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PROGRESS REPORT ON ADAPTATION OF CONTINUOUS WIRE METHOD FOR MEASURING TRANSIENT PHENOMENA

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PROGRESS REPORT ON ADAPTATION OF CONTINUOUS WIRE METHOD FOR MEASURING TRANSIENT PHENOMENA

By

Irving Jaffe and Donna Price

Working Group

I. Jaffe
D. Price
G. Roberson
J. Toscano

ABSTRACT: The development of a continuous ionization sensor which can be used to study detonation and pre-detonation phenomena in solid propellants and explosives is discussed. The system described is capable of following the progress of an ionized front down a charge and at the same time it measures the resistance or conductance of the front. During the evaluation of the technique, a number of explosives were used (TNT, Comp B, Pentolite). The results are discussed qualitatively.

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APPROVED BY: Carl Boyars, Chief
Physical Chemistry Division
CHEMISTRY RESEARCH DEPARTMENT
U. S. NAVAL ORDNANCE LABORATORY
WHITE OAK, SILVER SPRING, MARYLAND

The following progress report deals with one phase of the investigation of the sensitivity of propellants and explosives. It is supported by projects FR-59, Transition from Deflagration to Detonation, and NOL 323, Polaris Propulsion Unit Safety Study. The report follows the progress made in developing a continuous sensing technique which follows the position and electrical resistance of a reaction front. The system will be used to study the transition region to obtain new information which will contribute to the understanding of the sensitivity behavior of explosive materials.

R. E. ODENING
Captain, USN
Commander

for ALBERT LIGHTBODY
By direction

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PROGRESS REPORT ON ADAPTATION OF CONTINUOUS WIRE METHOD FOR MEASURING TRANSIENT PHENOMENA

I. INTRODUCTION

The continuous wire technique, a system which is able to sense a change in resistance caused by a change in the concentration of charges, has been used to measure detonation velocity (1) and critical diameter (2) and to study the electrical phenomena (change in resistance or conductivity) in explosives and propellants (3,4). It was believed that this technique could be used to give significant information about pre-detonation and detonation reactions of explosives. Consequently, the system has been developed through use, change, and redesign, to its present form which offers a possible quantitative tool to explore the transition from deflagration to detonation in an explosive or a propellant.

The experimental set-up is shown in schematic form in Fig. 1. Two wires, one a nichrome wire of known resistance and the other a copper wire of very low resistance, are cast in an explosive charge. A current of 0.200 amps is maintained in the circuit by a constant current generator and the potential drop across the cast wires is displayed by an oscilloscope (Tektronix 545). A much more detailed description of the electronic system is given in reference (1).

Figure 2 shows the configurations used in the following experiments. The donor, consisting of two tetryl pellets (each 2 in. diam. x 1 inch thick, ρ_o = 1.51 g/cm^3) is initiated by a detonator (Seismo, Olin Mathieson). By changing the Plexiglas* gap between the donor and the acceptor, the amount of energy transmitted to the acceptor can be controlled. At zero gap, the maximum energy is transmitted from donor to acceptor and a detonation is initiated in the typical acceptor explosive. Under these conditions the material separating the nichrome and copper wires becomes highly ionized and the resistance between them falls to approximately zero ohms. The potential is given by the equation

$$E = I (R_N + R_F)$$

where

R_N = resistance of the nichrome wire

R_F = resistance of the charged area

* Registered trademark, Rohm and Haas Corporation

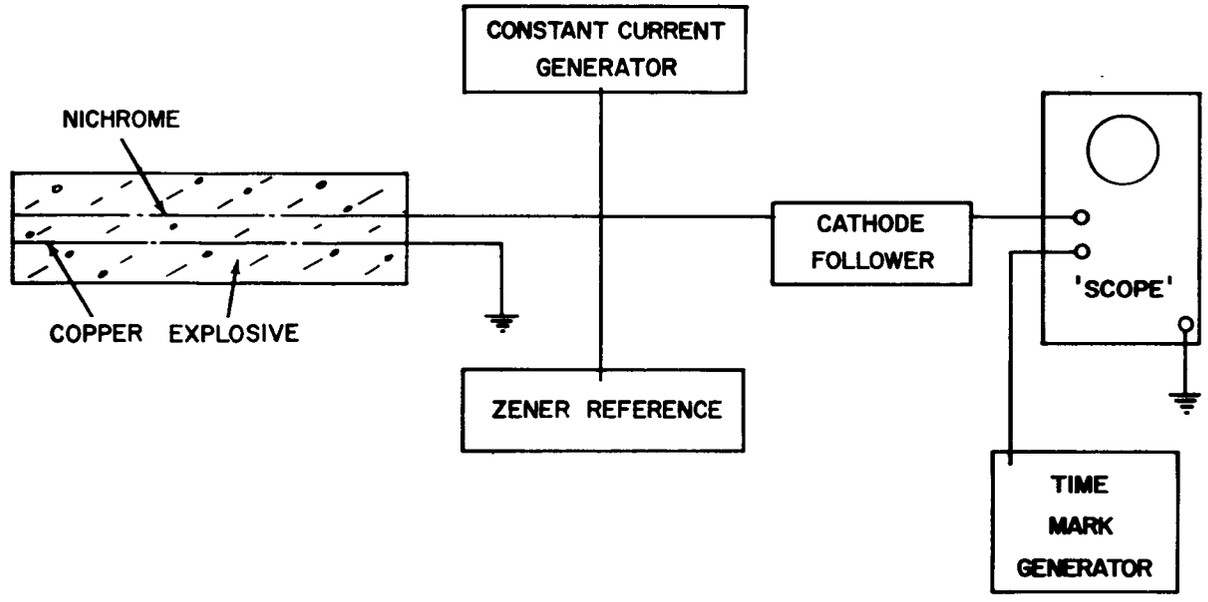

FIG.1 SCHEMATIC OF ELECTRONIC APPARATUS

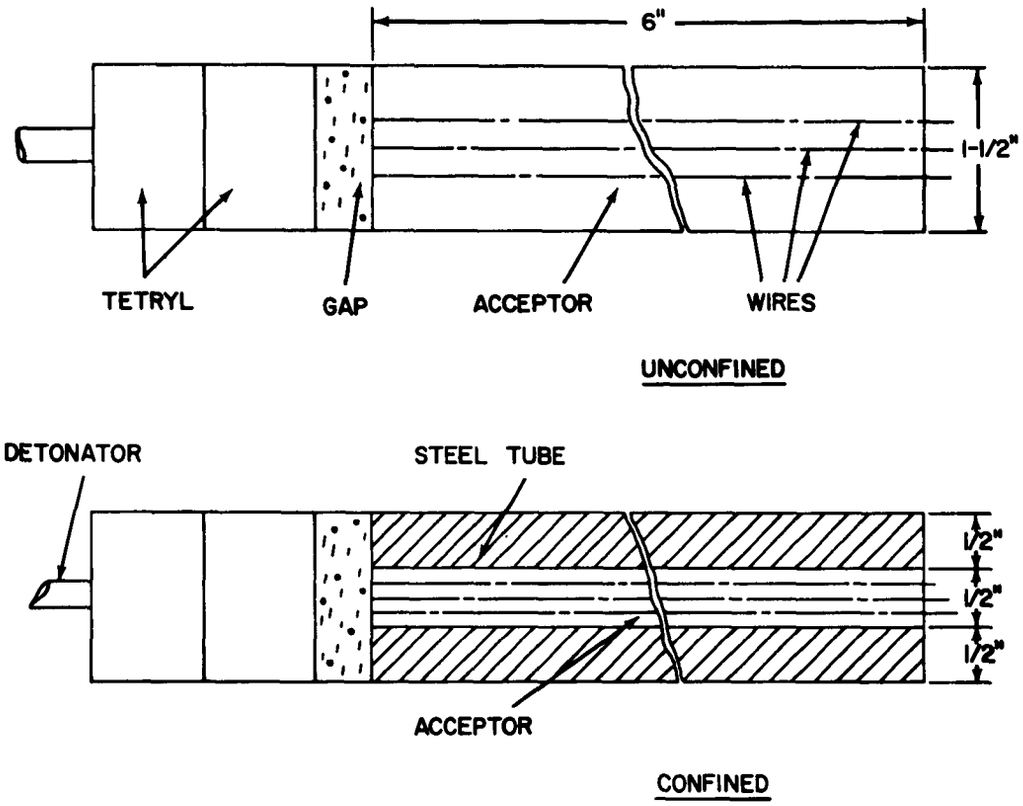

FIG. 2 CHARGE ASSEMBLY

For a detonation the charged area is a thin zone of high conductivity, R_F is approximately equal to zero, and the potential measured is directly proportional to the resistance of the nichrome wire, which in turn is proportional to the length of the wire left in the circuit ahead of the detonation front. Therefore the change of potential, measured as a function of time, can be converted to a distance-time curve from which the velocity of the detonation front can be obtained.

As the gap between the donor and the acceptor is increased, the energy transmitted to the acceptor is decreased until a 50% probability of detonation for the acceptor is obtained. At this stage, in many instances, there is a transition from deflagration to detonation which requires some finite period of time (a transition time). In such a transitional region, the charge can be low in density, and diffuse in area; R_F, the resistance of the reaction area can be large (many times that of the nichrome wire). The voltage measured would be determined by the sum of both nichrome and reaction zone resistances and thus provides only a qualitative description (location) of the reaction area.

To separate the resistance R_N from R_F and thereby obtain more quantitative data, a second copper wire was cast in the charge. The system now consisted of three wires; a common ground wire (copper) cast down the axis of the charge, a second copper wire to measure the resistance of the zone, and a nichrome wire. The copper has little or no resistance, thus any potential measured between the copper wire and ground would be determined by the resistance of the reaction area. From the known constant amperage and measured voltage, the resistance of the copper system (copper-ionized zone-copper ground) can be calculated and subtracted from the resistance measured in the nichrome system. Thus under conditions for which the reaction area is thin i.e., a front, it is possible to follow the position of the front in the explosive and obtain quantitatively the change in position and velocity of the reaction zone as well as the change in resistance (conductivity or ionization) of the reaction zone as a function of time, assuming the zone is uniform over the three wires. Under conditions for which the reaction area is diffuse, its resistance can still be measured but its position will have to be established by some other means than the present instrumentation.

II. TESTING THE ELECTRONIC SYSTEM

The first tests used cast Comp B and cast pentolite in confinement (Fig. 2) and were devised to determine the feasibility of using two separate electronic systems in a single charge. Each charge contained a copper wire down the axis of the charge

as the electrical ground. One-eighth inch off center another copper wire was placed and opposite this in the same plane one-eighth inch off center, the nichrome wire was placed. The wires were drawn taut and fastened into place before casting by a jig at either end of the steel tube. Two separate systems, each containing its own power supply and oscilloscope but having a common ground, were used (one for the copper-copper network and one for the nichrome-copper network). A dual beam oscilloscope (Tektronix 551) fitted with a Polaroid Land Camera was used to give a composite picture of both traces. This had the advantage of a common time scale, since both traces were initiated by the same pulse, and having both traces on the same photograph made it easier to reduce the data.

The voltage bias for the nichrome system was -94.8 volts and for the copper -82.7 volts. This difference of voltage was necessary to compensate for the resistance of the nichrome wire and thus permit the traces for both systems to appear on the oscilloscope at approximately the same time. The range of resistance which the entire system could register was 474 ohms for the nichrome system and 413 ohms for the copper system. A time scale (microseconds) and a voltage scale were recorded before each test. The charges were initiated by the standard tetryl donor and the oscilloscope was triggered by an ionization probe sandwiched between the tetryl pellets. The nichrome wire (AWG No. 40) had a resistance of 2.347 ohms/cm. which gave a total of approximately 35-36 ohms for an average length of charge of 15.24 cm. (6 inches). The Plexiglas gap ranged from 1.42 to 1.46 inches for Comp B; this is quite close to the 50% probability point (See Table 1).

Figures 3-5 show typical examples of the records obtained. For Comp B the results fell into two categories. The first, Fig. 3, shows a reaction which after a small transition period goes into detonation. The initial 12 to 13 microseconds was the time required for the shock to traverse a single tetryl pellet and the Plexiglas gap to the acceptor, at which time a sharp voltage drop occurs. (The ionization of the reaction zone increased.) The voltage on the copper trace does not drop to zero immediately, but gradually decreases and reaches zero volts after nine microseconds. (The ionization of the reaction zone was very large.) The nichrome trace is similar to the copper trace; however, it reaches a finite voltage and then decreases linearly with time. The reaction was in detonation over the linear protion of the nichrome trace. During the detonation, the resistance of the reaction zone was very small (see copper trace) and the zone proceeded down the charge at a constant velocity, reducing the resistance of the nichrome wire linearly (see nichrome trace).

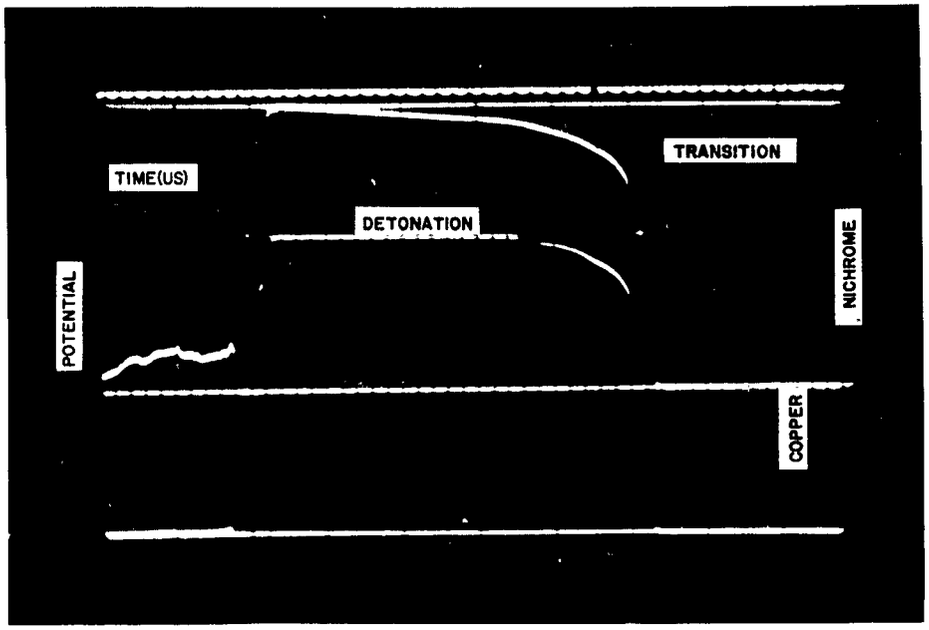

FIG. 3 – COMPOSITION – CONFINED – 143 CARD GAP

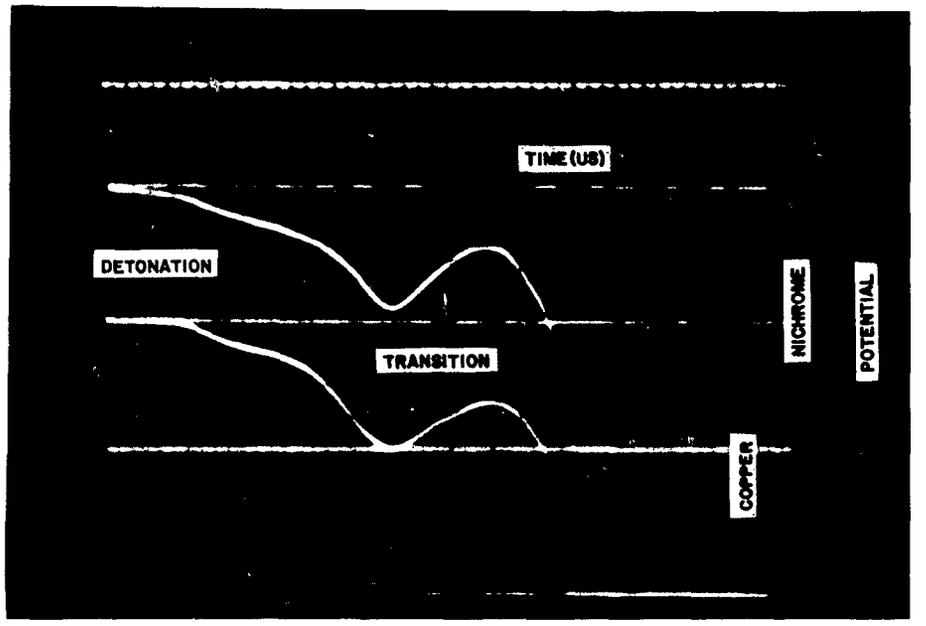

FIG. 4 - COMPOSITION B-CONFINED-145 CARD CAP

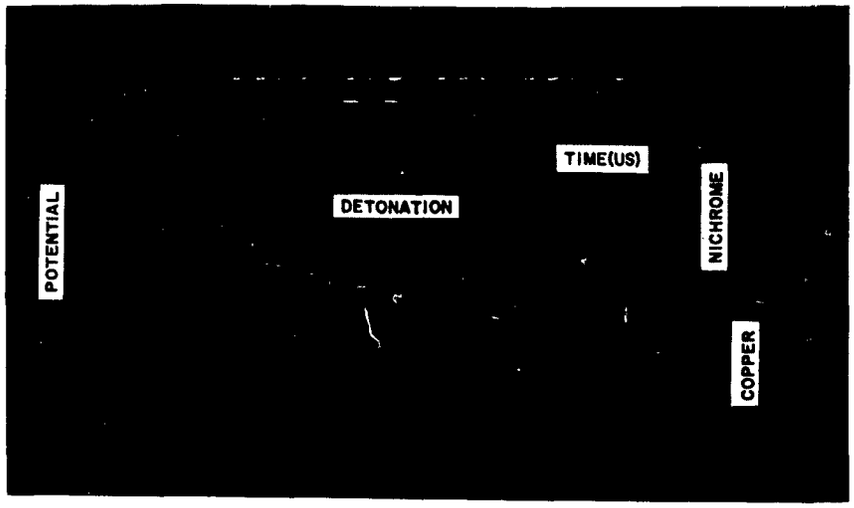

FIG. 5A – PENTOLITE – CONFINED – ZERO CARD GAP

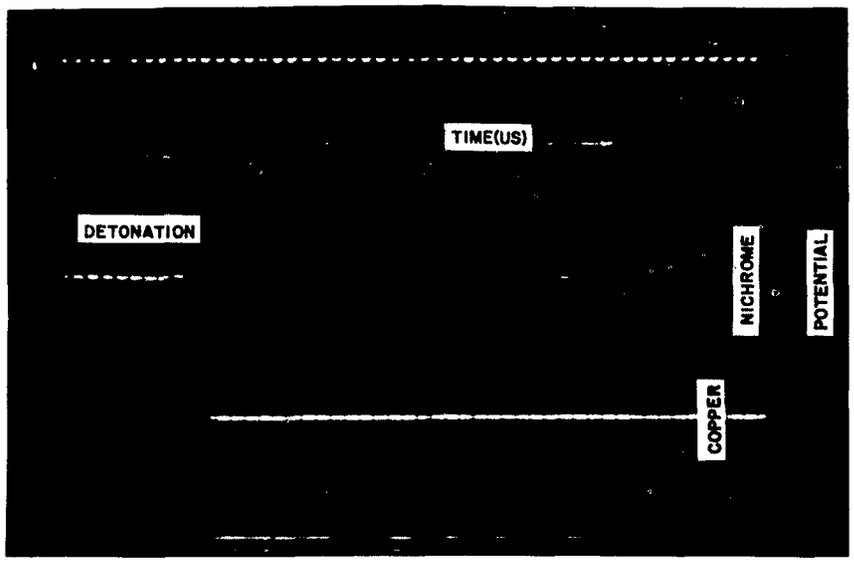

FIG. 5B – PENTOLITE – CONFINED – 200 CARD GAP

The second category for Comp B (Fig. 4) is somewhat more complex. The total transition period existed for thirty microseconds before detonation was obtained. During this period, the voltage reached a minimum and reversed itself. Apparently the ionization was decreasing and the reaction was failing. Eventually steady state detonation was obtained. This apparent reversal of the reaction (S-shaped curve) has been observed by other investigators. In the present work, it was obtained only in the highly confined charges, and it has not yet been determined whether it is a phenomenon associated with the circuitry (or some other incidental condition of the experiment) or whether it reflects the actual situation in the transitional region of the explosive. Moreover, in this marginal situation, it is quite possible that the reacting area is diffuse and that the nichrome to ground wires are shorted over an appreciable length rather than at a well defined point.

Table 1 contains the results for the four experiments run with Comp B. Each card making up the gap (column two) is 0.01 inch thick. The transition time (column three) is the period measured from the time the shock enters the acceptor to the time at which detonation first appears. The fourth column lists the positions in the charge where detonation occurred. Finally, the detonation velocity is given in column five. The detonation velocities listed for the third and fourth tests were measured from the relatively short portions of the traces (see Fig. 4). This may account for the lack of precision in the four measurements, but does not account for the low accuracy. The detonation velocity of Comp B is given in the literature (7) as 7.9 mm/microsecond.

TABLE 1 - COMPOSITION B - confined*

Expt. No.	Gap, No. Cards	Transition Time μsec	Position of Detonation cm	Detonation Velocity mm/μsec
2/60	142	4.3	<1	6.97
3/60	143	4.7	1	7.13
4/61	145	31.5	9.3	6.08
7/62	146	30.4	9.3	5.86

*These results are based upon the nichrome wire system

Pentolite, the second explosive used in this phase of the work, was also investigated near its 50% gap value. In contrast to Comp B, pentolite does not show a transition period during which the voltage is reversed. When pentolite detonates, the resistance in the reaction zone goes from off-scale (>400 ohms) to practically zero; the transition to detonation occurs almost instantaneously. At zero gap there is little or no delay time from initiation to detonation; however, as the gap is increased the delay time (time measured from the point of arrival of the shock front at the pentolite surface to detonation) becomes large, indicating an incubation period. Figure 5 compares the records obtained for a zero gap and for a 200 card gap. There appears to be no correlation between the data, delay time or position of detonation (see Table 2), and the size of the gap. The detonation velocity read from the trace is much higher in most instances than the value (7.5 mm/microsecond) found in the literature (7).

TABLE 2 - PENTOLITE - confined*

Expt. No.	Gap Cards	Delay Time μsec	Position of Detonation cm	Detonation Velocity mm/μsec
7/68	0	0.5	0	7.88
9/69	195	23.6	2.4	8.67
5/67	200	21.7	2.2	8.97
1/65	205	22.5	2.4	8.20
8/69	205	31.3	4.9	8.47
3/66	206	19.9	0.7	7.37
2/66	210		No reaction	

*Calculated from the nichrome system only

It is obvious from the data obtained that both precision and accuracy of the position measurements are low. This has resulted from viewing the region 400 to 0 ohms to study as much of the pre-detonation period as possible. (The actual burning to detonation transition presumably covers the range of thousands to 0 ohms.)

The oscilloscope traces are limited by the instrument to a constant area. In all cases the calibration lines are set to

include the maximum available area. What is varied is the magnitude of the voltage which can be observed in this area. Thus the accuracy to which a voltage can be determined is decreased as the voltage scale is increased. At a calibration of -94 volts, the precision is between 1 and 2%. This is equivalent to approximately five ohms or a length of two cm. of nichrome wire and a corresponding uncertainty in the location of the detonation zone. This error can be compounded in the transition zone where the potential must be obtained from both copper and nichrome records in order to determine the position and velocity of the front in the charge.

To observe the transition zone in its entirety, it is desirable to have a large potential bias so that the total ionization range from zero to infinity can be measured. This, however, reduces both the accuracy and precision of the measurements. If the potential drop between the systems can be cancelled electronically so that the voltage across the nichrome wire can be recorded in a lower voltage scale, the position of the reaction zone can be measured more precisely. Furthermore, a second record of the potential drop in the copper system can be made under a larger voltage bias to obtain greater coverage of the transition period.

III. THE DIFFERENTIAL OSCILLOSCOPE

As a result of the previous analysis, the experimental system was supplemented with an additional oscilloscope (Tektronix - type 53/54D) which was used to subtract the potential drop of the copper system (-82.7v) from the nichrome system (-94.8v). The resulting records obtained from the differential oscilloscope had a voltage scale of -12.1 volts and thus afforded greater precision. In effect this will follow the motion of the reaction zone without the complicating factor of the resistance due to the reaction zone. The supplemental system was tried in unconfined Comp B charges.

Figures 6 and 7 are typical records of a charge which detonated and a charge which failed. The "S" trace obtained for the confined Comp B charges above were not found here. Fig. 6A is quite similar to Fig. 3. The corresponding differential trace (Fig. 6B) is quite different. The differential trace suggests a stationary front lasting 3 μsec and located approximately four centimeters inside the charge. (Since this interpretation seems unlikely, it is more probable that the charged area created by the transitional reaction is a diffuse one and that conduction between the nichrome and ground wires is occurring over an appreciable length of these wires.) After this lapse of 3

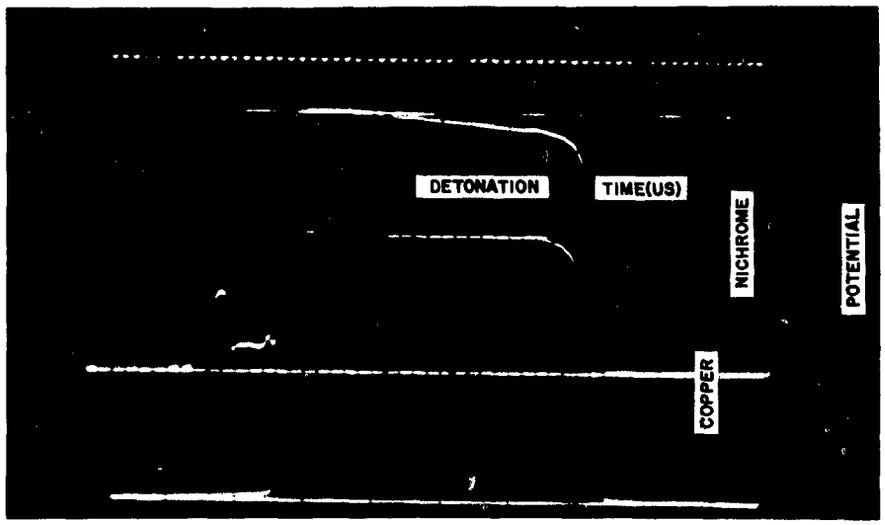

FIG. 6A – COMPOSITION B – UNCONFINED – 160 CARD GAP

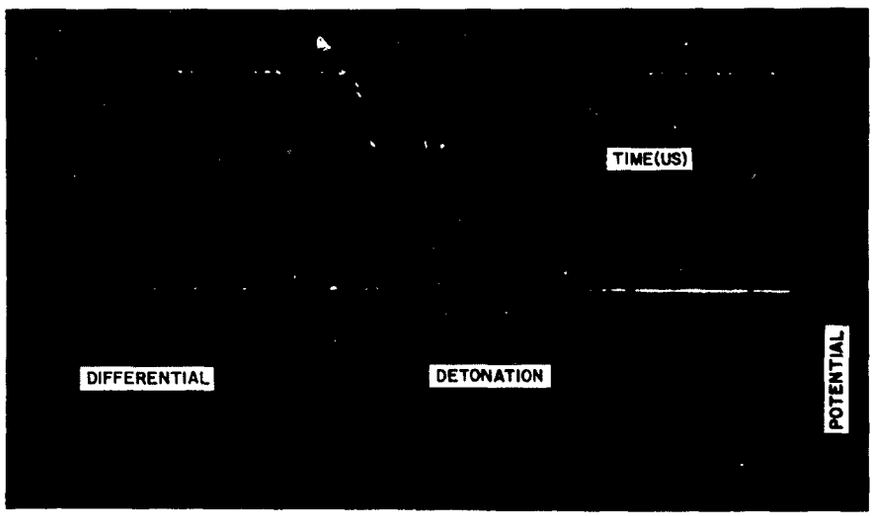

FIG. 6B – DIFFERENTIAL RECORD – COMP. B – UNCONFINED – 160 CARD GAP

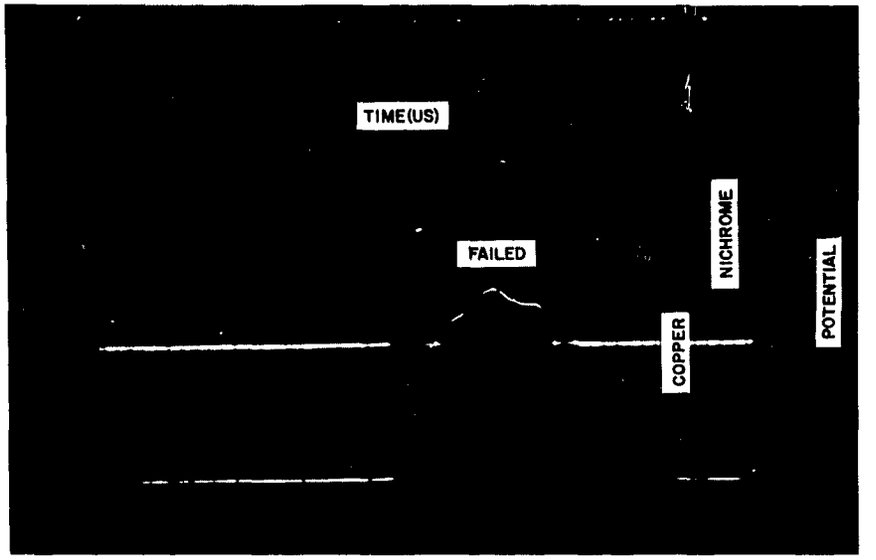

FIG. 7A-COMPOSITION B.-UNCONFINED-168 CARD GAP

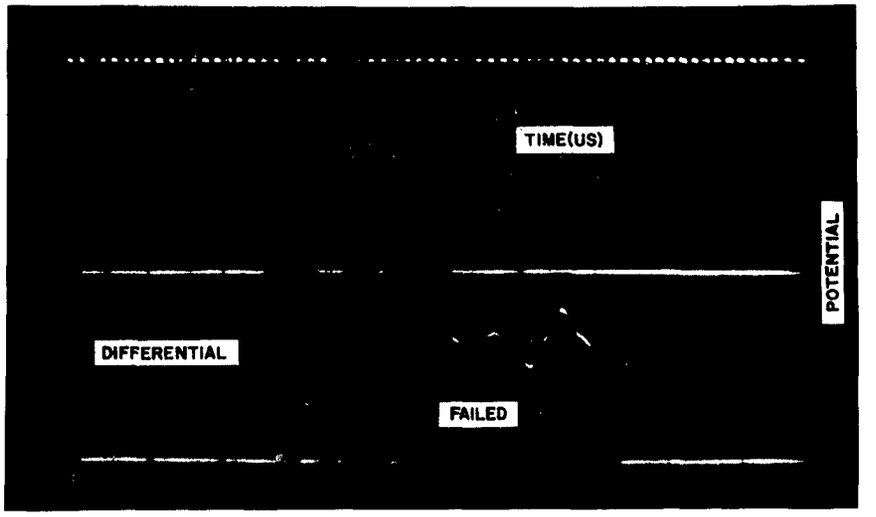

FIG.7B DIFFERENTIAL RECORD-COMP. B-UNCONFINED-168 CARD GAP

microseconds a detonation front has evidently formed and it moves down the charge at a constant velocity. Figure 7 is a record of a reaction which failed to detonate.

Because of the voltage scale used, the differential traces can be read with more accuracy than either the nichrome or copper traces. A 1 to 2% error will give a maximum error of 1.2 ohms or 0.5 cm. of nichrome wire; this is a four fold improvement over the previous method.

In many of the records, due to experimental difficulties, the base line for the calibration was not obtained. The trace made by the active sweep during the test, before the explosive went into reaction, was used in place of the calibration and was taken as -12.1 volts. This was used to obtain the results listed in Table 3.

TABLE 3 - COMPOSITION B - unconfined

Expt. No.	Gap Cards	Transition Time μsec	Position of Detonation cm	Velocity mm/μsec	System
3/73	160	10.7	1.7	6.88	Nichrome
		10.7	4.1	6.80	Differential
8/78	160	4.4	2.7	7.95	Nichrome
		4.4	4.8	7.38	Differential
9/79	162	No record			Nichrome
		8.3	2.0	6.59	Differential
6/76	162	These charges did not go into detonation (Fig. 7)			
5/75	165				
4/75	168				

The 50% point for the charge used here was approximately 162 cards, as compared to 143 cards (6) for bare Composition B, cast without wires. Apparently the wires, cast in the charge, sensitize the explosive slightly. The average velocity obtained from the small number of experiments made, based upon the "differential trace", is 6.92 mm/microsecond which is definitely below the 7.9 mm/microsecond cited in the literature (7) at a density of 1.70 g/cc. The spread between the results is quite large and, of course, the possibility exists that there may be two different rates for Comp B since a similar situation has

been observed for TNT (see below). The only conclusion from these tests is that detonation at the 50% gap occurs within the charge and not at the gap-acceptor interface.

At this point there still existed an uncertainty as to the validity of the results obtained. The electronic system was still unstable and unreliable, and it was quite possible that some of the phenomena observed were due to the electronic system rather than to the chemical reaction. A complete description of the electronic system, the modifications and tests made on it will be forthcoming in a subsequent report. The following tests were made after the system was modified.

IV. WIRE ALIGNMENT

Cast TNT, Bare and confined in heavy walled tubing such as used above, was tested. The TNT was chosen since it is the less energetic component of Comp B and probably contributes to the low unstable velocities (inverted curves) found in the confined Comp B tests.

Several of the bare charges were x-rayed after they were cast (Fig. 8), at 0° and 90° about the axis of the charge, to determine the homogeneity of the casting and the alignment of the wires in the casting. Some pores were found at the ends of the charge, but overall, the castings were good. The wires, however, were not aligned. Apparently, the wires expanded when the hot cast material was poured over them. As the casting cooled and solidified, the wires were trapped in the solid material and did not return to their original positions. This variation in distance between the copper and nichrome wires and the ground wire down the axis of the charge, could account for a portion of the inaccuracy in the data. It is assumed that the reaction zone is symmetrical about the axis of the charge and that the copper and nichrome wires are subjected to the same conditions. If these wires are displaced and the distance from copper to ground is different from the nichrome to ground distance, the results obtained by the differential could be inaccurate to an extent depending upon the magnitude of the resistance in the zone.

The data obtained from the experiments are listed in Tables 4 and 5. Figures 9, 10, and 11 are typical oscilloscope records. Precision and accuracy of these data are restricted by the same difficulties discussed above. The records were made using a large potential bias which decreases the accuracy of the measurements. However, the electronic system did respond well. The rise time from off-scale resistance to on-scale resistance (470 ohms or less) occurred in less than a microsecond.

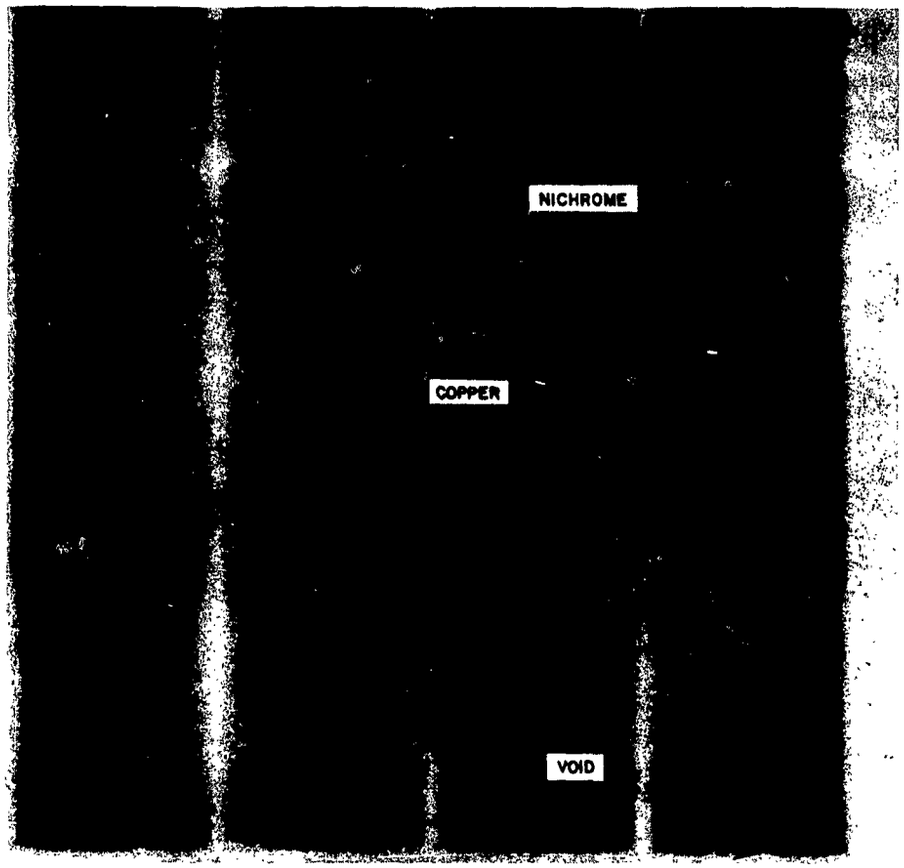

FIG. 8 – X-RAY OF TNT CHARGES

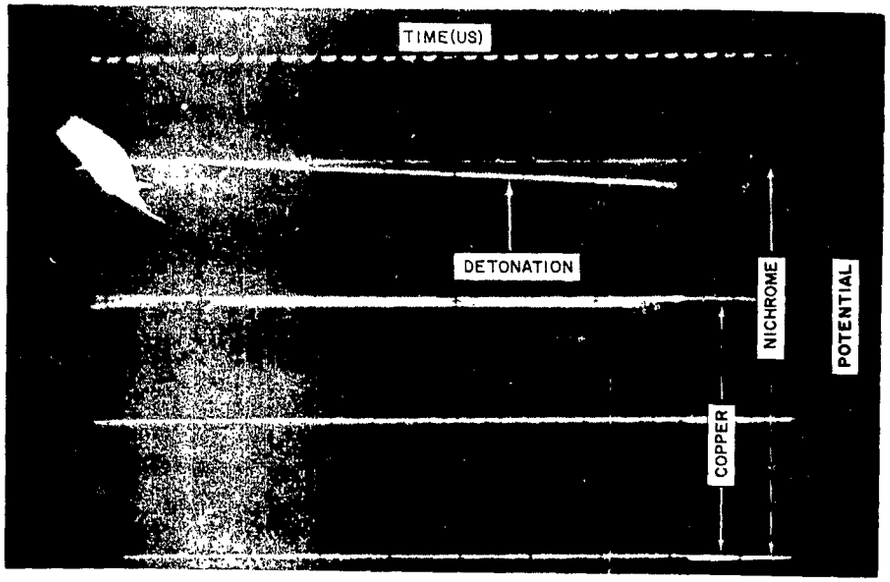

FIG 9A-TNT-CONFINED-50 CARD GAP

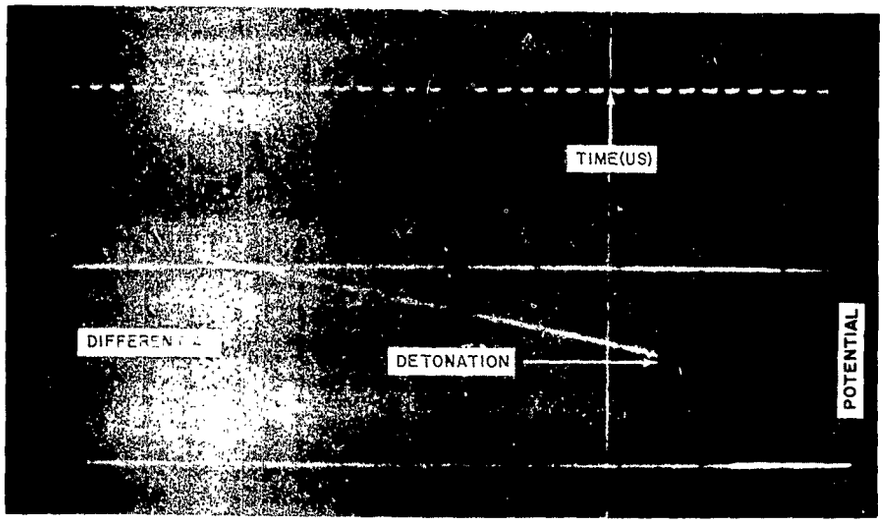

FIG 9B-TNT-CONFINED-50 CARD GAP

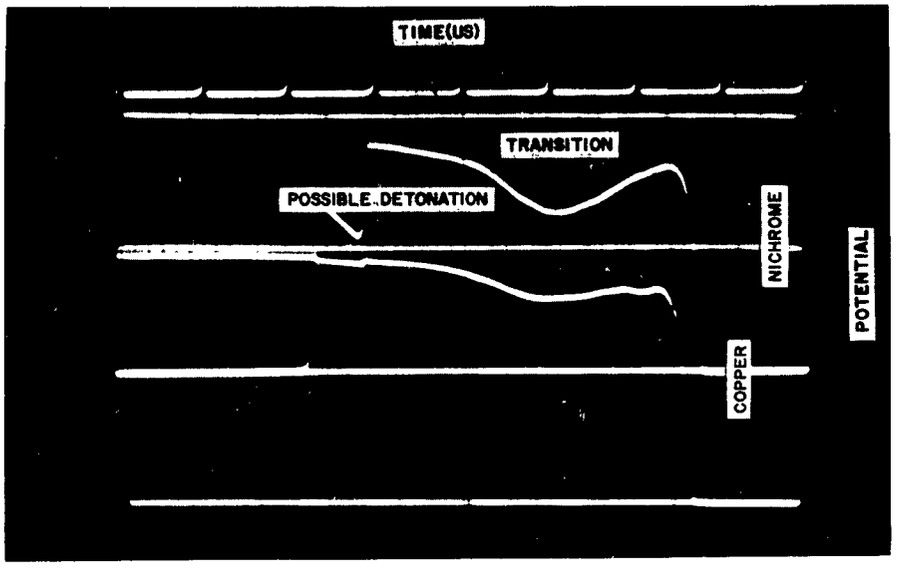

FIG. 10A—TNT—CONFINED—125 CARD GAP

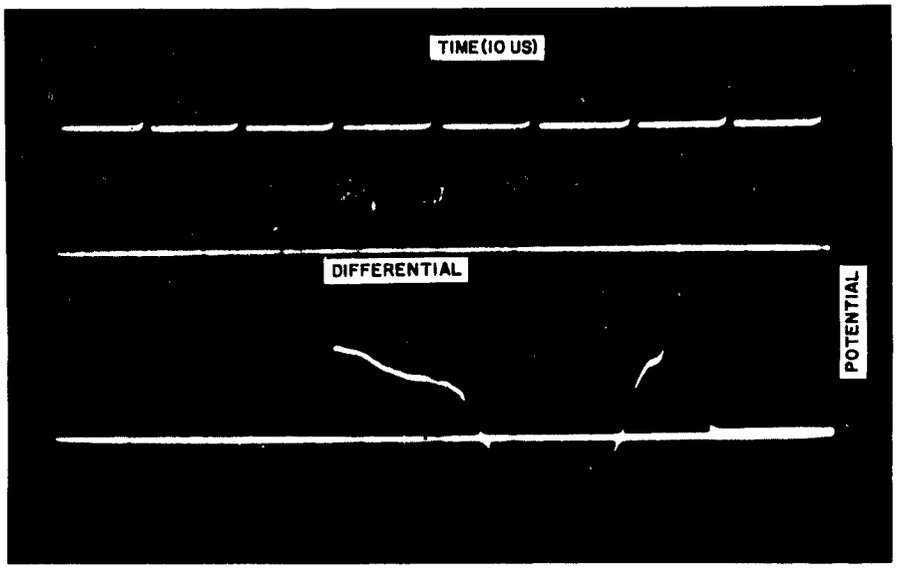

FIG. 10B—TNT—CONFINED—125 CARD GAP

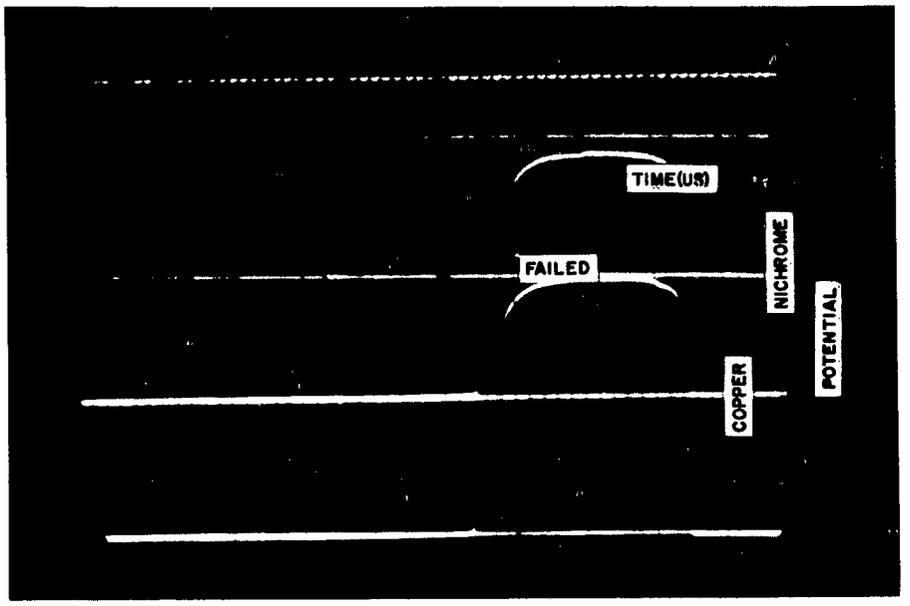

FIG. IIA-TNT-BARE-100 GAP CARDS

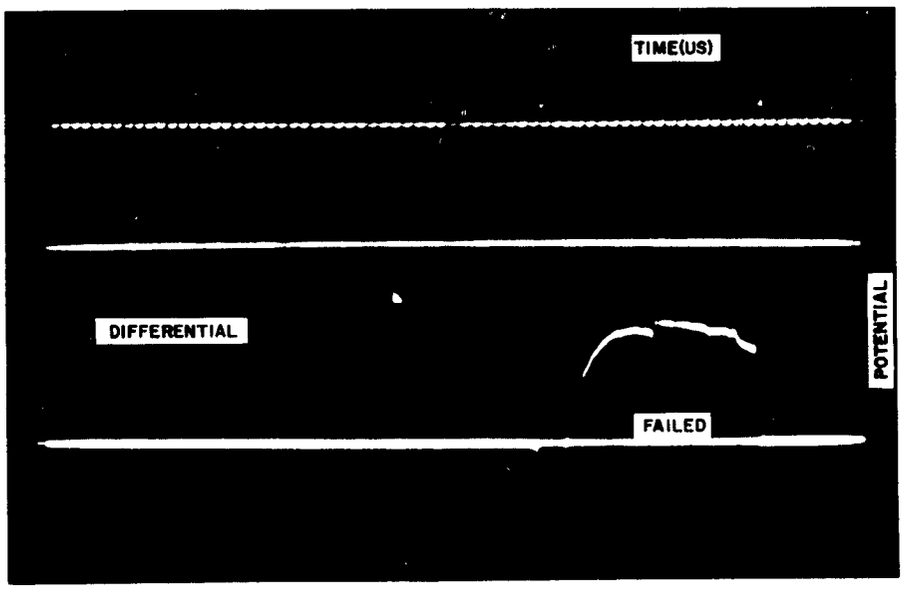

FIG. IIB-TNT-BARE-100 GAP CARDS

TABLE 4 - TNT - unconfined

Expt. No.	Gap No. Cards	Transition Time μsec	Position of Detonation cm	Detonation Velocity mm/μsec	System
3/95	0	<1	0.3	7.07	Nichrome
		<1	1.2	6.19	Differential
7/1	25	1.6	-3.6	7.48	Nichrome
		No record	-	-	Differential
8/1	25	-	No record	-	Nichrome
		0.7	1.7	5.90	Differential
9/2	25	<1	0.0	7.26	Nichrome
		<1	2.0	5.92	Differential
4/95	50	<1	0.0	5.40*	Nichrome
	50	0.9	3.0	4.30*	Differential
5/95	70	Failed - no detonation			

* Probably failing

TABLE 5 - TNT - confined

Expt. No.	Gap No. Cards	Transition Time μsec	Position of Detonation cm	Detonation Velocity mm/μsec	System
1/84	0	<1	0	7.31	Nichrome
		No record	-		Differential
6/88		No record	-	-	Nichrome
	0	<1	0	7.43	Differential
7/89	50	No record	-	-	Nichrome
		1.1	1.4	6.65	Differential
8/90	50	<1	-2.8	7.01	Nichome
		<1	2.0	6.27	Differential
3/86	125	No record	-	-	Nichrome
		22.7*	Reaction*, but questionable detonation		Differential
5/88	125	27.6*	"	"	Differential

* These records show the inverted curve (Fig. 10). It appears from the record that a longer charge might have gone into detonation.

The records obtained from the TNT charges are quite similar to those obtained for Comp B. As the 50% point is approached, the transition period becomes quite complicated for the confined TNT, and the inverted curves similar to those found in the confined Comp B appeared (Fig. 10). The prolonged inverted transition periods were absent for the unconfined TNT as they were for the unconfined Comp B.

The velocity data for the unconfined TNT charges are approaching a good precision. The results obtained for each system are within 2 to 3%, although the velocities calculated from the nichrome records are consistently higher than the differential results. This may be due to the greater inaccuracies involved in the nichrome measurement, i.e., the compressed scale and the possible variable resistance of the reaction zone during detonation.

V. PROPER ALIGNMENT OF WIRES

In the next series of experiments, proper alignment of the wires in the charges was attained. A system was devised to maintain a constant positive tension on the wires at all times during casting. Fig. 12 is a schematic which shows the arrangement of the wires in the mold. The wires are fastened at one end of the mold and then are threaded through the moveable lock at the opposite end of the mold. The spring is compressed and the wires are secured in the lock. Thus as the wires expand and contract, the tension is adjusted by the springs and the wires are held taut in position. Several charges were cast and x-rayed. A great improvement is evident when Figures 8 and 13 are compared.

Unconfined Comp B was used in this phase and the data obtained are listed in Table 6. Only the results from the "differential traces" were considered. The nichrome traces could not be interpreted with any accuracy. They were used to obtain a qualitative check of the more accurate differential traces. The results listed are for the unconfined cast Comp B charges containing three wires (nichrome, copper, and a copper ground wire). As the gap was increased, the incubation time increased. This is reasonable since the increase in gap decreases the amount of energy which is transmitted to the acceptor. Thus it should take a longer period of time to reach detonation. The mean detonation velocity (Expt. 1-3) is 6.39 mm/μsec. The greatest deviation from the mean is about 1%. That is a welcome increase in precision, but still leaves most of the same problems that were outstanding at the end of the previous phase: failure to obtain good records for nichrome and copper traces as well as the differential, markedly lower

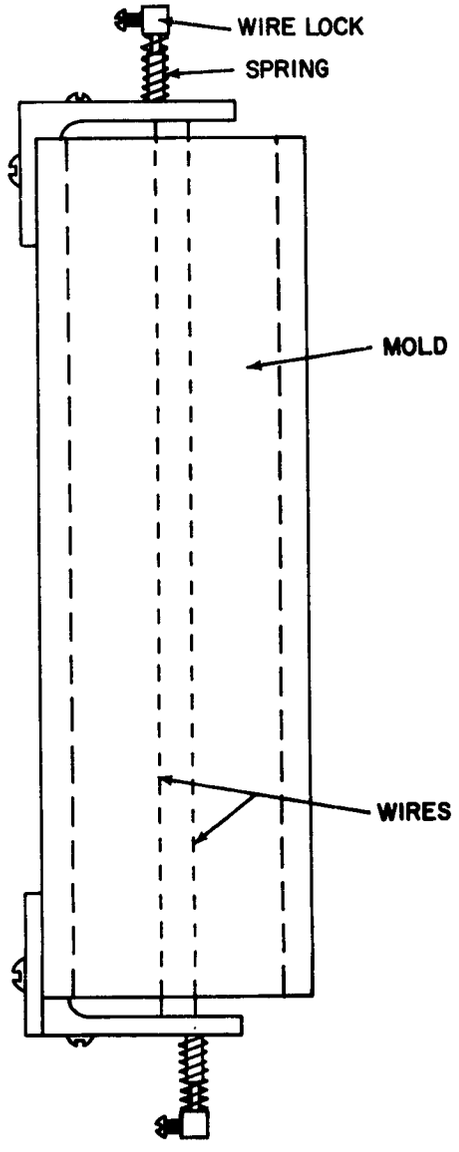

FIG. 12 MOLD ASSEMBLY

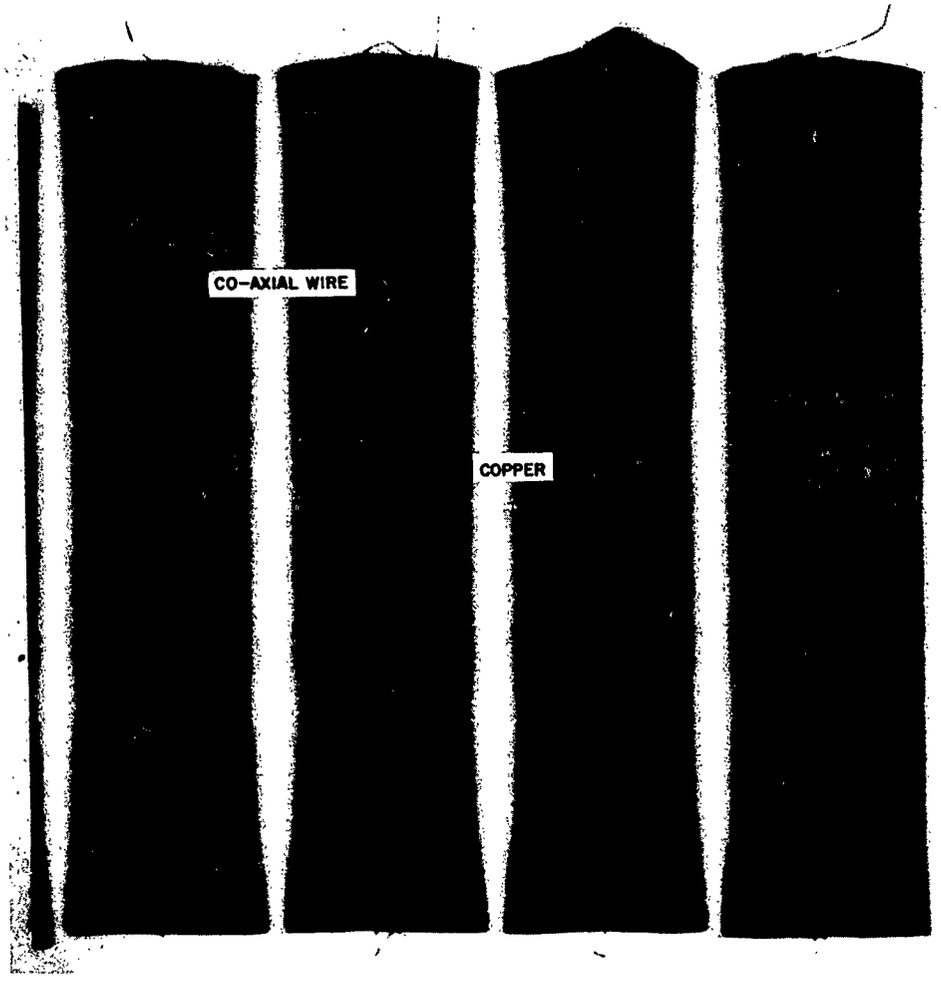

FIG. 13 – X-RAY OF CHARGES CAST IN MOLDS

TABLE 6 - RESULTS FROM DOUBLE-WIRE SYSTEM IN BARE COMP B

Expt. No. 96-6240	Gap No. Cards	Transition Time μsec	Position of Detonation cm	Detonation Velocity mm/μsec	Charge Length** mm
1-5	100	1.0	1.99	6.44	146
2-5	150	4.7	3.18	6.32	146
3-6	160	5.0	1.95	6.42	143
4-6	162	*	*	*	143
				Av 6.39	

* A reaction appeared to start after 5.5 μsec and at 1.85 cm., but it also appeared to be failing. Its approximate velocity from the differential trace was 5700 m/sec; from the nichrome trace (the only good nichrome trace obtained in this series) it was 8840 m/sec.

**Charge diameter 38.1 mm.

velocity value from the differential trace than that from the nichrome trace, and lower velocity value than that reported for steady state detonation of Comp B, as well as failure to reproduce established trend of run-distance vs shock strength. This last may be due to two factors: inadequacy of position measurement and effect of wires on charge sensitivity.

VI. THE CO-AXIAL WIRE

In considering the importance of exact wire alignment to insure that the nichrome and copper traces referred to exactly the same reacting area of the charge, it was decided to investigate the use of a coaxial wire in conjunction with a copper ground wire. This insures that the nichrome and copper traces arise from the same location of the reacting explosive, but it also introduces other problems such as: are the nichrome-ground and copper-ground systems independent, and what will short the two circuits - a charged area, a pressure zone, or both?

The co-axial wire* consists of a nichrome wire, insulated from a copper tube which sheathes the wire. The outside diameter of the copper tube is 0.018 inches and the diameter of the nichrome wire (no. 40) is 0.003 inches. Effectively the nichrome wire measures the resistance over a cross-sectional zone which is 0.0075 inches longer than the zone measured by the copper system. For a zone of 0.125 inches, this is a difference of 6%. Both wires, as a unit, will vary in the same manner if the cable should be kinked or curved. For large resistances (during the transition periods), the specific resistance of the zone will be high. The resistance of the nichrome wire should read somewhat higher than the actual value. However, knowing the ratio of lengths of the respective zones and the resistance of the zone as measured by the copper system, it is possible to correct the resistance measured by the nichrome wire. In the detonating phase, where the resistance of the zone is fairly small compared to the resistance of the nichrome wire, it can be neglected.

Several charges were cast using the co-axial wire under tension. Composition B was used, both confined and unconfined. The bare charges were 1½ inches in diameter while the confined charges were cast in six inch long tubes of the same stock of steel tube used in the NOL gap test (1.427 in. I.D. and 1.875 in. O.D.). Test results are given in Table 7.

---

* Wire was obtained from the Precision Tube Company

TABLE 7 - RESULTS FOR CO-AXIAL SYSTEM IN COMPOSITION B

Expt. No. 96-6240	Gap No. Cards	Transition Time μsec	Position of Detonation cm	Detonation Velocity mm/μsec		Charge Length mm
Bare Charges						
5-7	125	5.6	3.6	6.30[a]	7.58[b]	146
6-6	165	14.5	6.2	6.34	9.24	146
				Av. 6.32		
Confined Charges[c]						
7-8	141	12.3	5.7	7.17	-	152
8-8	143	11.2	2.6	7.00	9.36	152
				Av. 7.08		

a The differential traces were used

b From the nichrome traces

c Confined in gap test tubes 1.427 in. I.D. and 1.875 in. O.D.

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Results for the unconfined charges show good precision for the detonation velocity and agreement with the double-wire results on velocity (Table 6). However, the co-axial system seems to give larger values for both transition time and position of detonation. The confined Comp B charges were fired at gaps much smaller than the 50% value (201 cards under standard conditions, perhaps 10% less with the wires present). The measured velocities check very well those obtained from the nichrome trace in earlier work (Table 1, 2/60 and 3/60), but unhappily not that read from the nichrome trace in shot 8/8. Again the transition time and position of detonation are suspiciously larger than the comparable values in the double wire work of Table 1. However, the detonation velocity results are sufficiently promising to justify some further exploratory work with the co-axial system.

The data listed in Table 8 were obtained from the copper traces, experiments 7-8 and 8-8. The data were reduced and plotted on a semi-log scale as conductance (reciprocal ohms) after the time scale was adjusted in order to have the two experiments coincide in time. Figure 14 is a plot of these data through which a straight line can be drawn. The copper trace of 3/73 (unconfined Comp B, double wire system) also exhibits a linear display, but of different slope.

TABLE 8 - RESISTANCE OF THE TRANSITION ZONE

Time μsec	Potential volts	Resistance ohms	1/R mhos
Expt. No. 7-8			
15	17.1	85.0	0.012
16	9.4	46.7	.021
17	5.3	26.3	.038
18	2.7	13.4	.074
19	1.1	5.5	.183
Expt. No. 8-8			
15.2	16.6	82.8	.012
15.6	11.7	58.2	.017
16.2	9.2	45.5	.022
16.6	7.2	35.5	.028
17.2	5.7	28.3	.035
17.6	4.4	21.9	.046
18.6	2.3	11.4	.087
19.6	1.0	5.2	.192

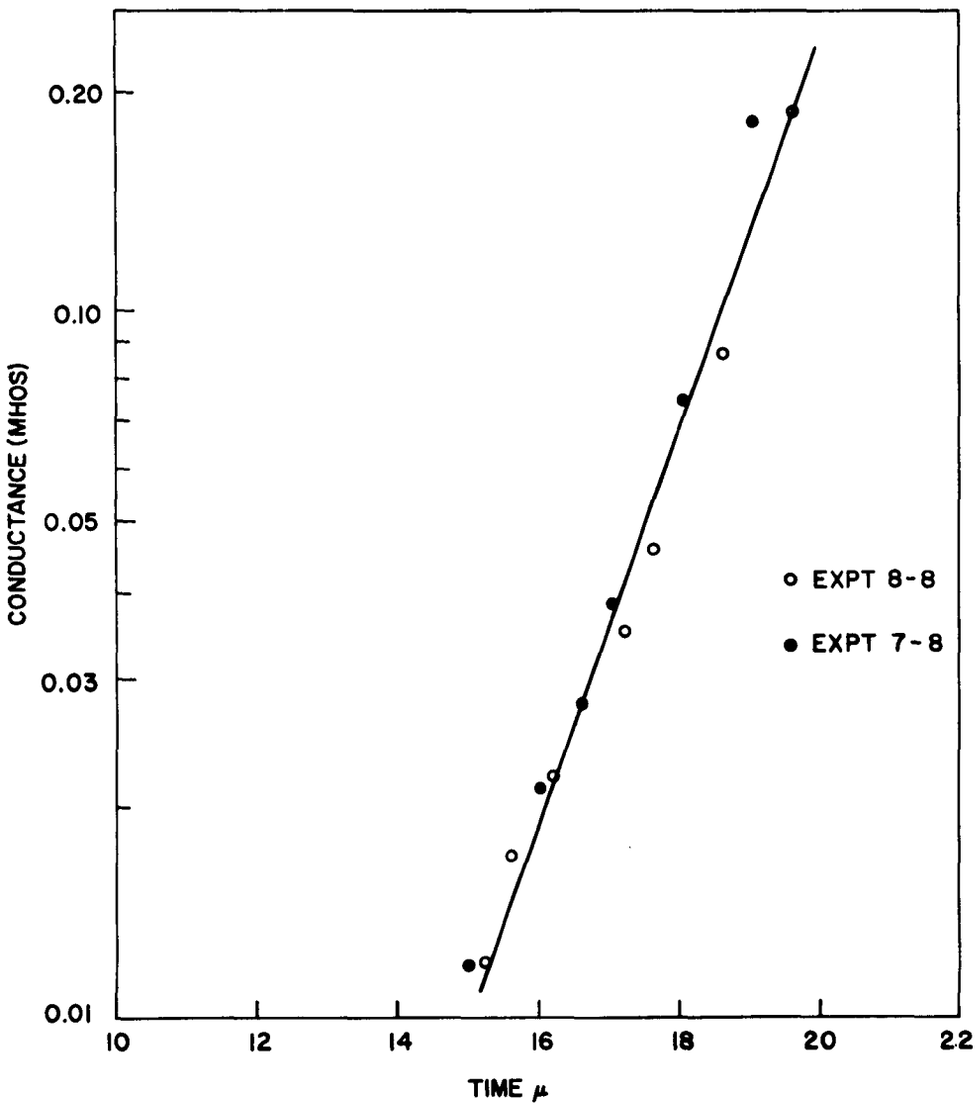

FIG. 14 CONDUCTANCE VS. TIME

VII. SUMMARY OF INFORMATION FROM PRELIMINARY DATA

Although the data reported here were obtained in tne course of developing the continuous wire technique and, therefore, cannot be considered as quantitative or as reliable as those that will be obtained with a perfected technique, they can nevertheless be used to obtain semiquantitative information which is new. As described above, the present records have been found inadequately precise for distance measurements. This and the various preliminary electronic circuits have made both distance and velocity measurements of little quantitative value. On the other hand, the time scale, within its limitation of 0.4 μsec rise time (imposed by the constant current supply), has proved most satisfactory. Consequently, as much information as possible has been developed from a knowledge of the charge length (152.4 mm, unless otherwise noted) and the time at which various events appear on the records.

In every case, tetryl boosters of 2 in. diameter x 2 in. length were used; their density is 1.51 g/cc and detonation velocity D, 7.1 mm/μsec. At zero gap, such a booster would not be expected to overboost cast Comp B (ρ_o = 1.72, D = 7.940) or cast pentolite (ρ_o = 1.64, D = 7.530). It might, conceivably, overboost cast TNT (ρ_o = 1.61, D = 6.780), and one case of this is suggested in the data.

Table 9 contains the data for highly confined charges of 0.5 in. diameter. For pentolite, at zero gap, the assumption of initiation at the shocked surface seems justified in view of the small total delay time (zero within the precision), the agreement between computed and ideal detonation velocities, and the small length of run to be expected in an unconfined charge - about 2.5 mm at 113 kbar (9). The detonation velocity was computed by dividing the length of the charge by the time interval for which the record showed a constant rate.

The same procedure and same justification was used for confirming a steady-state rate in the confined TNT at zero gap. For Comp B, no zero gap shot data are available; however, a 100-card gap shot of unconfined Comp B (see Table 10) exhibited a total delay time to detonation of only one μsec. Hence to a fair approximation, detonation can be considered to have started at the shocked surface. On this basis, the rate computed for Comp B is 6.9 mm/μsec. This is definitely lower than the steady state value of 7.94 and too high for no reaction of the less sensitive component, TNT. Comp B is RDX/TNT/Wax, 59.4/39.6/1.0, and if the TNT were reacting to give

TABLE 9 - TRANSITION DATA OBTAINED FROM CONFINED CAST CHARGES*

Shot No.	Gap No. Cards	Pressure in H.E.[a] kbar	Total Delay Time[b] µsec	Time at Constant Velocity Δt, µsec	Computed Velocity[c] mm/µsec	Maximum Measured Velocity[d] mm/µsec	Run Length[e] mm	Remarks
			Pentolite					
7/68	0	113	0.5	20.3	7.507	7.530	0	7.53 mm/µsec used in computations.
9/69	195	22.0	23.6	12.2			61	
6/68	195	22.0		13.4			52	
5/67	200	21.0	21.7	13.5			51	
1/65	205	20.0	22.5	10.5			74	
8/69	205	20.0	31.3	11.2			68	
3/66	206	19.7	19.9	13.5			51	
	210	18.8	No evidence of reaction				-	
			Composition B					
2/60	142	37.0	4.3	19.5	-	7.940	14	7.1 mm/µsec used in computations
3/60	143	36.6	4.7	21.0			3	
4/61	145	36.2	31.5	6.0			109	Records show 93 mm. of decreasing-increasing-decreasing resistance before constant velocity established.
7/62	146	36.0	30.4	7.0			102	
			TNT (hot cast)					
6/88	0	112	0.3	23.0	6.626	6.780	0	6.78 mm/µsec used in computations
7/89	50	75.0	1.1	21.1			9	
8/90	50	75.0	0.5	19.9			17	
3/86	125	41.2	After 23 to 28 µsec, S type curve similar to last two runs of Comp B obtained. However, these leveled off at low rates of 2 to 5 mm/µsec					
3/88	125	41.2						

All records from nichrome wire only, except for TNT where differential records were used.

*Confinement - a steel tube of 0.5 in. I.D. and 1.5 in. O.D.

Notes to Table 9

a. By use of Hugoniot data for unreacted TNT and Comp B-3 (7). Pentolite curve by interpolation on density.

b. The total delay time or time required to establish the constant velocity regime is the measured time at the start of this regime minus the transit time from the trigger probe to the location of the start of the regime. This transit time consists of time for detonation to travel through one tetryl pellet (3.5 μsec) plus the shock transit time through the Plexiglas gap.

c. Calculated as charge length (152.4 mm) divided by duration of constant velocity regime (Δt). This assumes that the regime started at the gap/explosive interface.

d. NOL values (5) at slightly higher charge densities than those reported previously (8).

e. The run-length is the distance from the shocked surface to the interior location at which the constant velocity regime starts. It is computed by

$$X_s = 152.4 - D\Delta t.$$

TABLE 10* - TRANSITION DATA OBTAINED FROM UNCONFINED CAST CHARGES**

Shot No.	Gap No. of cards	Pressure in H.E. kbar[a]	Total Delay Time[b] μsec	Time at Const.Vel. Δt(μsec)	Computed Velocity[c] mm/μsec	Max. Meas. Velocity[d] mm/μsec	Run Length[e] mm	Comments
			Composition B					
1-5†	100	53.0	1.0	21.1	6.9	7.94	0	Rate of 7.1 used in computation; see text.
2-5†	150	35.0	4.7	17.4			23	Charge length 146 mm.
3-6†	160	31.2	5.0	18.4			12	Charge length 143 mm.
3-73	160	31.2	10.7	17.7			27	
8-78	160	31.2	4.4	18.1			24	
4-6†	162	30.7	Reaction just failing					
9-79	162	30.7	8.3	24.0			-18	Charge length 143 mm.
6-76	162	30.7	Reaction, but failed					Negative value evidence of lower velocity than 7.1 mm/μsec used in computation.
5-75								
10-80	165-168	≤30.5	Reaction, but failed					
4-75								
			TNT					
3-95	0	112	-0.5	20.4	7.47	6.78	0	Rate of 6.78 chosen. Shot 3-95 believed over-boostered although this is rare for cast TNT.
8-1	25	88.3	0.7	22.5	6.77		0	
9-2	25	88.3	0.5	22.0			3	
4-95	50	75.0	0.9	25.2			-18	Negative value evidence of low metastable velocity. If reaction assumed to start at surface, rate is 6 mm/μsec; if reaction begins after a run length, rate is lower.
5-95	70	Evidence of reaction for 21 μsec, but leveled off at about 2 mm/μsec.						

*See notes Table 9 - Present Table from Differential Records Only.
**Charges 1.5 in. diam. x ca. 6 in. long.
†From Table 6; these charges prepared and fired much later than others of this table.

its metastable velocity of about 5 mm/μsec (10), then by simple additivity (8), Comp B would exhibit a metastable velocity of about 7.1 mm/μsec. This rate has been used in computing the location of the transition point in both the confined and unconfined charges of Comp B.

The confined pentolite data are interesting in a number of ways. First, the run lengths indicated are an order of magnitude larger than those found with the wedge test (9). If the Sultanoff curve (11) for pentolite (P vs run length) is valid and can be extrapolated (it goes only to 25 mm), the values found here are in a reasonable range. Second, the data indicate the large variation to be expected under minimal shock initiation; this can be attributed to the difficulties of reproducing cast charges exactly and of reproducing the hot spot pattern within the charge. Third, in every case except one, the average shock velocity prior to detonation i.e., run length/total delay time, is sonic or subsonic. Finally, if the total delay time is converted to the corrected delay time* the delay times so obtained are 13 to 22 μsec - again an order of magnitude greater than those found in the wedge test (9). Of the three explosives examined, only pentolite exhibited these very long delay times and pre-detonation runs (51 to 74 mm).

The data for confined Comp B is of interest in two ways: the presumptive evidence of a metastable velocity near the 50% point (use of 7.1 mm/μsec in the calculations give run-lengths consistent with the values read from the records) and the appearance, slightly nearer to the 50% conditions, of a long (30 μsec) interval in which some reaction is evidently occurring, but for which the records cannot be easily interpreted. A similar phenomenon occurs in the confined TNT and, indeed, may occur in the confined pentolite quite near the 50% point. It was not observed in the latter, but no runs were made between a gap of 206 cards (go) and one of 210 (no-go). Its occurrence in Comp B is attributed to the large amount of TNT in this charge; on the same basis, it would be expected in pentolite (PETN/TNT, 50/50). Near the 50% point, many of the average shock velocities prior to detonation for the Comp B appear subsonic (as did those for pentolite) although the overall velocity of shock plus predetonation reaction (runs 4/61 and 7/62) appears supersonic.

---

* The corrected delay time is that part of the total delay time, as defined in note b of Table 9, in excess of the time required for a front travelling the entire run-length at the high velocity constant rate to reach the position of detonation.

The total delay times for confined TNT are so small that the measurement here is meaningless except to indicate detonation very near the shocked surface. Although the run-length of 9 to 17 mm at 75 kbar is in good agreement with the wedge test value of 10 to 20 mm (10), this is probably fortuitous in that the present treatment cannot be expected to distinguish between 0 and 10 mm.

The data for unconfined charges of Comp B and TNT appear in Table 10. Notably lacking in these data is any evidence of the apparent fading and resurgence of reaction found in the confined charges. The phenomenon is therefore associated, in the present work, with the electrical measurements when the charge is encased in a metal tube although similar records for uncased charges have been reported by Clay, et al (3).

Again the metastable rate of 7.1 mm/μsec gives run distances for Comp B consistent with those read from the records. In this connection, comparison of the run-lengths with those of Table 3 is of particular interest: those from the nichrome trace are smaller than those from the differential trace and also closer to the values given in Table 10. Run 9-79 shows a definitely metastable rate (even lower than 7.1), but this reaction like the other two at the 162 card gap may be failing.

It should be remarked that this sample of Comp B either differs from that used on previous runs or has had its 50% initiating pressure lowered by the presence of the wires; it exhibits a 50% point at 30.7 kbar whereas controlled tests without the wires gave 37 kbar for unconfined charges (12). Presence of the wires would be expected to increase heterogeneity of the charge and thereby enhance hot-spot formation; this, in turn, would decrease the required pressure at the 50% point.

The first three charges of unconfined TNT, like the confined, showed essentially zero delay times and run lengths. Charge 4/95 exhibited a definitely metastable rate, and transition to this high though metastable rate probably occurred at an interior point.

VIII. IMMEDIATE OBJECTIVES OF FUTURE WORK

The first improvement needed for future work is in circuitry and recording so that all records (copper, nichrome, and differential traces) are obtained with each shot and can be clearly read. This was true for only two of the shots of this report (8/78 and 3/73), and for these two shots, the curve from the differential trace did not coincide with the curve obtained by taking the difference of the curves from the copper and

nichrome traces. This may be due to difference in precision (low for copper and nichrome traces, higher for the differential), but it might also be a distortion caused by the circuitry. Obviously we must obtain enough records to establish that the differential trace is indeed the potential difference desired.

An adequate number of clear records is also necessary to explain the differences in detonation velocity shown by the nichrome and by the differential traces. Similarly, although the two traces seem to give the same measure of total delay time, the run-length read from the differential trace is greater than that from the nichrome. Again, difficulty with or distortion by electronic circuitry is suggested.

Once the adequacy of the circuitry is established, it will be possible to continue improving precision of the measurements by selecting the proper potential difference to yield the maximum information with the desired precision in the region of special interest. In other words, certain sections of a record can be magnified although this may result in the loss of the record in other sections.

In several series of experiments a precise (repeatable) detonation velocity was measured, but it was so much lower than the steady-state value, that it was considered (perhaps improperly) inaccurate. Under the proper conditions, it has been demonstrated that the nichrome trace of a double-wire system measures the same steady-state velocity as that determined optically (13). Moreover, it has been established that TNT can exhibit a constant, metastable velocity of about 5300 m/sec (7). It is entirely possible that explosives in which TNT is a major component, such as pentolite and Comp B, can also exhibit metastable behavior. Resolution of this possibility will require more measurements at high shock conditions (assure steady-state rather than metastable propagation) as well as study of explosives containing no TNT e.g., DINA.

There have been repeated suggestions that wires within the charge affect its sensitivity. This must be clearly determined and the limits of reproducibility of charges containing wires established.

After these primary objectives are met, the improved method can be further modified as follows: (a) use of a magnified voltage scale to obtain more precise distance measurements in special regions of some runs, (b) use of supplementary probes for distance markers in transitions exhibiting the S shaped

curves, and (c) further comparison of coaxial wire records with single wire records.

Although much development remains to be done, the progress to date is encouraging and indicates an eventually successful adaptation of the continuous wire method to the study of pre-detonation phenomena.

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Measurement	MEAU	Solid	SOLI	Electronic	ELCO
Sensitivity	SENV	Shock	SHOC	System	SYST
Propellants	FUEL	Shock wave	SHWV	Differential	DIFE
Explosives	EXPL	Front	FRON	Oscilloscope	OSCS
Continuous	CONU	Resistance	REST	Alignment	ALIG
Wire	WIRE	Conductance	COND	Coaxial	COAX
Transient	TRNN	Technique	TECN	Method	METD
Phenomena	PHEO	TNT	TNTE		
Ionization	IONI	Composition B	COPB		
Sensor	SENO	Pentolite	PENI		
Detonation	DETO	Electrical	ELEC		
Predetonation	PRDT	Reaction	REAT		

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Naval Ordnance Laboratory, White Oak, Md.
(NOL technical report 63-136)
PROGRESS REPORT ON ADAPTATION OF CONTINUOUS WIRE METHOD FOR MEASURING TRANSIENT PHENOMENA, by Irving Jaffe and Donna Price. 7 June 1963. 38p. illus., tables. NOL tasks FR-59 and NOL 323. UNCLASSIFIED

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2. Explosives - Measurements
3. TNT
4. Pentolite
5. Composition B
I. Title
II. Jaffe, Irving
III. Price, Donna, jt. author
IV. Project
V. Project

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