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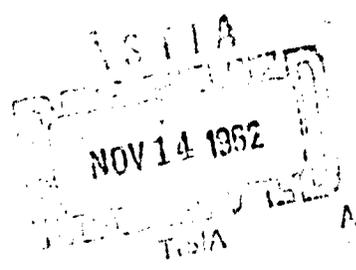
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**IONIZATION IN THE SHOCK INITIATION OF  
DETONATION**

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## IONIZATION IN THE SHOCK INITIATION OF DETONATION\*

### Abstract

Conduction-time ( or distance) curves measured by both the "parallel" and "perpendicular probe" methods in receptors of the "card gap", "SPHF plate" and plate impact methods of sensitivity are correlated and compared with the pressure-time (or distance) curves obtained by the aquarium method. Results indicate that detonation is initiated by a shockwave only upon establishment of (dilute) plasma conditions in the shock front. The ionization wave that establishes this coincidence is initiated at the inert barrier or SPHF plate after a time  $\tau$  following transmission of the shock into the receptor. After formation, requiring a finite time, the ionization wave builds up in intensity at the SPHF plate, flashes forward into the receptor charge and apparently triggers detonation (at the instant of arrival of a critical level of ionization) at the shock front. Therefore, the pressure in the shock front, while an important factor in the shock initiation of detonation, may not be the only, or even the most important one; strong ionization may also be an essential factor. Shock initiation of detonation appears to require the development of a strongly ionized reaction shock.

### Introduction

Shock pressure on the one hand, and heat conduction or the plasma mechanism on the other, have been proposed for the mechanism of shock initiation of detonation in the "card gap"<sup>(1)</sup> and SPHF (shock pass, heat filter) plate<sup>(2,3)</sup> methods. The shock pressure mechanism is due to Ubbelohde,<sup>(4)</sup> Kistiakowsky,<sup>(5)</sup> and Jacobs.<sup>(6)</sup> It was concisely described by Grocock and Griffiths<sup>(7)</sup> as follows:

"Entry of an intense shock wave into a receptor charge raises the temperature and pressure of the explosive. This causes the explosive to decompose exothermally and, if the rate of reaction is sufficiently high, more energy is fed into the shock wave than is lost by dissipative processes. The shock wave, which already has a very high velocity, is accelerated and its amplitude is increased, causing a further acceleration of the reaction rate. There is thus

a smooth conversion of a shock wave into a detonation wave, i.e., into a self-sustaining, shock-propagated reaction governed by hydrodynamic laws."

The heat conduction or plasma mechanism<sup>(8-10)</sup> affirms the importance of pressure and chemical reaction build up in the receptor preceding initiation of detonation, but postulates heat conduction in the reaction zone.\* The plasma mechanism suggests also that heat conduction is made possible by the plasma character of the detonation reaction zone. This "internal plasma" was first recognized from results of electrical probe measurements of conduction in the reaction zone wherein free electrons at concentrations in excess of  $10^{18}$ /cc were discovered.<sup>(8,11)</sup> Recent studies have verified these results while raising the lower limit of electron concentrations in the reaction zone to  $10^{19}$  to  $10^{20}$  or more in Pentolite and Composition B.<sup>(12-14)</sup> Considerable evidence has been gathered which supports the conclusions that the internal plasma is a necessary element in the detonation process and that it is the primary source of the brilliant "external plasma" generated at all free surfaces of condensed detonating explosives.<sup>(15-21)</sup> On the basis of the "plasma model" the reason that the detonation wave from a donor charge does not propagate through the inert plastic cards of the card gap test, or through a glass, steel, lucite, or other inert barrier of the SPHF plate test, is because the barrier eliminates the essential (internal) plasma, while permitting transmission of a (pure) shock wave. Thus, the detonation wave from the donor is destroyed by the inert barrier between the donor and receptor, and the plasma state must be reformed in the receptor if the detonation wave is to reform in it.<sup>(8,9)</sup> The abbreviation SPHF which stands for shock pass heat filter, consequently has been applied to inert barriers because of this characteristic.

Clay, et. al., by means of electrical probe and shock pressure measurements, and by double-donor systems, demonstrated that detonations in the condensed explosives receptors are always initiated at the instant a delayed

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\*The importance of transport phenomena in detonation has been treated classically by J. D. Hilschfelder and C. F. Curtis (J. Chem. Phys. 28, 1130, 1147 (1958); 30, 470 (1959). Also A. K. Oppenheim and R. A. Stern gave an excellent review of mechanisms including the plasma (TN No. DR 7, Feb., 1960-AFOSR-TN 60-124, University of California.)

ionization wave (originating at the SPHF plate) overtakes the shock wave, and that this wave must run into the shock from behind such that each initiation wave "knows its own donor". When it simply collided with a shock from another donor moving in the opposite direction, no detonation wave was initiated. <sup>(20,21)</sup> Also mention is made of the work of Gipson and Maček <sup>(22)</sup> which showed that when a long, confined explosive charge is ignited in a closed tube by a spark, a pressure wave first develops followed by an ionization wave, and detonation is initiated when the pressure wave, which may be either in the stage of buildup or decay, is overtaken by the ionization wave.

#### Experimental

The experimental observations of ionization and pressure were made by means of the rotating mirror framing and streak cameras in conjunction with pin techniques similar to those used in the measurements of conduction in the external detonation-generated plasmas. <sup>(18)</sup> Both parallel and perpendicular probe techniques were used. Whereas single pairs of perpendicular probes were used in the earlier investigation, here double pairs were used, and the distance between them as well as the distance from the SPHF plate was varied, the signal from each pair of probes being recorded by a separate oscilloscope. This made possible the determination not only of the average velocity of the ionization wave, but also its acceleration properties and the direction of propagation of the various disturbances occurring prior to and after the establishment of detonation. The probes were first assembled and the Composition B explosive cast into the assembly, thus insuring intimate contact between the probe surface and the explosive. Since the cast explosive gives the probe support, small piano wires substituted for the larger, stiffer, copper-coated, steel probes used in the studies of Ref. 18. The circuit diagram for the probe system is shown in Fig. 1.

The SPHF barriers comprised glass, lucite, steel and water as the inert medium between the donor and the receptor charges. By virtue of the transparency of glass, lucite and water, the shock could be observed as it moved through the inert medium by backlighting with a high explosive flash-bomb in a manner analogous to that used in calibrations of the card gap test. <sup>(2)</sup> In

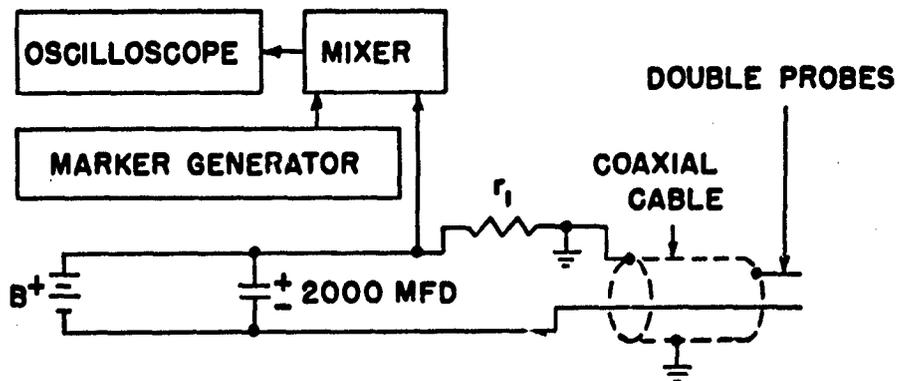


Fig. 1: Diagram of equipment for electrical probe measurements.

the case of steel, the time of the transit of the shock through the inert barrier was computed from the known (constant) shock velocity in steel. The donor charges were 5 cm diameter (d) x 20 cm long (L) cast Composition B. The receptor charges were also cast Composition B of 5 cm (d) with (L) being varied as desired, "long" charges having a length also of 20 cm. The method used in the pressure determinations is illustrated in Fig. 2a and b. (17,23,24) The setup of Fig. 2b is a modification of the aquarium technique in which the water is replaced by a 5 cm (d) cylinder of transparent lucite rod approximately 2.5 cm long. To transform the observed initial shock velocities transmitted into the "pressure gauge" material (water or lucite) the calibration  $p(V)$  curves measured in previous studies (23) were used.

To correlate the pressure measurements with the conduction data, perpendicular probe measurements were made simultaneously with the pressure measurements on the same charge. The probes were placed 0.5 cm from the end of the receptor charge immersed in the aquarium with care being taken that they were not wet by the water in the case of the assembly of Fig. 2a. The donor charge was then fired, and the resulting shock waves through the SPHF plate and the aquarium or lucite rod were recorded by the streak camera, and the conduction across the perpendicular probes were recorded by an oscillograph camera. The oscillograph was triggered in all cases by the detonation wave of the donor charge completing a circuit between two fine copper wires placed in a smooth V-notch filed in the end of the donor charge against the SPHF barrier. In the case of the use of water as the SPHF or inert barrier the trigger wires were taped against the side of the donor and the water contained in a polyethylene sleeve between the donor and receptor.

Finally, to determine if plate impact initiation exhibited the same type of ionization buildup as in the SPHF plate test 5 cm (d) x 20 cm (L) Composition B receptors with parallel probes 0.5 cm apart and starting 0.5 cm from the impact end of the charge were studied by the assembly shown in Fig. 3 using a plane wave explosive system as the plate driver.

The sensitiveness limit  $S_1^*$  varied somewhat from batch to batch of explosive. (3,17) Therefore, it was necessary to establish it carefully for each batch. Results here are expressed in terms of ratio  $S_1/S_1^*$  where  $S_1$  is the plate thickness and  $S_1^*$  the limiting thickness at which detonations occur.

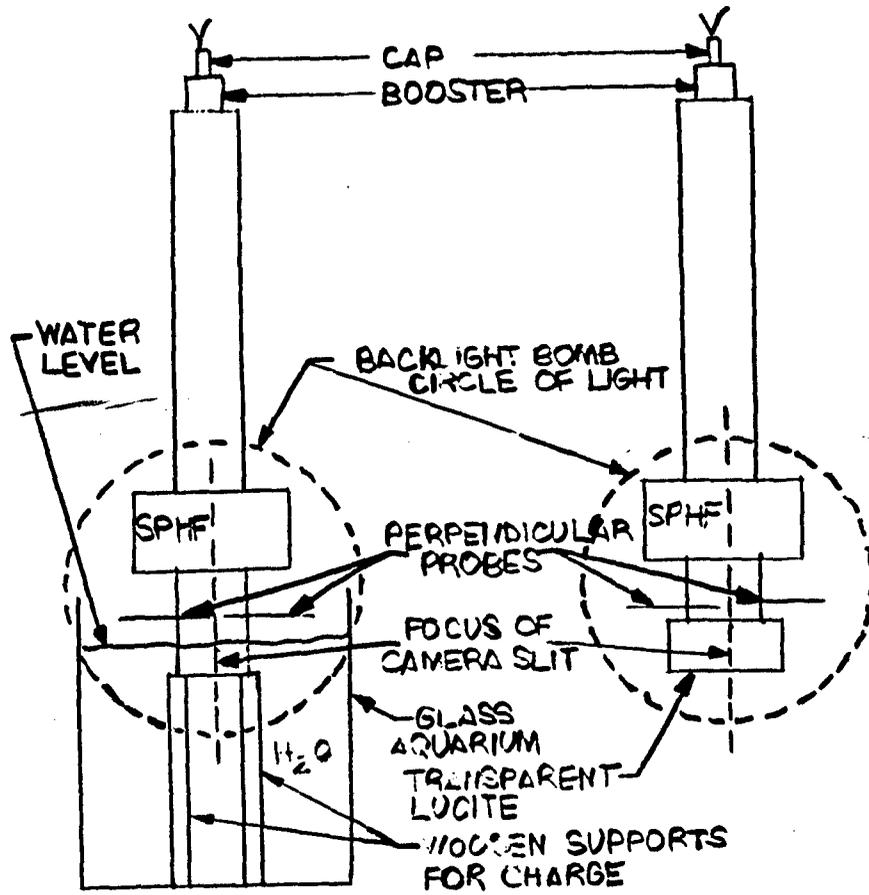
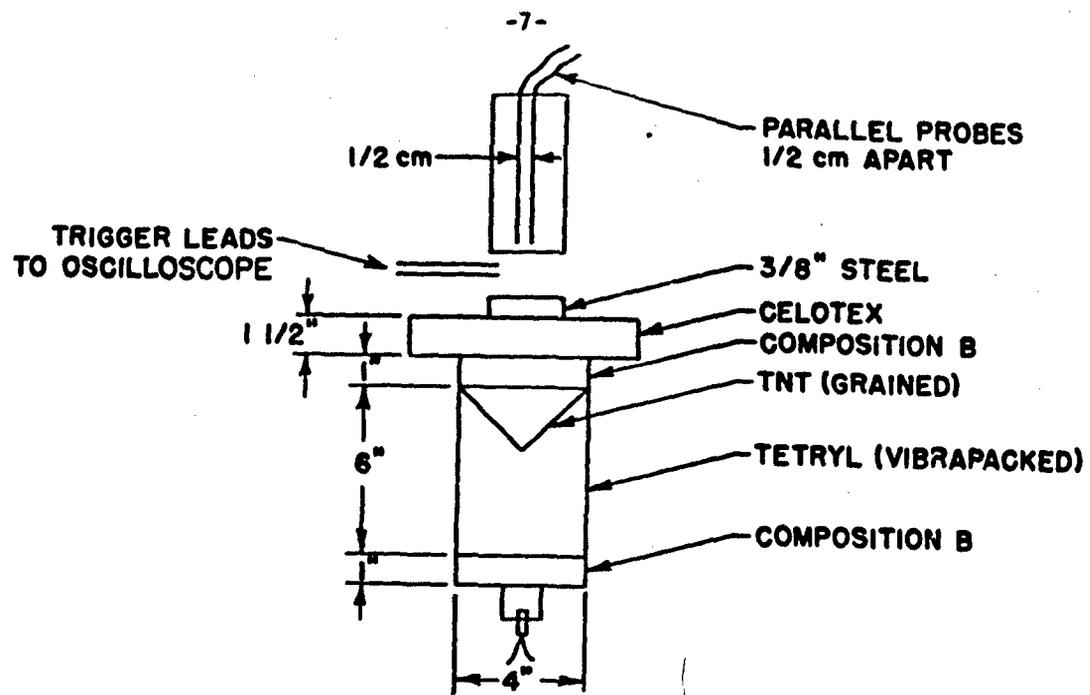


Fig. 2: Experimental setup used to determine pressure - distance and conduction distance curves simultaneously. (a) Aquarium method, (b) lucite method.



(a) Setup for initiating detonation in a receptor charge by means of an explosively driven plate. Ionization in the predetonation region measured by parallel probes.

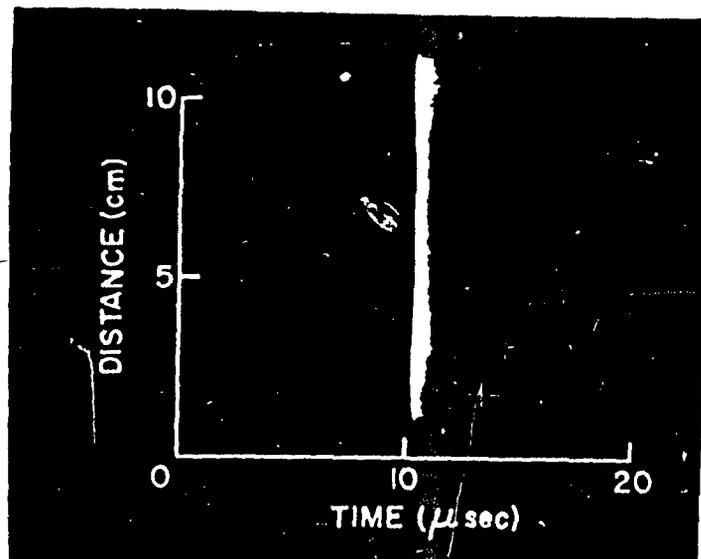


Fig. 3: (b) Reproduction of streak camera track showing emergent wave from plane generator.

Since we are concerned here primarily with conditions toward the sensitiveness limit  $S_1^*$ , most of the shots were made in the range  $0.85 < S_1/S_1^* < 1.05$ . Typical ionization wave traces obtained from the probe located 1 cm inside the receptor charge are shown in Fig. 4 both for glass and for lucite SPHF plates. Values of  $S_1^*$  ranges from 4.8 to 5.0 cm for lucite and 7.2 to 8.5 cm for glass. Values of  $S_2$ , the distance into the receptor where detonation occurred,  $\tau$  the time lag to obtain detonation in receptor, and the average shock velocity  $S_2/\tau$  were obtained from the simultaneous streak camera traces.

#### Results and Interpretations

Perpendicular probes: The first pulse in the conduction-time traces corresponded to an ionization wave resulting from the compression (and chemical reaction) produced by the initial shock wave. The second pulse seen on most of the conduction time traces was due to the reverse detonation wave, detonation generally being initiated in both directions in the receptor of the SPHF test. Sometimes, however, the reverse detonation wave did not develop, and the second peak was then absent. Initiation of a forward detonation wave but failure of the reverse wave occurred frequently near the sensitiveness limit and in small diameter receptors. However, it generally took place along the axis as well as along the periphery of the charge according to the results of correlated probe and streak camera studies. The third pulse, not always observed when the second one appeared, was due to reflection from the SPHF plate resulting from impact of the reverse detonation before the plate had finally desintegrated. This pulse may be amplified by the use of metal backing plates on glass and lucite and metal SPHF or completely eliminated by extending the period,  $\tau$ .

The data in Table I were obtained by correlating the streak camera traces with the corresponding conduction-time traces. The value  $t_1$  is the time to the first peak, measured from the instant of arrival of the shock wave at the receptor surface of the SPHF plate. The time  $t_2$  is the time to the second peak; it is related to  $\tau$  by the equation

$$\tau = t_2 - (S_2 - X)/D' = t'$$

where  $S_2 - X$  is the distance from a given probe to the plane where detonation

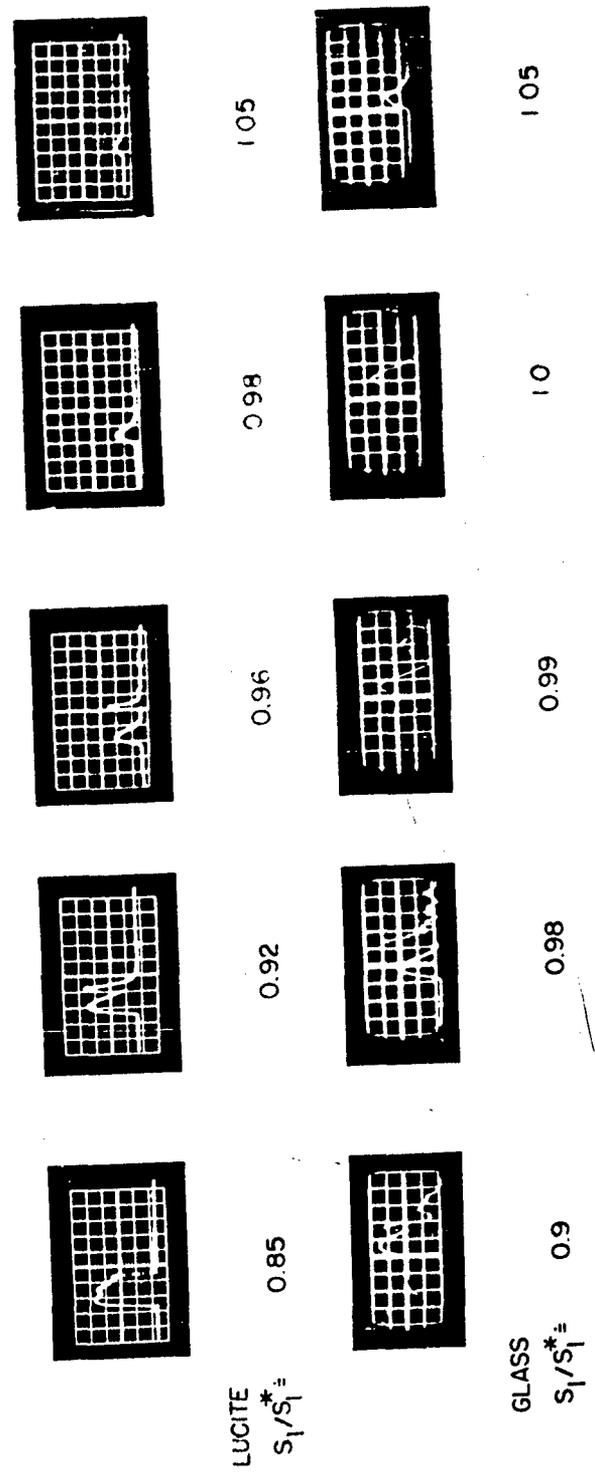
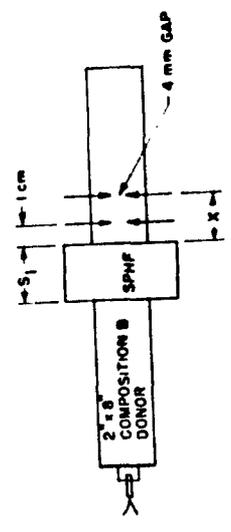


Fig. 4: Perpendicular probe traces of conduction 1 cm inside the receptor for  $0.9 S_1^* < S_1 < 1.05 S_1^*$ .

Table I. Data from perpendicular probes and streak camera traces recorded simultaneously in same (long) charge with lucite and glass SPHF plates.

SPHF Plate	No. of Shots	$S_1/S_1^*$	$\bar{\tau}_1$ ( $\mu$ sec)	$S_2$ (cm)	$\bar{\tau}_1$ ( $\mu$ sec)	$\tau_2$ ( $\mu$ sec)	$\frac{S_2 - X}{D_1}$ ( $\mu$ sec)	$\bar{\tau}$ ( $\mu$ sec)	$\frac{S_2 - X}{\tau - \tau_1}$ mm/ $\mu$ sec
Lucite	8	.98	20.2	6.05		n R*			7.5**
"	15	.97	17.2	4.5		n R*			5.9**
"	7	.85	5.95	1.75	3.9	6.6	1.5	4.9	12.0
Glass	3	.87	14.3	3.9	7.0	16.3	4.1	11.6	6.5
"	4	.89	12.5	3.8	7.9	16.4	4.0	11.8	7.3
"	2	.82	11.8	3.1	7.2	13.5	2.9	9.3	10.0

\* no return of detonation wave

\*\* Flash across velocity measured by double probe results over the last 0.5 cm before detonation

is initiated,  $\tau'$  is the effective rise time and  $D'$  the velocity of the reverse detonation wave. It should be noted that one measures an apparent time lag  $\tau'$  and corrects to the real time lag  $\tau$  by means of the streak camera trace as described in Ref. 8. The apparent time lag  $\tau'$  is the same as the real time lag  $\tau$  only if initiation of detonation occurs uniformly over the entire cross-section of the charge; if it occurs at a point on the axis  $\tau' - \tau = 3.0 \mu\text{sec}$ , the time for the spherical wave to propagate to the surface. The maximum value of this difference observed in this study was  $2.0 \mu\text{sec}$  showing that initiation generally occurs over a finite region or surface rather than at a point.

If one interprets that the peak of the first ionization wave in Composition B corresponds to the "flash-across" photographed in liquid explosives, then its average velocity between  $X$  and  $S_2$  is given by the extreme right hand column of Table I, and the resulting velocity characteristics are similar to those observed for the "flash-across" in liquids. (8,15,25) That is it was delayed at first but once formed, propagated at high average velocity to the shock front at which time normal high order detonation occurred. This interpretation seems reasonable because the luminosity of the "flash-across" in liquids is very faint, being barely photographable, and thus one would expect it to correspond to the region of maximum ionization in the rather broad ionization wave generated prior to the establishment of normal high order detonation. Though the determinations made in the above manner are quite inaccurate, the average "flash-across" velocity appeared to decrease as the ratio  $S_1/S_1^*$  approached unity. Measurements of the pressure-distance curve presented below for the same event showed that the flash across phenomenon is definitely not a hypervelocity detonation taking place in a compressed medium. (25,26) In fact, according to recent preliminary pressure measurements neither is the "flash-across" in liquids.<sup>27</sup> The mechanism of the initiation by shock apparently is the same in both liquids and solids. Detonation in liquid as well as solid explosive receptors initiated at the front of the shock wave, and not at the receptor surface of the SPHF plate. However, it is at this surface that the ionization wave begins.

Important information was obtained by studying the rise times of the ionization traces as a function of  $S_1/S_1^*$  and length into charges with lucite, and

the somewhat longer rise times with glass SPHF plates. Lucite transmits, as its fastest disturbance, a plastic wave and preserves relatively closely the shape of the p-t curve of the donor. (2) Fig. 5 shows the rise time  $t'$  with lucite SPHF plates as a function both of the thickness  $S_1$  of the barrier and the distance  $S_2$  into the receptor. Note that as the ionization wave approaches the shock wave, it "sharpen up", assuming a form progressively closer to its form in detonation, and that the rise time of the normal detonation wave of Composition B is about 1.5  $\mu$ sec.

The conduction-time curves were obtained for glass only at  $X = 1.0$  cm. The results showed greater rise time than for lucite at corresponding  $S_1/S_1^*$  ratios values ranging from 3.3  $\mu$ sec at  $S_1/S_1^* \sim 0.7$  to 4.8  $\mu$ sec at  $S_1/S_1^* \sim 0.98$ . As indicated above, the longer rise times reflect the influence at the higher velocity of the elastic wave relative to the plastic wave in glass. (20,21) This effect is shown below to be even more pronounced in its influence on the shape of the conduction-time traces with parallel probes. It is interesting that the average ionization rise time in the reverse detonation wave proved to be 1.1  $\mu$ sec for both glass and lucite SPHF plates. It was, therefore, steeper than in the forward detonation wave, a fact probably associated with a shorter effective reaction time in the reverse wave since part of the explosive reacts in the pre-detonation period.

Fig. 6 presents plots of reduced amplitude of the ionization wave vs distance for lucite, each plot being for a different value of  $S_1/S_1^*$ . Here the scale is based on unity for the amplitude of the ionization wave in the normal detonation wave. Note that the ionization in the predetonation regime was high and rose rapidly with distance into the receptor at  $S_1/S_1^* \ll 1.0$ , but as  $S_1/S_1^*$  approached unity, the ionization amplitude in the predetonation region remained small (in the range 0.2 to 0.4 all the way up to  $S \doteq 0.9 S_2$ ) for an appreciable time before undergoing a sudden rise to unity. The dotted curve shows the results obtained with lucite for short receptors of length only  $X + 0.5$  cm. The much lower ionization amplitude in this case  $S \ll S_2$  is due to reflection of a release wave from the free surface into the ionization wave before it passes over the probes. This result reveals a strong influence of pressure on ionization. The effect is more extensively illustrated in Fig. 7 which shows typical oscilloscope traces for a short and a long receptor charge.

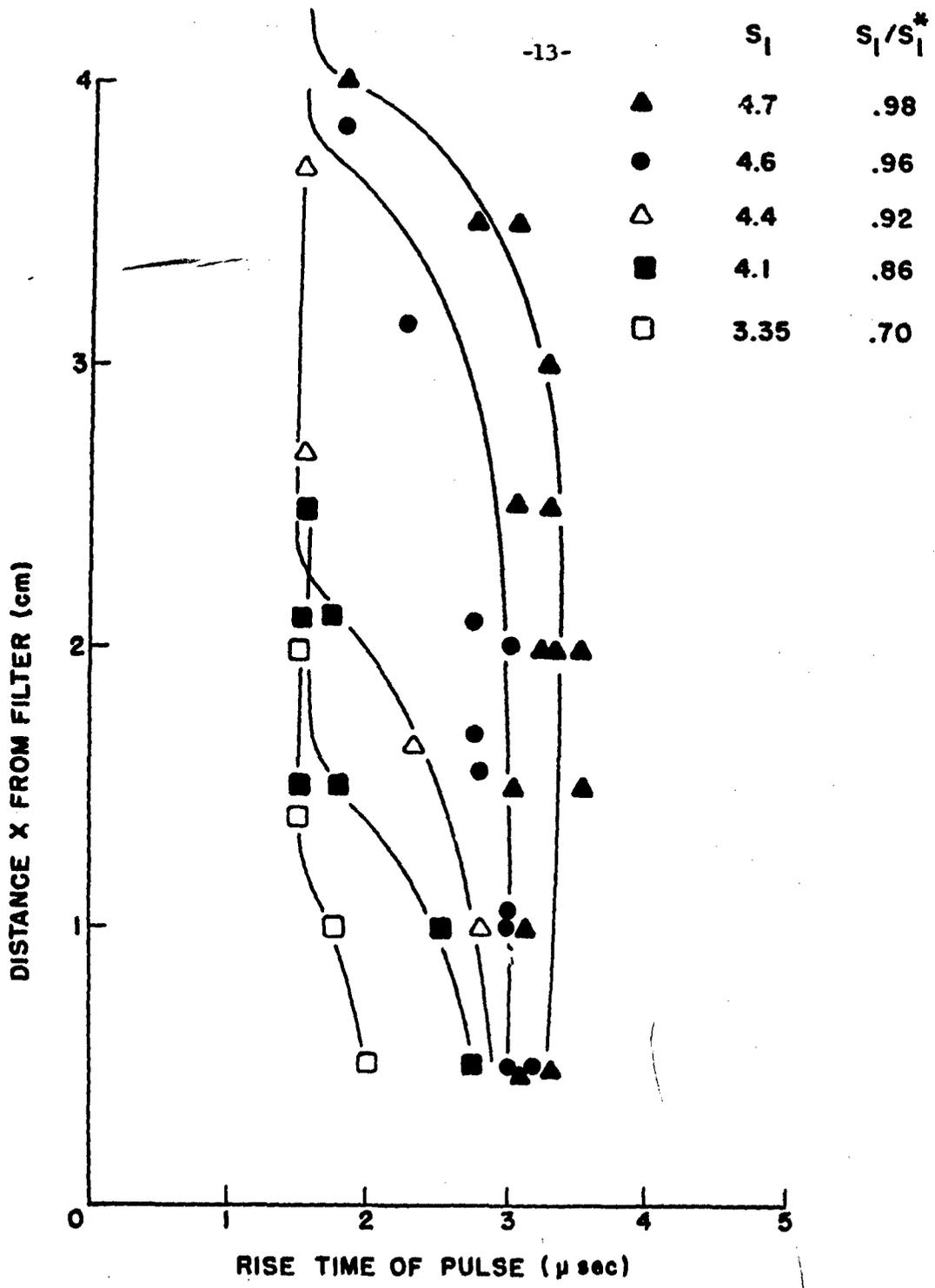


Fig. 5: Pulse rise time versus distance into the receptor for different lucite SPHF plate thicknesses.

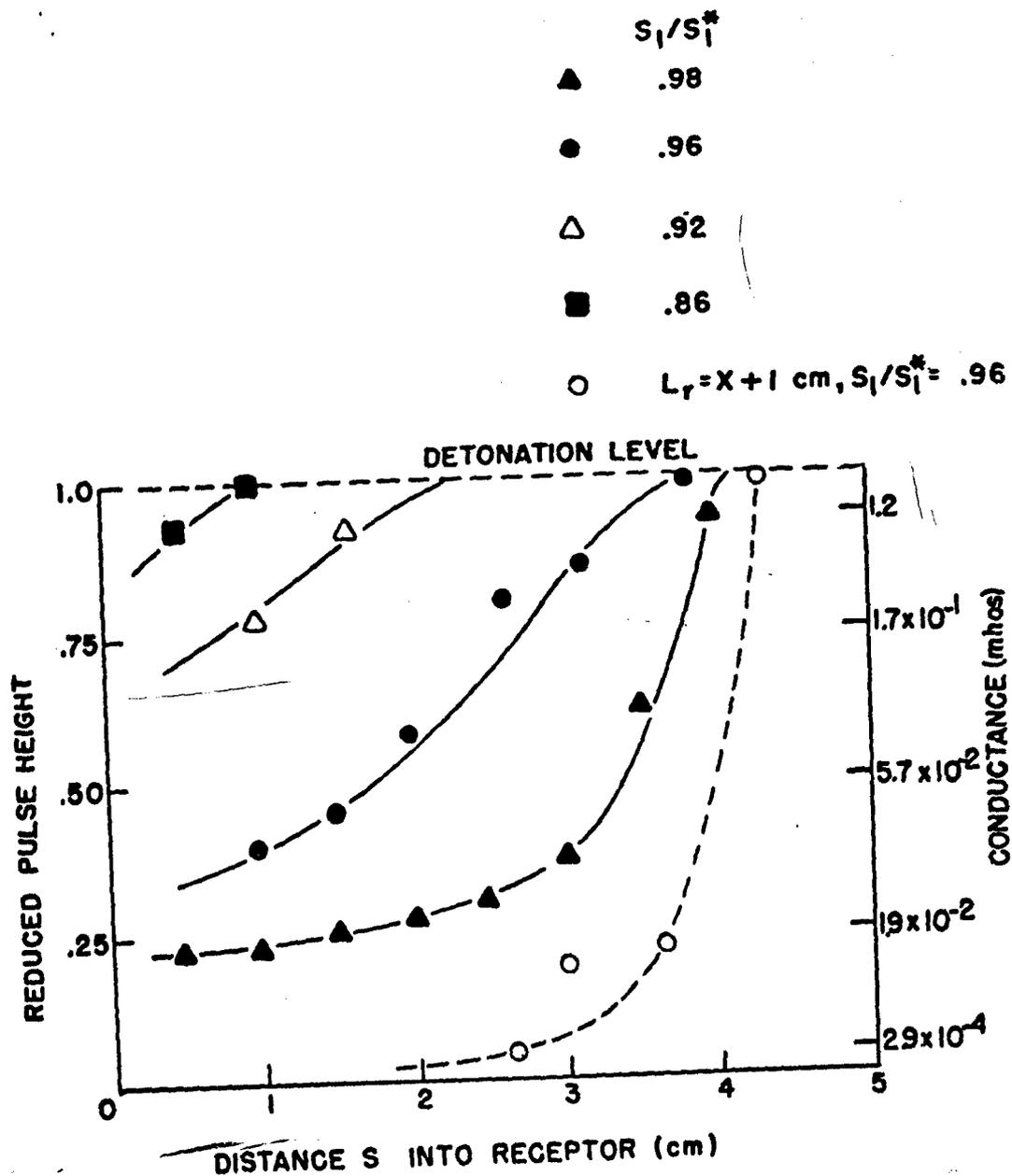
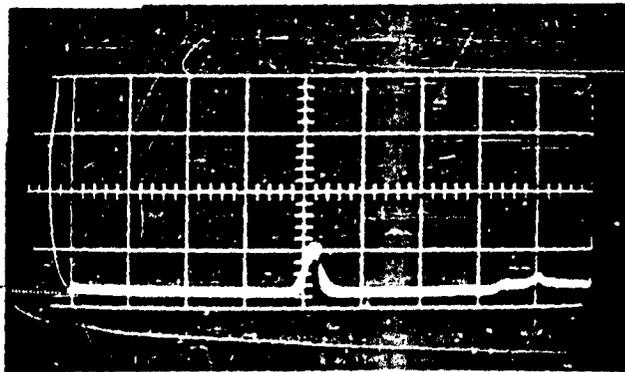
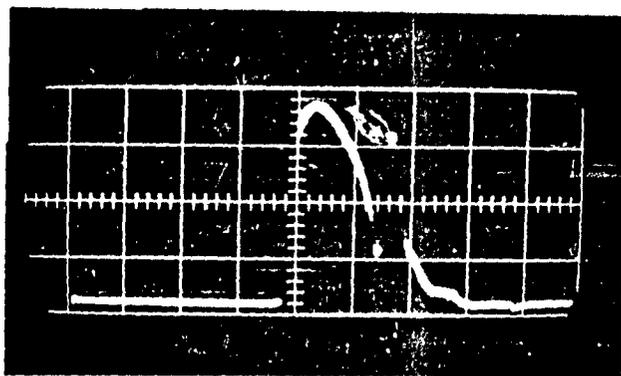


Fig. 6: Reduced pulse height versus distance into receptor for different lucite filter thicknesses.



(a) Probes 3.1 cm from filter, receptor length 3.4 cm,  $S_1/S_1' = 0.96$ .



(b) Probes 3.15 cm from filter, receptor length 8",  $S_1/S_1' = 0.96$ .

Fig. 7: Illustration of the effect of a free face on conductance in the predetonation region.

The probes being at the same distance from the SPHF plate in each case and close to the end of the short charge. It provides an explanation also (on the basis of the plasma mechanism) why receptors of length  $L_r < S_2$  invariably fail to detonate irrespective of the ratio  $S_1/S_1^*$ .

Parallel probes: Fig. 8 shows five traces, each from typical parallel probe shots near the sensitiveness limit using SPHF barriers of glass, steel, lucite, and water of relative thickness  $S_1/S_1^*$  between 0.89 and 1.08. The parallel probe method integrates all conduction along the length of the receptor charge (except that right at the SPHF plate) in contrast to the perpendicular probe system which gives "point" conduction-time data. In the results, Fig. 8, the probes were separated 0.5 cm and ran the entire length of the receptor charge except for a small space at the SPHF plate noted. The sweep was 5  $\mu$ sec/cm and the gain adjusted to 10 volts/cm with a battery voltage of +45.0 and a resistance  $r_1 = 16.0$  ohms.

The relative magnitude of the conduction in the receptor (conduction being proportional to the height of the voltage rise) was found to decrease sharply in the predetonation period with small increases of thickness  $S_1$  of the SPHF plate near the sensitiveness limit. (Note that the detonation period is identified by high, constant conductance.) Since all initiating waves were generated by identical donors the initial shock pressure on the donor side of a given type of SPHF plate was about a constant. Note, however, the large variations in the integrated conduction with small changes in  $S_1$  near the sensitiveness limit. At small values of  $S_1$  the total (integrated) conduction increased with time in the interval  $\tau$  between entrance of the shock into the receptor and initiation of detonation. In the cases of glass and steel there was first observed a slight inflection in the rise portion as one approached the sensitiveness limit. Still nearer the sensitiveness limit  $S_1^*$  the traces exhibited maxima-minima characteristics before undergoing a shape increase in ionization when detonations were initiated. For plates thicker than  $S_1^*$  the second rise portion corresponding to detonation was, of course, absent. However, these inflections, or maxima-minima, were not observed with lucite and water. They are, therefore, due to the fact that the plastic wave travels slower than the elastic one in glass and steel thus spreading out the p-t curve of the wave transmitted into the receptor. Note especially that as  $S_1$  approached  $S_1^*$  the maxima-minima

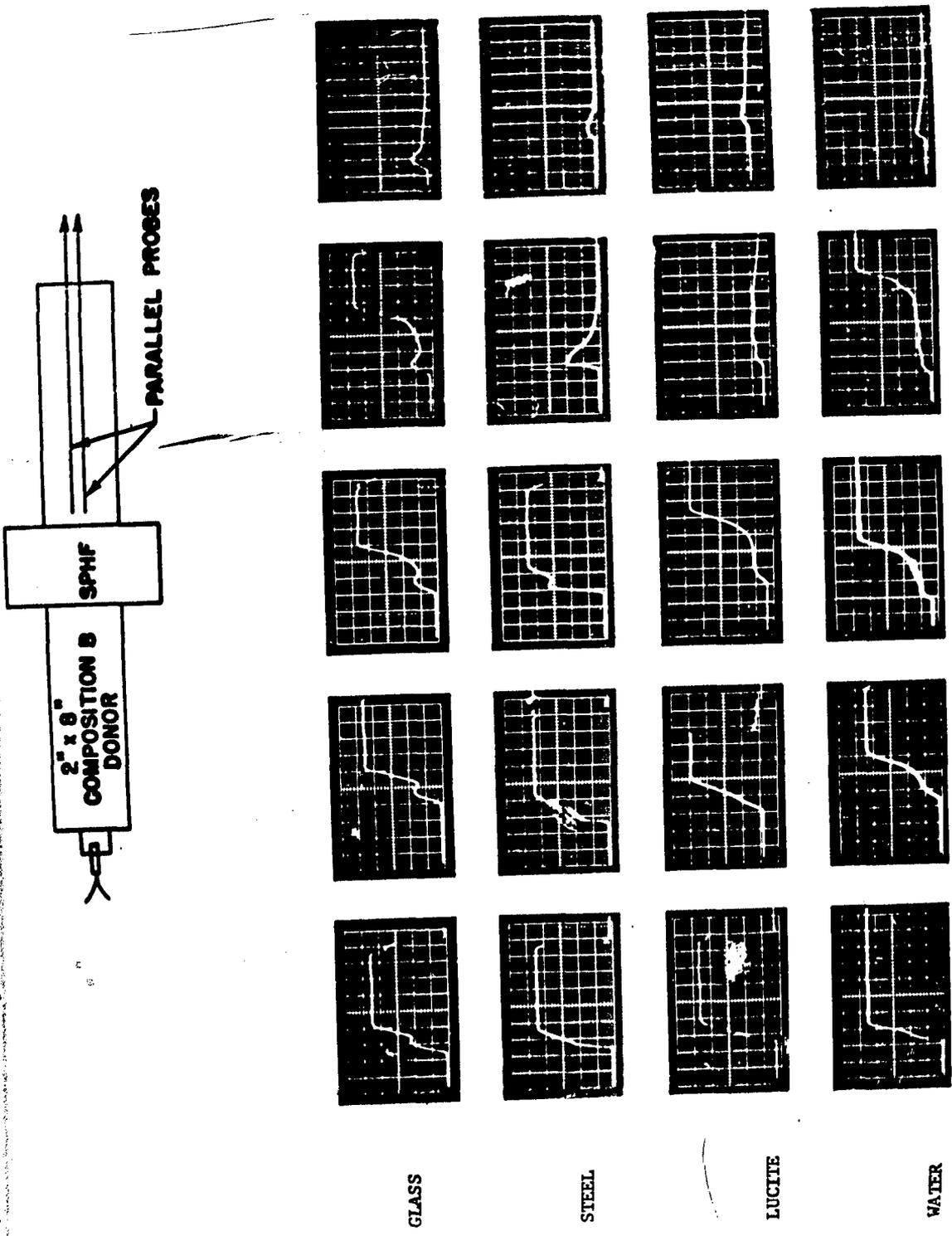


Fig. 8: Parallel probe traces of conduction in initiation of detonation in receptor for  $0.89 S^* < 1.08 S^*$  and  $L_r \gg S_2$  for SPHF plates of different materials.

became more and more pronounced. Coupled with the effect of pressure on the rate of build up of ionization in the receptor, this factor accounts for the observed effects in glass and steel. The maxima-minima were absent in lucite and water. This effect was not properly resolved in the work of Clay, et. al.,<sup>(20)</sup> although it was considered as an explanation for the longer rise times with glass than with lucite in the perpendicular probe studies.

Of considerable significance are the two curves in Fig. 8 for lucite at  $S_1/S_1^* \approx 1.0$ . Note that for the first one the total ionization acutely remained nearly constant, at a reduced height (relative to detonation) of about 0.15, for nearly ten microseconds before finally undergoing rapid acceleration to detonation. The same situation is exhibited by the curve at  $S_1/S_1^* = 0.99$  with water as the inert barrier except in this case the ionization level remained low about 25  $\mu$ sec before suddenly accelerating to the detonation level. These curves are not really unusual; they are obtained as a rule right at the sensitiveness limit. In fact, this effect can even be greatly exaggerated if one uses a thin metal foil on the receptor surface of the SPHF barrier when the barrier thickness is almost  $S_1^*$ . For example, Fig. 9 shows three traces in which detonations were observed with a water SPHF barrier and metal foils at  $S_1$  values about equal to  $S_1^*$ . Most striking is the center curve of Fig. 9 where the ionization is seen at first to rise to about 0.05 on the reduced scale, subside to about 0.02 for about 20  $\mu$ sec and then suddenly accelerate to full scale on an interval of only 5  $\mu$ sec. These results, together with actual shock pressure vs distance curves at  $S_1/S_1^*$  near unity described in the next section cast doubt on the shock pressure buildup mechanism because shock initiation of detonation in receptors may actually follow a preliminary decay, rather than uniform build up in shock pressure prior to the (sudden) initiation of detonation.

Pressure-distance curves: In measurements of the pressure variations in the receptor charges as a function of distance X for the SPHF plate-receptor interface, several series of shots were made using the setups of Fig. 2a and b. Fig. 10 shows several curves of  $p(X)$  using glass and lucite SPHF barriers at different values of  $S_1/S_1^*$ . The initial velocities of the shock waves were measured by reading the slopes of the distance-time curves recorded by the streak camera at the receptor-water or receptor-lucite inter-



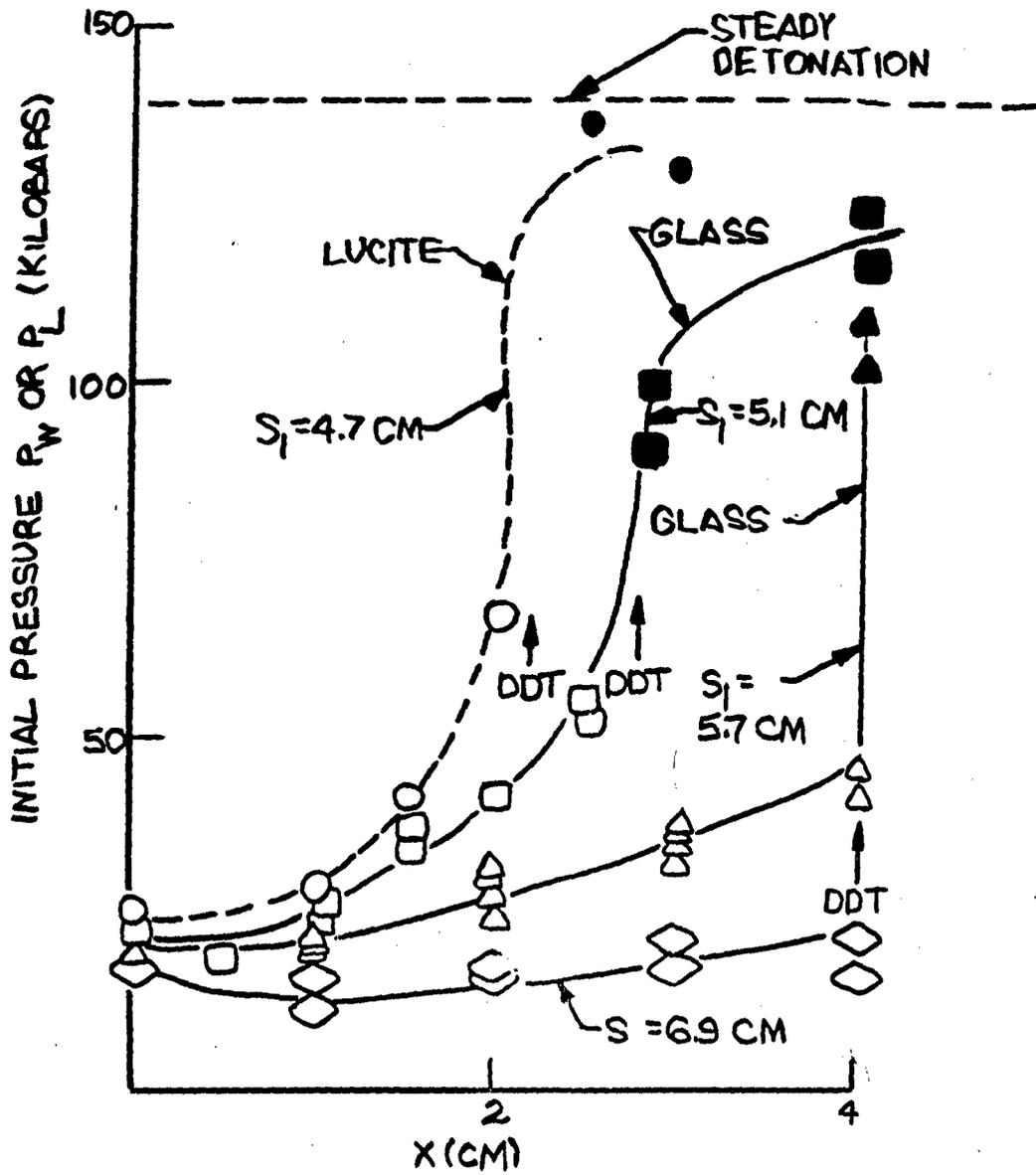


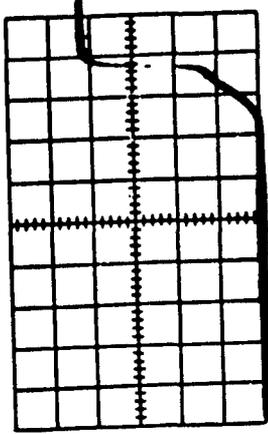
Fig. 10: Pressure ( $P_w$ ) - distance curves measured from plate - receptor interface in SPHF method.

face. These velocities were then transformed into pressures by use of the  $p(V)$  calibration curves for water and lucite.<sup>(23)</sup> The results shown in Fig. 10 reveal a pressure increase with distance whenever  $S_1$  is appreciably less than  $S_1^*$ . However, at  $S_1 \sim S_1^*$  this was not necessarily the case, the results showing that the pressure dropped initially with distance from the SPHF barrier near the sensitiveness limit, an effect exaggerated when metal foils are employed, as mentioned above. It should, however, be noted that the velocity of the shock wave transmitted into the aquarium or lucite from the end of the receptor in general underwent a slight increase before it attenuated in most cases, owing to the fact that the peak of the pressure pulse entering the aquarium or lucite from the receptor lagged behind the front. This finite rise time of the pressure pulse made difficult high accuracy measurements of the slope of the pressure-distance curves.

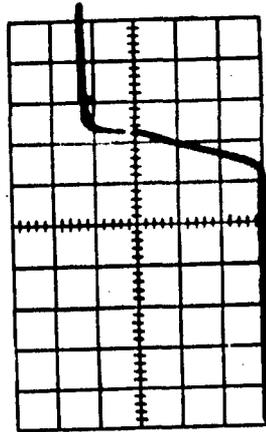
Impact initiation: In plate impact initiation studies a 5 cm x 5 cm x .9 cm steel plate was placed 5 cm from the receptor, and the oscilloscope trace was triggered by the high velocity plate at a point about midway in its free flight toward the receptor. The velocity of the plate and its kinetic energy of impact were regulated by varying the thickness of celotex between the plane wave generator and the steel plate. Plane wave generators of considerably larger diameter than the driver plate were used to obtain a reasonable uniform loading over the plate. The measured maximum time variation across the wave front was 0.2  $\mu$ sec with only 0.1  $\mu$ sec variation over the front of the wave driving the plate. Fig. 11 shows an example of oscilloscope traces obtained in the plate impact initiation method. The sweep rate was again 5  $\mu$ sec/cm and the vertical gain 10v/cm, the battery voltage was 47 volts and the terminal resistor was 17.5 ohms. In Fig. 11 (a) the celotex was 2.5 cm thick and in (b) it was 3.7 cm, the latter being closer to the detonability limit than for the former, and the rate of increase of conduction in the former prior to the rapid climb to detonation was lower. Slightly thicker layers of celotex lengthened this region. The mechanism of detonation is clearly the same as for the SPHF plate shock initiation.

#### The Effect of Different SPHF Plates on the Time Lag to Detonation

The observations that the parallel probe traces were dependent upon the SPHF plate material as illustrated in Fig. 8 and also the fact that the



1 1/2" CELOTEX SHEET



1" CELOTEX SHEET

Fig. 11: Parallel probe conduction results for impact initiation using the setup in Fig. 3.

presence of thin metal foils at the barrier-receptor interface in the case of non-metallic barriers tended to alter the nature of the traces (see Fig. 9) suggested further examination of the so called catalytic effect.<sup>17</sup> Fig. 12 contains a plot of the data of Pack, et. al., for the initial peak pressure in the receptor vs time lag to detonation for card gap barriers of glass, steel, brass, and aluminum taken from Ref. 17. It was reasoned that since at a given peak pressure of the incident wave in the receptor, detonation occurred with a shorter time lag for metal barriers than for glass, then some sort of catalytic effect was present. Also in Fig. 12 are similar pressure vs time lag data for lucite and water barriers which were obtained during the present study. The results for these two materials were so nearly equal that they are indicated as a common line. Note that lucite and water, both of which are non-metals, let to smaller time lags for given peak pressures of the wave in the receptor than did glass or steel. Over the range of pressures that prevailed in the barriers, glass and steel both exhibit elastic-plastic wave separation, i. e., the compressional wave did not propagate as a pure shock wave, whereas the disturbance propagated as a shock in water and in lucite. Aluminum also exhibits shock behavior at pressures greater than 150 kb. Apparently, the difference in results was largely due to the shape of the wave front entering the receptor rather than any catalytic effect from a metal.

In order to determine whether thin metal foils on the receptor charge produced any effect upon the parallel probe conduction traces, series of shots were fired using 5 cm (d) x 20 cm (L) Composition B donors and receptors with water barriers. In order to provide a true comparison this work entailed statistical shooting, and the charges in each case came from the same casting. The 50/50 go-no go barrier thickness  $S_1^*$  was first of all determined for a control system without metal foils, and this was compared to the  $S_1^*$  determined with the metal foil on the receptor. For 0.005 cm thick Ag foil  $S_1^*$ , the 50/50 sensitiveness limit and its corresponding 95% confidence interval was determined to be  $5.8 \pm 0.20$  cm while for the control  $S_1^*$  was  $5.4 \pm 0.29$  cm. At the 95% level of confidence one could not, state that the two sensitiveness limits were different on the basis of the 32 trials that were used. In the case of 0.005 cm Al foil and 0.005 cm Cu foil there

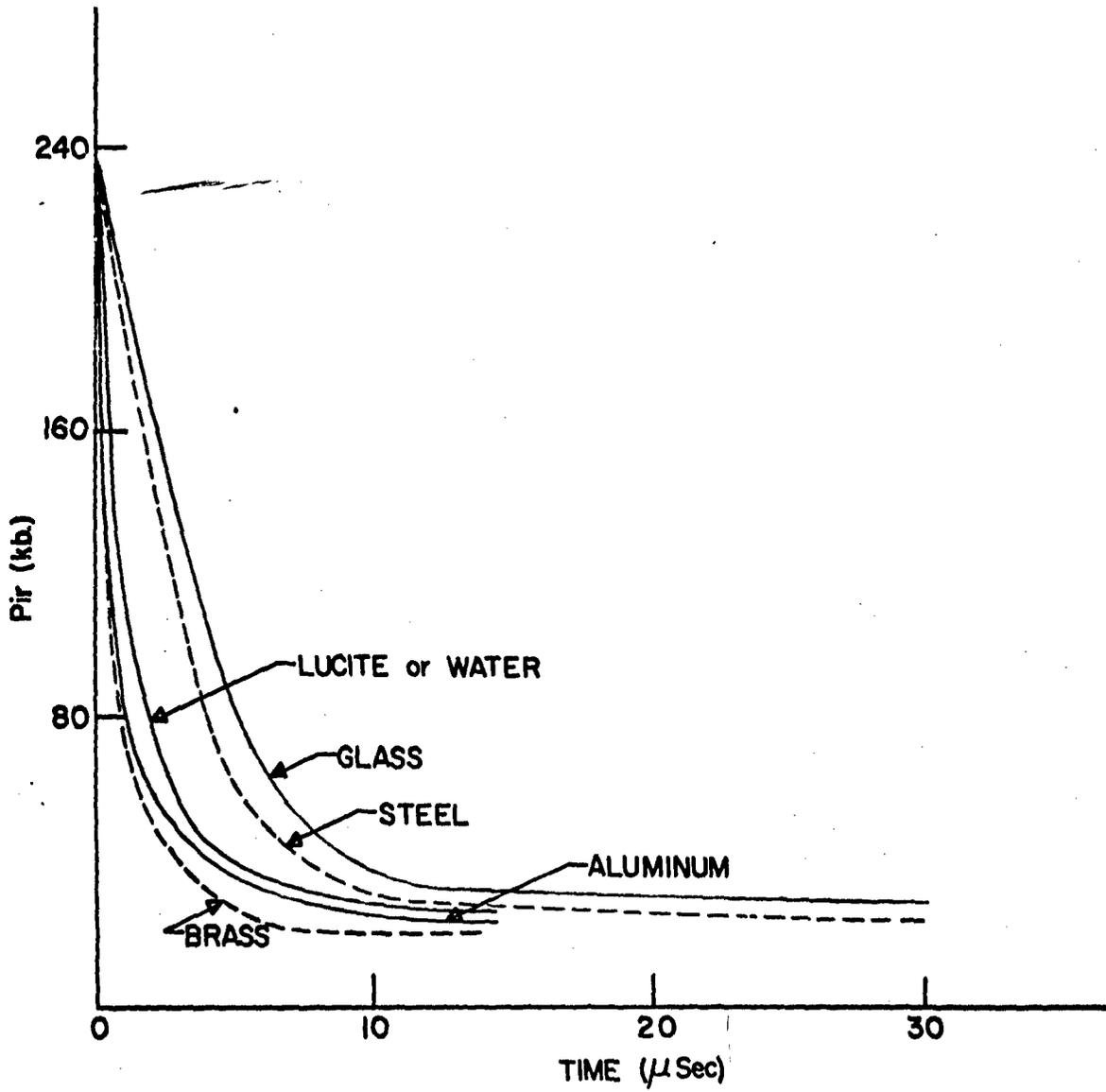


Fig. 12: Initial peak pressure in the receptor charge vs time to detonation for different SPHF plates.

was also found to be no significant change from the control experiments on the basis of the number of trials carried out. Fig. 13 shows the "up and down" test results for silver and copper. A series was also completed using glass barriers and copper foil. The "up and down test" results of Fig. 14 for this series again show no significant effect of the 0.005 cm copper foil.

Fig. 15 is a plot of initial peak conductance measured with parallel probes vs time to detonation for the shots which detonated. The data for water barriers falls along smooth curve. The shots with and without foils are about equally distributed on either side of the line, showing, therefore, no significant effect of the foils in this regard.

It is apparent, therefore, that any catalytic effect of promoting detonations resulting from the presence of a metal in contact with the receptor charge, which might possibly exist, must be small. At the 95% confidence level, on the basis of the number of trials performed, the sensitiveness limit was not affected significantly. However, there did appear to be a tendency for it to be somewhat longer when the entry face of the receptor charge was coated with a metal foil. One other fact which indicated the presence of some type of small effect from the metal foils was the enhancing of the rise and decay in conduction-time traces from parallel probes for barrier thicknesses near the sensitiveness limit illustrated in Fig. 9.

#### Summary and Conclusions

In the shock initiation of Composition B such as occurs in the card gap or SPHF test and initiation by plate impact a "broad" ionization wave is generated in the receptor charge. The rise time of this wave is slow at first; it apparently lags behind the pressure front. However, as the initial shock proceeds into the receptor the ionization wave was found to sharpen, and after the ionization wave had sharpened to a steep fronted wave which merged with the shock front the transition to high order detonation occurred. The merging of the ionization wave with the shock wave, permitting conduction of heat to the shock front, is believed to be a necessary condition for detonation to occur rather than simply a byproduct of detonation. The "flash-across" phenomenon observed in liquids apparently corresponds to the peak or nearly the peak of the ionization wave in Composition B, the velocity characteristics being similar in both cases.

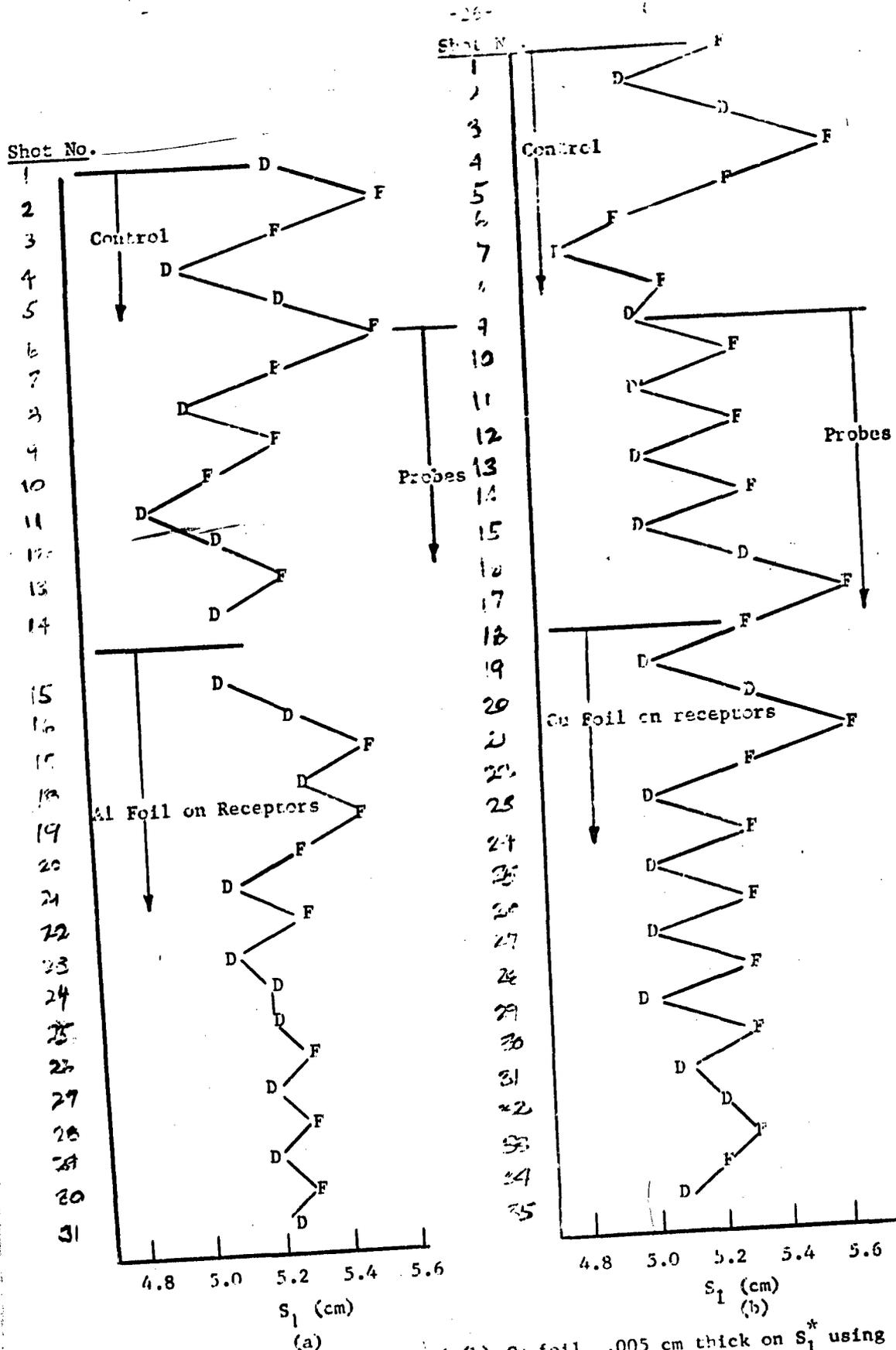


Fig. 13: Effect of (a) Al foil and (b) Cu foil, .005 cm thick on  $S_1^*$  using 2'' x 8'' Composition R donors and receptors and water barriers.

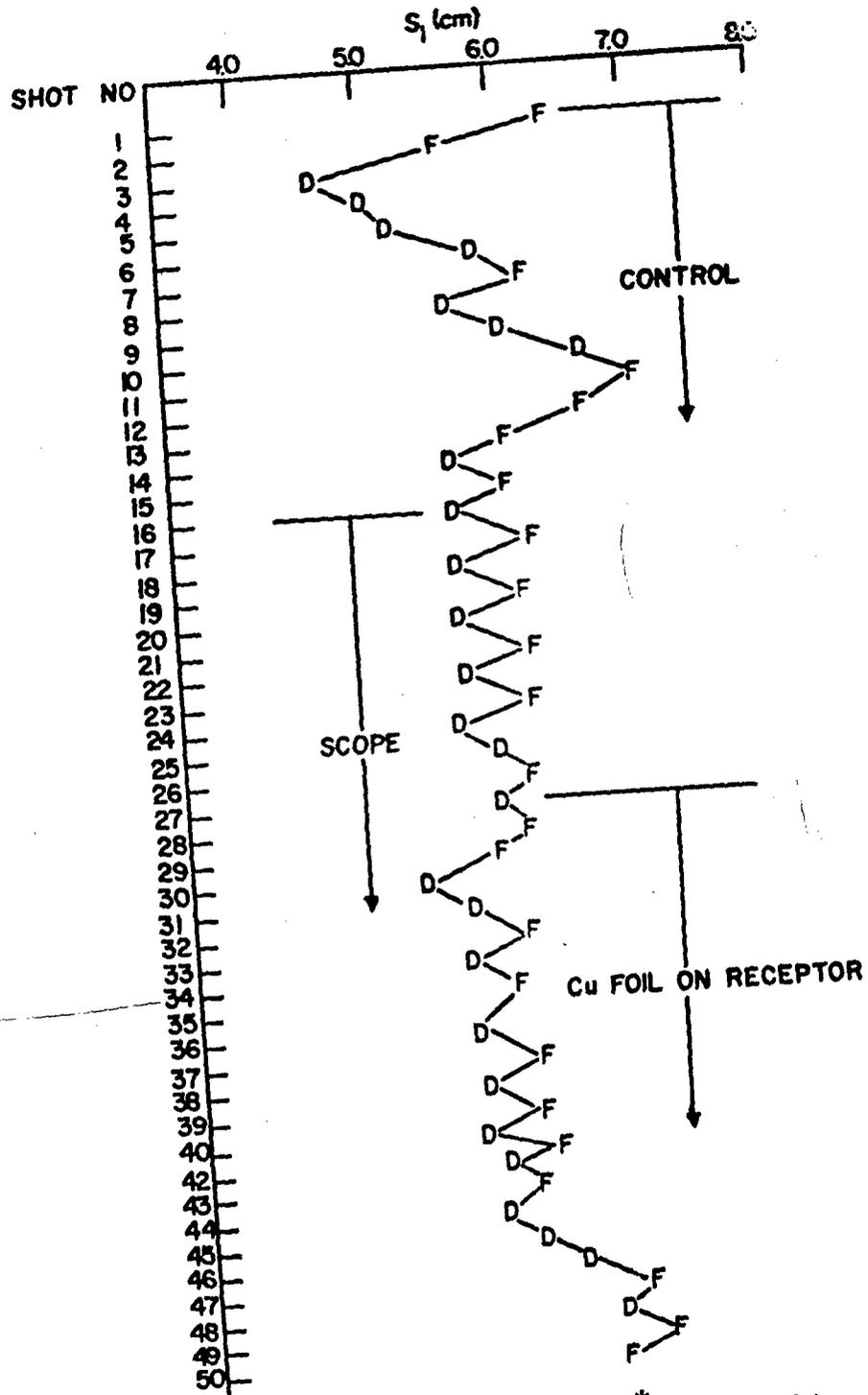


Fig. 14: Effect of .005 cm thick Cu foil on  $S_1^*$  for 5 cm (d) x 20 cm (L) Composition B donors and receptors using glass SPHF plate.

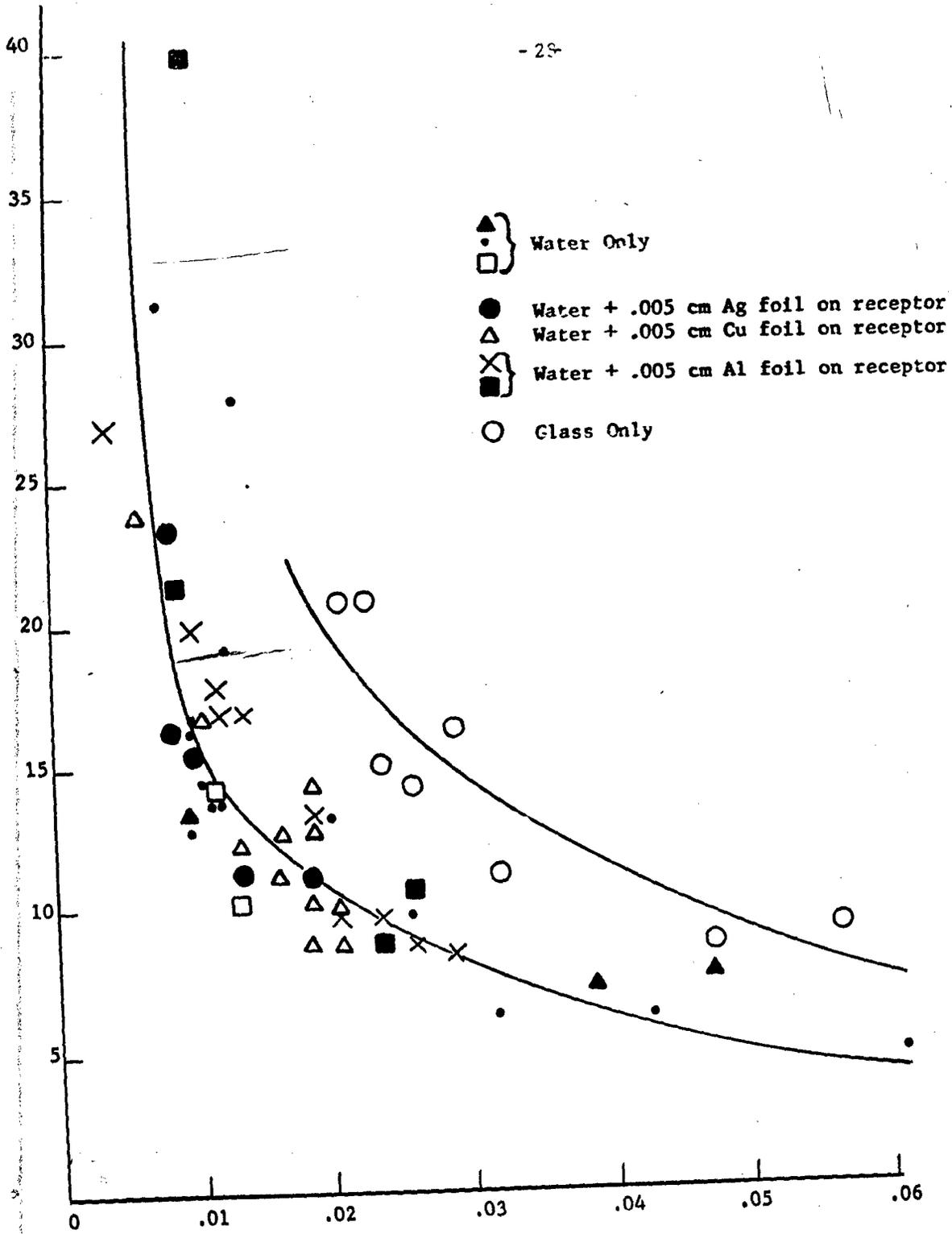


Fig. 15: Initial peak conductance vs time to detonation from parallel probes in 2" (d) x 8" (L) Composition B charges using water or glass barriers.

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