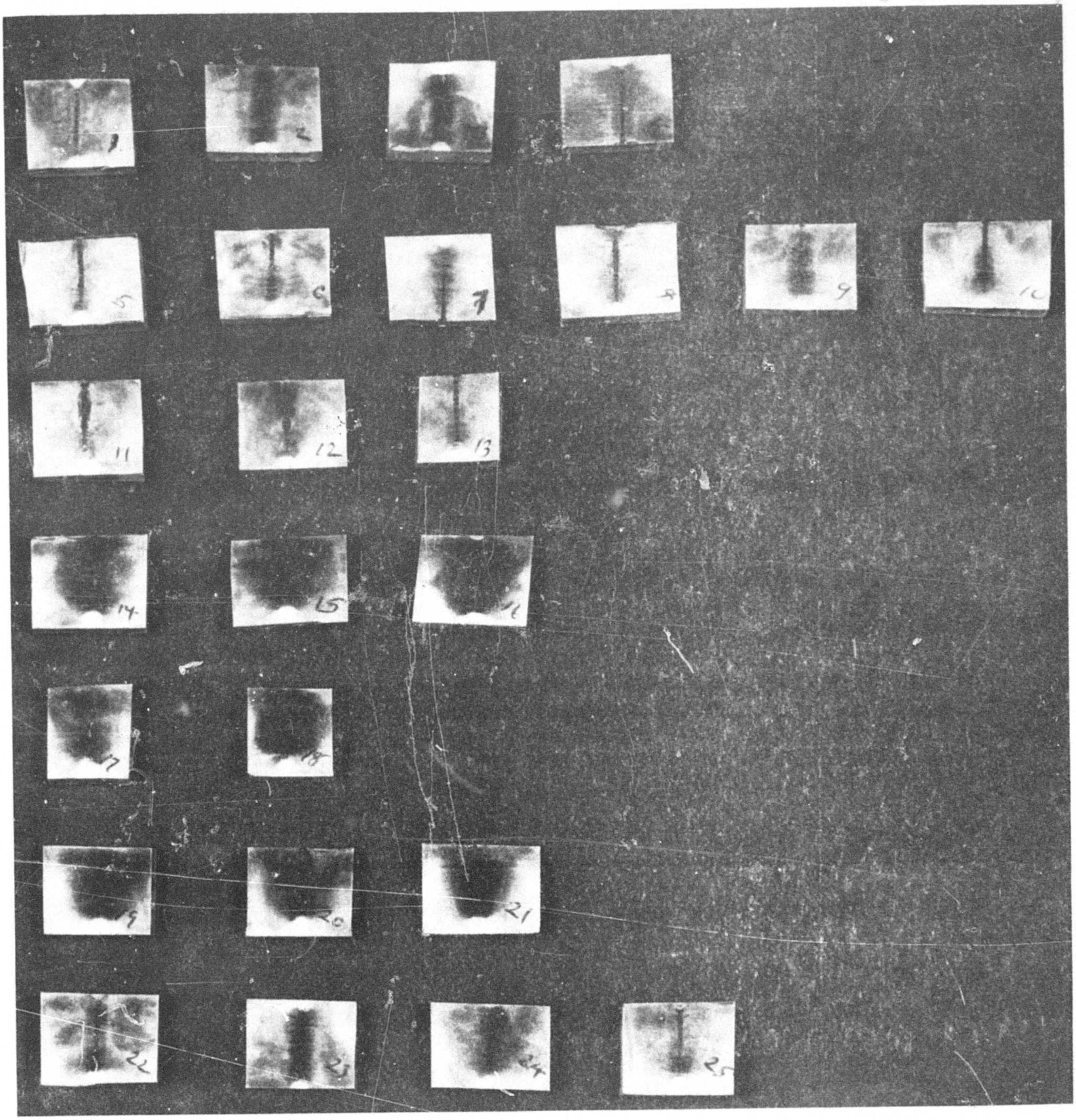
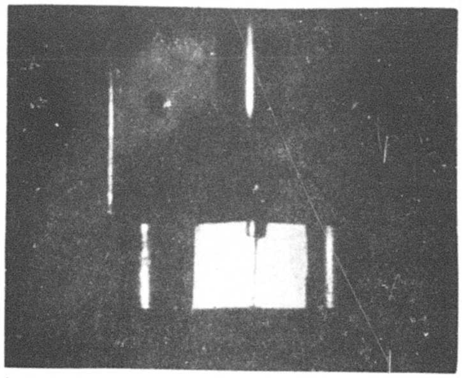
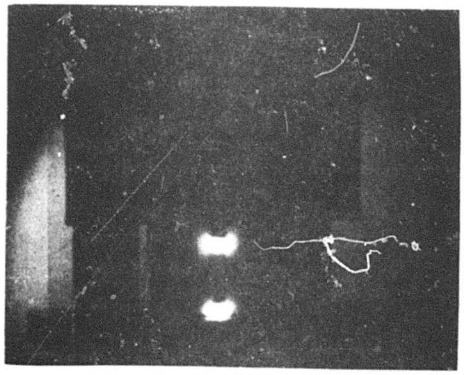


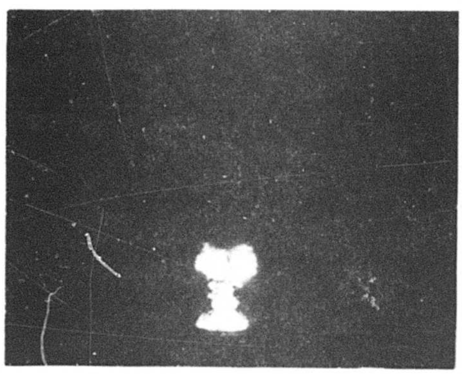
FIG. 6. SILASTIC WITNESS BLOCKS



(a) Wire in mount before application of firing pulse



(b) 5.3μsec after application of firing pulse



(c) 6.2μsec after application of firing pulse

FIG. 7. TYPICAL PHOTOS OF EXPLODING TUBE

(Number 27 TNT Filled Tube)

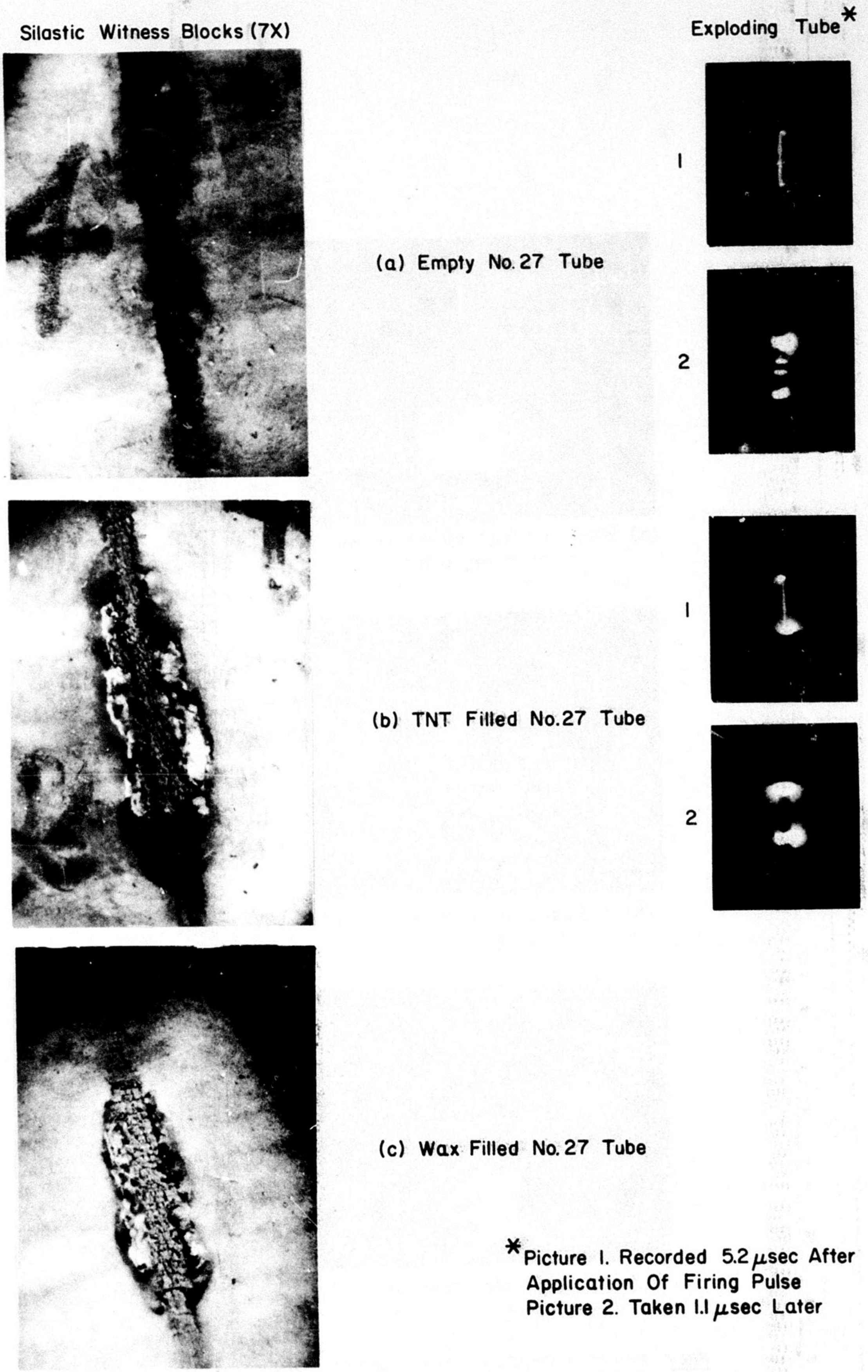


FIG. 8. TYPICAL WITNESS BLOCK SIGNATURE AND HIGH SPEED PHOTOGRAPHS

density was calculated by measuring the current and dividing by the cross sectional area of the element.

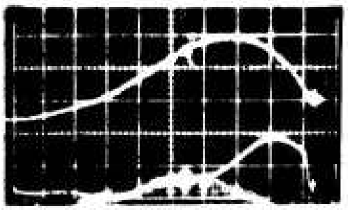
A preliminary study was made of both types of elements, those with tubes and those with wires. Several of each, listed in Table 3, were fired by the discharge of a 10 µf capacitor charged to 5 kv. Typical oscillograms are shown in Figure 9. Examination of the current and voltage traces (Fig. 9) revealed, for each specific element, a reproducible discontinuity in the waveform. The voltage drops off suddenly and the current dips and then resurges. It was our assumption that at this discontinuity the wire was undergoing a change in state and we consider the time interval from the application of the pulse until the current dip as the response time. To verify the condition of the element at response time, we made high speed photographs of the element just before and immediately after the event. Figure 10b and 10c together with traces of the current and voltage included in Fig. 10a, respectively, show the wire still intact with a plasma starting down the wire; and then with the plasma complete, expanding radially from the wire (which is probably in a completely molten and gaseous state). After the discontinuity or dip of the current trace, a finite time elapses before a resurge is noted. This interval is known as the dark time or dwell. Dwell, some experimenters believe, is caused by the sudden change in state of the conducting medium which then presents a relatively high impedance path, causing the current to drop sharply. The gaseous wire filament is held in this condition by inertial and magnetic forces for a brief but measurable time, then the path is ionized, again creating a low resistance path. Any energy remaining on the firing capacitor is then discharged causing a resurgence in the current. Our observations of this phenomenon in air do not show a well defined dwell and resurge because the plasma associated with high voltage discharge permits conduction around the wire through the ionized air. Further, much dwell as is detectable is too short to be measured. Surrounding the wire with a material such as (TNT) of higher dielectric strength than air retards the growth of the high voltage plasma, and the dwell and resurgence are clearly seen. Figure 11a and 11b show voltage and current traces of an exploding wire in air and in an initiator section surrounded by TNT.

Currents listed in Table 3 were maximum measured values occurring at or before response. Current density is calculated by dividing this current by the cross sectional area of the element. In the case of the #27 tube and the 1.5 mil wire the response or dip follows the peak current; and initiation of this tube is probably marginal for our input conditions (5 kv) (poor output was observed for #27 tubes tested at 4 kv). The smaller tubes, #28 and #29 react slightly before peak current; and the 6.3 mil Nichrome wire, as expected, reacts much more quickly, well before maximum current is reached.

The results of these preliminary tests indicate that the time of response of the element, considered in relation to the current dissipation time, may be useful in making the selection of the test value of input energy. If response time occurs before or at the same time as current peak then it seems that the output of the wire is maximum. Once this input response time relationship has been defined, we can intelligently select practical input conditions for further testing.

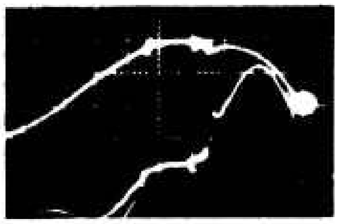
(a)

#27 TUBE



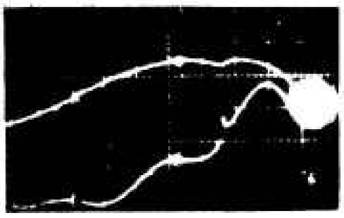
(b)

1.5 MIL WIRE



(c)

#28 TUBE



(d)

#29 TUBE

(e)

6.3 MIL WIRE

HORIZONTAL DEFLECTION = 2 μsec/div

LOWER TRACE IS VOLTAGE
VERTICAL DEFLECTION = 2,500 v/div

UPPER TRACE IS CURRENT
VERTICAL DEFLECTION = 4,000 amps /div

FIG. 9. TYPICAL OSCILLOGRAM TRACES OF EXPLODING INITIATING ELEMENTS

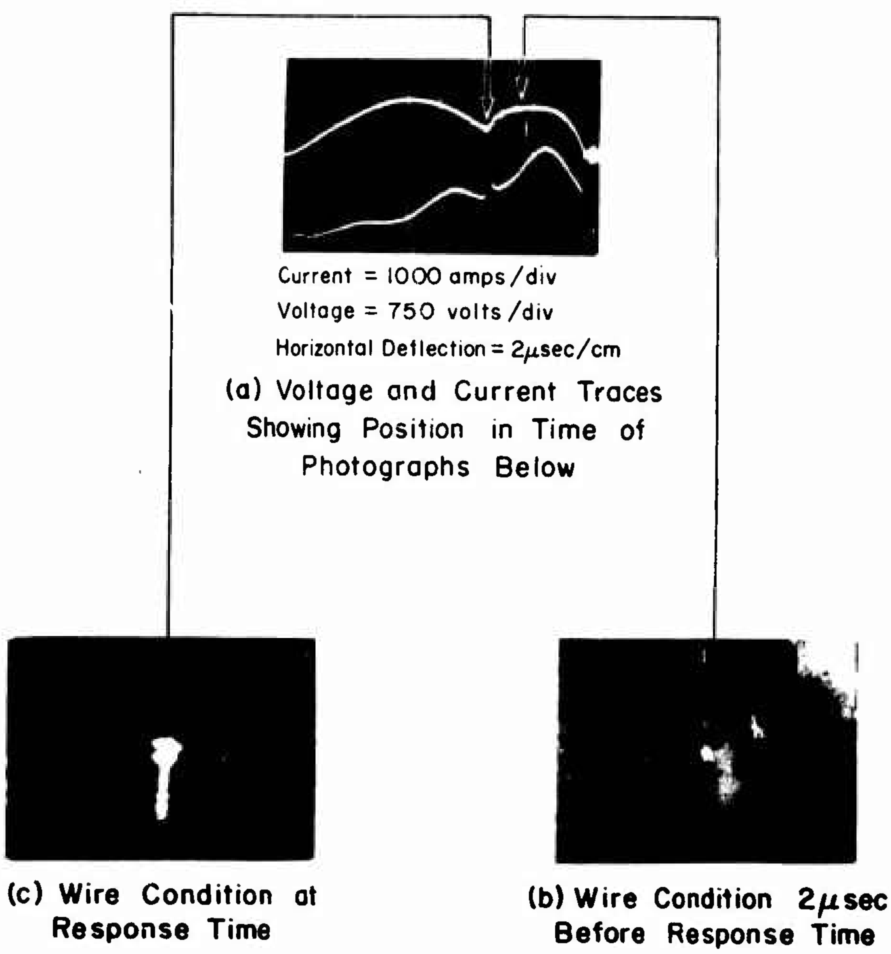


FIG. 10. 0.0063 NICHROME WIRE FIRED IN AIR AT 2KV

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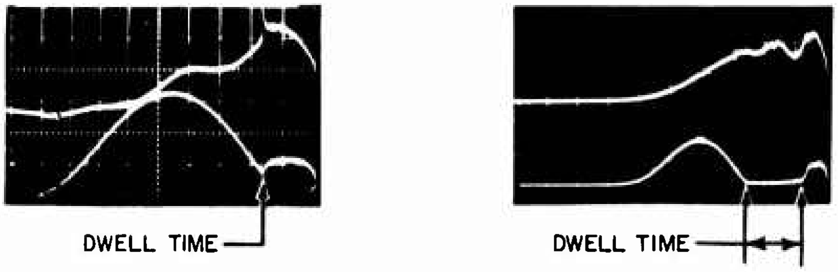
Table 3

FIRING CHARACTERISTICS OF INITIATING ELEMENTS

Element*	Sample Size	Cross-Sec. Area (cm^2)	Current (amp)	Current Density (amp/cm^2)	Response Time (μ sec)
#27 tube	5	0.00101	5600	5.6×10^6	7.0
1.5 mil (s.s. wire)	5	0.00113	6400	5.7×10^6	7.0
#28 tube	3	0.00075	6200	8.3×10^6	5.0
#29 tube	3	0.00060	5500	9.2×10^6	5.0
6.3 mil (Nichrome wire)	4	0.0002	3200	16×10^6	2.7

*All tubes were stainless steel, unfilled

TOP TRACES ARE VOLTAGE - 1000 volts/div
BOTTOM TRACES ARE CURRENT - 1000 amps/div



(a) 0.004 Nichrome Wire
Fired in Air at 2KV
(Horizontal Deflection = 2μsec/div)

(b) 0.004 Nichrome Wire
Fired in TNT at 2KV
(Horizontal Deflection = 5μsec/div)

FIG. 11 COMPARISON OF DWELL TIMES FOR WIRES FIRED IN AIR AND TNT

3.2.4 Characterization of Wire Elements Fired in Air

The relationship between input energy, response time, and current density of wire elements fired in an air environment was investigated.

Our study of wire elements was limited to half-inch lengths of Nichrome wires of various diameters, fired with a 10 µf or 1 µf capacitor, and one sample of gold wire fired with 10 µf. Tables 4 and 5 summarize our findings, which are presented graphically for the tests fired with 10 µf in Figures 12 and 13. A sequence of oscilloscope traces for various input energies is shown in Figure 14, for tests performed on 6.3 mil Nichrome wire.

As the input energy is decreased, decreasing the current density, the response time increases. A value of input energy will eventually be reached at which the time necessary for the wire to explode (occurrence of response time in relation to current peak) exceeds the time required for the dissipation of the energy stored on the capacitor, and EBW action may fail to occur. The curves of current density as a function of input energy show the current density for the 4-mil wire falling off faster than the 6 or 8-mil wires with decreasing energy. This relationship is even more pronounced for the 2.25 mil wire. The cause is most probably the thermal behavior of the wire which would tend to limit the absolute values of the current and hence drastically reduce current density in the wire.

One of the goals of our program is to define the optimum input conditions for the reliable initiation of high explosive, such as TNT; input energies to be used for verification were therefore selected for each specific wire diameter, for conditions where the response occurred near the peak of the current pulse.

Table 4. FIRING CHARACTERISTICS OF INITIATING ELEMENTS
(10 μf Capacitor)
(Minimum Sample Size of 3 For Each Input Condition)

Wire Element (diam.-inches)	Capacitor Potential (kv)	Input Energy (joules)	Current Density (amps x $10^6/cm^2$)	Response Time (microseconds)	Occurrence of Response Time in Relation to current Peak
0.00225 Nicrome	5.0	125.0	39.0	0.6	before
	4.0	80.0	27.0	1.0	before
	3.0	45.0	15.6	1.2	before
	2.0	20.0	5.8	2.1	before
	1.5	11.3	3.1	3.2	before
	1.0	5.0	-	4.5	well after
0.004 Nicrome	5.0	125.0	20.0	1.4	before
	4.0	80.0	17.3	1.7	before
	3.0	45.0	12.3	2.0	before
	2.0	20.0	8.0	3.2	before
	1.5	11.3	5.0	4.5	before
	1.2	7.2	3.7	6.0	before
	1.0	5.0	2.5	9.6	well after
0.0063 Nicrome	5.0	125.0	16.0	2.1	before
	4.0	80.0	14.0	2.7	before
	3.0	45.0	10.0	3.8	before
	2.0	20.0	7.5	6.0	at peak
	1.5	11.3	6.0	8.0	slightly after
	1.0	5.0	3.5	-	well after
0.008 Nicrome	5.0	125.0	13.8	3.0	before
	4.0	80.0	12.9	3.5	before
	3.0	45.0	9.3	4.6	at peak
	2.0	20.0	6.4	8.6	slightly after
	1.5	11.3	5.2	-	well after
	1.2	7.2	3.8	-	well after
0.006 gold	5.0	125.0	30.8	2.4	before
	4.0	80.0	28.6	2.8	before
	3.0	45.0	23.0	3.8	before
	2.0	20.0	16.5	5.8	slightly after
	1.8	16.2	14.3	7.0	well after
	1.5	11.3	12.1	8.0	well after

Table 5

. IRING CHARACTERISTIC OF INITIATING ELEMENTS
(1 µf Capacitor)
(Minimum Sample Size of 3 For Each Input Condition)

(diam.-inches)	Capactor Potential (kv)	Input Empty (joules)	Current Density (amps x $10^6/cm^2$)	Response Time (microseconds)	Occurence of Response Time in Relation to Current Peak
.00225 Nichrome	4.7	11.0	18.7	1.0	before
	3.2	5.1	14.0	1.6	before
.004 Nichrome	4.7	11.0	16.0	1.6	before
	4.0	8.0	12.3	2.0	at peak
	3.2	5.1	11.0	2.8	slightly after
.0063 Nichrome	4.7	11.0	10.4	2.5	slightly after
	4.0	8.0	9.4	2.0	after
	3.2	5.1	7.7	4.3	well after
.008 Nichroms	4.7	11.0	7.1	2.5	slightly after
	4.0	8.0	5.9	3.2	after
	3.2	5.1	4.6	3.6	well after

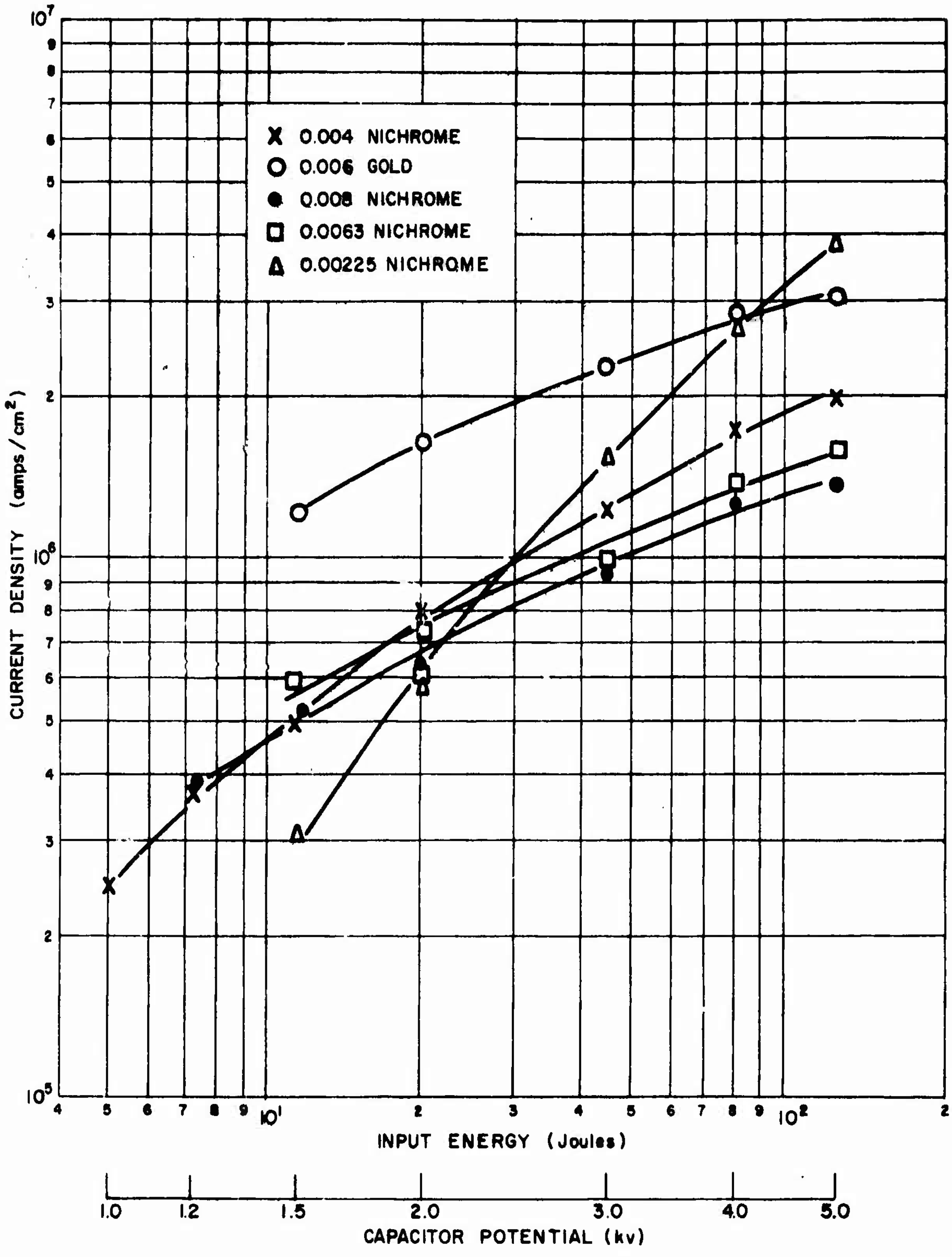


FIG. 12. CURRENT DENSITY AS A FUNCTION OF INPUT ENERGY

(Wires Tested in Air, 10μf)

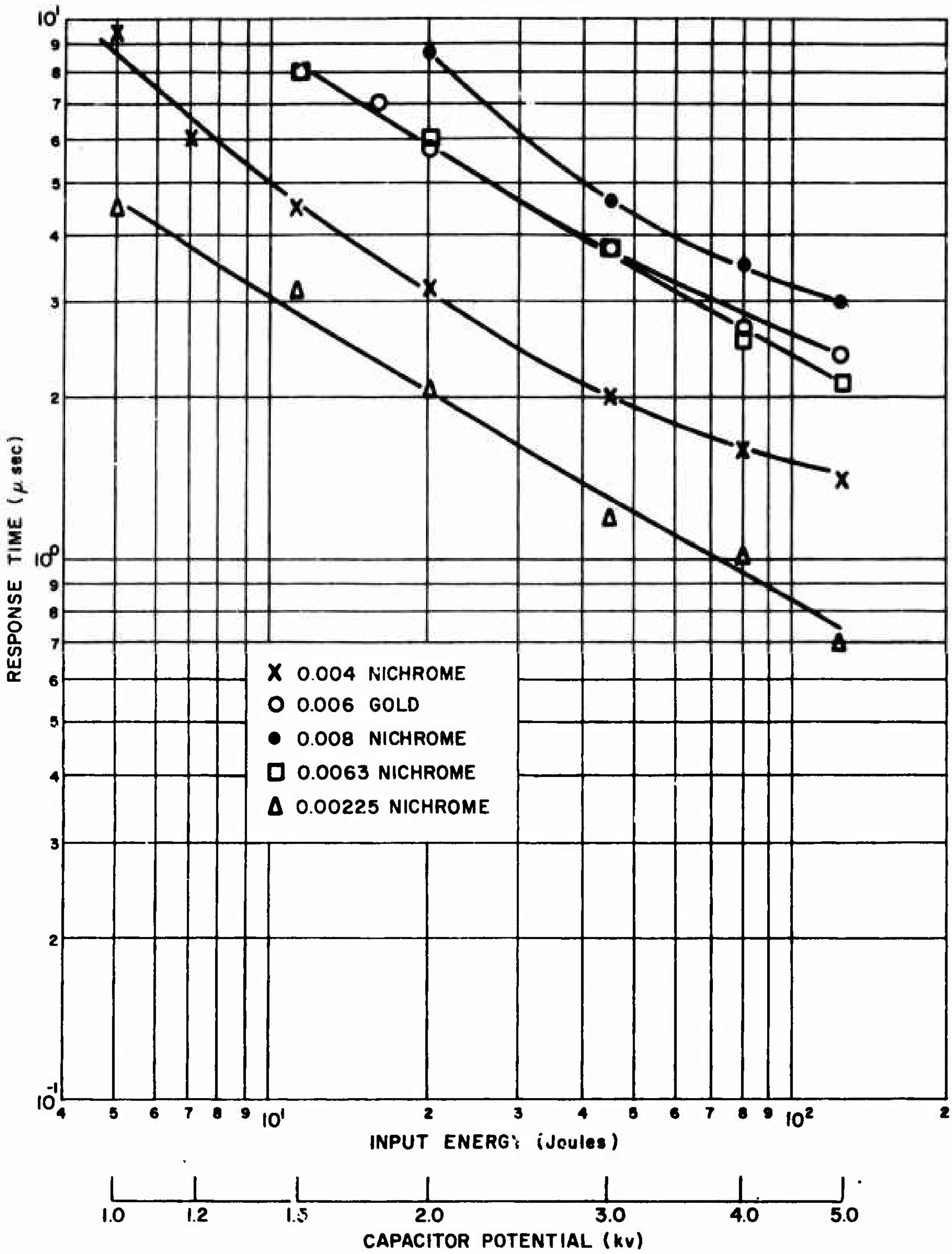


FIG. 13. RESPONSE TIME AS A FUNCTION OF INPUT ENERGY

(Wires Tested in Air, 10μf)

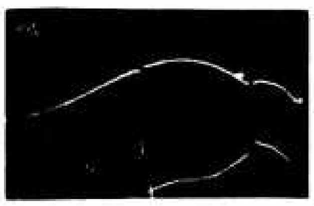
(a)

Input = 125 Joules (5KV)

Current Density = 16×10^6 amps/cm^2

Response Time = 2.1μsec

(b)



Input = 80 Joules (4KV)

Current Density = 14×10^6 amps/cm^2

Response Time = 2.7μsec

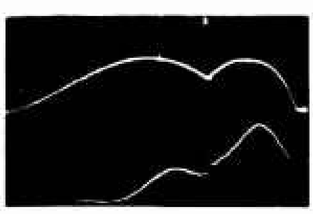
(c)

Input = 45 Joules (3KV)

Current Density = 10×10^6 amps/cm^2

Response Time = 3.8μsec

(d)

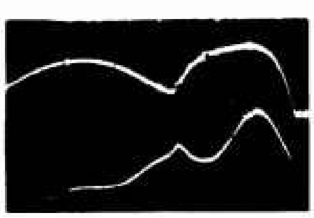


Input = 20 Joules (2KV)

Current Density = 7.5×10^6 amps/cm^2

Response Time = 6.0μsec

(e)



Input = 11.3 Joules (1.5KV)

Current Density = 6×10^6 amps/cm^2

Response Time = 8.0μsec

FIG. 14. 0.0063 WIRES FIRED IN AIR FOR VARYING INPUT ENERGY (10μf)

3.2.5 Functioning Reliability of Initiating Elements

The ability of wire elements to initate TNT was investigated for varying input conditions. The element under test was incorporated into an initiator section, surrounded with cast TNT, and confined. Initiator output was determined by observing the depth of dent produced in an aluminum witness block. In all of our tests, the wire element either initiated TNT satisfactorily or it did not initiate it at all. The results are summarized for 10 µf capacitor discharge in Table 6, and for 1 µf in Table 7.

The test results listed in Table 6 and 7, although derived from a sample lot somewhat smaller then desired, indicate that the 6.3-mil Nichrome wire fired from a 10 µf power source, is the most efficient of these tested. Good initiation was recorded for capacitor voltage as low as 1.5 kv. When wire diameters are smaller than 6.3-mils, more voltage is needed to insure initiation of TNT. Sample of 4-mil wire caused initiation at 2.0 kv but not 1.5 kv. The 2.25-mil wire failed for three tests using 2 kv. An examination of Figure 12 shows that in those cases in which TNT was satisfactorily initiated the current density was at least 6 x 10^6 amps/cm^2, except for failures of the gold wire at 1.5 kv.

For a 1.0 µf capacitor the 4-mil Nichrome wire was better than the 6.3-mil wire. The 4-mil element when tested with 1.0 µf capacitor, required approximately 6 joules for initiation of the TNT, but 11.2 joules was required for the same results with a 6.3-mil wire fired from a 10 µf capacitor.

The results of the tests of gold wire were interesting. Because the resistivity of gold is much less than that of Nichrome, current densities were much greater in the 6-mil gold wire than in the 6.3-mil Nichrome. The response time of the gold wire was almost indentical to that of the Nichrome, yet the Nichrome initiated TNT with an input of 1.5 kv, while there were failures of the gold wires for the same voltage. It is possible that initiation of the TNT is due not solely to the shock wave of the exploding wire but also to hot molten particles. Since the gold wire, with high current density, is more efficiently exploded and vaporized than the Nichrome wire, the subsequent production of molten particles is at a minimum. Also contributing to the initiation of the TNT would be the energy expended by the plasma associated with the electric discharge of the initiating pulse. For a relatively low capacitor voltage (1.5 kv) this plasma is much smaller, and initiation is supported by the acceleration of wire particles which, in the case of gold, may be insufficient.

As one result of these studies of initiating elements we have been able to reduce the input energy required for reliable initiation of TNT. Even though the amount of testing was limited, the results made it clear that we can accomplish detonation with a 10 µf capacitor charged to 2 kv at most, or with a 1.0 µf capacitor charged to about 3.5 kv. This reduction of the required voltage from the 5 kv previously used to 2 kv is of practical significance, for we can considerably reduce the physical size of the capacitor by specifying a lower dielectric strength.

Table 6. INITIATION OF TNT FILLED INITIATOR SECTIONS
(10µf Capacitor)

Wire diam. (inches) Nichrome wire	Capacitor Voltage (kv)	No. Tested	No. Initiations TNT	% Response	Remarks
.008	2.0	2	2	100	
.0063	2.0	6	6	100	
.0063	1.8	1	1	100	
.0063	1.5	2	2	100	
.0063	1.2	3	1	33.3%	Non Fires Charred TNT
.004	2.0	3	3	100	
.004	1.8	3	2	66.6	Non Fire
.004	1.5	3	0	0	Charred TNT
.004	1.2	1	0	0	
.00225	2.0	3	0	0	
Gold Wire					
.006	2.0	3	3	100	
.006	1.5	3	0	0	

Table 7. INITIATION OF TNT FILLED INITIATOR SECTION
(1.µf Capacitor)

Wire Diam. (inches) Nichrome	Capacitor Voltage (kv)	No. Tested	No. Initiations TNT	% Response	Remarks
.0063	4.7	1	1	100	
.0063	4.3	3	1	33.3	Non fires
.0063	4.0	2	0	0	Charred TNT
.004	4.7	2	2	100	
.004	4.3	3	3	100	
.004	4.0	1	1	100	
.004	3.7	2	2	100	
.004	3.5	2	2	100	
.004	3.2	1	0	0	

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The curves shown in Figure 15, derived from the data of Tables 6 and 7, relate probability of initiation of TNT to capacitor voltage for the various kinds of wire elements. Although there were not enough tests performed for accurate definition, the curves are presented as a guide to the general response of wire elements.

Time limitation did not permit us to expand this phase of the investigation for other wire material. A recent publication Reference 3, indicates that there are at least two distinct classes into which wires such as platinum, gold, copper and aluminum can be put, depending on their thermal properties. They have found that certain advantages are to be had by selection of one or another material for the initiation of insensitive explosives. Unfortunately most of their findings are not directly applicable since the explosives they are working with are at least one magnitude more sensitive than TNT.

3.2.6 Vulnerability of Initiating Element

An important consideration in the design of an initiating element is not only how reliably it performs its intended function, but how it responds to stimuli that may be applied accidentally such as stray RF energy, or intentionally for the purpose of telemetry. It is possibly that an input signal, though insufficient to produce high order detonation, may cause local burning and a low order explosion which could result in extensive damage. On the other hand an unwanted input pulse might burn out the initiating element and thus produce a dud. With these considerations in mind, tests were performed on 6.3-mil Nichrome wire elements to define the wire response (breaktime characteristics) for applied current pulses. These results, shown in Figure 16, were then used as a guide to select current magnitudes with which to subject elements incorporated in initiator sections filled with TNT.

Five initiator sections were tested by applying pulses of constant current to the initiating element. Items 78, 79, and 80 were pulsed, respectively, with 1.2 amps applied for 10 seconds, 2.1 amps applied for 10 seconds, and 2.1 amps applied for 30 seconds. None of the wire elements broke. These were then pulsed with 10 µf charged to 5 kv. All three initiators fired high order. Two initiator sections(test nos. 81 and 82) were respectively pulsed with 5 amperes and 2 amperes. In both cases the 6.3-mil initiating element broke but did not initiate or burn the TNT.

A current of 2.1 amperes applied for a duration of 30 seconds (test no. 80) did not harm the initiating element or the surrounding TNT, and the initiator still fired reliably when a firing signal was applied. The initiating element has a resistance of approximately 0.7 ohms, which means we had applied a power of about 3.0 watts for 30 seconds without adverse effects.

3.3 Initiator Section

The initiator section was described in Section 2.1 and as there explained, this assembly has been used for several types of tests for different purposes as well as being the initiator or booster for the initiation of high explosive.

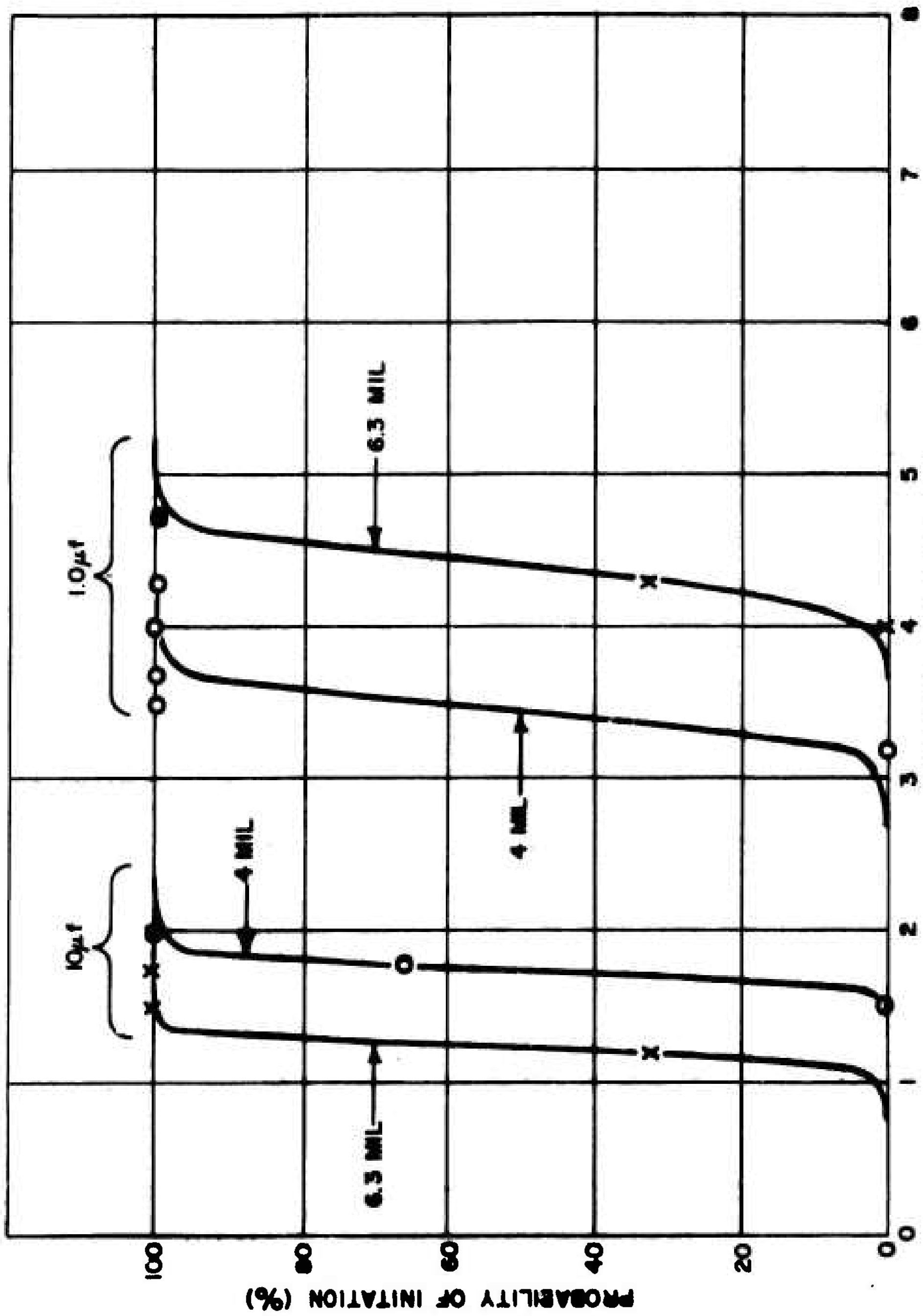

FIG. 15. INITIATION RELIABILITY OF WIRE ELEMENTS AS A FUNCTION OF INPUT PARAMETERS

(Nichrome Wire)

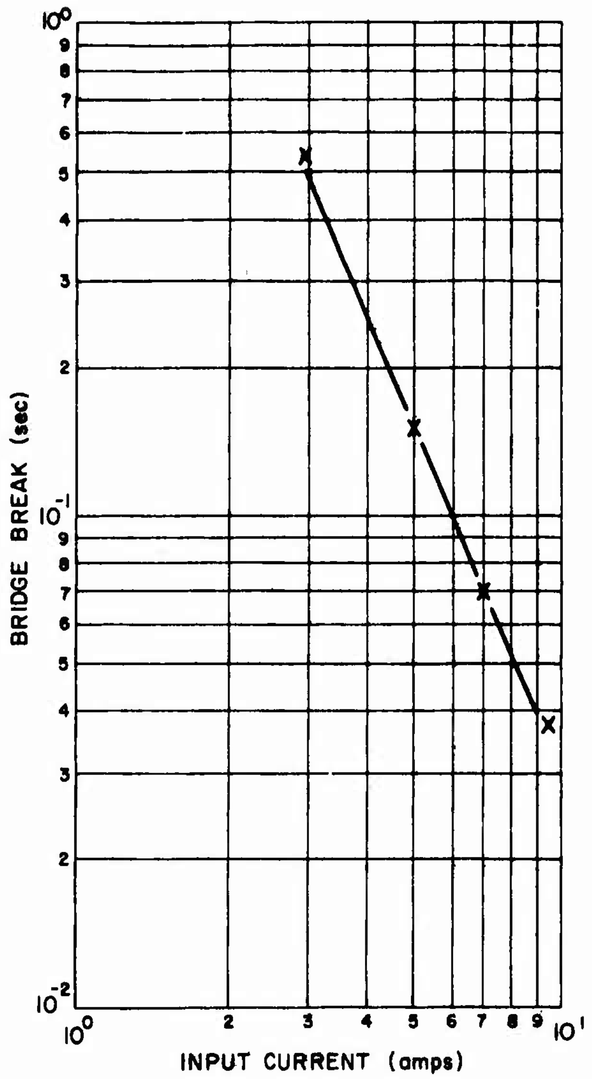

FIG. 16. BRIDGE BREAK AS A FUNCTION OF INPUT CURRENT

(0.0063 Nichrome Wire, $\frac{1}{2}$" Long, Air)

The experimental results obtained from the use of the initiator section which concern the development of the element were discussed in Section 3.2. The results which are reported here concern mostly the development of the initiator section barrier, and chronologically come before most of the initiator element development using this initiator section.

At the beginning of this contract we redesigned the initiator section to solve the high voltage leakage problem and to improve the strength and durability of the part. In the new design the firing line was fitted with General Radio coaxial connectors, which reduced the interference to other apparatus generated by the firing pulse, and improved the electrical connections from the firing unit to the initiation element in the initiator section.

Using the 27-gage stainless steel empty tube as the initiation element, which at that time appeared to be the best, we started a program to find the best barrier thickness.

Brass barriers were tried, having thicknesses of 0.02, 0.04, 0.06, 0.08 and 0.10 inch. For results of the tests, see Table 8. The depth of dent in a sintered brass dent block was approximately proportional to the barrier thickness; see Figure 17. We made two additional shots using barriers of Elastuf Type A-2 steel, .040 and .060 inch thick. The steel barrier was used to avoid the use of a brass barrier whose thickness was greater than half the diameter. To compare the strength of the brass and steel barriers we computed the static pressure that would shear the barrier, using the ultimate shear strength of 36 kpsi for brass and 80 kpsi for Elastuf type A-2. These data are plotted in Figure 17. On the ordinate we have the static pressure in psi with the static rupture point of each thickness of barrier labeled. The abscissa represents depth of dent in inches. The points on this graph represent the average dent made by three shots, with exception of one point which involved only two shots. The data obtained with steel barriers do not fall directly on the curve for the brass barriers but are close enough to indicate that, for greater barrier strength, the ratio of dent depth to barrier strength is less. We did not continue with any thicker barrier except for one test discussed later, because of the risk of rupturing the test confinement. It should be noted that more TNT was consumed, as barrier strength was increased. In none of these series of tests, however, was all the TNT consumed, except for one set of shots using a .060 steel barrier. From this curve we selected a brass barrier of .070 thickness as a standard for a comparison of variation in the initiator element.

A comparison was made of the dents produced by the TNT-filled and the unfilled 27-gage tube initiating element. It was found that, even though the TNT-filled tube did give a slightly larger dent than the unfilled tube, this was not a significant increase in depth. A far greater improvement in outout of the initiator section could be made by increasing the barrier thickness.

Prior to beginning the initiator element study we changed from the sintered brass witness block to a block made from aluminum alloy 2024-T4. These

Table 8

INITIATOR SECTION STUDY

Test No.	Initiating Element Size	Tube Cavity	Barrier Inches	Barrier Material	Dent in Sintered Brass	Average Dent
9	27	empty	.020	brass	.010	
10	27	empty	.020	brass	.008	.008
11	27	empty	.020	brass	.007	
12	27	empty	.040	brass	.022	
13	27	empty	.040	brass	.022	.022
14	27	empty	.040	brass	.022	
15	27	filled TNT	.040	brass	.023	.023
16	27	filled TNT	.040	brass	.024	
17	27	empty	.060	brass	.041	
18	27	empty	.060	brass	.035	.038
19	27	empty	.060	brass	.038	
22	27	empty	.080	brass	.055	
23	27	empty	.080	brass	.050	.052
24	27	empty	.080	brass	.052	
27	27	empty	.100	brass	.060	
28	27	empty	.100	brass	.070	.062
29	27	empty	.100	brass	.057	
32	27	empty	.040	A-2 steel	.047	
33	27	empty	.040	A-2 steel	.048	.051
34	27	empty	.040	A-2 steel	.058	
35	27	empty	.070	brass	.041	
36	27	empty	.070	brass	.040	.040
37	27	empty	.070	brass	.038	
41	.015	solid wire	.070	brass	.038	
42	.015	solid wire	.070	brass	.043	.044
43	.015	solid wire	.070	brass	.050	
44	27	filled TNT	.070	brass	.043	avg. with tests 48, 49
45	29	empty	.070	brass	.035	
46	29	empty	.070	brass	.042	.040
47	29	empty	.070	brass	.043	
48	27	filled TNT	.070	brass	.043	.045
49	27	filled TNT	.070	brass	.048	
50	27	empty	.060	A-2 steel	.067	
51	27	empty	.060	A-2 steel	.068	.070
52	27	empty	.060	A-2 steel	.074	

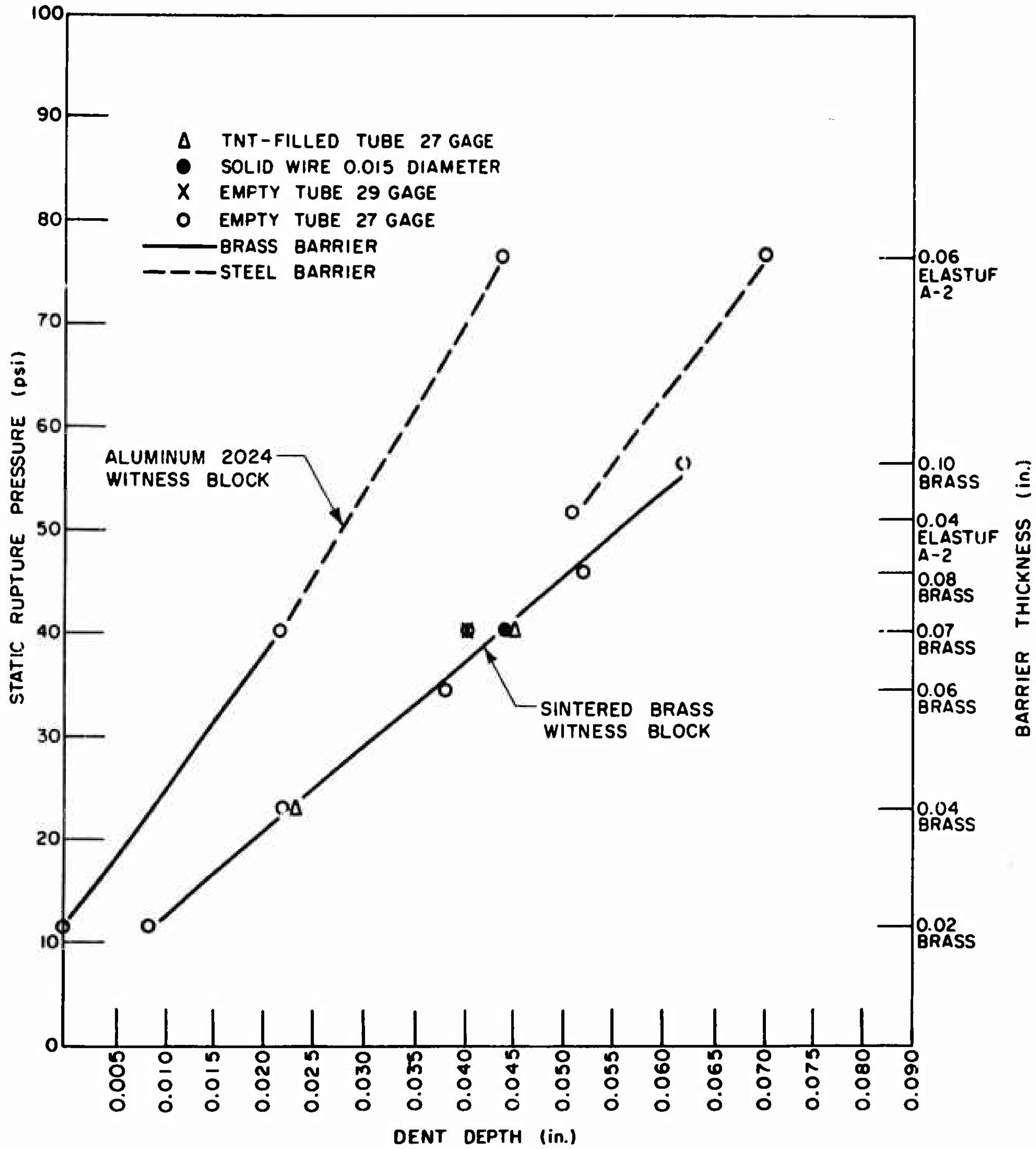

FIG.17. BARRIER THICKNESS VS. DENT DEPTH FOR INITIATOR SECTION TEST

blocks were cut one inch long from bar stock one inch wide by ½ inch thick. Figure 17 shows a plot of the dents obtained in aluminum alloy for several barrier strengths; it indicates good dent production within the range of output.

The evaluation of the output of the initiator section depends mainly upon the depth of dent; another measure used was the amount of cast high explosive remaining in the cavity after explosion. In general the amount of TNT remaining correlated ratherwell with the dent depth. However, from the estimates of the amount of high explosive left we could obtain additional output information from a group of shots with the same barrier thickness. For instance 6.3-mil and 4-mil Nichrome wire, with a brass barrier .070-inch thick would more consistently use all the TNT than heavier elements. No other initiator elements would do this. Except when the .060 Elastuf steel barrier was used.

In the group of tests under conditions best suited for total consumption of the TNT it was necessary to replace the initiator section confinement because of damage to the higher pressures. We fired one initiator section shot with a very thick steel barrier to see the effects on the section and confinement if a barrier did not rupture. The initiation section was strained about .016 inch and was no longer usable; the seal held with only slight leakage of gas.

We made all of the initiator section confinements heavier around the high pressure area for the remaining shots. In general these higher pressure shots would shorten the life of the initiator sections. (U)

3.4 Barrier and Gap Test

We have been unable to find reports of any work on the initiation of small charges of cast insensitive high explosives such as TNT, which are directly applicable to this study. Such reports might have been of substantial assistance.

In the present initiator section we are using a barrier to confine the high explosive during the ignition phase of the initiation process. This barrier is a major contributor to the success of the initiator design. More information is needed, however, to improve the initiator barrier arrangement; there may be a possibility that a barrier or barrier-air gap arrangement may aid in conversion from deflagration to detonation further along the explosive train.

A barrier gap test arrangement described in Section 2 was initiated by a fixed low output system consisting of a M-6 blasting cap with an attenuating air gap and a barrier. The gap and barrier could be adjusted to produce an output like the initiation section or at least a reproducible output for repeated testing.

Our first shot, No. 6 in Table 9, was initiated with an M-6 blasting cap in direct contact with a 0.02-inch brass barrier which in turn

Table 9. BARRIER GAP TEST

	Initiator	Air Gap	Barrier	Air Gap	Output	Dent
6	M-6	none	.020	none		.025
7	M-6	.62	.020	none		.002
8	M-6	.62	.020	none		.002
20	M-6	.62	.020	.10		.004
21	M-6	.62	.020	.10		.004
25	M-6	.62	.020	.21		.002
26	M-6	.62	.020	.21		.003
30	M-6	.62	.020	-		>.10*
31	M-6	.62	.020	-		>.10*
38	M-6	.62	.060	none		.004
39	M-6	.62	.060	none		.002

*Sintered brass dent block

was directly against the 5/16-inch diameter charge of cast TNT. All of the remaining shots were made with an 0.62-inch attenuating air gap between the end of the blasting cap and the barrier. Both arrangements are shown in Figure 5.

This first shot, No. 6, initiated the cast TNT high order, and a dent of 0.025 inch was measured in the steel dent block. This shot was made to establish the effect of direct contract initiation, to form a base for comparison of the lower output test we were setting up.

The next two shots, Nos. 7 and 8, had a 0.62 inch air gap between the output end of the blasting cap and the .020 inch brass barrier to give us a fixed low output; they produced very small dents, about 0.002 inch. In both cases the confinement was split into halves, the first shot shattering its confinement. Figure 18 is a photograph of the confinement after the shot clearly showing the result.

Six more shots were made in this series, two shots each with a 0.10-inch air gap after the 0.020-inch barrier, two with 0.21 inch air gap, and two shots with a .060 inch barrier and no air gap; see Table 9. The dents ranged from .002 inch to .004 inch and there was very little difference in the confinement damage.

The variations resulted in almost no detectable difference in the initiation of TNT. We see several possible reasons. First, we may not have tried an appropriate range of barriers and gap sizes, or, second, we may be trying to improve a secondary level of detonation which is not amenable to improvement by the barrier gap method; or, third, our output measurements were too insensitive to indicate a difference.

A comparison was made between the output of the M-6 cap followed by a.62-inch air gap and the 0.02-inch barrier and the output of the initiater section. The M-6 system produces a dent greater than 0.10 inch against sintered brass. The best dent made by the initiator section was about .060 inches deep in sintered brass.

3.5 Initiator Section and Heavy Confinement

The detonation of the main charge was successfully accomplished as shown by the results of the heavy confinement shots in Table 10. The first two shots were made with models where the heavy outer confinement enclosed the business end of the main charge (designated as "closed end" in Table 10) hence, the order of detonation was estimated by visual inspection of the remains. See Figure 19.

The other shots, listed in Table 10 were made in open ended confinement tubes butted against steel witness blocks and the output was assessed by the depth of the dent and visual examinations of the damage to the confinement. See Figure 20 and 21. The term "high order detonation" is generally accepted as meaning a detonation advancing at a steady state which approaches the maximum ideal velocity predicted by hydrodynamic theory for the density, charge diameter and confinement of the high explosive. The detonation velocities obtained in our

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FIG. 18. RESULTS OF THREE SHOTS OF BARRIER GAP TEST

UPPER: Cast TNT Initiated with M6 Blasting Cap

LOWER TWO: Cast TNT Initiated with M6 Blasting Cap Thru 0.62 Air Gap

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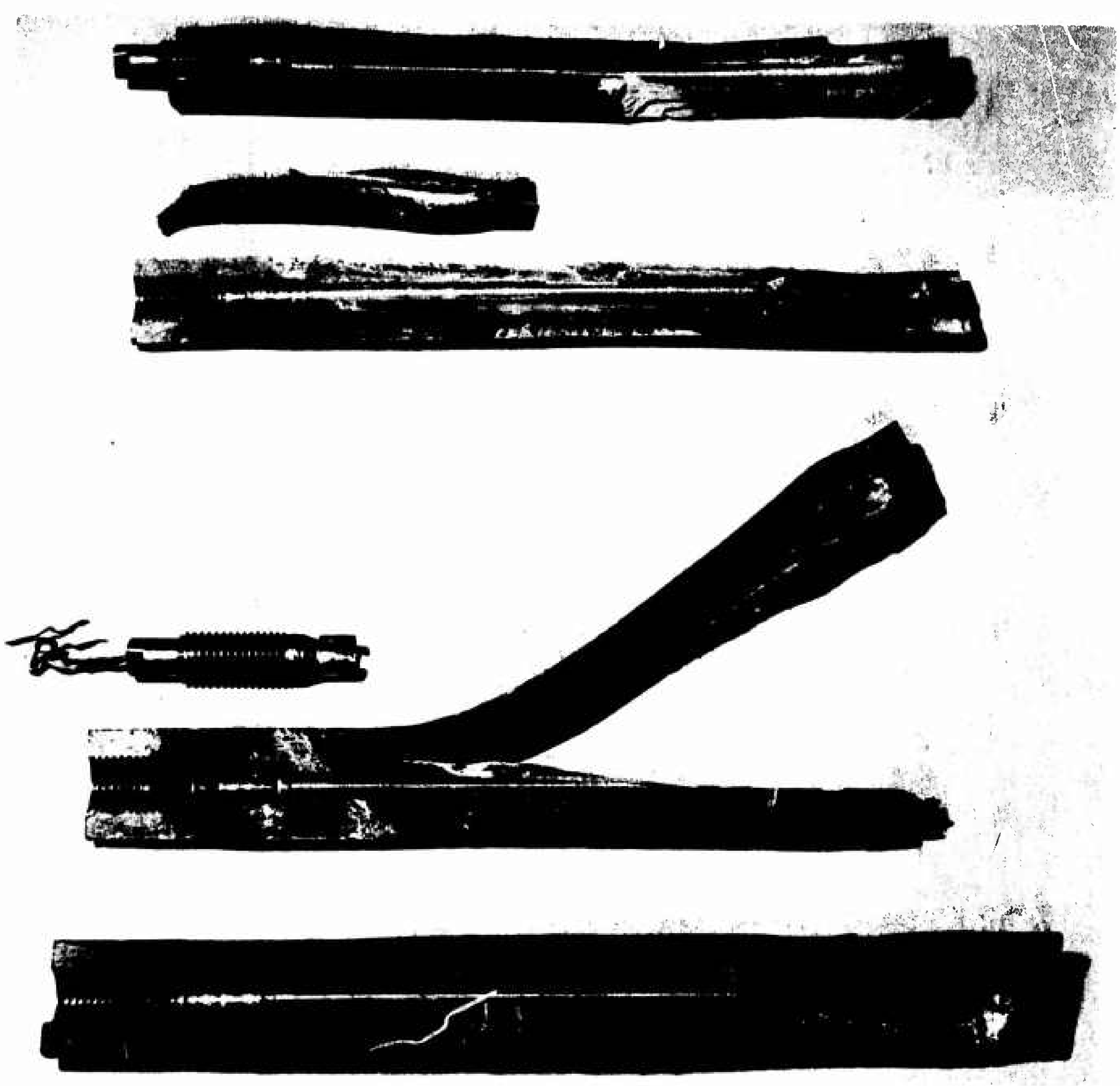

FIG. 19. EFFECT UPON HEAVY CONFINEMENT WITH CLOSED END USING 1/4 INCH DIAMETER CHARGE OF TNT
UPPER: SHOT NUMBER 90
LOWER: SHOT NUMBER 40

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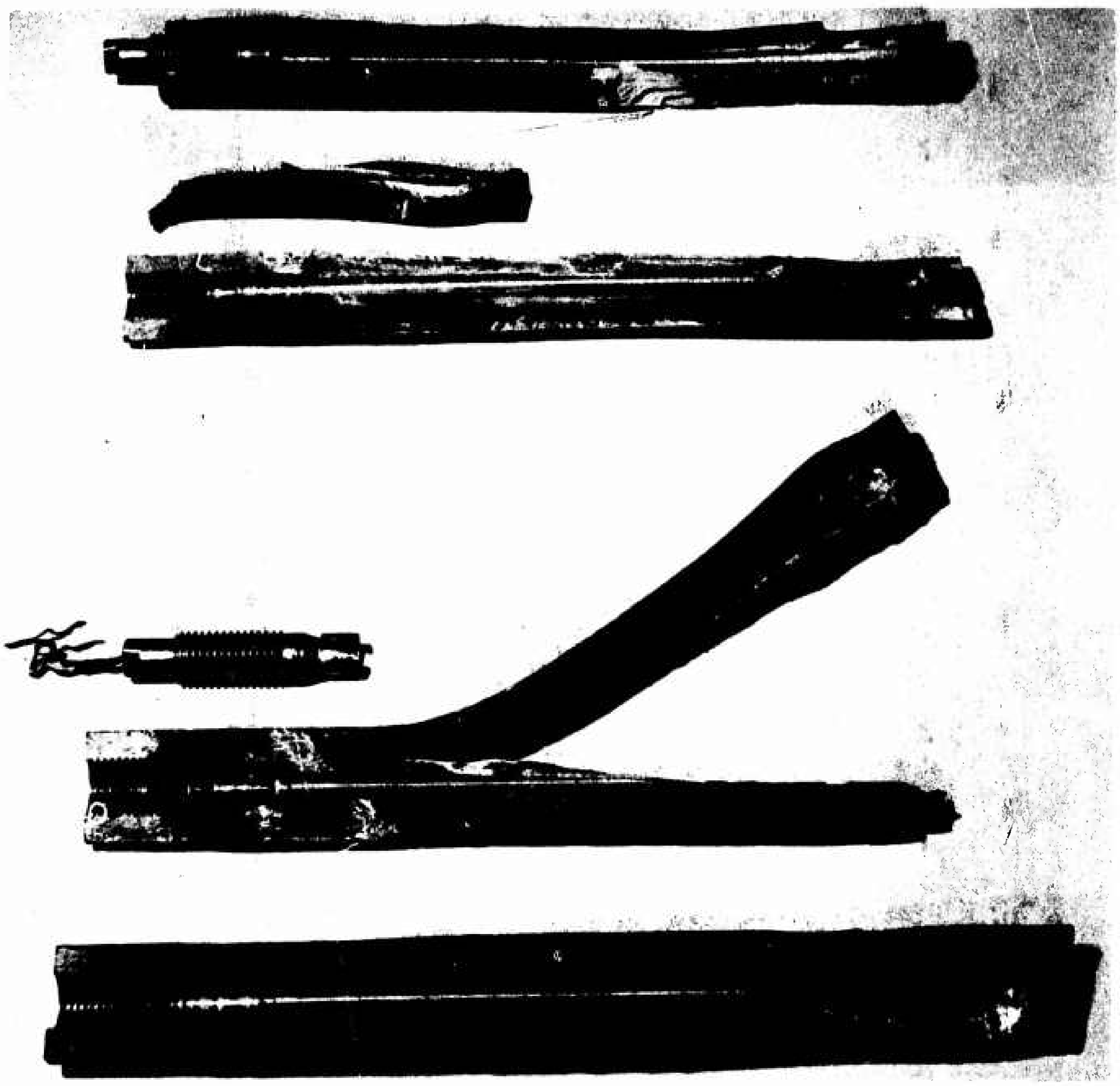

FIG. 19. EFFECT UPON HEAVY CONFINEMENT WITH CLOSED END USING 1/4 INCH DIAMETER CHARGE OF TNT
UPPER: SHOT NUMBER 90
LOWER: SHOT NUMBER 40

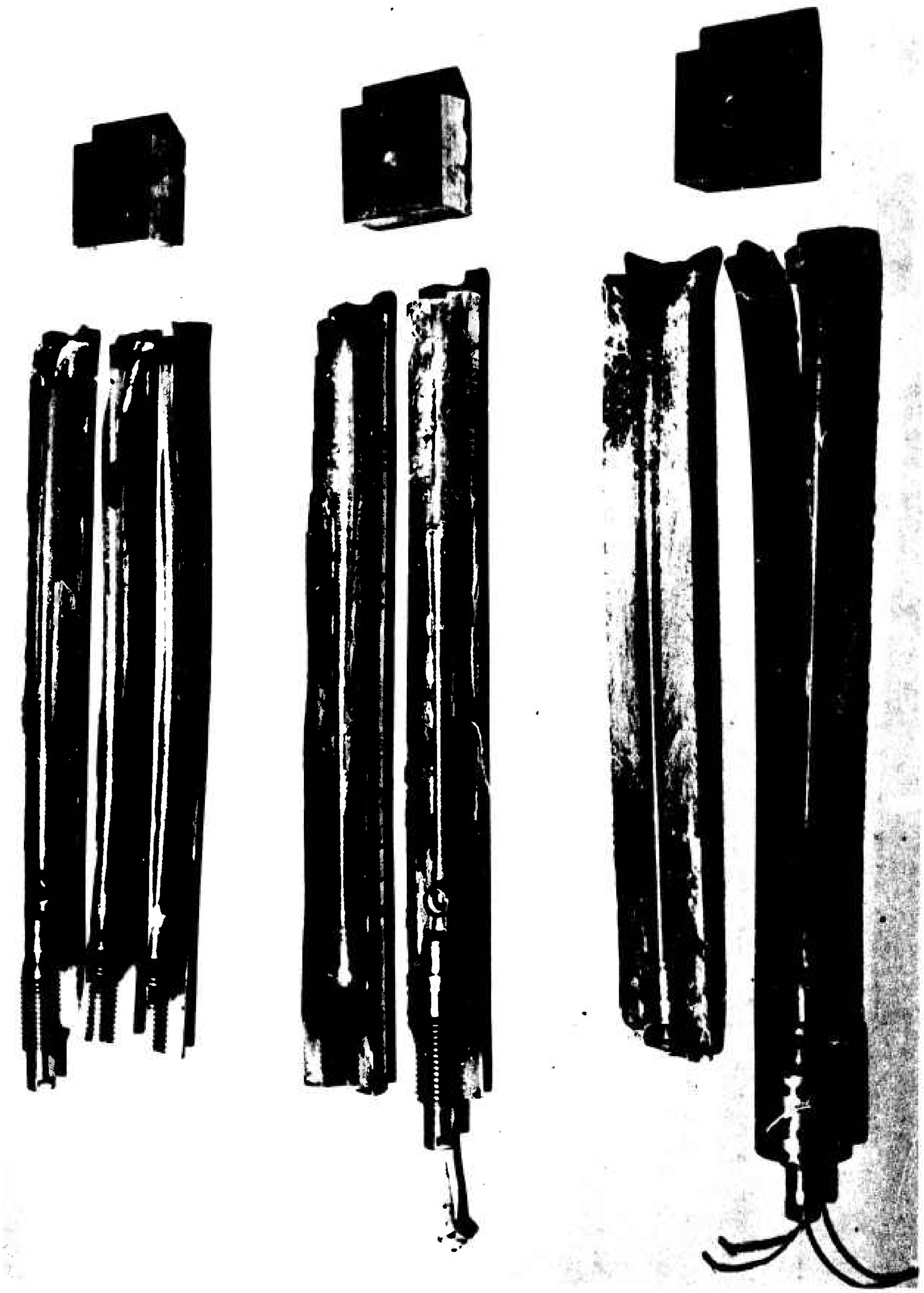

FIG. 20. EFFECT UPON HEAVY CONFINEMENT WITH OPEN END USING 1/4 INCH DIAMETER CHARGE OF HIGH EXPLOSIVE

UPPER: SHOT NUMBER 152 USING TNT
CENTER: SHOT NUMBER 151 USING TNT
LOWER: SHOT NUMBER 150 USING TNTF

CONFIDENTIAL

FIG.21. EFFECT UPON HEAVY CONFINEMENT WITH OPEN END USING 1/4 INCH DIAMETER CHARGE OF TNT

UPPER: SHOT NUMBER 153
LOWER: SHOT NUMBER 154

CONFIDENTIAL

 This page is unclassified.

Table 10. RESULTS OF HEAVY CONFINEMENT SHOTS

Number	Input charge on 10μ fd capacitor k volts	Initiating Element	Explosive	Confinement condition	Output steel dent inches	Estimated Detonation vel M/sec	Functioning Time μ sec
40	5	#27 tube stainless steel	TNT	split open	(closed end)	-	-
90	2	.0063 nichrome	TNT	split open	(closed end)	-	-
94	2	.0063 nichrome	TNT	split open	.055	6400	-
141	2	.0063 nichrome	TNT	split open	.053	6300	1000
142	2	.0063 nichrome	TNT	intact	.047	5800	820
143	2	.0063 nichrome	TNT	intact	.040	5300	790
144	2	.0063 nichrome	TNT	intact	.043	5500	700
145	2	.0063 nichrome	TNT	intact	.054	6300	810
146	2	.0063 nichrome	TNT	split open	.051	6100	900
147	2	.0063 nichrome	TFET	intact	.047	5800	480
148	2	.0063 nichrome	DFTNB	intact	.053	6200	300
149	2	.0063 nichrome	PF	split open	.055	6400	280
150	2	.0063 nichrome	TNTF	split open	.036	4900	1000
151	2	.0063 nichrome	TNT	split open	.045	5600	810
152	2	.0063 nichrome	TNT	split open	.036	4900	1200
153	2	.0063 nichrome	TNT	split open	.038	5100	600
154	2	.0063 nichrome	TNT	split open	.050	5900	1000

Note: Outer confinement of Elastuf A2 steel 0.07" thick barrier of Elastuf A2, and a charge diameter of 1/4" by 10" long used in all tests.

test (estimated from the size of the dent) do approach the ideal. The detonation velocity of a one-inch cylinder unconfined cast TNT of density 1.56 g/cm3 is 6640 meters/sec (Reference 4). The detonation velocity to be expected of our ½ inch diameter charge of confined cast TNT will probably be similar to this value since the small diameter will reduce the velocity and the heavy confinement will tend to counterbalance the decrease. Estimates of the detonation velocities that we achieved in the tests ranged from 4900 meters/sec to 6500 meters/sec.

One shot was made with each of the new fluoroexplosives TFET, DFTNB, PF, and TNTF. Each of the four gave what were considered high order results and PF was rated best since the expanded bore of the confinement and the damage started at 3 to 4 in. after the initiator element as compared to no less than 8 inches using TNT. The shorter functioning time obtained for the shots with DFTNB and PF tends to indicate greater sensitivity than TNT.

We conclude from these firings that the system will work as well or better with the fluoroexplosives as it does for TNT and that most of our findings based on TNT can be applied to designs involving the new materials. One of the differences to be noted, as mentioned above is the length of the main charge column required to achieve high order detonation. With TNT our present length of 10 inches may not be long enough to guarantee a very high reliability figure, on the other hand a design using PF may produce the same results in half the length. More tests are needed to determine these sizes. Based on 17 successful firings without a failure, the reliability of the present unit appears to be at least 86% with 90% confidence.

4. CONCLUSIONS AND RECOMMENDATIONS

The initiation of TNT in the section preceding the main charge has been reliably started by using bridge elements made of Nichrome wire. Half inch lengths of 6.3 mil diameter Nichrome wire imbedded in confined TNT was the optimum of the wires tested when the input was 2 kv from a 10µf capacitor. Satisfactory results were also obtained for 4 mil diameter Nichrome when the input was reduced to 3.5 kv from a 1µf capacitor.

The one sample of gold wire (6 mil) used in the study was found to be less efficient than comparable Nichrome elements.

The use of explosive-filled tubes (such as the #27 hypodermic filled with TNT) offered no apparant advantage. These conclusions are based on our interpretation of the results of the effects produced by the fired elements against Silastic witness blocks, the current and voltage signatures, and actual test firings in TNT. Our results suggest that there is one wire diameter of a given type for which a minimum energy from a specific power source will provide reliable initiation.

The differences in behavior of the initiator sections using gold and Nichrome wires also appear to indicate that the mode of initiation cannot be ascribed solely to EBW action. Hot particles propelled into the explosive may be a contributing factor and certainly the degree of confinement is significant.

The vulnerability of the initiating element to stray electrical energy does not appear to be any problem. The TNT loaded sections containing 6.3 mil diameter Nichrome wires were subjected to a constant current of 2.1 amperes (3 watts) for 30 seconds with no adverse effects. These units functioned properly when the firing pulse was applied. Time did not permit experimental assessment of the current that could be applied safely to the 4 mil diameter Nichrome elements but we expect it would have no difficulty in meeting the 1 ampere requirement.

The output of the initiator section, that section containing the initiating element and boostering explosive ahead of the main charge, was significantly improved by increases made in rupture barrier. The strongest barrier in our design was 0.06 Elastuf A2. The limited studies on the use of a gap subsequent to the barrier did not provide sufficient information to determine if any gains could be made by the inclusion of the gap. This possibility should be explored in any future investigation.

Sixteen shots were made using 10µfd capacitor charged to 2 kv which resulted in an estimated minimum reliability of 86% with 90% confidence. The output of this heavy confinement was deemed capable of initiating large charges of high explosive. Four shots were made using one each of the four fluoro-explosives and results were comparable with the success with the TNT shots.

Future extensions of this work should include determinations of the system performance under temperature extremes and its ability to initiate large unconfined charges. A better understanding of the mode or modes of initiation that lead to the detonation in this system will also be helpful to optimize the parameters of the design. We expect further reductions to be made in the electrical input required and large reductions in the outer confinement and total weight of the actual initiator.

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3. Leopold H.S., Initiation of Explosive by Exploding Wires: V - Effect of Wire Material on Initiation of PETN by Exploding Wires, NOLTR 64-146 Naval Ordnance Laboratory, White Oak 24 October 1964.

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APPENDIX I

CAPACITOR DISCHARGE FIRING SOURCE

Unclassified

CAPACITOR DISCHARGE FIRING SOURCE

The instrumentation used to deliver energy to the initiator element was designed and built at the Franklin Institute. Figure I-1 is a schematic diagram of the firing circuit. This equipment uses a GL7171 Ignitron as the switching element to deliver a capacitor discharge pulse through 8 feet of RG-8/u coaxial cable. Available at the instrument panel is a provision for monitoring the current through the load by recording the voltage drop across a calibrated 0.05 ohm resistance in series. The voltage across the load may also be monitored by observing the voltage drop across a resistance network, in parallel, located at the panel side of the firing line. The resistive and inductive characteristics of this system are, respectively, 0.17 ohms and 1.6 microhenrys.

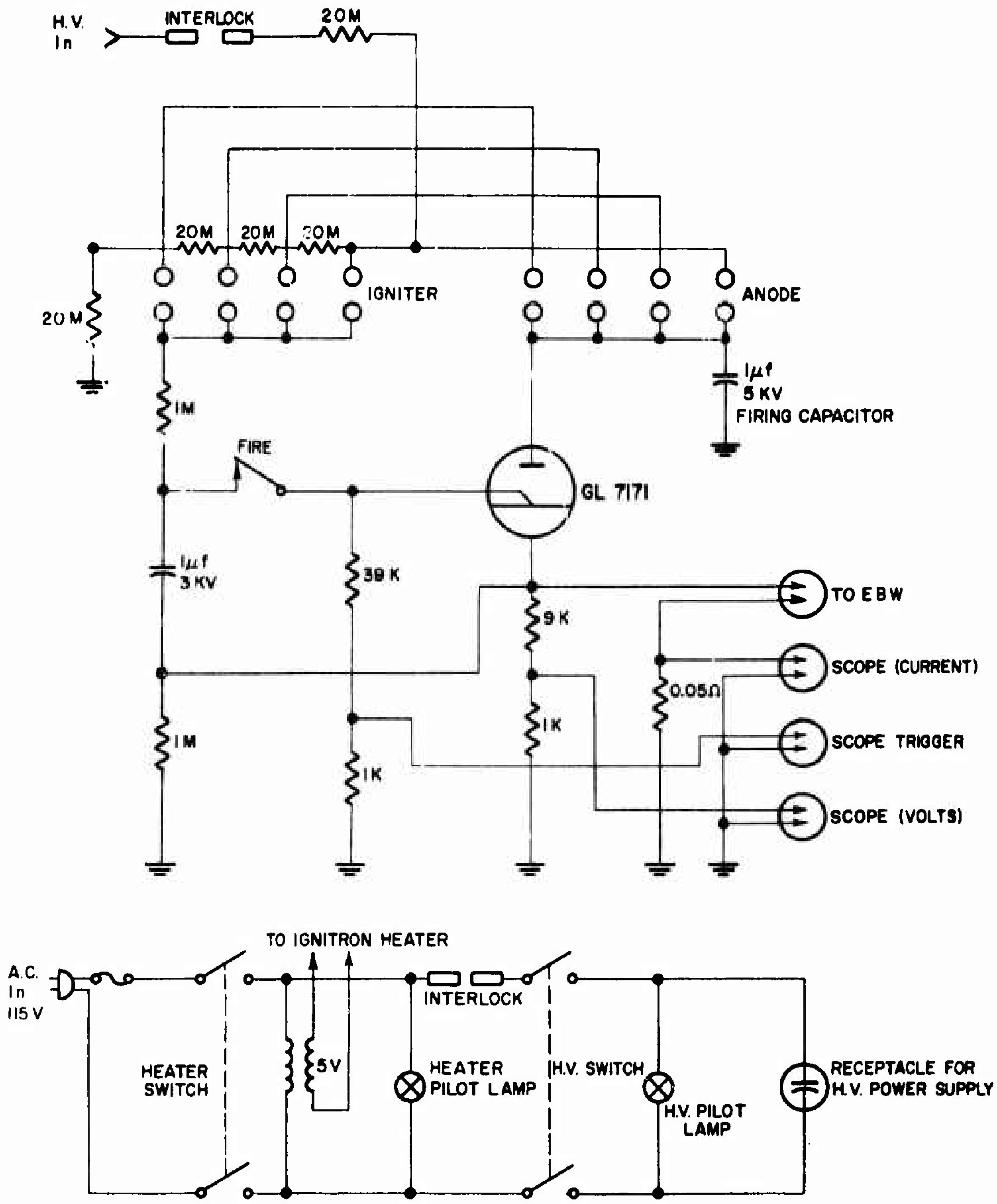

FIG. I-1. FIRING CIRCUIT

APPENDIX II

TEST DATA

	Input		Initiating Element (bridge)					Initiator Section		Main Charge			
Test No.	Volt K Volt	Cap. μfd	Material Type	Length In.	O.D. In.	I.D. In.	Remarks	Charge	Barrier	Air Gap	Main Charge	Confinement	Initiat Sectio
1	5	10	Stain St'l.	.5	.01	.007	Filled	TNT	.020	--	--	--	Dent .0
2	5	10	Stain St'l.	.5	.016	.007	Filled	TNT	.020	--	--	--	Dent .0
3	5	10	Stain St'l.	.5	.016	.007	Filled	TNT	.020	--	--	--	Dent .0
4	5	10	Stain St'l.	.25	.016	.007	Filled	TNT	.020	--	--	--	Dent .0
5	5	10	Stain St'l.	.25	.016	.007	Filled	TNT	.030	--	--	--	Dent .0
6	-	-	-	-	-	-	M-6 Blasting Cap	-	.020	None	.31 Dia	1 in OD	Dent .0
7	-	-	-	-	-	-	M-6 Blasting Cap	-	.020	.62*	.31 Dia	1 in OD	Dent .0
8	-	-	-	-	-	-	M-6 Blasting Cap	-	.020	.62*	.31 Dia	1 in OD	Dent .0
9	5	10	Stain St'l.	.5	.016	.007	Empty	TNT	.020	--	--	--	Dent .0
10	5	10	Stain St'l.	.5	.016	.007	Empty	TNT	.020	--	--	--	Dent .0
11	5	10	Stain St'l.	.5	.016	.007	Empty	TNT	.020	--	--	--	Dent .0
12	5	10	Stain St'l.	.5	.016	.007	Empty	TNT	.040	--	--	--	Dent .0
13	5	10	Stain St'l.	.5	.016	.007	Empty	TNT	.040	--	--	--	Dent .0
14	5	10	Stain St'l.	.5	.016	.007	Empty	TNT	.040	--	--	--	Dent .0
15	5	10	Stain St'l.	.5	.016	.007	Filled	TNT	.040	--	--	--	Dent .0
16	5	10	Stain St'l.	.5	.016	.007	Filled	TNT	.040	--	--	--	Dent .0
17	5	10	Stain St'l.	.5	.016	.007	Empty	TNT	.060	--	--	--	Dent .04
18	5	10	Stain St'l.	.5	.016	.007	Empty	TNT	.060	--	--	--	Dent .0
19	5	10	Stain St'l.	.5	.016	.007	Empty	TNT	.060	--	--	--	Dent .0
20	-	-	-	-	-	-	M-6 Blasting Cap	-	.020	.62-.1*	.31 Dia	1 in OD	Dent .0
21	-	-	-	-	-	-	M-6 Blasting Cap	-	.020	.62-.1*	.31 Dia	1 in OD	Dent .0
22	5	10	Stain St'l.	.5	.016	.007	Empty	TNT	.080	--	--	--	Dent .05
23	5	10	Stain St'l.	.5	.016	.007	Empty	TNT	.080	--	--	--	Dent .05
24	5	10	Stain St'l.	.5	.016	.007	Empty	TNT	.080	--	--	--	Dent .05
25	-	-	Stain St'l.	.5	.016	.007	M-6 Blasting Cap	-	.020	.62-21*	.31 Dia	1 in OD	Dent .0
26	-	-		-	-	-	M-6 Blasting Cap	-	.020	.62-21*	.31 Dia	1 in OD	Dent .0
27	5	10	Stain St'l.	.5	.016	.007	Empty	TNT	.100	--	--	--	Dent .06
28	5	10	Stain St'l.	.5	.016	.007	Empty	TNT	.100	--	--	--	Dent .07
29	5	10	Stain St'l.	.5	.016	.007	Empty	TNT	.100	--	--	--	Dent .05
30	-	-	-	-	-	-	M-6 Blasting Cap	-	.020	.62	--	1 in OD	Dent >.1
31	-	-	-	-	-	-	M-6 Blasting Cap	-	.020	.62	--	1 in OD	Dent >.1
32	5	10	Stain St'l.	.5	.016	.007	Empty	TNT	.040-A2	--	--	--	Dent .04
33	5	10	Stain St'l.	.5	.016	.007	Empty	TNT	.040-A2	--	--	--	Dent .04
34	5	10	Stain St'l.	.5	.016	.007	Empty	TNT	.040-A2	--	--	--	Dent .05
35	5	10	Stain St'l.	.5	.016	.007	Empty	TNT	.070	--	--	--	Dent .04
36	5	10	Stain St'l.	.5	.016	.007	Empty	TNT	.070	--	--	--	Dent .04
37	5	10	Stain St'l.	.5	.016	.007	Empty	TNT	.070	--	--	--	Dent .03
38	-	-	-	-	-	-	M-6 Blasting Cap	-	.060	.62*	.31 Dia	1 in OD	Dent .00

TEST DATA 1

tiator Section		Main Charge			Initiator Section	Functioning Time	Remarks
arge	Barrier	Air Gap	Main Charge	Confine-ment			
NT	.020	--	--	--	Dent .013		Used G.R. connector & selastic insulation - tested at 5 KV
NT	.020	--	--	--	Dent .019		Half round dent sintered Brass. Results Consistent.
NT	.020	--	--	--	Dent .012		TNT remained in initiator section. Note Chamber No. 2 is oversize, use #1 only
NT	.020	--	--	--	Dent .008		Used all steel obturation plug ass'y & half length element
NT	.030	--	--	--	Dent .016		Made little off. Heavy barrier made some difference see photos for results
-	.020	None	.31 Dia	1 in OD	Dent .025		
-	.020	.62*	.31 Dia	1 in OD	Dent .002		*Input side barrier
-	.020	.62*	.31 Dia	1 in OD	Dent .002		*Input side barrier
NT	.020	--	--	--	Dent .010		Compare with shot 1, 2 & 3. Filled tube better.
NT	.020	--	--	--	Dent .008		TNT remain. More consumed with larger dent.
NT	.020	--	--	--	Dent .007		(Note element by new man)
NT	.040	--	--	--	Dent .022		Dent increased due to thicker barrier - unburned
NT	.040	--	--	--	Dent .022		TNT still remain
NT	.040	--	--	--	Dent .022		
NT	.040	--	--	--	Dent .021		Filled tube - shot is like 12,13,&14 - shot 16 used more TNT and other four gave round dent
NT	.040	--	--	--	Dent .024		
NT	.060	--	--	--	Dent .041		
NT	.060	--	--	--	Dent .035		
NT	.060	--	--	--	Dent .038		
-	.020	.62-.1*	.31 Dia	1 in OD	Dent .004		*.62 gap into side barrier - .1 gap on outside
-	.020	.62-.1*	.31 Dia	1 in OD	Dent .004		Barrier - one 3 part over 2 part
NT	.080	--	--	--	Dent .055		TNT unburned still remaining
NT	.080	--	--	--	Dent .050		
NT	.080	--	--	--	Dent .052		
-	.020	.62-21*	.31 Dia	1 in OD	Dent .002		*.62 gap on input side barrier - .21 gap on output side
-	.020	.62-21*	.31 Dia	1 in OD	Dent .003		Barrier - one 3 part other 2 part - 2 part look thicker orolk
NT	.100	--	--	--	Dent .060		Unburned TNT still remaining
NT	.100	--	--	--	Dent .070		
NT	.100	--	--	--	Dent .057		
-	.020	.62	--	1 in OD	Dent >.10		Compare output to initiation element, using brass dent Block
-	.020	.62	--	1 in OD	Dent >.10		
NT	.040-A2	--	--	--	Dent .047		Note: use elastuf A2 barrier
NT	.040-A2	--	--	--	Dent .048		
NT	.040-A2	--	--	--	Dent .058		
NT	.070	--	--	--	Dent .041		This is to be standard control for series of test
NT	.070	--	--	--	Dent .040		
NT	.070	--	--	--	Dent .038		
-	.060	.62*	.31 Dia	1 in OD	Dent .004		Shot 38 appeared to be higher order than #39

Test No.	Input: Volt K Volt	Input: Cap. μfd	Initiating Element (bridge): Material Type	Length In.	O.D. In.	I.D. In.	Remarks	Initiator Section: Charge	Initiator Section: Barrier	Main Charge: Air Gap	Main Charge: Main Charge	Main Charge: Confinement	In S
39	--	--	--	--	--	--	M-6 Blasting Cap	--	.060	.62*	.31 Dia	1 in OD	De
40	5	10	Stain St'l.	.5	.016	.007	Empty	TNT	.070-A2	None	.25 Dia	1.5 OD	
41	5	10	Stain St'l.	.5	.015	--	Solid	TNT	.070	--	--	--	De
42	5	10	Stain St'l.	.5	.015	--	Solid	TNT	.070	--	--	--	De
43	5	10	Stain St'l.	.5	.015	--	Solid	TNT	.070	--	--	--	De
44	5	10	Stain St'l.	.5	.016	.007	Filled	TNT	.070	--	--	--	De
45	5	10	Stain St'l.	.5	.013	.007	Empty	TNT	.070	--	--	--	De
46	5	10	Stain St'l.	.5	.013	.007	Empty	TNT	.070	--	--	--	De
47	5	10	Stain St'l.	.5	.013	.007	Empty	TNT	.070	--	--	--	De
48	5	10	Stain St'l.	.5	.016	.007	Filled	TNT	.070	--	--	--	De
49	5	10	Stain St'l.	.5	.016	.007	Filled	TNT	.070	--	--	--	De
50	5	10	Stain St'l.	.5	.016	.007	Empty	TNT	.060-A2	--	--	--	De
51	5	10	Stain St'l.	.5	.016	.007	Empty	TNT	.060-A2	--	--	--	De
52	5	10	Stain St'l.	.5	.016	.007	Empty	TNT	.060-A2	--	--	--	De
53	5	10	Stain St'l.	.5	.016	.007	Empty	TNT	.070	--	--	--	Dal
54	5	10	Stain St'l.	.5	.016	.007	Empty	TNT	.070	--	--	--	Dal
55	5	10	Stain St'l.	.5	.016	.007	Empty	TNT	.070	--	--	--	Dal
56	5	10	Stain St'l.	.5	.016	.007	Empty	TNT	.020	--	--	--	Dal
57	5	10	Stain St'l.	.5	.016	.007	Empty	TNT	.020	--	--	--	Dal
58	5	10	Stain St'l.	.5	.016	.007	Empty	TNT	.020	--	--	--	Dal
59	5	10	Stain St'l.	.5	.016	.007	Empty	TNT	.060-A2	--	--	--	Dal
60	5	10	Stain St'l.	.5	.016	.007	Empty	TNT	.060-A2	--	--	--	Dal
61	5	10	Stain St'l.	.5	.016	.007	Empty	TNT	.060-A2	--	--	--	Dal
62	5	10	Ni	.5	.008	.003	Empty	TNT	.070	--	--	--	Dal
63	5	10	Ni	.5	.008	.003	Empty	TNT	.070	--	--	--	Dal
64	5	10	Ni	.5	.008	.003	Empty	TNT	.070	--	--	--	Dal
65	5	10	Stain St'l.	.5	.016	.007	Empty	TNT	.03B+.12 St'l.	--	--	--	--
66	5	10	Nichrome	.5	.008	Solid	--	TNT	.070	--	--	--	Dal
67	5	10	Nichrome	.5	.008	Solid	--	TNT	.070	--	--	--	Dal
68	5	10	Nichrome	.5	.008	Solid	--	TNT	.070	--	--	--	Dal
69	5	10	Nichrome	.5	.006	Solid	--	TNT	.070	--	--	--	Dal
70	5	10	Nichrome	.5	.0063	Solid	--	TNT	.070	--	--	--	Dal
71	5	10	Nichrome	.5	.0063	Solid	--	TNT	.070	--	--	--	Dal
72	5	10	Nichrome	.5	.0063	Solid	--	TNT	.070	--	--	--	Dal
73	5	10	Nichrome	.5	.0063	Solid	--	TNT	.070	--	--	--	Non
74	5	10	Nichrome	.5	.0063	Solid	--	TNT	.070	--	--	--	Non
75	5	10	Nichrome	.5	.0063	Solid	--	TNT	.070	--	--	--	Den
76	5	10	Nichrome	.5	.0063	Solid	--	TNT	.070	--	--	--	Den
77	5	10	Nichrome	.5	.0063	Solid	--	TNT	.070	--	--	--	Den
78	5	10	Nichrome	.5	.0063	Solid	Prepulsed 1.20 A & 10 sec .85 Ω/.85 Ω	TNT	.070	--	--	--	Den
79	5	10	Nichrome	.5	.0063	Solid	Prepulsed 2.10A & 10 sec .80 Ω/.81 Ω	TNT	.070	--	--	--	Den

TEST DATA 2

Section Carrier	Main Charge Air Gap	Main Charge	Confinement	Initiator Section	Functioning Time	Remarks
.060	.62*	.31 Dia	1 in OD	Dent .002		
.070-A2	None	.25 Dia	1.5 OD	--		
.070	--	--	--	Dent .038		
.070	--	--	--	Dent .043		
.070	--	--	--	Dent .050		
070	--	--	--	Dent .043		
070	--	--	--	Dent .035		
070	--	--	--	Dent .042		
070	--	--	--	Dent .043		
070	--	--	--	Dent .043		
070	--	--	--	Dent .048		
060-A2	--	--	--	Dent .067		
060-A2	--	--	--	Dent .068		
060-A2	--	--	--	Dent .074		
070	--	--	--	Dal .013		Aluminum dent block used * 24T4 QQA267 (2024)
070	--	--	--	Dal .018		
070	--	--	--	Dal .024		
020	--	--	--	Dak .001		
020	--	--	--	Dak .001		
020	--	--	--	Dak .001		
060-A2	--	--	--	Dal .044		All TNT used in this shot - This shot was better than previous shots using same conditions 50,51,5
060-A2	--	--	--	Dal .045		
C[illegible]0-A2	--	--	--	Dal .044		
070	--	--	--	Dal .018		
070	--	--	--	Dal .019		
070	--	--	--	Dal .018		
.12 St'l.	--	--	--	--		Initiator section confinement strained .016
070	--	--	--	Dal .020		More TNT remain after this shot
070	--	--	--	Dal .019		than shots 63,64,65
070	--	--	--	Dal .018		
070	--	--	--	Dal .023		Note all TNT used up in these
070	--	--	--	Dal .024		shots (looks very good)
070	--	--	--	Dal .020		
070	--	--	--	Dal .025		Used all TNT
070	--	--	--	Nonfire		Misfire Suspect something wrong with firing set
070	--	--	--	Nonfire		Misfire (RG8 cable replaced)
070	--	--	--	Dent .039		TNT remaining
070	--	--	--	Dent .045		All TNT used
070	--	--	--	Dent .040		All TNT used
070	--	--	--	Dent .018		All TNT used
070	--	--	--	Dent .019		All TNT used

Test No.	Input: Volt Volt	Input: Cap. μfd	Initiating Element (bridge): Material Type	Length In.	O.D. In.	I.D. In.	Remarks	Initiator Section: Charge	Barrier	Main Charge: Air Gap	Main Charge	Confine-ment	Init Sec
80	5	10	Nichrome	.5	.0063	Solid	Propulsed 2.10 A & 30 sec .77 /.78	TNT	.070	--	--	--	Dal
81	-	--	Nichrome	.5	.0063	Solid	Prepulsed 7.0 A Opened .69/open	TNT	.070	--	--	--	--
82	-	--	Nichrome	.5	.0063	Solid	Prepulsed 5.0 A Opened .75/open	TNT	.070	--	--	--	--
83	5	10	Nichrome	.5	.0063	Solid	--	Silicone G	.070	--	--	--	No D
84	2	10	Nichrome	.5	.0063	Solid	--	TNT	.070				Dal
85	2	10	Nichrome	.5	.0063	Solid	--	TNT	.070	--	--	--	Dal
86	2	10	Nichrome	.5	.0063	Solid	--	TNT	.070	--	--	--	Dal
87	2	10	St'l 302	.5	.003	Solid		TNT	.070	--	--	--	Nonf
88	2	10	St'l 302	.5	.003	Solid		TNT	.070	--	--	--	Dal
89	2	10	St'l 302	.5	.003	Solid		TNT	.070	--	--	--	Dal
90	2	10	Nichrome	.5	.0063	Solid		TNT	.070-A2	None	.25 Dia	1.50 D	--
91	2	10	Nichrome	.5	.0063	Solid		TNT	.070	--	--	--	Dal
92	2	10	Nichrome	.5	.0063	Solid		TNT	.070	--	--	--	Dal
93	2	10	Nichrome	.5	.0063	Solid		TNT	.070	--	--	--	Dal
94	2	10	Nichrome	.5	.0063	Solid		TNT	.070-A2	None	.25 Dia	1.50 D	St'l
95	2	10	Nichrome	.5	.004	Solid		TNT	.070	--	--	--	Dal
96	2	10	Nichrome	.5	.004	Solid		TNT	.070	--	--	--	Dal
97	2	10	Nichrome	.5	.004	Solid		TNT	.070	--	--	--	Dal
98	1.2	10	Nichrome	.5	.004	Solid		TNT	.070	--	--	--	Noni
99	1.5	10	Nichrome	.5	.004	Solid		TNT	.070	--	--	--	Noni
100	2.	10	Nichrome	.5	.004	Solid		TNT	.070	--	--	--	Dal
101	1.5	10	Nichrome	.5	.0063	Solid		TNT	.070	--	--	--	Dal
102	1.5	10	Nichrome	.5	.0063	Solid		TNT	.070	--	--	--	Dal
103	1.5	10	Nichrome	.5	.0063	Solid		TNT	.070	--	--	--	Dal
104	1.5	10	Nichrome	.5	.004	Solid		TNT	.070	--	--	--	No
105	1.5	10	Nichrome	.5	.004	Solid		TNT	.070	--	--	--	No
106	2.	10	Nichrome	.5	.008	Solid		TNT	.070	--	--	--	Dal
107	2.	10	Nichrome	.5	.008	Solid		TNT	.070	--	--	--	Dal
108	2.	10	Gold	.5	.006	Solid		TNT	.070	--	--	--	Dal
109	2.	10	Gold	.5	.006	Solid		TNT	.070	--	--	--	Del
110	2.	10	Gold	.5	.006	Solid		TNT	.070	--	--	--	Dal
111	1.5	10	Gold	.5	.006	Solid		TNT	.070	--	--	--	Non
112	1.5	10	Gold	.5	.006	Solid		TNT	.070	--	--	--	Non
113	1.5	10	Gold	.5	.006	Solid		TNT	.070	--	--	--	Non
114	2.	10	Nichrome	.5	.00225	Solid		TNT	.070	--	--	--	Non
115	2.	10	Nichrome	.5	.00225	Solid		TNT	.070	--	--	--	Non
116	2.	10	Nichrome	.5	.00225	Solid		TNT	.070	--	--	--	Non
117	4.7	1	Nichrome	.5	.004	Solid		TNT	.070	--	--	--	Dal
118	4.7	1	Nichrome	.5	.004	Solid		TNT	.070	--	--	--	Dal
119	4.7	1	Nichrome	.5	.004	Solid		TNT	.070	--	--	--	Dal

TEST DATA 3

Initiator Section		Main Charge					
Charge	Barrier	Air Gap	Main Charge	Confinement	Initiator Section	Functioning Time	Remarks
TNT	.070	--	--	--	Dal .019		25% left
TNT	.070	--	--	--	--		Wire broke with high current - TNT not effected
TNT	.070	--	--	--	--		Wire broke with high current - TNT not effected
Silicone G	.070	--	--	--	No Dent		--
TNT	.070				Dal .021		All TNT used
TNT	.070	--	--	--	Dal .023		All TNT used
TNT	.070	--	--	--	Dal .023		All TNT used
TNT	.070	--	--	--	Nonfire		Miss fire - bridge may have been broken (TNT was charged)
TNT	.070	--	--	--	Dal .019		All TNT used
TNT	.070	--	--	--	Dal .020		All TNT used
TNT	.070-A2	None	.25 Dia	1.50 D	--		High order in heavy elastuf confinement
TNT	.070	--	--	--	Dal .018		All TNT used
TNT	.070	--	--	--	Dal .019		All TNT used
TNT	.070	--	--	--	Dal .019		All TNT used
TNT	.070-A2	None	.25 Dia	1.50 D	St'l .055		High order - open end for dent heavy elastuf confinement
TNT	.070	--	--	--	Dal .017		Very little TNT left
TNT	.070	--	--	--	Dal .020		Very little TNT left
TNT	.070	--	--	--	Dal .017		Very little TNT left
TNT	.070	--	--	--	Nonfire		Browned TNT
TNT	.070	--	--	--	Nonfire		Browned TNT
TNT	.070	--	--	--	Dal .020		Use all TNT
TNT	.070	--	--	--	Dal .020		All TNT used
TNT	.070	--	--	--	Dal .016		All TNT used
TNT	.070	--	--	--	Dal .017		All TNT used
TNT	.070	--	--	--	No Fire		Browned TNT
TNT	.070	--	--	--	No Fire		Browned TNT
TNT	.070	--	--	--	Dal .019		Very little TNT left
TNT	.070	--	--	--	Dal .009		Very little TNT left
TNT	.070	--	--	--	Dal .023		All TNT used
TNT	.070	--	--	--	Dal .022		All TNT used
TNT	.070	--	--	--	Dal .021		All TNT used
TNT	.070	--	--	--	Non Fire		Did not initiate TNT
TNT	.070	--	--	--	Non Fire		--
TNT	.070	--	--	--	Non Fire		--
TNT	.070	--	--	--	Non Fire		Did not initiate TNT
TNT	.070	--	--	--	Non Fire		--
TNT	.070	--	--	--	Non Fire		--
TNT	.070	--	--	--	Dal .021		All TNT used
TNT	.070	--	--	--	Dal .022		All
TNT	.070	--	--	--	Dal .023		All

2

Test No.	Input: Volt K Volt	Input: Cap. µfd	Initiating Element (bridge): Material Type	Length In.	O.D. In.	I.D. In.	Remarks	Initiator Section: Charge	Initiator Section: Barrier	Main Charge: Air Gap	Main Charge: Main Charge	Main Charge: Confine-ment
120	4.0	1	Nichrome	0.5	0.0063	Solid		TNT	0.070	--	--	--
121	4.7	1	Nichrome	0.5	0.0063	Solid		TNT	0.070	--	--	--
122	4.0	1	Nichrome	0.5	0.0063	Solid		TNT	0.070	--	--	--
123	4.3	1	Nichrome	0.5	0.004	Solid		TNT	0.070	--	--	--
124	4.3	1	Nichrome	0.5	0.004	Solid		TNT	0.070	--	--	--
125	4.3	1	Nichrome	0.5	0.004	Solid		TNT	0.070	--	--	--
126	4.0	1	Nichrome	0.5	0.004	Solid		TNT	0.070	--	--	--
127	3.7	1	Nichrome	0.5	0.004	Solid		TNT	0.070	--	--	--
128	3.2	1	Nichrome	0.5	0.004	Solid		TNT	0.070	--	--	--
129	3.7	1	Nichrome	0.5	0.004	Solid		TNT	0.070	--	--	--
130	3.5	1	Nichrome	0.5	0.004	Solid		TNT	0.070	--	--	--
131	3.5	1	Nichrome	0.5	0.004	Solid		TNT	0.070	--	--	--
132	4.3	1	Nichrome	0.5	0.0063	Solid		TNT	0.070	--	--	--
133	4.3	1	Nichrome	0.5	0.0063	Solid		TNT	0.070	--	--	--
134	4.3	1	Nichrome	0.5	0.0063	Solid		TNT	0.070	--	--	--
135	1.2	10	Nichrome	0.5	0.0063	Solid		TNT	0.070	--	--	--
136	1.2	10	Nichrome	0.5	0.0063	Solid		TNT	0.070	--	--	--
137	1.2	10	Nichrome	0.5	0.0063	Solid		TNT	0.070	--	--	--
138	1.8	10	Nichrome	0.5	0.004	Solid		TNT	0.070	--	--	--
139	1.8	10	Nichrome	0.5	0.004	Solid		TNT	0.070	--	--	--
140	1.8	10	Nichrome	0.5	0.004	Solid		TNT	0.070	--	--	--
141	2.0	10	Nichrome	0.5	.0063	Solid		TNT	.07-A2	None	.25 D	1.50 D
142	2.0	10	Nichrome	0.5	.0063	Solid		TNT	.07-A2	None	.25 D	1.50 D
143	2.0	10	Nichrome	0.5	.0063	Solid		TNT	.07-A2	None	.25 D	1.50 D
144	2.0	10	Nichrome	0.5	.0063	Solid		TNT	.07-A2	None	.25 D	1.50 D
145	2.0	10	Nichrome	0.5	.0063	Solid		TNT	.07-A2	None	.25 D	1.50 D
146	2.0	10	Nichrome	0.5	.0063	Solid		TNT	.07-A2	None	.25 D	1.50 D
147	2.0	10	Nichrome	0.5	.0063	Solid		#1	.07-A2	None	.25 D	1.50 D
148	2.0	10	Nichrome	0.5	.0063	Solid		#2	.07-A2	None	.25 D	1.50 D
149	2.0	10	Nichrome	0.5	.0063	Solid		#3	.07-A2	None	.25 D	1.50 D
150	2.0	10	Nichrome	0.5	.0063	Solid		#4	.07-A2	None	.25 D	150 D
151	2.0	10	Nichrome	0.5	.0063	Solid		TNT	.07-A2	None	.25 D	150 D
152	2.0	10	Nichrome	0.5	.0063	Solid		TNT	.07-A2	None	.25 D	150 D
153	2.0	10	Nichrome	0.5	.0063	Solid		TNT	.07-A2	None	.25 D	150 D
154	2.0	10	Nichrome	0.5	.0063	Solid		TNT	.07-A2	None	.25 D	150 D
155	2.0	10	Nichrome	0.5	.0063	Solid		TNT	.070	--	--	--
156	2.0	10	Nichrome	0.5	.0063	Solid		TNT	.070	--	--	--
157	2.0	10	Nichrome	0.5	.0063	Solid		TNT	.070	--	--	--

...tor Section	Main Charge					
Barrier	Air Gap	Main Charge	Confinement	Initiator Section	Functioning Time	Remarks
0.070	--	--	--	Non Fire		Browned TNT
0.070	--	--	--	Dal .025		All TNT used
0.070	--	--	--	Non Fire		Browned TNT
0.070	--	--	--	Dal .023		
0.070	--	--	--	Dal .025		
0.070	--	--	--	Dal .022		Very little TNT left
0.070	--	--	--	Dal .024		
0.070	--	--	--	Dal .025		
0.070	--	--	--	Non Fire		Charred or browned TNT (No Fire)
0.070	--	--	--	.025		
0.070	--	--	--	.025		
0.070	--	--	--	.026		
0.070	--	--	--	.024		
0.070	--	--	--	No Fire		Charred
0.070	--	--	--	No Fire		Charred
0.070	--	--	--	.025		
0.070	--	--	--	No Fire		Charred
0.070	--	--	--	No Fire		Charred
0.070	--	--	--	.025		
0.070	--	--	--	.017		
0.070	--	--	--	No Fire		Charred
.07-A2	None	.25 D	1.50 D	St'l .053	1000 μs	Split in half
.07-A2	None	.25 D	1.50 D	St'l .047	820 μs	Confinement intact - sawed open
.07-A2	None	.25 D	1.50 D	St'l .040	790 μs	Confinement intact
.07-A2	None	.25 D	1.50 D	St'l .043	700 μs	Split in thirds
.07-A2	None	.25 D	1.50 D	St'l .054	810 μs	Confinement intact
.07-A2	None	.25 D	1.50 D	St'l .051	900 μs	Confinement intact
.07-A2	None	.25 D	1.50 D	St'l .047*	480 μs	Confinement intact *Jet Hole .120
.07-A2	None	.25 D	1.50 D	St'l .053	300 μs	Confinement intact
.07-A2	None	.25 D	1.50 D	St'l .055*	280 μs	3 large, 4 small pcs. High order 3 to 4 in from start *Jet Hole .157
.07-A2	None	.25 D	150 D	St'l .036	1000 μs	Split in half - one half almost split again
.07-A2	None	.25 D	150 D	St'l .045	810 μs	Split in half
.07-A2	None	.25 D	150 D	St'l .036	1200 μs	Split in thirds
.07-A2	None	.25 D	150 D	St'l .038	600 μs	Split in thirds
.07-A2	None	.25 D	150 D	St'l .050	1000 μs	Split in thirds
.070	--	--	--	Dal .024		Used all TNT }
.070	--	--	--	Dal .025		
.070	--	--	--	Dal .027		

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1. ORIGINATING ACTIVITY (Corporate author) The Franklin Institute Research Laboratories Philadelphia, Pennsylvania	2a. REPORT SECURITY CLASSIFICATION CONFIDENTIAL 2b. GROUP Gp-4

3. REPORT TITLE

Exploding Bridge Wire Initiation of Case Explosives

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

Final Report (16 March 1964 to 16 March 1965)

5. AUTHOR(S) (Last name, first name, initial)

Amicone, Raymond G., Mayer, David W., Goldie, Victor W.

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
December 1965	69	4

8a. CONTRACT OR GRANT NO. AF 08(635)-4181	9a. ORIGINATOR'S REPORT NUMBER(S) B2200
b. PROJECT NO. 2511	
c.	9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report) ATL-TR-65-92
d.	

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	Directorate of Armament Development Research and Technology Division (AFSC) Eglin Air Force Base, Florida

13. ABSTRACT

Good progress has been made in the development of a system to initiate relatively insensitive explosives like TNT without the use of primary explosive. The initiation is triggered by the use of an exploding bridgewire and the reaction in the surrounding high explosive is enhanced by confinement by a barrier whose rupture adds to the build up of detonation in the main column of high explosive. The results show that high order detonations are achievable with this system. Seventeen shots were made all of which resulted in high order judged by dent in steel block or the condition of the damage to the confinement. Further studies are recommended to optimize practical designs.

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
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