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# EXPLOSIVES RESEARCH LABORATORY

## STUDIES ON DEFLAGRATION TO DETONATION IN PROPELLANTS AND EXPLOSIVES

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April 1, 1961 to June 30, 1961

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DEPARTMENT OF
THE INTERIOR

# STUDIES ON DEFLAGRATION TO DETONATION

# IN PROPELLANTS AND EXPLOSIVES

Quarterly Report

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Prepared for:

Advanced Research Projects Agency
Office of the Secretary of Defense
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# STUDIES ON DEFLAGRATION TO DETONATION IN PROPELLANTS AND EXPLOSIVES

## INTRODUCTION

Electrical methods have been devised to study the initiation of detonation in reactive substances; however, a correlation of the results obtained by such methods with the luminous exothermal reactions seen photographically is necessary to a fuller understanding of the mechanism of the initiation and growth of detonation. In the past, considerable reliance has been placed on an evaluation of the event when using a resistance element method for determination of the position of an ionized front. Additionally, comparisons have been made between the movement of the compressional waves and the ionized waves during the growth and propagation stages preceding detonation and following establishment of hydrodynamic detonation in both high explosives and propellants.

During the current reporting period, the Cordin streak camera component of a new streak-framing camera facility has been applied to explosives and propellants, preliminary to an attempt to compare the relative positions of the luminous zone, the ionization zone, and the compression wave activity during the initiation process. Application of the streak photographic method involves novel techniques that are being developed to sense the radiation at the core of the strand or grain.

Attempts to cause thermal initiation to undergo a transition to detonation in an essentially unmodified high performance-double base propellant under complete confinement have not been successful. A production-type propellant having a shock sensitivity

comparable to a pure compound explosive was used in these tests. Attempts to reorient the base grains to create minute cavities by predistortion of the strand have not been successful; however, a method is being developed to subject the material to dynamic stress loading during the burning phase in order to set up strong compression and tension wave activity in the undecomposed material.

## EXPERIMENTAL

### Application of streak photographic techniques to propellant and explosives detonability studies

The Cordin streak camera is a rotating mirror camera having up to 5 mm/μsec. image speed, using 5-1/2"-wide Aero film. As such, it is capable of both good spacial and time resolution on relatively small charge sizes, i.e., an image-object size ratio of 0.5 has been used with image speeds of 3 mm/μsec. for display of detonation in both the high-performance double-base propellant as well as in ordinary explosives.

A method for sensing the performance of the reactive material at the grain or charge core has been devised and is being developed and refined. This method in its basic form consists of placing a transparent wafer longitudinally into the charge and forming an image of the wafer edge on the camera entrance slit. A wafer width image greater than the slit width employed allows only the luminous radiation emanating from the wafer to enter the camera. Two configurations, using glass wafers, have been preliminarily evaluated: (1) a glass wafer passing across the entire width of the strand or grain where the luminosity along the wafer surfaces is transmitted through the wafer to the edge, and (2) a wafer extending into the axis of the charge with an axial port through

which propane is flowed during the test -- the propane was used in an attempt to attenuate the luminosity due to the strong shock waves in the axial port.

The second method appears to be better in that the front luminosity recorded is from the detonation zone, whereas the radial wafer appeared to indicate strong shock luminosity ahead of the detonation in spite of the presence of propane in the axial cavity. Typical records for direct shock wave initiation of high-density tetryl are shown in figures 1 and 2 for the diametric and radial wafers, respectively.

Other instrumentation

Concurrent to the high-speed streak photographic studies, development of the pressure-resistance element system for the continuous determination of compression wave position was continued. Several variations of pressure-resistance element probes have been tested and, to date, the probe configuration that has resulted in optimum display of the wave velocity consisted of a 0.0031" Molecu[1/] resistance wire that has been coiled on an AWG #34 Sodereze[2/] core wire, coated with Pliobond[3/] and pulled through a 0.023" o.d. annealed aluminum tube[4/] having a 0.0015" wall thickness as shown

1/ Trade name of a polyester enameled resistance wire manufactured by the Molecu Wire Corp., Eatontown-Freehold Pike, Scobeyville, New Jersey.

2/ A polyurethane base insulated copper wire available from the Phelps-Dodge Copper Products Corp., Inca Manufacturing Div., Fort Wayne, Indiana.

3/ Pliobond is a trade name of the Goodyear Tire and Rubber Co., Akron, Ohio.

4/ Thin walled-small bore tubing available from Precision Tube Co., North Wales, Pennsylvania.

in the photograph of figure 3. Closely spaced turns have proven most satisfactory; in this case, 224 turns/inch provide a linear resistance of about 20 ohms/cm. The effect of pitch is shown in figure 4 where a coil of 224 turns/inch is compared with 160 turns/inch both with and without the Pliobond matrix. The explosive used was nitromethane which was initiated by a 50-gram tetryl booster, having an $\ell/d$ ratio of 0.615.

A comparison was made between copper and aluminum pressure probe tubes in a water-filled vessel by placing them on a diameter of a plastic vessel parallel to and equidistant from the axis; an explosive-derived shock wave was transmitted longitudinally through the vessel. The oscilloscope waveforms produced indicated that the aluminum probe provided better performance characteristics, probably due to its lower ductility, in that the perturbation at the point of transition between the over-driven and sonic segments of the trace is better defined. This is illustrated in the drawing and dual beam oscillogram of figure 5.

We have frequently observed, both from photographic and resistance element records, that interactions between waves resulting from an explosive donor-barrier produce regions of variable pressure and/or ionization intensity within the receptor charge. This effect is doubtless sensitive to charge geometry and may be the cause of anomalies that exist in the use of the card-gap test for determination of detonability. Interrelated are the magnitude of the initiating impulse, the size, wall thickness, material, and shape of the container, and, of course, the basic physical properties of the material itself. In shock-wave initiation by explosive donors, the material is being subjected to a steep pressure discontinuity followed by a relatively long sustained pres-

sure pulse provided by gross movement of the gaseous detonation products or barrier material into the receptor material. The generation of a pure shock wave, i.e., a pressure spike followed by a rarefaction wave, is difficult to experimentally produce. However, it may be possible to create a pure shock wave by applying an explosive-donor technique to an acceptor in a confining vessel if the direct end-on explosive force (impulse due to the donor) is decoupled from the acceptor. The shock in the vessel walls would create lateral waves in the acceptor material. The ultimate interactions of the lateral waves may create shock activity of sufficient intensity to initiate detonation. Furthermore, basic studies of these interactions are possible by schlieren and shadowgraph photography and should provide an insight into mechanisms involved in card-gap detonability evaluation.

Along the same line, a Mr. M. Zippermayr, in a 1959 publication[5/], dealt with initiation of detonation in liquid explosives; he takes issue with the theory of Bowden et al.[6/] in their postulation that adiabatic heating of occluded gases in bubbles is the initiation stimulus. He feels that the expansion of a bubble and the release of a local shock wave is the key to initiation of detonation and that interactions and other released shock waves are possibly due to the presence of reflective walls. A reason why thermal initiation of a reactive material does not readily transit to detonation is explained by Mr. Zippermayr as follows:

> ". . . .'Thermal initiation' can, in this connection, be looked upon as a process characterized by high dampening. A given high temperature difference,

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5/ Zippermayr, M., Chimia (Switz.) 13, 56-63 (1959).
6/ Bowden, F. P. and Yoffe, A. D., "Initiation and Growth of Explosion in Liquids and Solids", Cambridge, 1952.

> accordingly, leads always to eventual equilibration with the surroundings and not to periodic, alternating, mutual effect of temperature vibrations. Such a consideration makes the fact more understandable that stimulation by mechanical means is more effective than stimulation by thermal means. . . .".

Thus, the proposed study of thermal initiation of a propellant during a period of strong compression and tension activity may be a realistic approach to a detonability evaluation.

## High-performance double-base propellant studies

Thus far, we have been unable to cause a transition from burning to detonation to occur in highly confined strands of the production-type, high-performance double-base propellant. Pure thermal ignition has been used both at the end as well as near the center of propellant strands with total enclosure consisting of a sleeve-type steel confining vessel described in an earlier report[7/]. Attempts to reorient the base grain in the binding matrix have been unsuccessful in obtaining any change in physical form which is apparent when microscopically analyzed. A fresh approach becomes desirable with reconsideration of earlier propellant tests in which a closure plug was weighted and permitted to pop-off and close at a frequency of several cycles per second. A few preliminary tests were made to determine the practicality of using a vessel with spring-loaded closure in which two ignitors are placed in the propellant body. One is located at the surface in the ullage space between the strand end and the pop-off cap; the other is near the

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7/ Bureau of Mines Quarterly Report, "Studies on Deflagration to Detonation in Propellants and Explosives", Office of the Secretary of Defense, ARPA Order No. 44-61, January 1, 1961 to March 31, 1961.

vessel bottom and is activated when the burning reaches a pre-determined point when compression and tension waves of high intensity in the propellant strand have been established. It is thus planned to simulate a condition that might arise from oscillatory burning. Instrumentation provided will include both compression and ionization resistance element probes.

A recent trip to the U. S. Naval Propellant Plant at Indian Head, Maryland, was made to use their high-speed framing camera on further studies on shock interactions involved in card-gap sensitivity tests. Again liquid monopropellants were used in the belief that their detonability characteristics are not unlike solid propellants and, importantly, their transparency makes them more amenable to photographic study. In addition, a few orienting tests were also made on monopropellant materials that were subjected to the shock and thermal stimuli produced by an exploding wire immersed in the body of the material. A framing-camera sequence of this type for nitromethane is shown in figure 6. A capacitive discharge energy of 150 joules was applied to the ignition element, a .003" Pyrofuze[8/] wire. This ignitor wire alone is capable of an exothermic alloying reaction when heated to about 650°C. and produces a temperature of about 2000°C. In spite of the combined energies from the shock created by the electrical source and heat from the alloying processes, no detonation occurred; this may be construed from Zippermayr's hypothesis as a result of having only compressional wave activity prior to wall rupture and liquid breakup.

8/ A trade name of the Sigmund Cohn Corp., Mt. Vernon, New York.

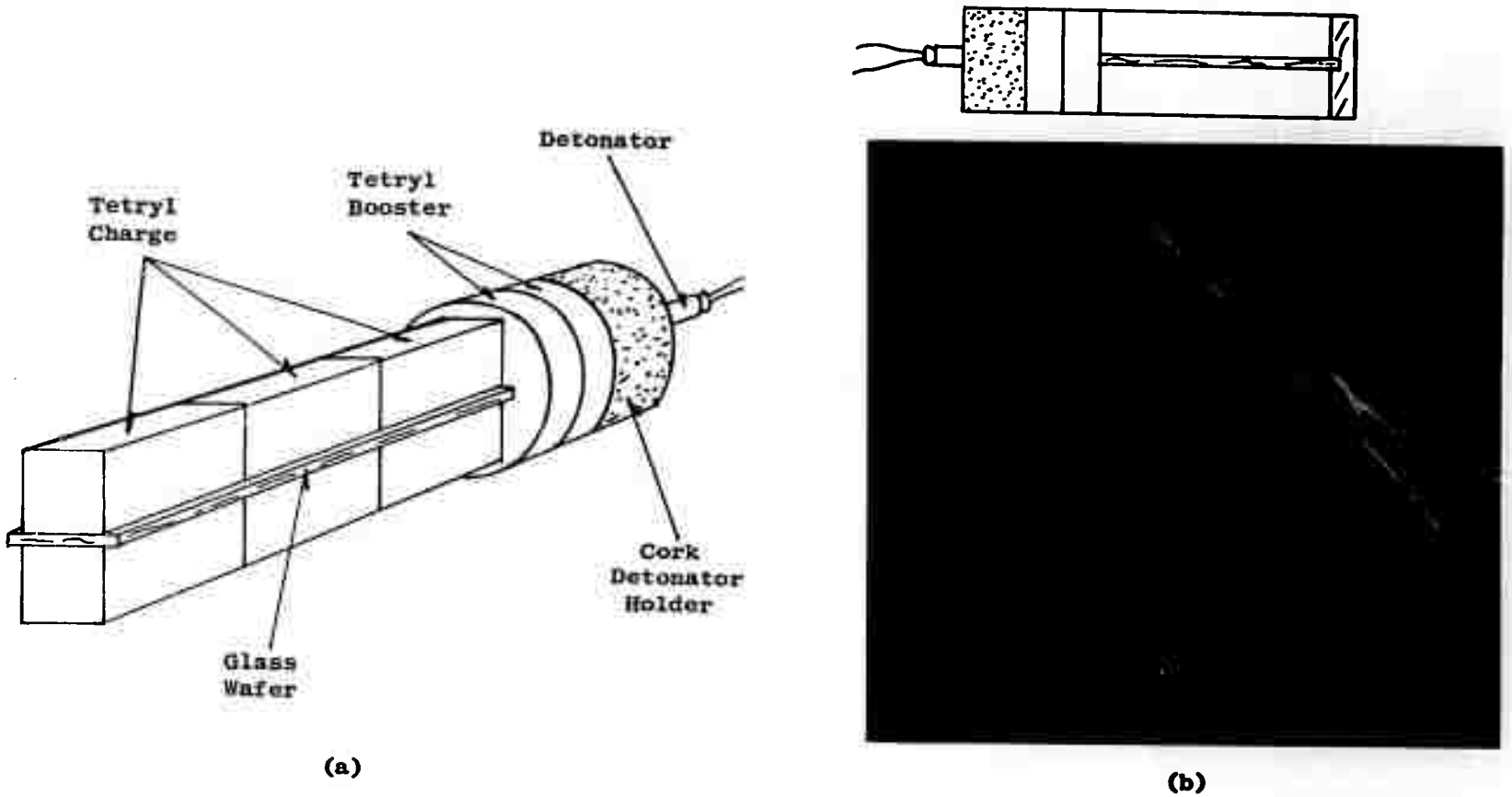



Figure 1. - Charge configuration and streak photographic record obtained by the use of a transparent wafer passing through a tetryl charge ($\rho = 1.62$ g/cm$^3$). The drawing (a) shows the position of a .060"-thick glass wafer; the glass edge was imaged on the camera slit (not shown are opaque covers that were placed on the charge sides facing the camera). The streak record (b) shows a well-defined trace in which the front velocity is that of the detonating tetryl. The velocity of the slower trace is approximately sonic for glass and is due to the shock at the glass-air interface. Time is increasing top to bottom and the image-sweep velocity is 3 mm/μsec.; the object to image ratio is 0.44. The radiation was sampled on the charge axis and was contiguous with the donor surface.

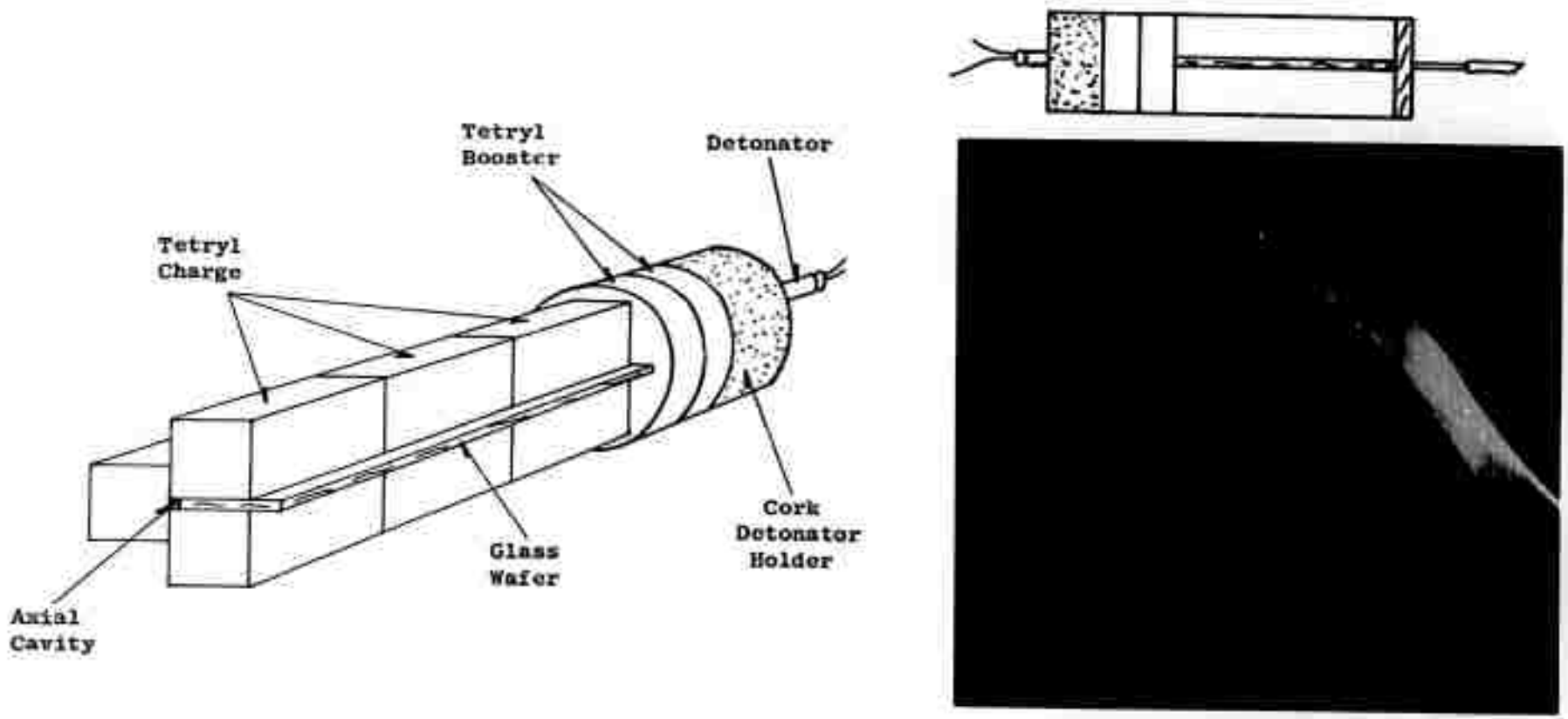



Figure 2. - A setup similar to figure 1 except that the wafer passed only to the charge core. An axial void was provided between the explosive and the glass wafer; during the test, propane was flowed through the void to minimize shock luminosity. The drawing (a) shows a composite charge consisting of tetryl pellets having a square cross-section. The streak camera record in (b) shows that, in spite of the presence of propane, the leading trace was due to shock activity in the cavity and was 11 mm/μsec.; the lower edge of the luminous wedge represents the anticipated velocity of 7.6 mm/μsec. in the tetryl. Both have the same origin; however, early stages of an event would be obscured by the precursor shock luminosity. Time is increasing top to bottom and the image sweep rate is 3 mm/μsec. The object to image ratio is 0.44.

Figure 3. - A photographic enlargement (about 8 X) of a pressure-type resistance element probe for the continuous measurement of the leading compression wave velocity. Insulated 0.003" diameter resistance wire is coiled around an AWG #34 insulated core wire and inserted into an aluminum tube having an i.d. of 0.020" and a wall thickness of 0.0015". Circuit continuity is established by collapse of the tube onto the resistance element.

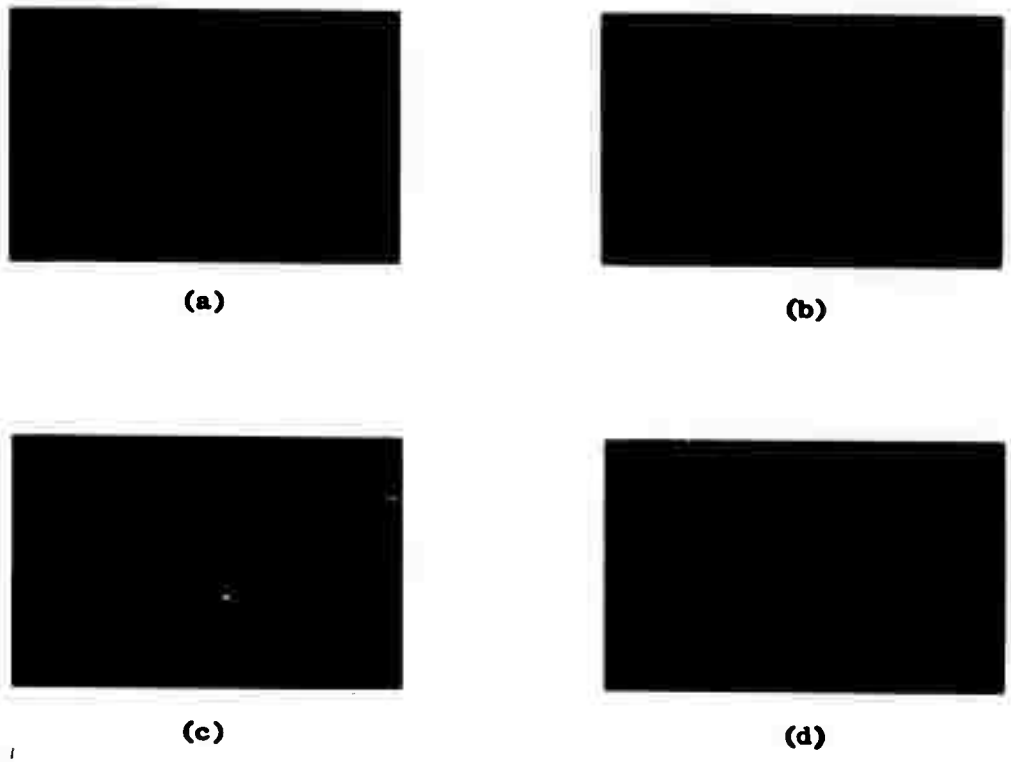
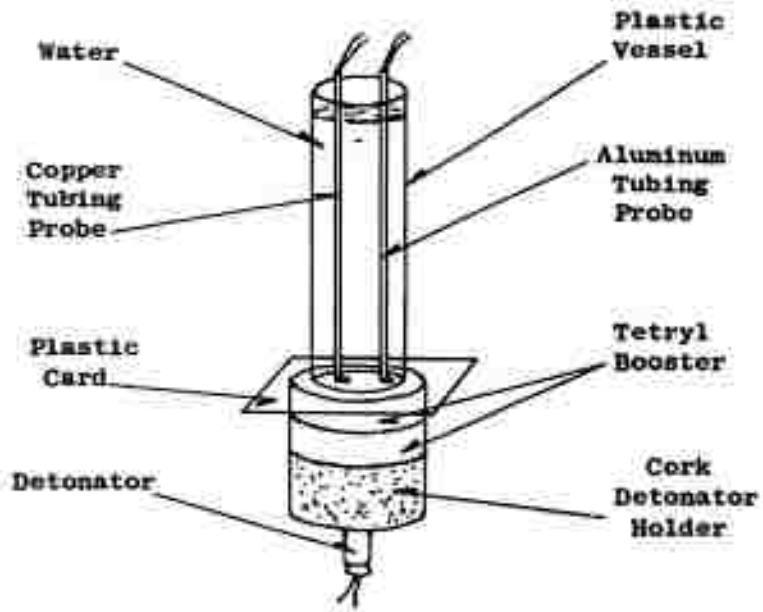



Figure 4. - Comparison of the results from the use of four pressure-type resistance element probes in detonating nitromethane. The charge diameter was 23 mm. and initiation was accomplished with a 50-g. tetryl donor ($\rho$ = 1.62 g/cm$^3$) having a single 0.010" cellulose acetate card between the donor and the nitromethane. Effects of resistance element pitch and elimination of the inter-element void are shown where (a) a pitch of 160 turns/inch without cement can be compared to (b) 160 turns/inch with cement, and (c) 224 turns/inch without cement can be compared to (d) 224 turns/inch with cement. A cross comparison of (b) and (c) with (d) would indicate that the shorter pitch with the cement fill provides the optimum trace. Time is on the abscissa increasing from left to right and is 2 μsec./div.; distance from the initiated end is increasing top to bottom and is 2.3 cm./div. A terminal velocity of 6.13 mm/μsec. is indicated.




(a)

(b)

Figure 5. - A comparison of the performance of copper and aluminum pressure-type resistance element probes in a plastic 23-mm. i.d. cylindrical vessel filled with water and shock excited by an explosive donor. A drawing of the configuration is shown in (a); a dual beam oscillogram (b) shows the waveforms produced. The aluminum probe (lower trace) appears to more accurately indicate compression wave propagation in that the trace discontinuity resulting from overdrive and decay to sonic velocity is better defined. Time is increasing from left to right and is 10 μsec./div.; distance increases top to bottom and is 5.55 cm./div. The pressure was attenuated to a level insufficient to cause probe collapse in 30 μsec. or after traveling 6.6 cm. through the water.

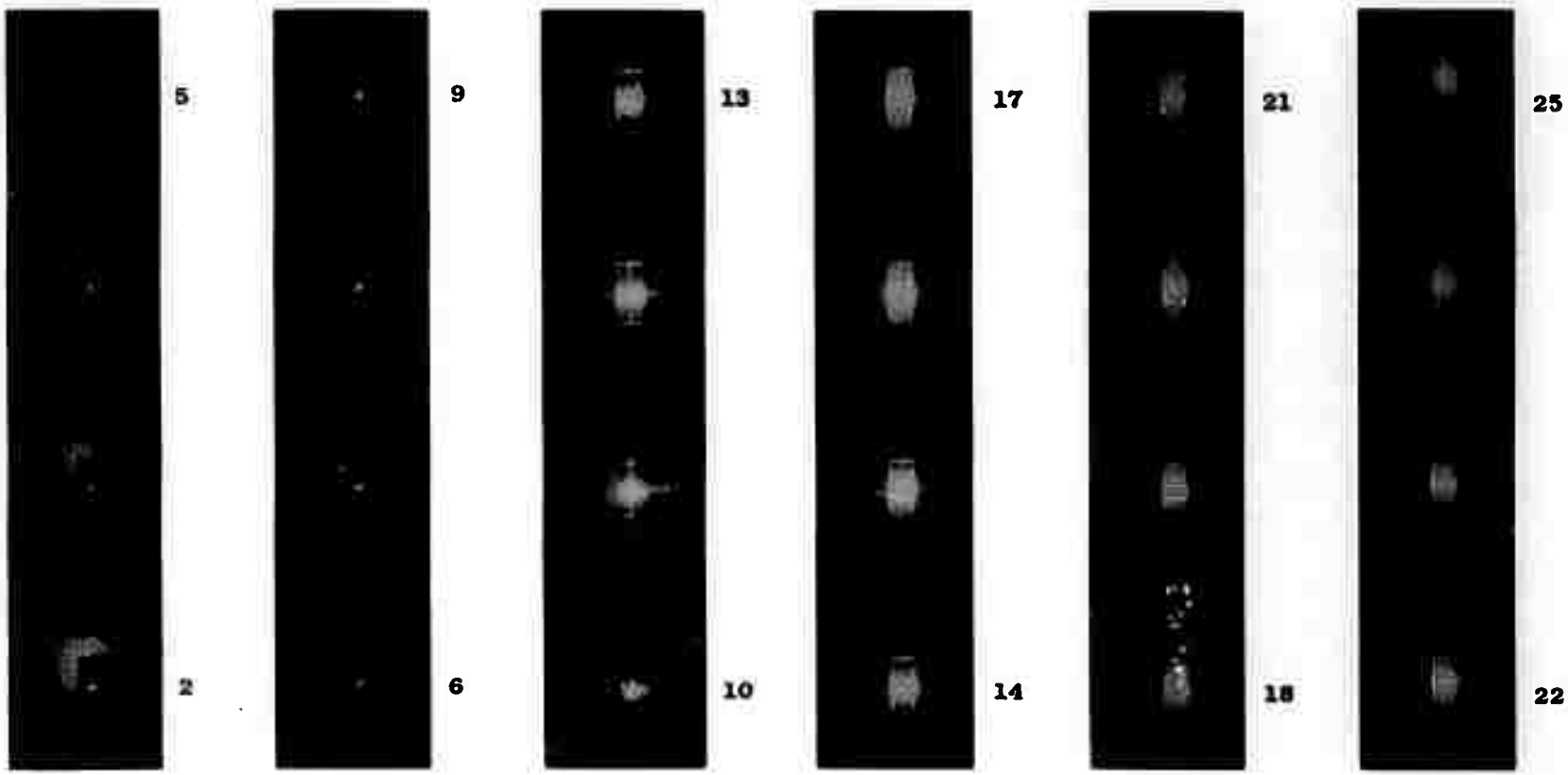



Figure 6. - A high-speed framing camera sequence of an attempt to initiate nitromethane in a glass vessel with the energy derived from an exploding bridge wire. The bridge was a 1 cm.-long single strand of Pyrofuze wire, 0.003" diameter, having a single overhand knot near its midpoint; it was supported by colinear electrodes. A capacitive discharge energy of 150 joules was applied to the wire that, by its nature, is capable of producing a temperature of 2000°C. by an alloying reaction when the wire is electrically heated to about 650°C. Background grid line spacing is 1 cm.; camera framing time is 1.4 μsec. and interframe time is 4.2 μsec.

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