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On the Performance of Primers for Artillery Weapons

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ON THE PERFORMANCE OF PRIMERS FOR ARTILLERY WEAPONS

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Project No. TB3-0110V Of The Research And
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Aberdeen Proving Ground, Md.
March 1953

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ABSTRACT

Certain basic operational requirements of artillery primers are discussed. It is shown that static firing tests of primers can be used advantageously in evaluating the suitability of given primers in particular weapon systems. An attempt is made to explain the causes of some deficiencies in conventional primers. Simple design changes are suggested as means of improving the performance of artillery primers.

INTRODUCTION

Interest in the general problem of the ignition of propellants is increasing for a number of reasons. One reason is that the demands which are made on each component of a weapon system become more stringent as efforts are made to improve the performance of conventional weapons under conditions which may be classed as normal operation. These components include, of course, ignition systems. As efforts are increased to extend the range of conditions under which weapons must perform satisfactorily the increase in demands on ignition systems is quite marked. For example, the desire to increase muzzle velocities, rates of fire and safe ambient temperature ranges, at the same time decreasing muzzle velocity dispersion, calls for even closer control of ignition conditions. The design of unconventional weapons introduces special requirements of igniters which are too diversified to discuss at this point. Another major reason for increased interest in practical ignition problems is that more widespread use of ballistic measuring instruments, such as piezoelectric pressure gauges, is revealing certain defects in conventional weapon systems which have been in use for many years.

Recent ignition studies by a number of workers have included a variety of theoretical and experimental investigations on specific aspects of the over-all problem. Because the problem is so complex and so few of the aspects are understood in a satisfactory manner, it is not surprising that there exist no suitable straightforward design standards for even the simplest practical ignition systems. As a consequence, it is frequently necessary that such design problems involve the arbitrary choice of a particular ignition system and a subsequent large amount of development work.

A cursory look at the ignition problem shows that, although it is complex, its solution rests largely on the solution of problems in chemistry and hydrodynamics. The present report will attempt to point out some of these problems, to give some appreciation of their importance and to describe several experimental igniters which have been designed, on the basis of scanty observations and measurements, to improve the performance of particular artillery weapons.

It is probably worthwhile to consider at this point the general role of igniters in the operation of weapons. For the sake of later discussions the ignition system is assumed merely to be the means by which the combustion of a propellant can be initiated and caused to become self-supporting. By this loose definition the word primer is suitably descriptive of the role of an igniter in an actual weapon.

The tasks which a primer must perform are many and varied. The primarily desired characteristic of an ignition system is that it ignite the maximum possible fraction of the propellant charge in as short a time as possible without having harmful effects on either the performance or strength of any part of the weapon system. It is desirable for obvious reasons that actual conditions simulate the usual assumptions of interior ballistic theory that the total propellant surface ignites simultaneously and instantaneously. (In practice both considerations are important where synchronization problems are involved, as in shipboard guns, multiple mounts and a variety of other applications.)

In a given weapon a primer may be called upon to ignite propellants of different compositions and granulations at various temperatures and over a wide range of densities of loading and physical configurations of the charge. A consideration of the general types of weapons is even more revealing to show the wide variety of conditions under which primers are expected to operate satisfactorily.

In small arms, for example, the primer element is placed at one end of the propellant charge. Rockets usually are ignited by means of squibs which are fixed to the charge or are located in close proximity to the charge. Mortar charges are so arranged that a portion of the propellant is in the same general region as the primer, while other propellant increments (which are added for use in the higher zones of fire) are located in a region which permits accessibility of the increments for removal under field firing conditions but which does not present optimum ignition conditions. The problem becomes even more complex for recoilless weapons, rocket-assisted weapons and other unconventional guns. In practically all conventional artillery weapons, ignition systems are rather simple, consisting of a tubular primer which extends along the axis of the propellant chamber for a length which is commensurate with the fraction of the chamber occupied by the propellant. The discussion which follows relates to the performance of percussion-type artillery primers and the roles they play in the ignition process.

ARTILLERY PRIMERS

At the outset of a discussion of standard Army artillery primers, it should be pointed out that present primers reflect strongly the dictates of manufacturing practices. Simplicity of manufacture is an essential consideration in primer design, but, on the other hand, the extent to which the designs are stereotyped indicates that the full importance of certain design features has not been appreciated.

Most artillery primers are of a simple tubular construction, having a uniform size and distribution of vents through the tube wall and a simple means of closing the ends. The breech end closure is normally a threaded element which contains the percussion charge, while the forward end is closed by a threaded plug, a rolled section of the body or a paper diaphragm. The charge of black powder is loaded by a pouring operation and is prevented from entering the body vents by thin foiling paper which lines the inside of the tube. The particle size and composition of the black powder are fixed for most primer applications, and because this composition is somewhat hygroscopic the end closures and the vent holes are coated with a waterproofing lacquer. In general, most artillery primers can be considered to be scale models of other primers.

To serve as illustrations of primers whose construction and functioning will be described in general terms, five standard Army primers are shown in cross section by Fig. 1. All of the primers under discussion are of the percussion type; i.e., they are initiated by the impact of a firing pin on a primer plug which is in contact with a small percussion charge of high explosive. The gaseous products of decomposition of the percussion charge flow through small openings in a percussion element anvil and via a single orifice to the primer body which contains the black powder charge. These gases ignite the black powder, whose gaseous products of combustion spread through the entire powder bed and ultimately discharge through the primer vents to the propellant region.

The uniformity of design features among various primers is worthy of further scrutiny. In most artillery-type primers the same amount of percussion charge is employed, regardless of the amount of black powder which it is expected to ignite. For example, the same percussion charge is used to ignite the 400-grain powder charge in a long M-49 primer as is employed to ignite the 55-grain charge in a short M-38 primer.

The amount of black powder which is used in artillery primers varies considerably, as does the orientation of the powder in the primer bodies. In some primers the black powder fills virtually the entire tube, while in other primers as little as one-third of the tube is occupied, the filled portion being the zone adjacent to the percussion element. The portion of the primer body which contains the black powder may be vented over most or but a small part of its length. Similar differences may be noted for the use of foiling paper, since some primers do not employ such paper in the section which does not contain black powder initially.

STATIC FIRING EXPERIMENTS

In order to gain a better knowledge of the performance of artillery primer-propellant systems in general, it is important to understand, by means of quantitative measurements, the characteristics of specific primers. Accordingly the Ballistic Research Laboratories set up a simple exploratory experiment to study, in simple static tests, some of the characteristics of a number of standard Army primers.

Some of the variables which can be measured quantitatively are listed herewith:

(a) Times

1. Time interval from the impact of the firing pin on the primer body plug to the start of venting of the percussion element gases.
2. The duration of venting of percussion element gases.
3. Interval from the start of percussion element venting to the ignition of the first portion of the black powder.
4. The time of earliest venting of the primer body.
5. The interval between initial venting of the primer body and the venting of the last vent to discharge gas.
6. The duration of black powder combustion or gas venting.
7. The duration of post-venting combustion (combustion of black powder outside the primer body).

(b) Flame Propagation Velocities

1. Of the percussion element gases prior to ignition of black powder.
2. Of the burning front passing through the black powder bed after ignition of a portion of black powder.

(c) Pressures

1. Pressure-time relationships at given positions along the primer.
2. Variations of pressure with position along the primer.

(d) Nature of Venting Process

1. Character of the venting products of combustion.
2. Sequence of venting relative to vent positions.
3. Regularity of venting relative to the circumferential location of vents.

4. Extent of the venting of unburned black powder.
5. Effect of the characteristics of the foiling paper on the sequence of venting at various positions along the primer.

Quantitative data to be presented below pertain to a number of these variables, but much additional work remains to be done before the functioning of primers can be described in complete detail.

In a simple experimental study of the functioning of standard primers it seems logical to investigate their performance when fired statically under atmospheric conditions, since this is the condition which obtains early in the course of a gun firing. Accordingly, a simple test device was constructed, using as its firing mechanism the breech section of a 37mm gun, with an adaptor to hold primer bodies so that the entire vented length of the primer body was accessible for visual observation and for the mounting of measuring devices.

A general photographic view of the test apparatus appears in Fig. 2. Because this makeshift test device was unsatisfactory for use in extended test programs, a simple pendulum apparatus was constructed for use in the later stages of the experimental work; this apparatus is shown in Fig. 3.

Two photographic techniques are used to observe the over-all performance of primers, high-speed motion picture cameras capable of recording as high as 14,000 exposures per second and a single-frame camera giving exposure times as short as one microsecond. Pressure-time relationships are determined by means of ferrule-type resistance pressure gauges having access to the inside of the primer bodies. In order to correlate specific events, a provision is made to record the instant of impact of the firing pin on the primer cap as the illumination of an argon lamp on photographic records and as a pip on pressure-time records. A movable lamp of the same sort is employed to mark a second position on motion picture records so that it is possible to correlate film measurements with lengths along the primer. Other lights which flash at millisecond intervals provide time scales for the motion pictures and pressure-time records.

An additional method of measuring time intervals during the venting process involves the use of small paired ionization probes whose exposure to the primer gases establishes the circuit continuity required to actuate high-speed electronic counters. Some light intensity-time data have been obtained for the discharging gases, but since the interpretation of these data is difficult no further reference will be made to these measurements.

RESULTS OF STATIC FIRINGS

In order to describe the sequences of events which take place in the functioning of a black powder primer, attention is directed to Fig. 4. This sequence of photographs shows some of the events taking place in a primer, which in this case is a standard M-31A2 primer having a transparent window along most of its length. At the instant of impact of the firing pin on the percussion cap an argon lamp is intensified in light output (by shorting out a resistor in the circuit); this light provides a reference point from which distances along the primer body can be measured toward a second light placed at a known position. In the case of the firing which is illustrated by Fig. 4, the camera speed is 11,500 frames per second. From the photographs it can be seen that for a period of about 350 microseconds no gas discharge is visible within the black powder region. The percussion element gases then illuminate a portion of the powder region and disappear about 260 microseconds later. A relatively long delay follows, during which time the black powder evidently is heated and starts to burn near the percussion element end of the primer. The opaque portion of the primer body obscures the flame from view, however, and it is not until the flame front reaches the window section that the flame becomes visible. The velocity of propagation of the combustion front is quite low about 2 inches per millisecond in this example, but somewhat higher in other firings. In any case the time duration of this step in the process is long, as is the time of the venting process along the length of the primer.

One additional observation should be made at this point. It is evident from the photographs that the propagation of flame along the primer does not take place in the form of a clear-cut front, but rather is fastest between the primer body and the black powder bed where the packing permits freest flow. Because of this irregularity, no reliability is placed on flame velocity data derived from measurements made by means of the ionization probes placed at the vents.

Some quantitative data which describe the functioning of the percussion elements are now given to indicate the uniformity of these portions of primers. With the firing mechanism used, the time delay between impact of the firing pin on the percussion element plug and venting of the percussion element is 249 ± 21 microseconds. This value is obtained readily through the use of ionisation probes or high-speed photography. The total venting time is about 800 microseconds and the period of active venting is about 360 microseconds, as indicated in Fig. 5. Some uncertainty about the duration of the venting is introduced by the fact that it is impossible to state during what fraction of the total exposure time of a given motion picture frame an event takes place for either the first or last frame to record the event.

Within a primer body the percussion element gases appear to leave the percussion vent at sonic velocity relative to the atmosphere and to decrease in velocity rapidly. In the example of Fig. 4, the luminosity disappears at a position about two-thirds of the primer length from the percussion end. More careful measurements will be required to chart reliably the flow of percussion element gases through the black powder bed, but rough measurements indicate subsonic flow through virtually all of this region.

Fig. 6A is a still camera record of a percussion element during the entire venting process. There is evidence of an over-expanded region between the end of the flash cone and an area in which a luminous front is visible. The definite curved line in the photograph suggests the existence of a steady-state shock front. Fig. 6B shows similar information for a percussion element from which the flash cone has been removed. Fig. 7A, a four-microsecond exposure, shows a possible zone of similar construction, and in addition some detail about the physical structure of the exhaust. Fig. 7B, a one-microsecond exposure, shows a shock front very clearly. The motion picture data of Fig. 5 fail to yield a complete description of the venting process, but do show a major portion of the total luminosity at the same distance from the percussion element as the assumed spherical front noted in the still photographs.

Attention is now directed to photographs which show outside views of primers during the venting process. Fig. 8 is a view of an M-38B2 primer, which is one of the primers shown in Fig. 1. In this example the light which indicates impact of the firing pin has been removed from the enlarged photographs. Time intervals from the instant of impact are indicated, however, and it can be seen that the vent nearest to the percussion element discharges gas about 900 microseconds after firing pin impact. Approximately 270 microseconds later the second vent discharges vigorously, and finally after an additional 1730 microseconds the third vent discharges. The important time intervals from impact of the firing pin are: (a) approximately 250 microseconds for the percussion element to detonate and discharge any of its gaseous products; (b) 650 microseconds from the start of percussion element discharge to the venting of combustion products; (c) 1480 microseconds from the start of percussion element discharge until the entire length of the primer is venting. The additional observation that the primer discharges actively for a period of more than 10 milliseconds indicates that this particular type of primer is quite slow in its action. It should be noted, however, that the example considered is that of a primer discharging to atmospheric pressure. It can be expected that when a primer functions within a propellant chamber both the external pressure and the internal pressure will rise more rapidly and the burning will take place more rapidly than in a static test.

Again it should be pointed out that the M-38 primer has certain deficiencies which make its performance unreliable. One difficulty which can be pointed out immediately is that the gases from the percussion element raise the pressure within the primer body sufficiently that one or more vents blow free before the black powder ignites. The result is that the rate of pressure rise is low and the burning of black powder proceeds so slowly that the primer as a whole acts very inefficiently as an ignition system. That the percussion element gases are capable of venting a short primer body prematurely can be shown very readily. If an M-38 primer body is emptied of its black powder and is then fired statically, at least one of the vents is seen to be open after the completion of the test. If an inert material of about the same particle size as the black powder is used to fill the primer body, more vents are ruptured by the percussion element gases than if the primer body is empty. Employing this procedure, an actual test of five M-38 primers showed at least five vents of the total number of ten rupturing for each primer tested.

If the free volume within a primer is sufficiently great to permit expansion of the percussion element gases to a pressure below the rupture pressure of the foiling paper which covers the vent holes, then rupture of the paper occurs only after combustion of the black powder charge elevates the pressure to the value required for rupture. This can be shown by means of test results obtained with M-28 primers, which have the same density of loading of black powder as does the M-38 primer, but greater total free volume in which the pressure of the gases from the percussion element can equalize. Fig. 9 is a photographic record of the venting of an M-28 primer.

This photographic record shows venting which takes place in a rather regular manner, starting at the vent nearest to the percussion element and proceeding vent-by-vent toward the forward end.

Still another primer is shown in Fig. 10, an outside view of a modified T-33 primer (with a 300-grain charge instead of the normal 400-grain charge) during the venting process. This primer has a greater vent area per unit weight of charge than does either the M-28 or the M-38 primer. (The approximate values for the subject primers are as follows: 0.0028 in^2/grain of charge for the M-28; 0.0023 for the M-38; 0.0029 for the modified T-33, if the forward end is open during the venting process.) The effect of this "over-venting" is shown in the long time required for the burning of the black powder. (Pressure-time data yield the additional information that the black powder burns at very low pressures, as is to be expected for an over-vented tube. As another example of the performance of over-vented primers, it is pointed out that the M-22A3 primer (charge of 65 grains, vent area/charge ratio of 0.0057) burns very slowly.

Fig. 10 also shows that considerable venting takes place through the open foward end. Although the photographs are not able to distinguish between powder gases and unburned powder, it is suspected that a great deal of the black powder is ejected unburned through the forward end, particularly when the forward closure is weak.

GENERAL DEFICIENCIES IN PRIMER PERFORMANCE

Because it is possible to point out some deficiencies of standard primers on the basis of simple photographic studies, a few such deficiencies are mentioned at this point, as follows:

a) Primers can, depending on certain design features, be relatively slow-acting. This fact suggests that simultaneous ignition of the entire propellant region is not realized when such ignition systems are used. (As a matter of fact, it is probable that slow-acting primers in some particular weapons continue to burn after the projectile has been ejected.)

b) The primer vents do not discharge simultaneously along the length of a primer body. As will be seen later, progressive venting can result in the ignition of a portion of the propellant bed sufficiently in advance of ignition in other regions of the propellant that unwanted pressure waves are set up within the chamber of a weapon.

c) The failure of some vents to exhaust at any time during the venting period makes possible an unsymmetrical pattern of ignition. Under such conditions, pressure oscillations may result and if these oscillations are severe enough they may exceed the rated strength of the gun chamber.

d) Irregular circumferential venting can result from the fact that the foiling paper may overlap beneath a given row of vents and accordingly require a higher pressure before these vents will rupture. This deficiency seems to be realized only for primers which operate at very low pressures, and is probably not very common.

e) Primers which are open at the forward ends can be expected to operate irreproducibly, inasmuch as black powder can be ejected unburned at these points. If such occurs on a large scale, it can be expected that the subsequent burning of the black powder within the propellant will produce a great amount of heat in a localized region.

f) An effect opposite to that which can occur in a propellant region with open-end primers can be seen for primers whose bodies are not vented near the percussion element. In order that propellant at the breech end of the gun chamber can be ignited, gases must flow from a forward vent of the primer or else the gases generated by the burning of a forward portion of the propellant must act as the igniter for the propellant which is located near the breech.

EFFECT OF PRIMER PERFORMANCE ON GUN PERFORMANCE

Since the over-all performance of a weapon is the point of real interest in evaluating the suitability of a given ignition system, it is of interest to discuss the possible effects of particular irregularities in primer performance on gun performance in general. Before this can be done, however, it is necessary to look in some detail at a few of the irregularities encountered in guns and to discuss probable reasons for these irregularities.

The mechanism of propellant burning must be considered at the outset of this discussion, since it gives a clue to the reasons for pressure irregularities which appear in gun firings. The burning of a propellant at low pressures can be examined in some detail in the laboratory, and it is rather obvious that a single mechanism does not suffice to describe the phenomenon. Various steps in the decomposition process can be pointed out, but it is of immediate interest here to note that two general types of burning are possible. These two general types of burning are frequently referred to as flame burning and fizz burning - flame burning being defined as the burning of a propellant to final products and fizz burning as burning to intermediate reaction products. In the case of fizz burning a large fraction of the energy originally available in the solid propellant is not made available to do work in the weapon. By the addition of sufficient heat to the products of fizz burning these products can be made to react to completion, and the total energy then realized by the two-stage reaction is equal to the energy realizable from flame burning.

The process of propellant burning can be viewed in general terms from the standpoint of the amount of energy which must be added to a propellant grain to permit either type of burning mentioned above. If the energy added to a unit weight of propellant is less than a certain amount, say E_1, no burning will result. If, on the other hand, sufficient energy, say E_2, is added, flame burning will result. If energy is added in an amount between E_1 and E_2, fizz burning will occur. Furthermore, the products of fizz burning are capable of reacting very rapidly to completion if the required additional energy is made available. Because the reaction of these intermediate products can take place with violence, it is undesirable to permit such products to accumulate and to react on a scale so great as to overtax the strength of the containing weapon.

The possibility of the sudden reaction of accumulated gases in localized regions points to the serious problem of pressure pulses (more commonly referred to as pressure waves) which have been observed in a number of weapons. Assume that a given amount of propellant undergoes fizz burning and that the incompletely reacted gases accumulate in a small region. If these gases receive an added amount of energy sufficient to initiate complete reaction, the pressure will rise suddenly in this region. The resulting pressure wave will then move outward from the reaction zone (as any other sound wave) toward the extremities of the gun chamber.

It is to be expected that such a pressure wave will be attenuated during its travel through a closely packed propellant bed if the propellant merely extracts energy from the passing wave and does not ignite. If, on the other hand, additional propellant ignites and generates gas in the region which the pressure wave traverses, the wave will tend to increase in amplitude. The relative magnitudes of these two effects, accordingly, will determine whether the pressure wave is attenuated or amplified during its travel to the extreme ends of the chamber. On reaching either end of the gun chamber (say the breech face or the projectile base) the pressure wave will be reflected and move back towards its zone of origin. If some of the closely packed propellant has been burning since the moment of the first passage of the pressure wave toward the end of the chamber, the movement of the pressure wave will be less strongly impeded on the return trip. Furthermore, the wave will have a greater chance of igniting or enhancing the burning of propellant which has been receiving energy during this period. Upon returning to the region of origin the pressure wave will encounter a zone of propellant which is burning vigorously and, as in regions showing less vigorous burning which it will have passed earlier, it will increase the burning rate and hence the rate of pressure rise. The expected result, then, will be the generation of a stronger wave whose movement will be similar to the motion of the parent wave.

The occurrence of pressure waves in guns has been observed for many years, and such waves are seen to be most serious when the ignition of the charge is localized at one end of the chamber. These observations may be explained rather simply, by the mechanism described above, for the case of a pressure wave whose pressure amplification (by virtue of the gases evolved during propellant combustion) exceeds the pressure attenuation (resulting from expansion through the bed and loss of heat by transfer to the propellant) during its passage through the propellant bed. Such a condition seems to exist in a number of weapons. For such cases, it is obvious that the farther a pressure wave moves the greater will be its intensity on returning to the zone of origin. The optimum condition, therefore, is that realized by central ignition of the charge - in other words, for the circumstance in which the total distance traveled (hence also the time required for transit) to and from a single reflecting surface is a minimum*.

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*(It should be noted that if a pressure wave reaches the magnitude of a shock front the reflected wave may show a pressure increase of several fold. If such an increase occurs, the conditions described above become even more severe.)

The effect of symmetry of ignition on pressure oscillations within a gun chamber has been pointed out rather clearly in the firings of very quick propellants in a 105mm howitzer dual-granulation study. In this work it was desired to use in the base charge of the howitzer a very quick propellant and in the charge increments required for higher zones of fire a somewhat slower propellant. On the basis of easy assembly of propellant bags around the primer body it was desirable to place the bag of very quick propellant at the base of the cartridge case, where it would remain for all zones of fire. On the basis of keeping pressure oscillations to a minimum, however, it appeared desirable to distribute the quick propellant along the entire length of the chamber. In order to measure the magnitude of pressure fluctuations under each circumstance, a series of experimental rounds was fired, using in each instance a charge of 6.0 ounces of 0.0023-inch disc propellant of M-9 composition. The orientations of the various charges were as shown in Fig. 11, which also points out that the pressures are much more regular for the uniformly distributed charge than for a charge which is located near an end of the chamber. The propellant which was used for these firings represents about the quickest propellant available, and hence the test conditions were quite extreme. For coarser propellants the same general behavior would be expected, but the pressure fluctuations would probably be less severe.

Two basic requirements of an optimum ignition system are obvious from the discussions of the nature of fizz burning and pressure waves. The first desired characteristic is that an igniter be capable of supplying energy to the propellant at a rate which will eliminate, or keep to a minimum, fizz burning of the propellant. The other characteristic is that symmetry of ignition be realized in order that the severity of pressure waves may be kept to a minimum. Actually, simultaneity of ignition throughout a propellant region is the desired condition, and it is only because this condition cannot be realized in practice that the desirability of a symmetrical pattern of ignition is emphasized.

In addition to the desired characteristics of sufficiency, simultaneity and symmetry of energy release from a primer, a fourth general characteristic is desired. This characteristic is regularity of performance, which describes round-to-round variations and which in the broadest sense manifests itself as reproducibility of projectile muzzle velocity. Although this characteristic is less specific than the others noted, its importance cannot be over-emphasized. Its value is obvious for multiple weapons where synchronization of more than one igniter-propellant system demands good regularity. In addition, it can be remarked that interior ballistic phenomena which take place during early projectile motion are thought to affect very strongly the later history of projectile travel. Since the early burning could determine to a large extent the pressure-travel relationships, it is not unlikely that round-to-round variations in muzzle velocity can be traced to irregularities in ignition and early burning.

THE DESIGN OF SPECIAL PRIMERS

In view of the fact that some standard black powder primers appear to have characteristics which are undesirable for certain gun applications, thought has been given to means by which their operation can be improved. The following discussion considers the improvement of particular characteristics.

It appears desirable, for example, for a primer to vent along its length as nearly simultaneously as possible. (One can hope that the sudden opening of a large number of vents will not cause so extreme a pressure drop that the burning rate of the black powder, and hence the rate of gas evolution, will drop suddenly. This hope seems to be borne out in actual tests.)

One possible means of achieving simultaneous venting is that of graduating the thickness of the foiling paper so that its rupture strength varies in proportion to the pressure existing along the primer body at the instant of rupture. General pressure-time-position relationships are shown schematically in Fig. 12. Since the pressure is greater near the percussion element and than elsewhere in the primer prior to rupture, it is desirable that the restraining paper be thicker in this region than elsewhere. On the assumptions of uniform properties of the restraining material and failure in shear around the periphery of vents of uniform size, the desired pressure-resistance proportionality factor is seen to be a constant multiplied by the thickness of the restraining material.

Let $F_{restraining}$ = shear path x unit shear strength

= shear circumference x shear thickness x shear strength

= $\pi D t S_s$

where: D = vent diameter

t = foiling paper thickness

S_s = shear strength of paper

The applied force causing failure:

$$F_{failure} = \text{applied force}$$
$$= \text{pressure x cross-sectional area under vent}$$
$$= P(\ell)\,\frac{\pi D^2}{4}$$

where: $P(\ell)$ = gas pressure at instant of failure --- a function of position (ℓ) along the primer body

At the instant of failure, $F_{restraining} = F_{failure}$.

$$F_{restraining} = F_{failure}$$
$$\pi D t S_s = P(\ell)\,\frac{\pi D^2}{4}$$

$$t = \frac{D\,P(\ell)}{4\,S_s}$$, and for uniform properties of the rupturing material behind vents of uniform size:

$$t = \text{constant x } P(\ell)$$

For several reasons the assumption of failure in shear is open to question. In the first place, the paper is non-uniform in physical properties. Secondly, the water-proofing lacquer adds, in a rather uncontrollable manner, to the strength of paper. Furthermore, this added strength appears to be a large fraction of the total strength. For the purpose of designing a series of experimental primers, the value of this constant has been taken as 200 in.^{3}/lb. (force)-- a value estimated from actual pressure-time data. On the basis of simple calculations which use this rough value for the constant, it can be shown that a paper liner must be prohibitively thick near the breech end in order that the paper at the forward positions may be thick enough to hold up in actual assembly operations. (Some such model primers have been constructed and fired, however, and a general slight improvement in primer performance has been realized.)

GRADUATION OF VENT SIZE

A more practical solution to the problem appears to lie in the use of a uniformly thick foiling paper (or other types of retaining material) with vent holes which are graduated from small vents at the percussion element end to somewhat larger vents at the forward end. From the simple relationships noted earlier, the diameters of the vents along the primer must be adjusted to be inversely proportional to the pressures expected to exist just prior to rupture. One particularly interesting primer of this type which has been developed and tested (jointly by the Development and Proof Services and the Ballistic Research Laboratories of the Aberdeen Proving Ground) performs quite satisfactorily. This primer is the T-88E1, which is shown schematically in Fig. 13.

The T-83E1 primer is a modified T-33 primer. The changes in design include the substitution of a threaded steel plug for the paper diaphragm in the forward end, the reduction of the black powder charge from 400 grains to 300 grains and the addition of vent holes in the breech end of the body over the length which is normally unvented in the T-33 model. These added holes are 0.0625 inch in diameter near the breech end and 0.125 inch in diameter for the middle section. The normal holes, 0.180 inch in diameter, are left unaltered. The improvement in overall performance is shown in Fig. 14, from which it can be seen that the T-88E1 model vents in a much shorter time than does the modified T-33 primer (See Fig. 10). Furthermore, venting of the T-88E1 starts at about the mid-primer position, while venting of the modified T-33 primer starts at the vent nearest to the breech and progresses slowly toward the forward end.

One further improvement in performance could be made possible through a change in the arrangement of the vent holes. As with any orifice, the rate at which gases discharge through a vent is proportional to the cross-sectional area of the vent. Accordingly, if a uniform gas discharge rate is desired along the length of a primer, the smaller vents must be used in greater number than the large vents - in the inverse ratio of diameters squared, to be specific. This factor can prove to be a limitation insofar as ease of manufacture is concerned, particularly for long primers in which the sizes of holes would vary widely.

DOUBLE TUBE PRIMERS

If it is possible to depart from the requirements of simultaneous discharge of vents along the entire primer length, further simplifications can be made. For example, if symmetrical gas discharge will substitute satisfactorily for simultaneous discharge, a completely different primer design can be used to advantage. It has been seen earlier that one of the main difficulties met in primer design is that of moving the initiating gases from a percussion element through a closely packed bed of black powder. An improvement in design can therefore be realized if these gases can be led down the length of the primer and caused to discharge at the mid-primer position, so that combustion of the black powder proceeds from that point toward both ends of the primer. Possible designs are shown in Fig. 15. The main element which has been added to the design is the hollow tube which leads from the percussion element cup to roughly the mid-primer position. This inner tube is closed at its forward end and is vented at positions symmetrical with respect to the mid-primer position.

The performance of double-tube primers discussed above is illustrated in Fig. 16, 17 and 18. The patterns of venting are obviously symmetrical about the mid-primer points and the times required for venting are short. This type of primer performs well in gun firings, but conclusive data are not yet available. Two definite advantages can be hoped for in such a double-tube design, however. In the first place, it is possible to realize symmetrical ignition in very long primers - a condition difficult to realize for conventional single-tube primers having uniform vents or for single-tube primers having graduated vents in which it is desired to avoid the combination of very small vents and thick lining materials. The second advantage is that, with the inner tube, finely divided black powder (with its attendant large total burning surface and short burning time) can be employed more successfully. With a single-tube assembly the finer black powder would restrict the flow of gases along the primer length more than would the normal coarse powder, and hence the time required to vent the entire primer length would be substantially longer.

RESULTS OF GUN FIRINGS USING ALTERNATE PRIMER DESIGNS

Some gun firing data are available to compare the over-all performance of a standard type of primer (modified T-33) with two modified versions of this primer (T-88E1 and a double-tube primer employing a T-33 body). All of the firings have been reported in Report No. 12 of Project TA1-1302.

The weapon system under discussion is a 76mm gun, T-91, firing a special projectile and several types of propellants. In the course of charge assessment studies, the weapon showed pressures which were very high and variable, with the most serious pressure oscillations occurring at low temperatures, and failure of the breech of the gun occurring at temperatures as high as 10°F. Typical early pressure-time records for the weapon system are shown in Fig. 19.

The character of the firing records and the make-up of the primer-propellant system suggested that heat was being transferred to the propellant at a rate insufficient to permit uniform ignition, and that fizz burning, followed by the detonation of accumulated gases, was setting up the severe pressure oscillations. Fig. 10 shows that the modified T-33 primer vents very slowly along the forward half of the body and that the forward end of the primer has a weak closure which can open readily to discharge unburned black powder. The burning of this ejected black powder could be expected to provide a great deal of energy rapidly, and it was thought possible that the release of energy from this localized source could bring about the complete reaction of any accumulated products of fizz burning.

Closed chamber firings were called on to investigate the possibility of fizz burning of one of the propellants at low temperatures. Samples of the M-17 propellant were cooled to about -33°C. in a closed chamber and ignited by means of an 0.5 gm igniter charge of 0.013-inch thread nitrocellulose. Fig. 20 shows that the pressure rise was both slow and smooth until the pressure reached about 11,000 psi; at this pressure level the rate of pressure increase became much higher - and indeed continued to rise at a high rate until all of the propellant was consumed. A comparison round which employed the same amount of the thread igniter plus 0.5 gm of black powder showed a smooth pressure-time history during the entire burning period. In view of these and other similar data the use of a more intense ignition system in the gun was suggested.

Gun firings were then conducted with the two modified primers, which static tests showed to be superior to the T-33 primer. Firings with each of the two modified primers showed no serious pressure oscillations, (See Fig. 21) even at temperatures as low as -40°F. Furthermore, the maximum pressures were reduced markedly and were more uniform from round to round. There was strong evidence of improved uniformity in muzzle velocity, but a sufficient number of firings has not yet been made to permit confirmation of this belief. (Improvements in muzzle velocity dispersion would be expected to accompany improved ignition, however, and it is interesting to note that the muzzle velocities for the few rounds which were fired with the modified primers showed a surprisingly low dispersion, even at the lowest temperatures.)

INTERNAL PRESSURE MEASUREMENTS FOR CONVENTIONAL PRIMERS

With only meager substantiating data, several general observations are made about pressure-time relationships within conventional primers which are fired statically. One of the most striking observations is that the maximum pressures measured at corresponding points in similar primers show considerable variation among primers. In Fig. 22, which shows pressure-time relationships for two M-31A2 primers, it can be see that the maximum pressure for one primer is approximately 55 percent of the maximum pressure for the other, the actual values being about 1260 and 2280 psi.

A similar remark can be made about the maximum pressures reached at various positions along a particular primer. Since such measurements have not been made simultaneously on single primers, specific data are not cited. In general, however, it can be said that the maximum pressures reached near the breech end of a primer are lower than the maximum pressures reached at mid-primer, which in turn are lower than the maximum pressures reached at the forward end of the primer. Also, it is apparent from individual pressure measurements that the rate of pressure rise at forward positions is somewhat higher than at rearward positions, and it is not unlikely that the combustion front within the black powder approaches shock conditions near the forward ends of long primers. The relationships between rate of pressure equalization, change in packing of the black powder and its burning rate along the primer length, and other factors make analysis of the conditions at any instant difficult. In general, however, it appears that the longer is the time that a flame front moves along a primer body the higher is its instantaneous velocity. The measurements which show very high pressures at the forward ends of some primers are borne out by the fact that long experimental primers (say from about 18 to 27 inches in over-all length) frequently bulge or rupture at the forward ends. A short primer which has the same cross-sectional area, same vent area per unit length, and same density of loading as a given long primer would be expected to reach the same maximum pressures as the long primer, if the primers act as vented vessels with free flow of gases throughout the packing of powder for pressure equalization. Since easy pressure equalization is not realized, however, there appears to be a danger in constructing from the same tubing very long primers whose strength is expected to equal that of short primers.

One additional point should be mentioned about the rupture of experimental primer bodies, although no detailed explanations are offered for the contradictory results obtained from firings. Let us assume that a given primer body is capable of holding 1000 grains of black powder of a given size, that a number of experimental primers are loaded with the full charge of powder, that the forward ends are closed, and that the primers are fired statically. After static firings have been made, it is observed that the primer bodies are intact. Now assume that similar primer bodies are loaded with a reduced charge, say 600 grains of powder, which is held at the percussion element end of the body by means of a cardboard diaphragm. After these primers have been fired statically it is observed that some of the bodies are intact, while others have bulged or opened at the forward ends.

The question then arises from the above results why the reduced charge ruptures the primer bodies while the full charge does not cause rupture. (This difference does not always occur as assumed, but within a series of small numbers of firings it has been observed.) Assuming uniform strength of the tubing which is used for the primer bodies, one must look for differences in the manner in which the powder burns. In the case of the full charge the powder can move forward but slightly under the force of gases generated at the percussion end early in the burning process. In the case of the reduced charge considerable motion is possible, and it is not unlikely that a portion of the charge attains an appreciable velocity before striking the forward closure. If such occurs, there exists the possibility that a number of grains will be crushed, so that a much increased powder surface will result, making possible subsequent rapid burning when this portion of the powder is ignited. Even if crushing does not occur, it is possible that the powder particles can be pressed firmly together so that burning will be faster and the rate of pressure rise higher there than elsewhere, at least until the black powder is forced back toward the percussion element. (There is some experimental evidence that the black powder can move forward rapidly in primers which are only partially filled. For example, frequently the cardboard diaphragms which serve to hold the black powder at the percussion element ends of primers are found extruded through the forward vents of primers which are fired statically.) This matter bears extensive investigation, as do pressure phenomena in general.

EJECTION OF UNBURNED BLACK POWDER FROM PRIMERS

As is to be expected, the entire black powder charge does not burn within a primer body, and this fact should be taken into consideration in specific artillery ignition systems. For example, if the forward end of a primer is closed by means of a loose paper diaphragm, it is possible that a large portion of the black powder can be ejected unburned through this opening. Even along the body of the primer, black powder can be ejected unburned through the vents, in quantities depending on the operating characteristics of the primer in question. Data obtained on the recovery of unburned black powder from static firings of several standard artillery primers show the following: 20 percent of the original charge for type M-38; 10 percent for type M-28; 3 percent for the body section and 1.5 percent for the forward end of type M-40; 6 percent for the body section and 4 percent for the forward end of type M-49. Recovery was made in a large armored box which housed the entire primer firing mechanism. In the case of the M-40 and M-49 primers the box was sectioned so that the forward ends and the body vents exhausted into separate compartments. No estimate was made of the quantity of black powder which burned after being exhausted to the atmosphere.

The size of black powder particles relative to the size of vents should have some influence on the ease with which the former is ejected from a primer. Static tests which were conducted on M-28 primers having a 150-grain charge of FFFG powder (all particles smaller than the primer body vents) showed an average of 27 percent of the original powder charge ejected unburned.

RETAINING DIAPHRAGMS

In connection with the use of paper diaphragms to close the forward ends of primers, an interesting point arises which can be extended to the use of similar diaphragms elsewhere within a primer body. Such a diaphragm is particularly useful, largely for reasons of simplicity in manufacture, for retaining the black powder charges at the breech end of primers which are partially filled. The question arises about the orientation of the diaphragm; namely, whether the open or the closed end of the diaphragm should face the percussion element end of the body. If the open end of the diaphragm faces the percussion element the cup is so placed as to resemble the skirts frequently used as rear gas seals on projectiles which are designed for smoothbore weapons. It is to be expected that, as the gas pressure rises, the open portion of the diaphragm is pressed tightly against the primer body, thereby effecting a seal to prevent the immediate escape of gas. If such occurs the black powder has a better opportunity to burn reliably than if the diaphragm moves freely and prevents pressure build-up. This possiblity has not been checked experimentally, but many results are available to show the desirability of fixing the diaphragm so that motion or rupture of the diaphragm does not occur until the gas pressure has risen appreciably.

In the design of special artillery rounds there occasionally arises the requirement of venting the igniter products in a rather localized zone which is some distance from the percussion element. (A possible example is that of a finned projectile whose boom and fins are initially within the propellant region and whose geometry essentially separates the propellant into two general regions. In this case it may be desirable to lead the igniter gases along the inside of the boom so that they discharge at such a position as to have easy access to both regions of propellant.) For this purpose it is possible to call upon a primer which contains a rupture disc capable of holding back the products of black powder combustion until a reasonably high pressure is reached. The gases can then be vented rapidly along a small section of the tube. A schematic drawing of such a primer is shown in Fig. 15 and a photographic record of the venting pattern for a static firing is shown in Fig. 23. From the latter it can be observed that all of the vents discharge at very nearly the same time. (One frame of the motion picture record represents about 80 microseconds.)

SUMMARY

The simple static tests which have been described herein offer an easy means of assessing roughly the suitability of artillery primers for particular applications in weapons. In order that weapon design data may be derived from such tests, it is of great importance that additonal quantitative data be obtained and that experiments be directed toward an understanding of the performance of primers in systems wherein the external pressures, with respect to the primer, simulate the pressures which prevail in actual weapons. In any case, it is worthwhile that attempts be made to correlate data obtained from static tests of primers with actual gun firings of these primers.

Certain aspects of gun performance have not been considered in this discussion, since the study has been exploratory in nature. The effect of primer performance on gun flash, for example, requires detailed study. At the present time it appears as if improvements in ignition systems will make possible reduced gun flash, but it is not clear whether a primer should exhaust a slight excess of its products of combustion in the forward portion of the propellant charge in order to be an effective flash suppressor.

The results of firings with certain weapons indicate that strict attention to intense, symmetrical ignition is not required in all cases. In the case of charges which are of coarse granulation and which have considerable free chamber volume (hence easy flow of primer gases) it appears as if a wide choice in primers can be made. Closely packed charges of fine granulation require more care in the selection of ignition systems, however.

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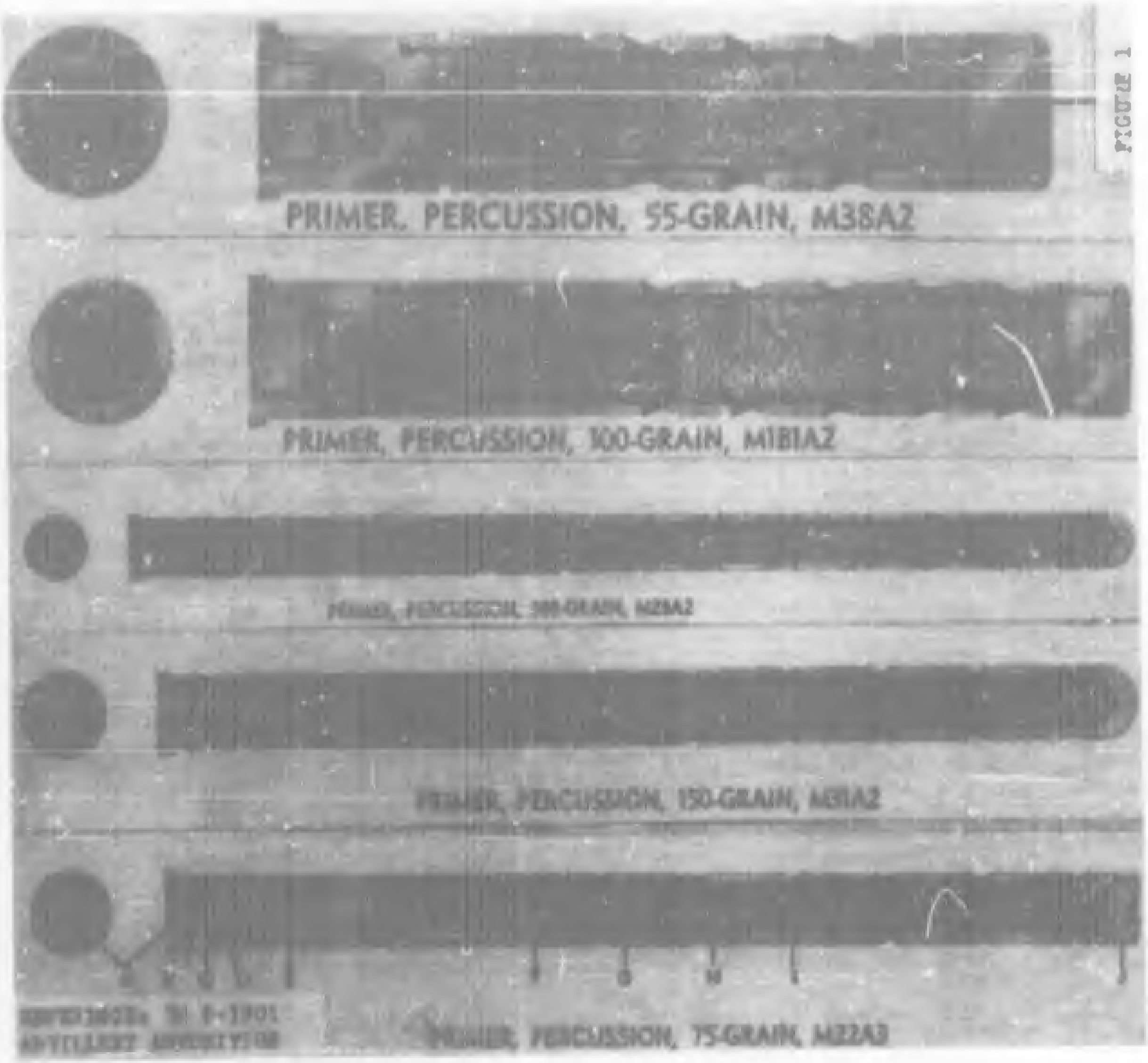
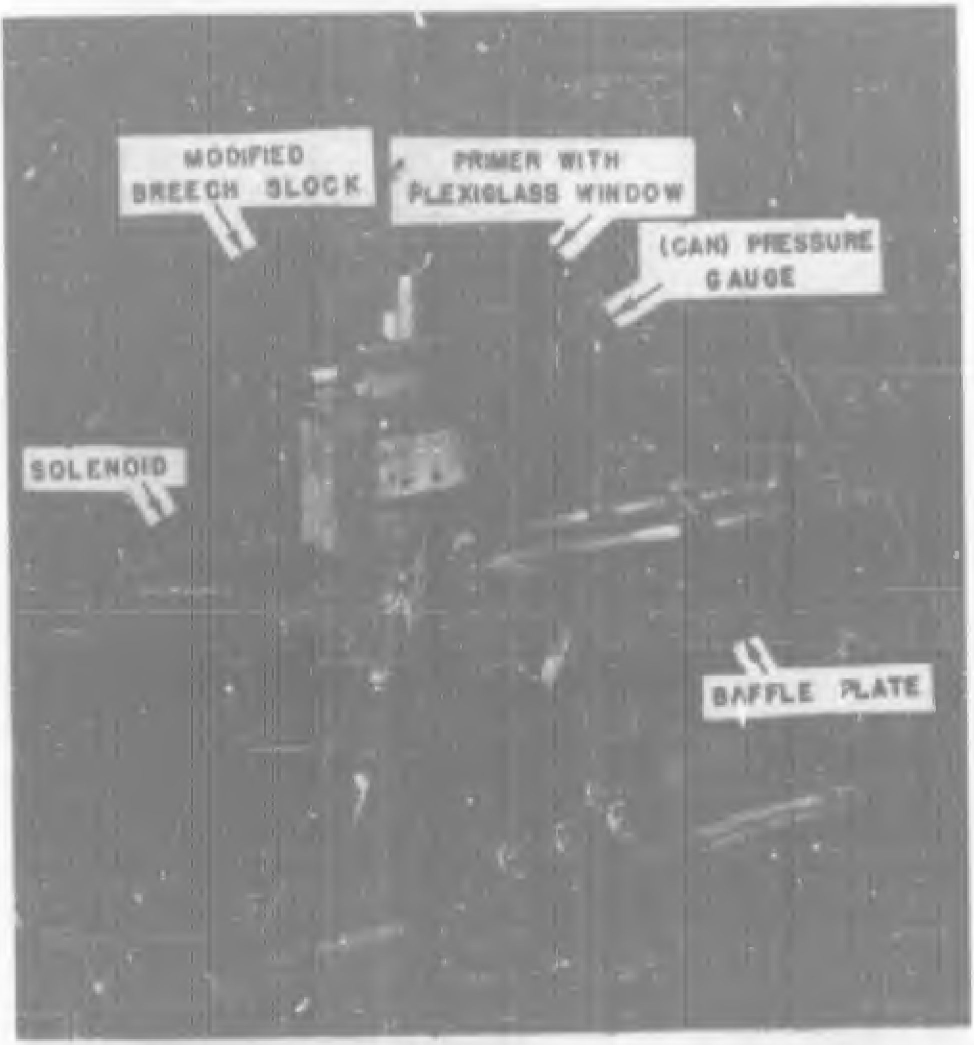


A - FIRING PLUG
B - PRIMER CUP
C - PERCUSSION ELEMENT CHARGE
D - ANVIL
E - PRIMER CHARGE
F - DIAPHRAM
G - FOILING PAPER
H - BODY
I - BODY VENT
J - BODY PLUG

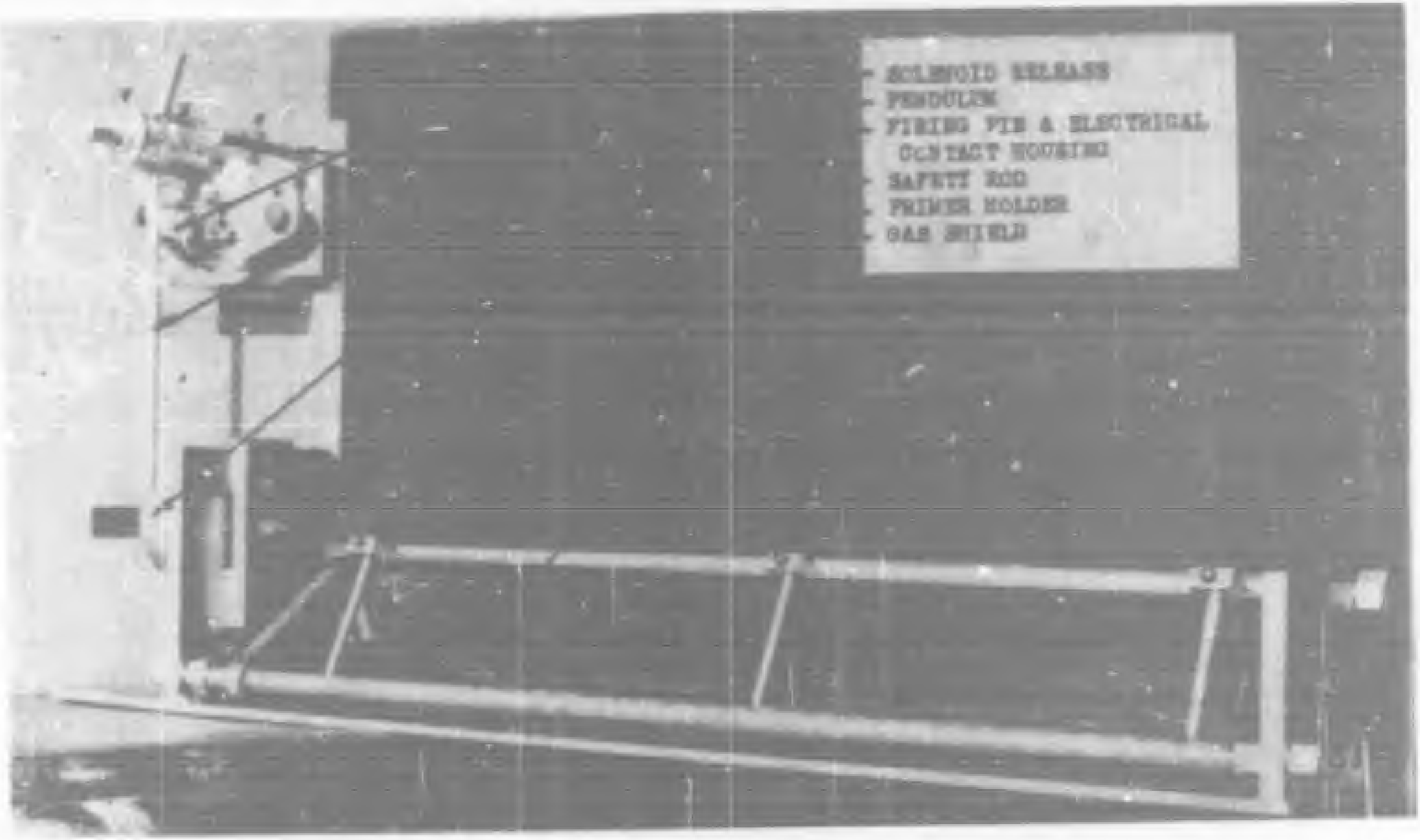
OVER-ALL PRIMER LENGTH	
M38A2	2.84"
M1B1A2	3.71"
M28A2	10.26"
M31A2	7.68"
M22A3	7.68"

FIGURE 1



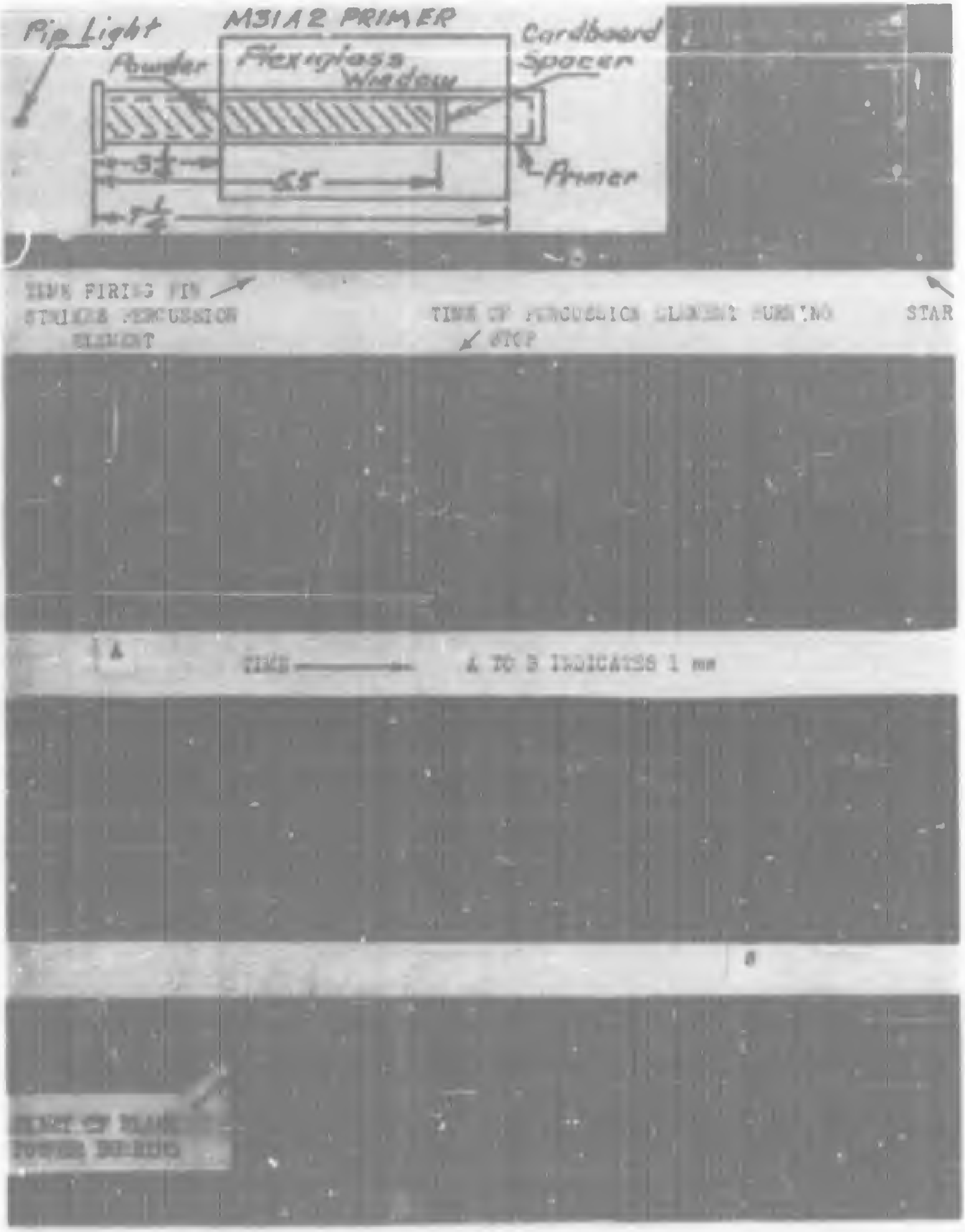
A GENERAL VIEW OF THE EXPERIMENTAL STATIC FIRING MECHANISM

FIGURE 2



ALTERNATE STATIC FIRING MECHANISM

FIGURE 3



PHOTOGRAPHIC RECORD OF GAS FLOW IN AN M31A2 PRIMER BODY

FIGURE 4

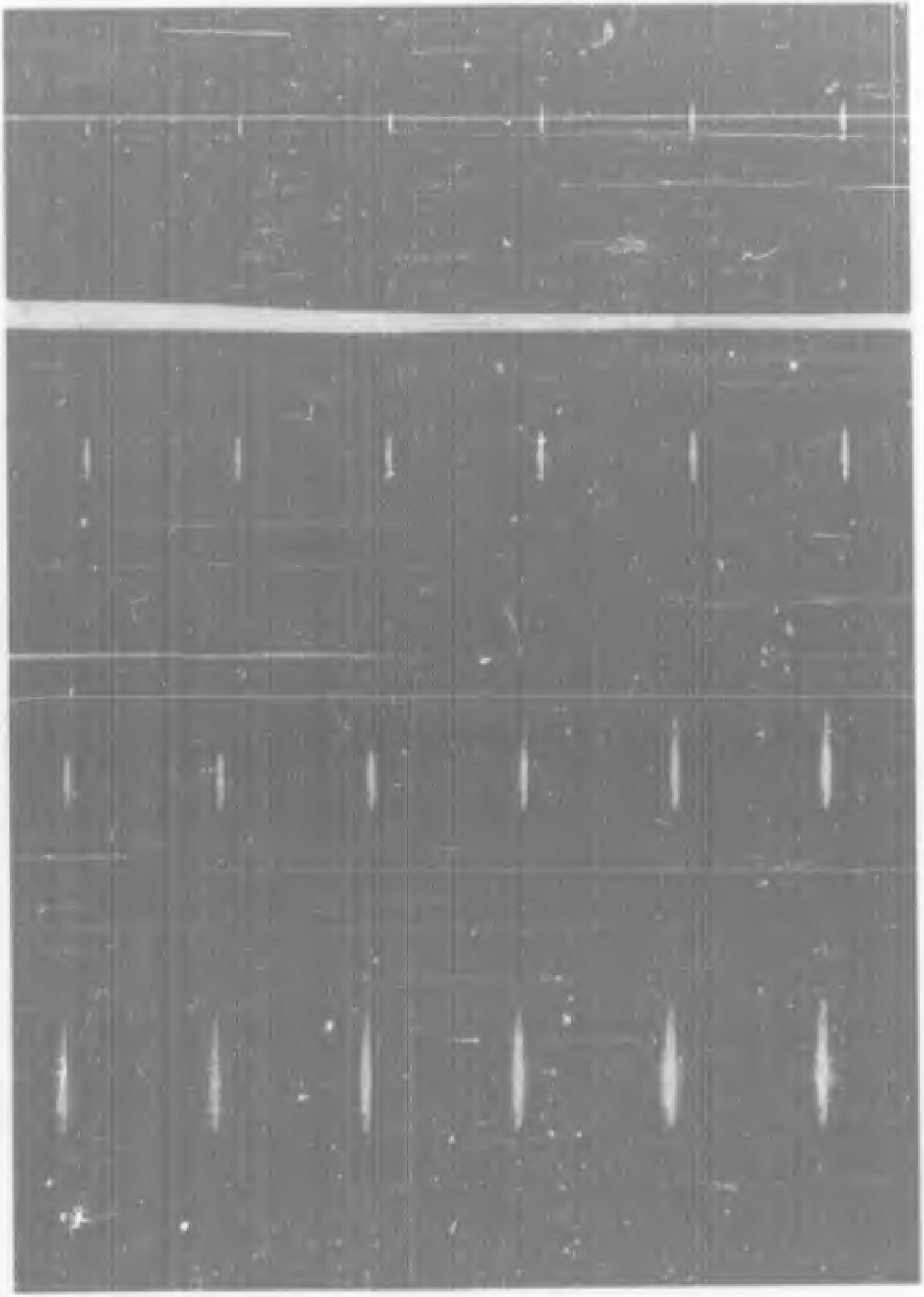
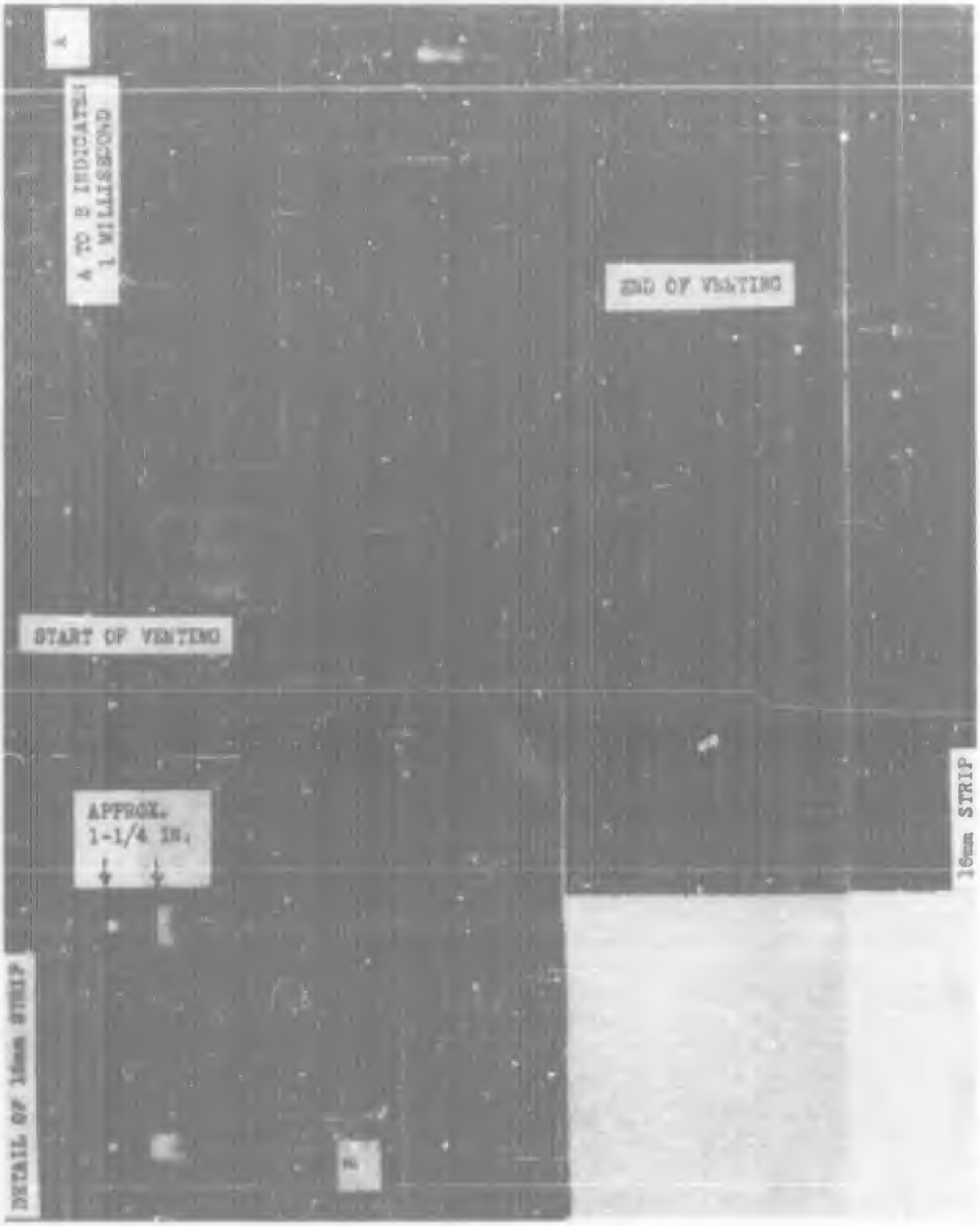
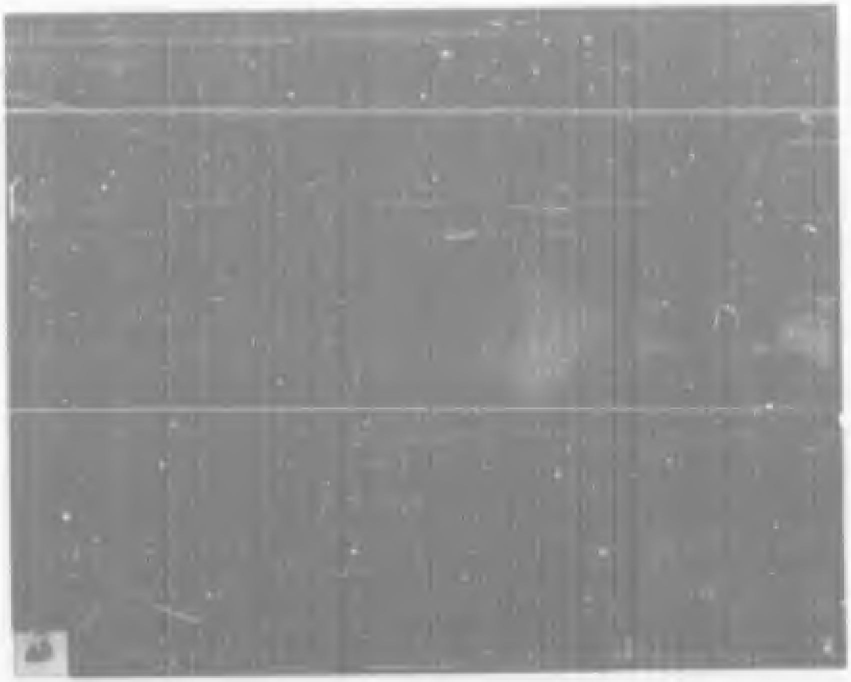


FIGURE 4 (CON'T)



HIGH-SPEED MOTION PICTURE OF M-38
PERCUSSION ELEMENT VENTING

FIGURE 5

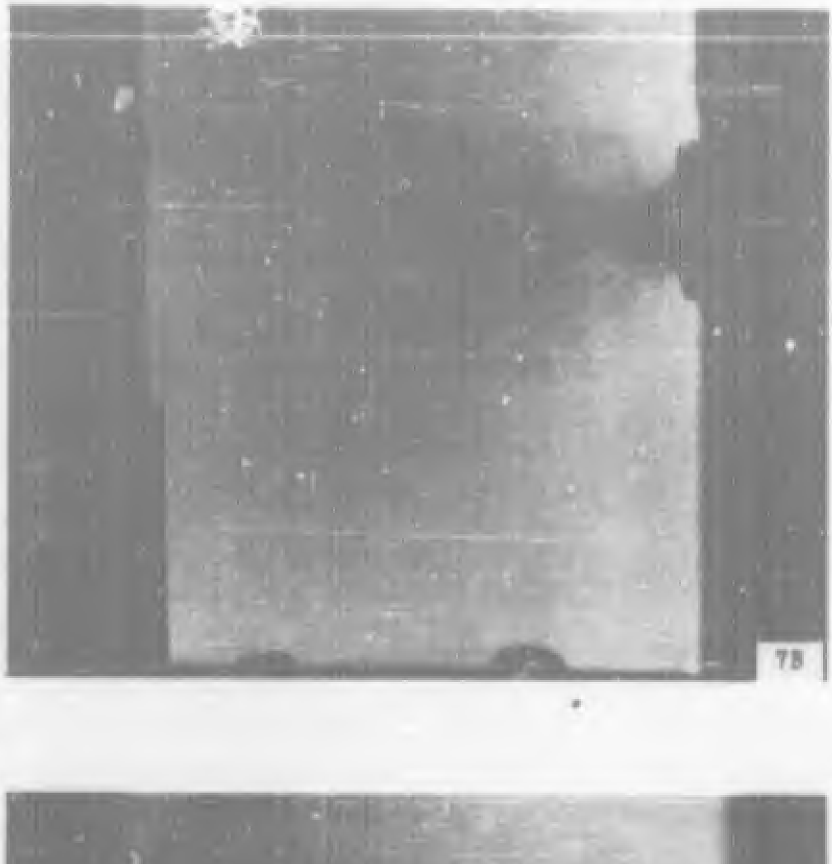


PERCUSSION ELEMENT FOR M38B2 PRIMER WITH CUP ATTACHED. SELF-ILLUMINATED.

PERCUSSION ELEMENT FOR M38B2 PRIMER WITH CUP REMOVED. SELF-ILLUMINATED.

FIGURE 6

Faraday Shutter Pictures



4 μsec exposure

1 μsec exposure

FIGURE 7

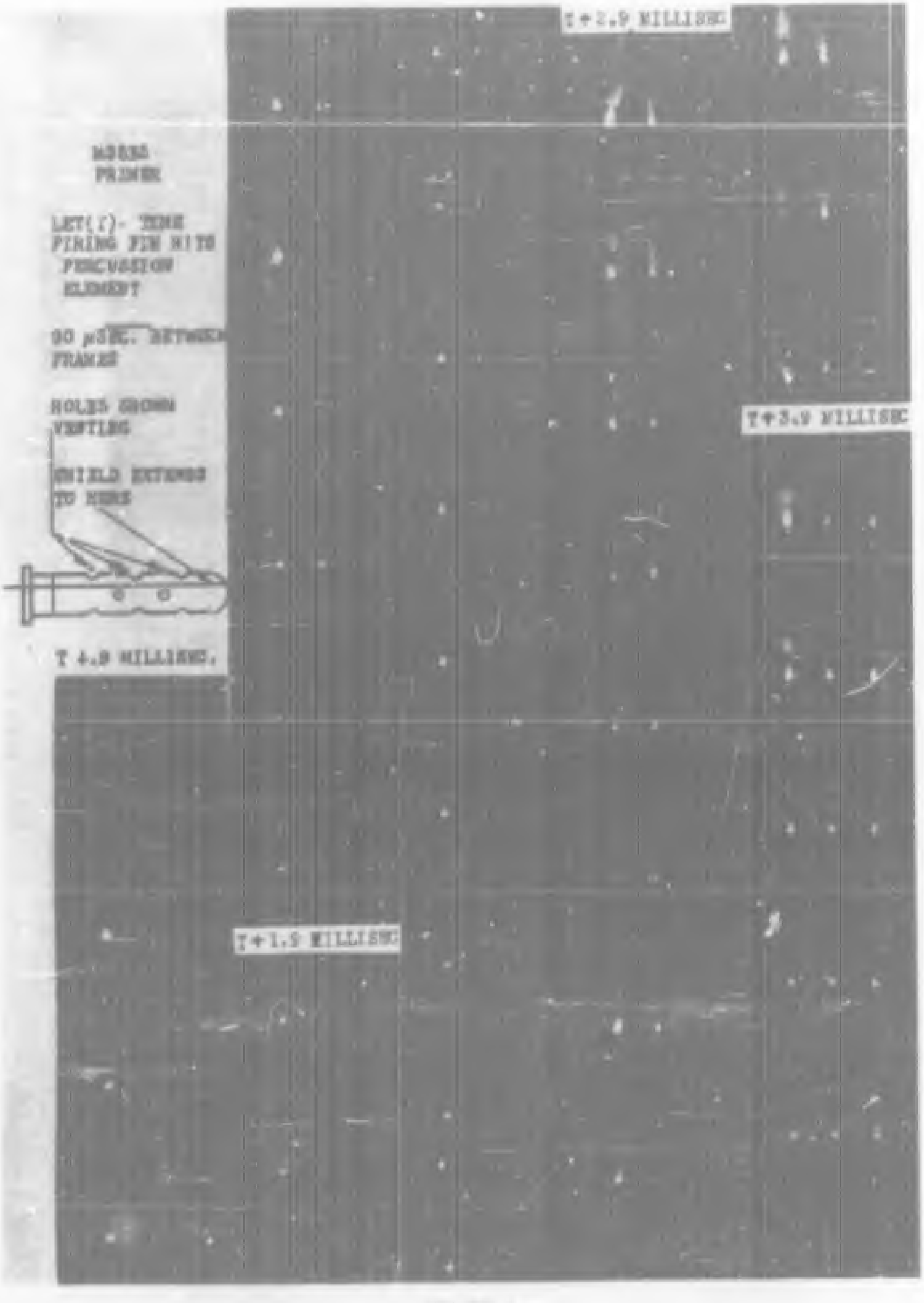
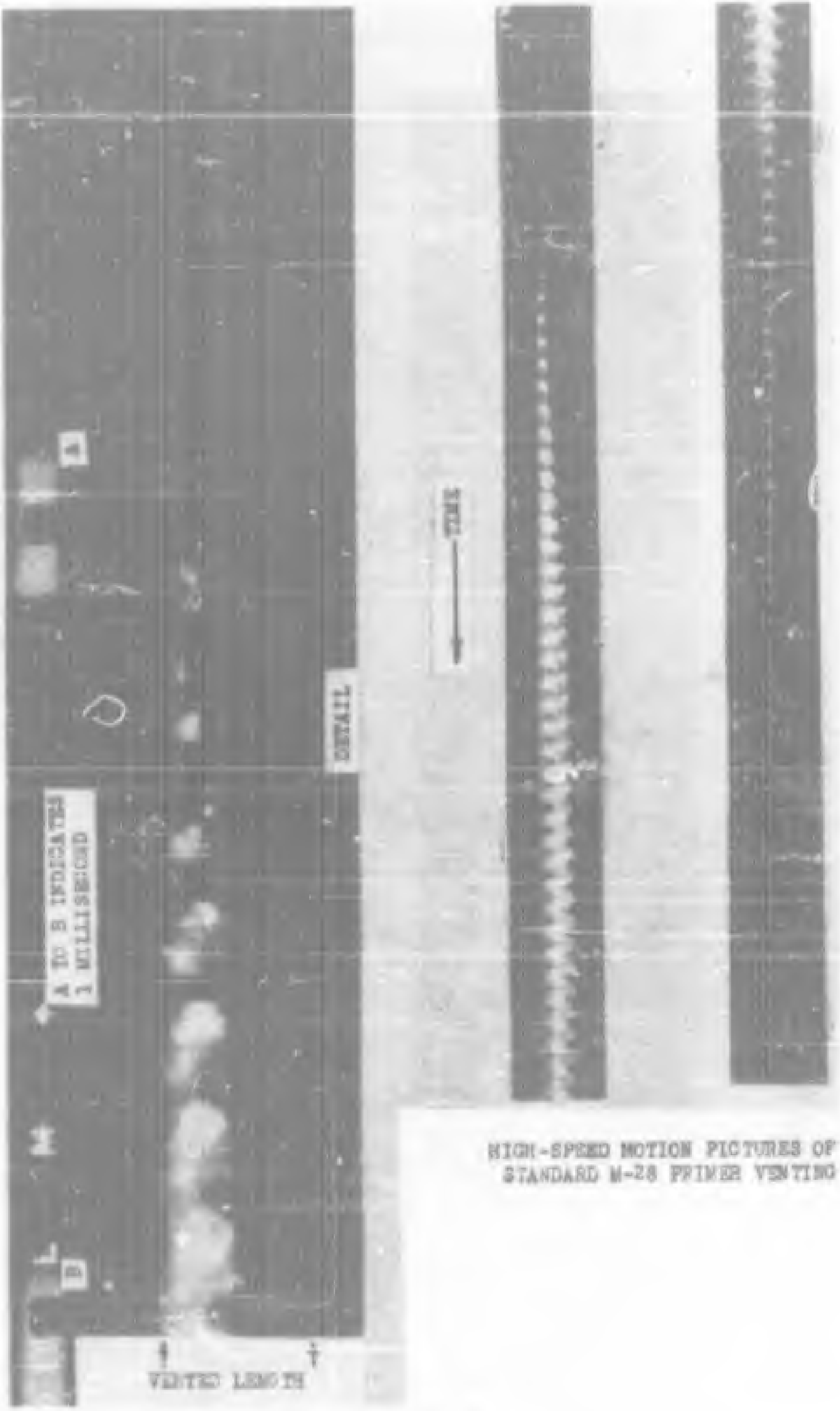


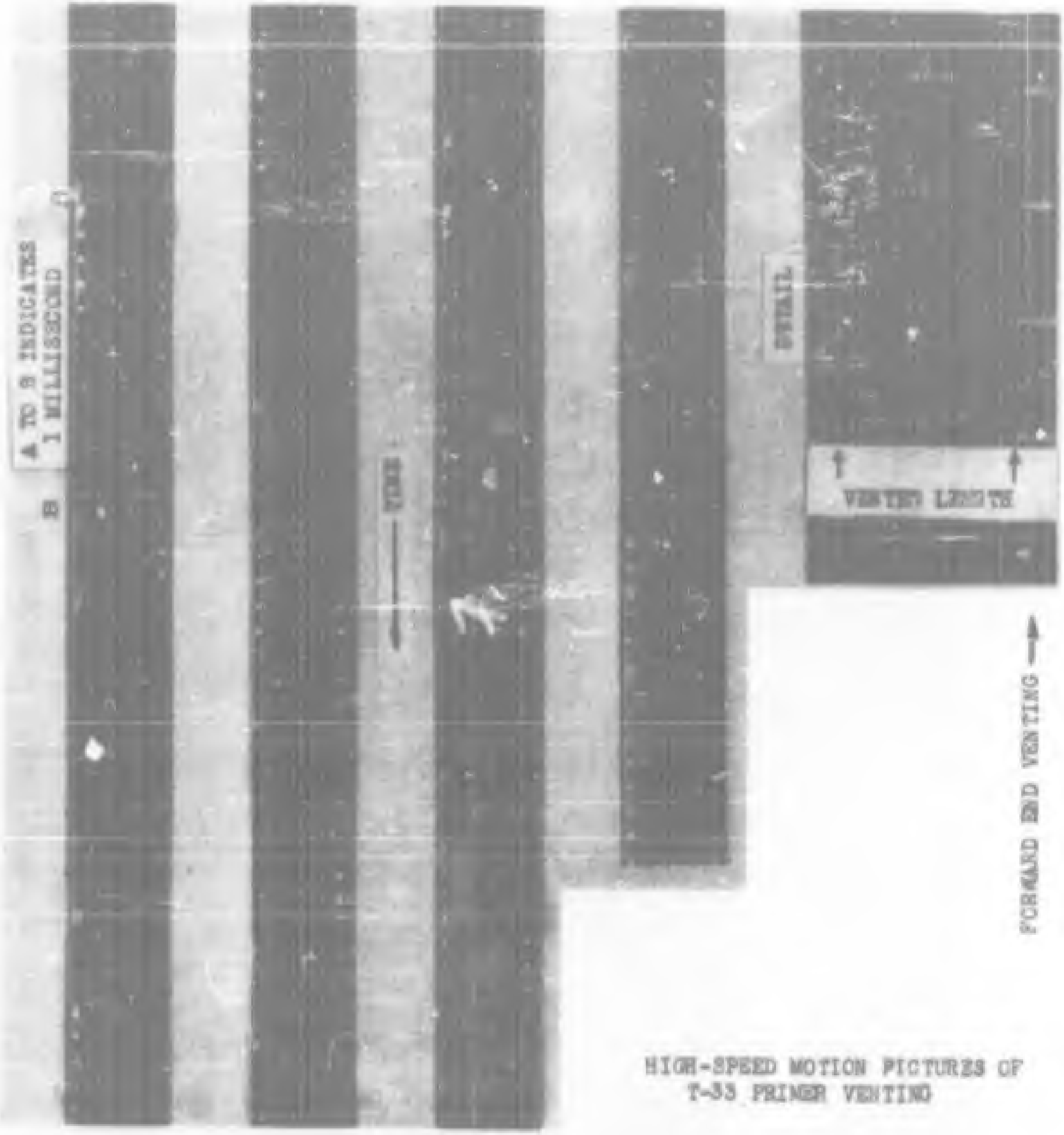
FIGURE 8

HIGH-SPEED MOTION PICTURE OF
M38B2 PRIMER VENTING



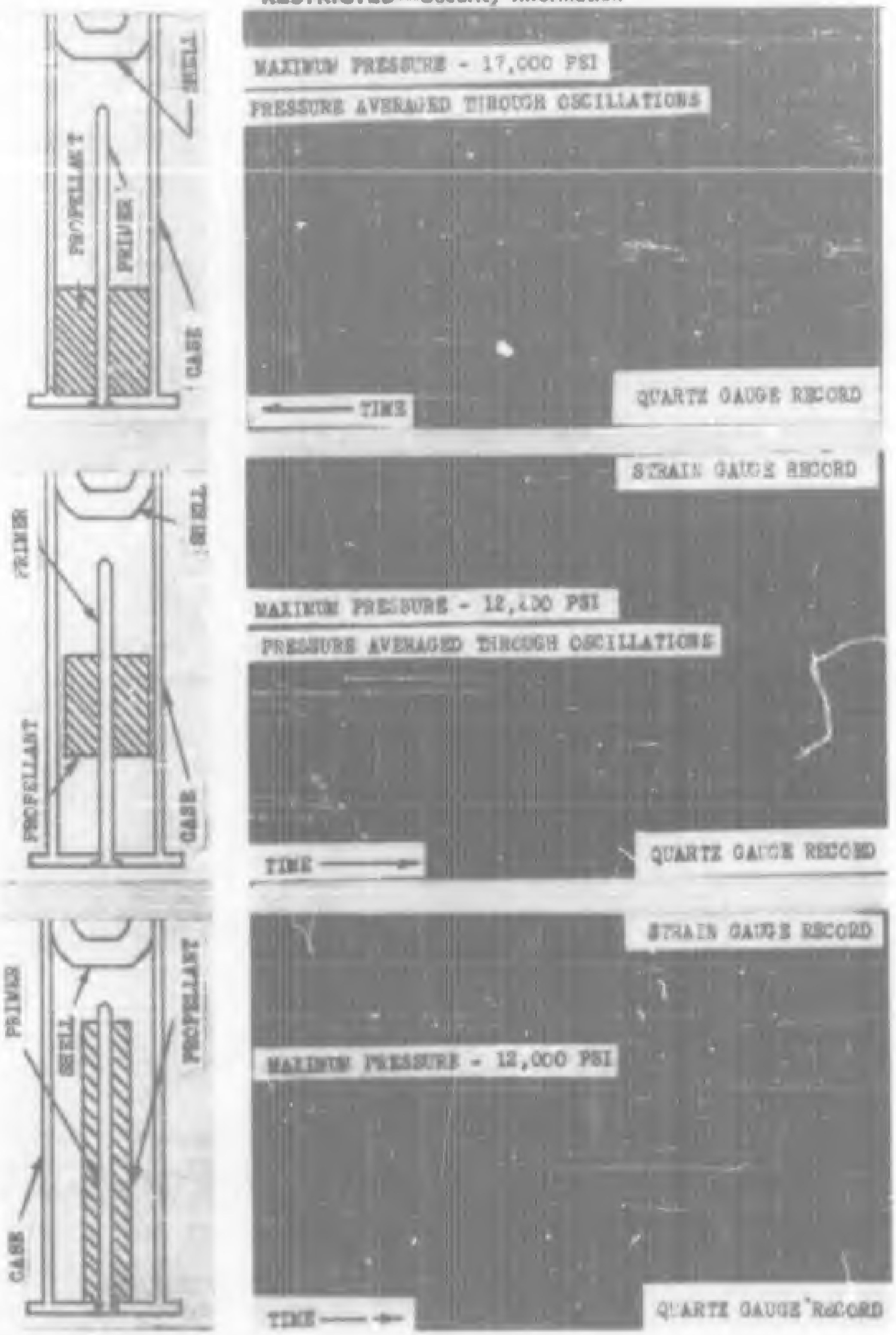
HIGH-SPEED MOTION PICTURES OF
STANDARD M-28 PRIMER VENTING

FIGURE 9



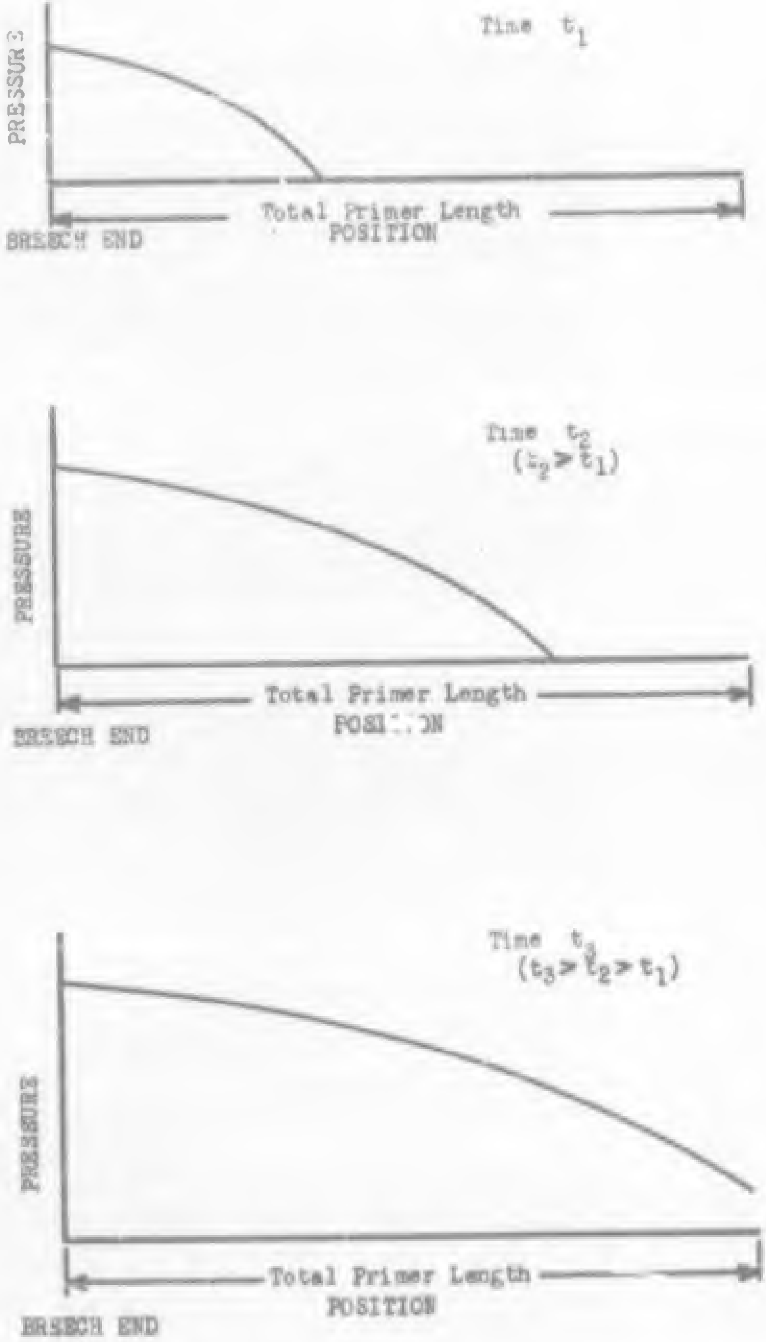
HIGH-SPEED MOTION PICTURES OF
T-33 PRIMER VENTING

FIGURE 10



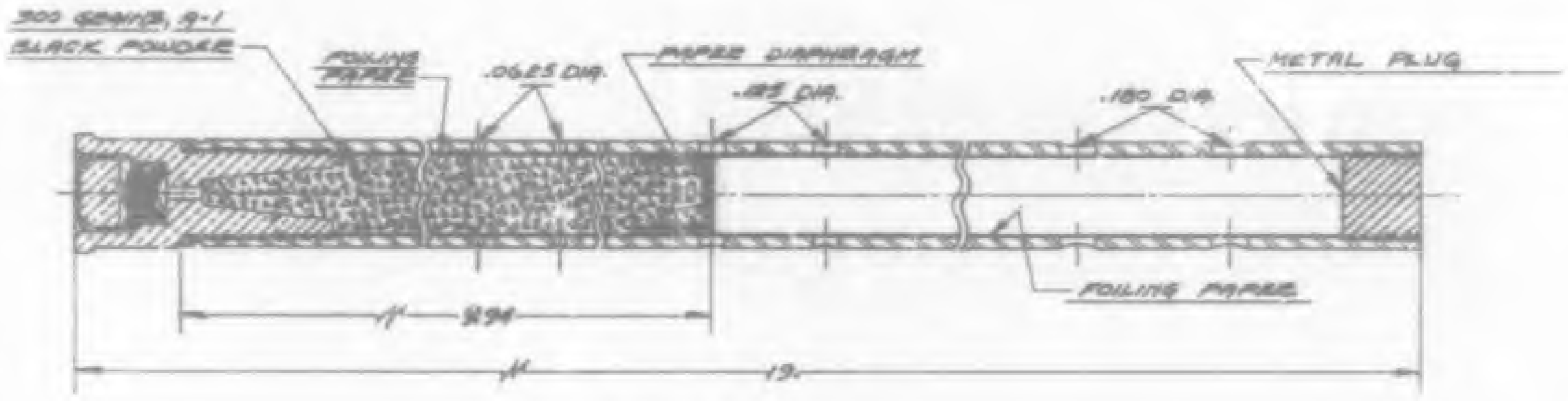
CHAMBER PRESSURE RECORDS FOR THREE ORIENTATIONS OF PROPELLANT IN A 105 MM HOWITZER

FIGURE 11

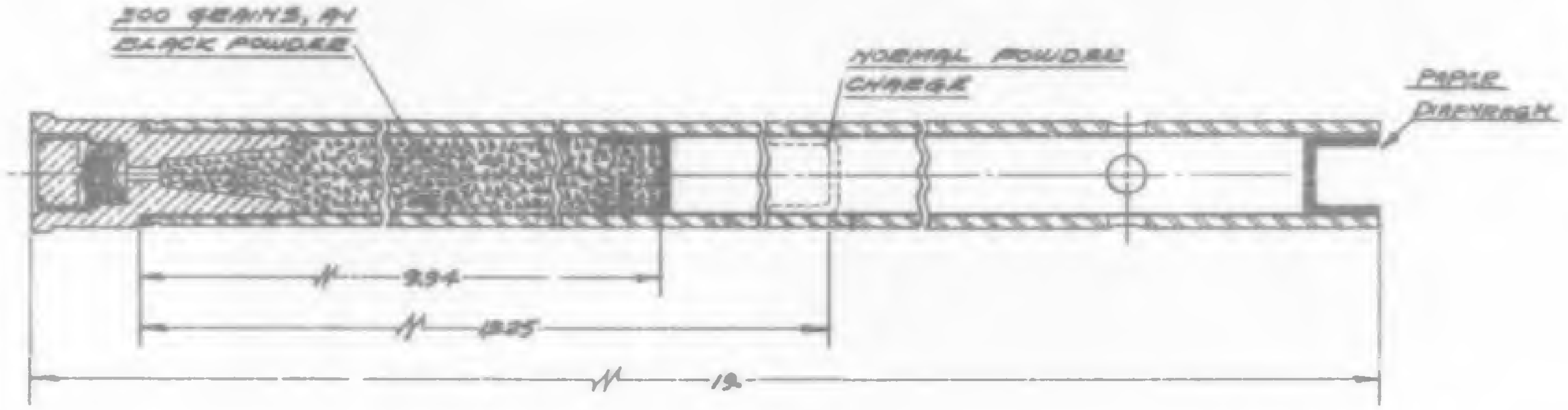


GENERAL PRESSURE-TIME-POSITION RELATIONSHIPS
INSIDE A PRIMER DURING EARLY BURNING.

FIGURE 12



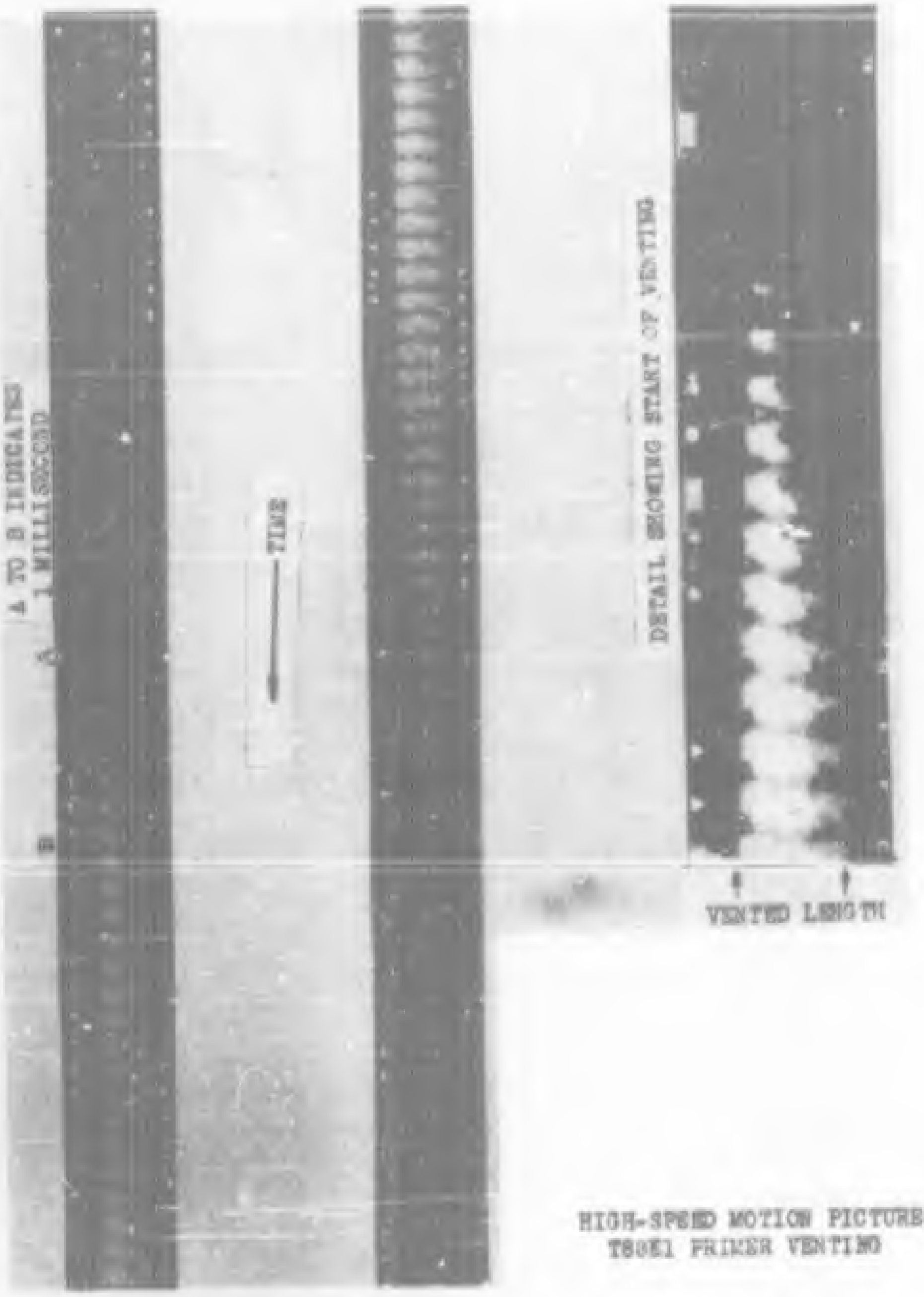
T-66E1



MODIFIED T-33

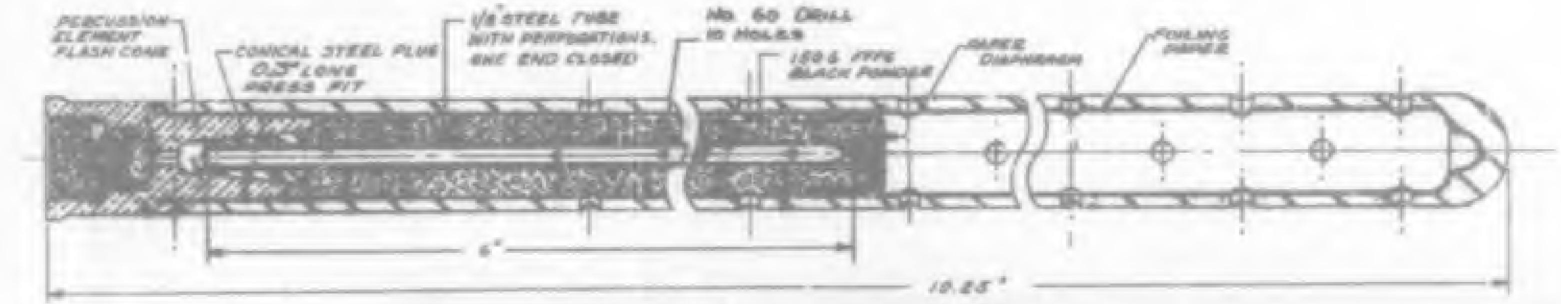
FIGURE 13

EXPERIMENTAL PRIMERS

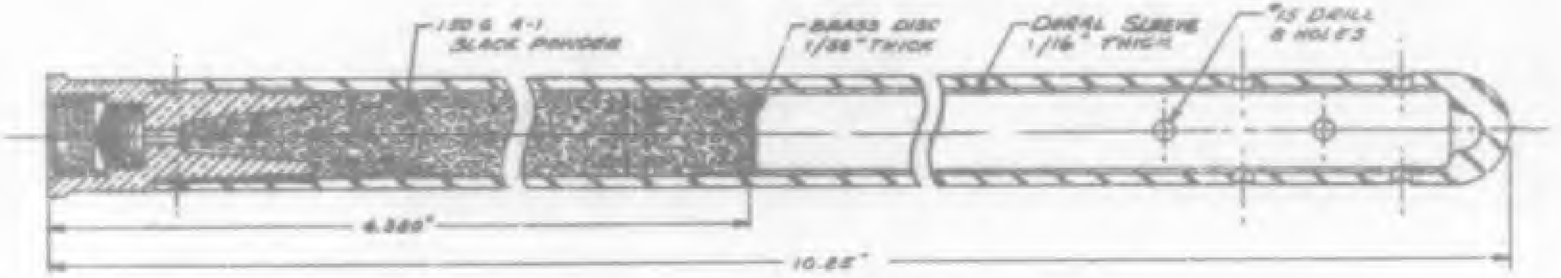


HIGH-SPEED MOTION PICTURES OF
T88E1 PRIMER VENTING

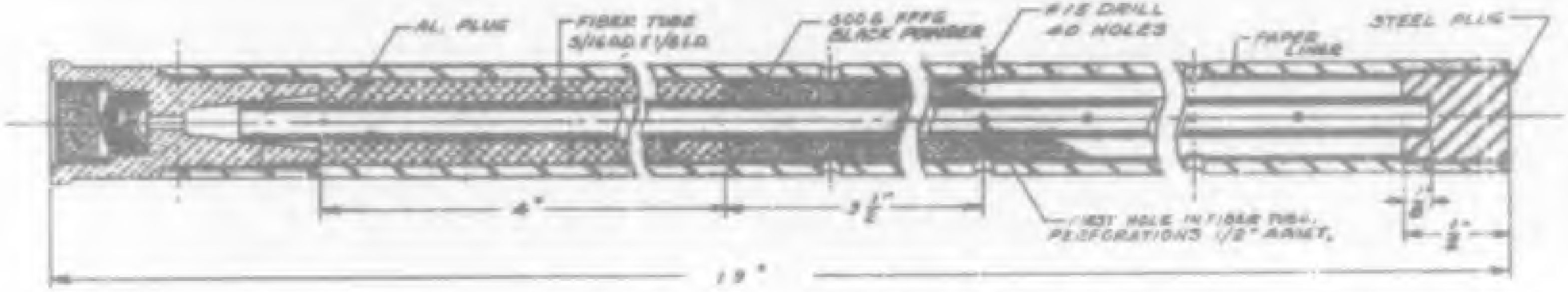
FIGURE 14



DOUBLE TUBE PRIMER
(M28 BODY)

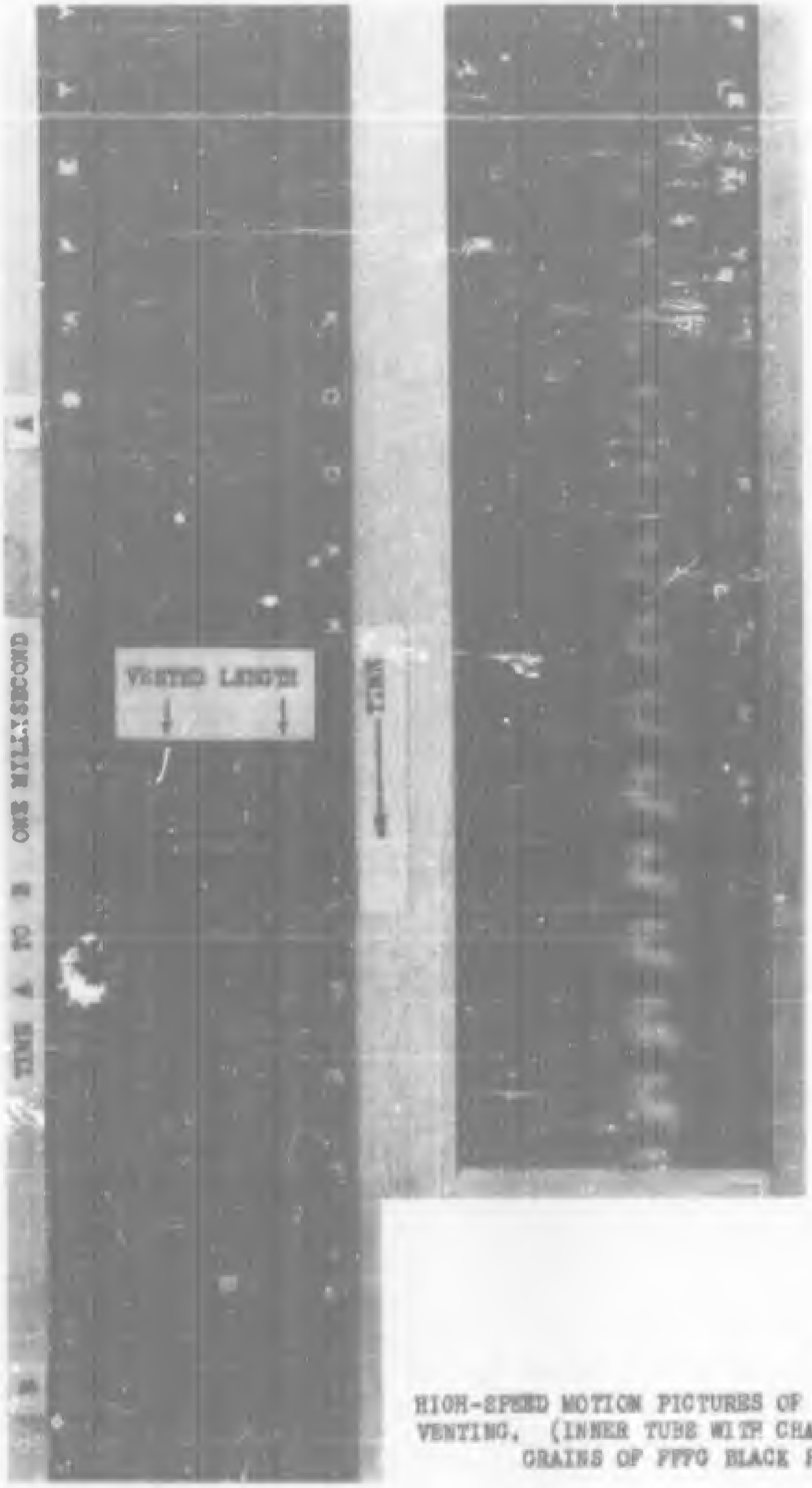


M-28 MODIFIED



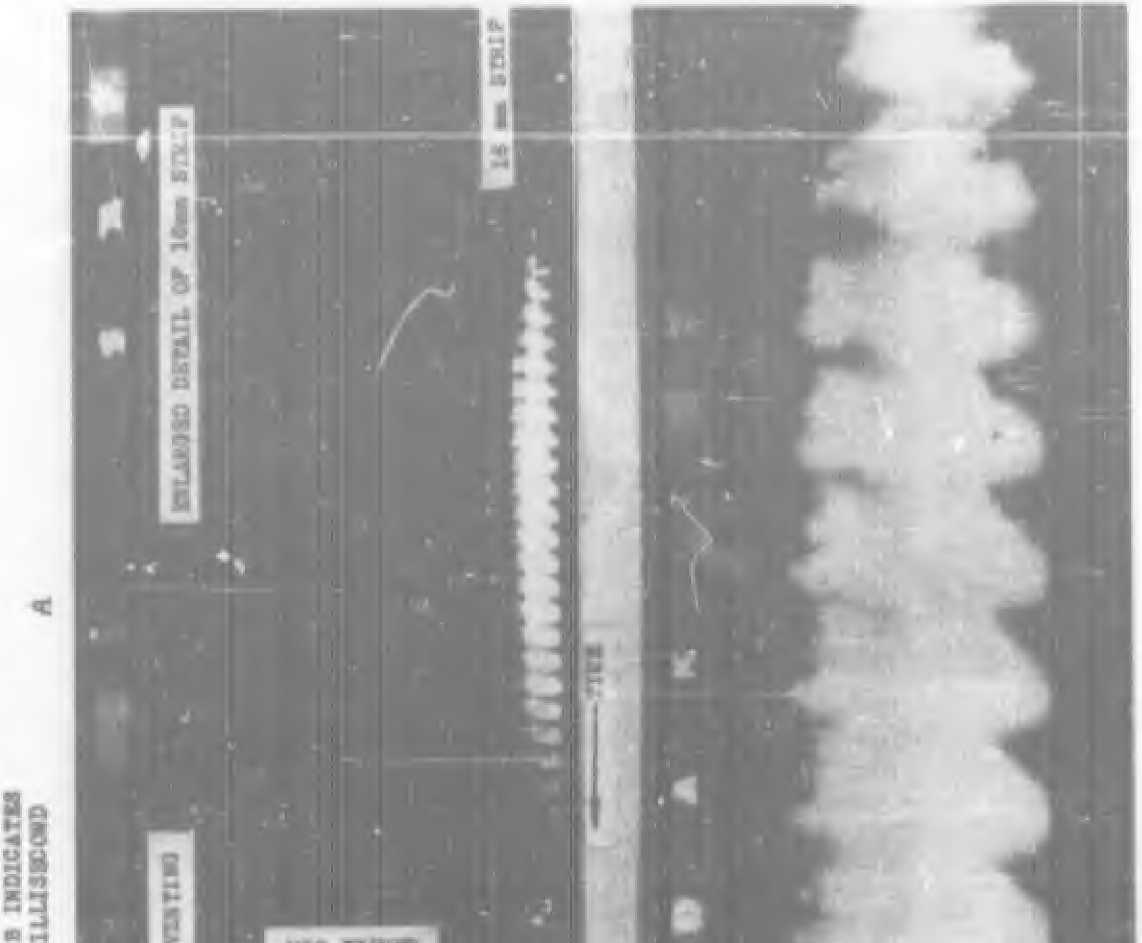
DOUBLE TUBE PRIMER (EXPERIMENTAL)
T-33 BODY

FIGURE 15
EXPERIMENTAL PRIMERS



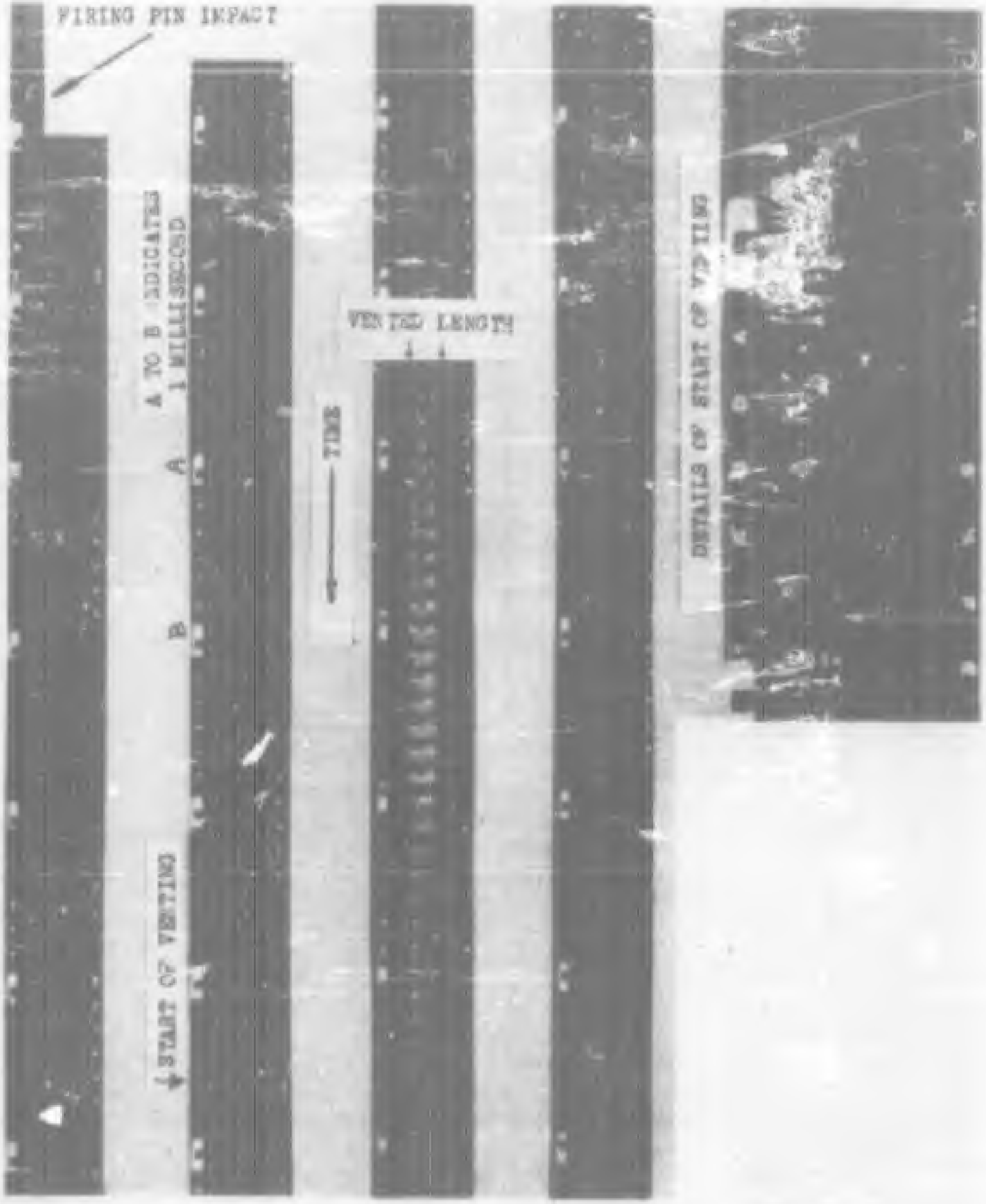
HIGH-SPEED MOTION PICTURES OF T-33 PRIMER VENTING. (INNER TUBE WITH CHARGE OF 300 GRAINS OF FFFG BLACK POWDER)

FIGURE 16



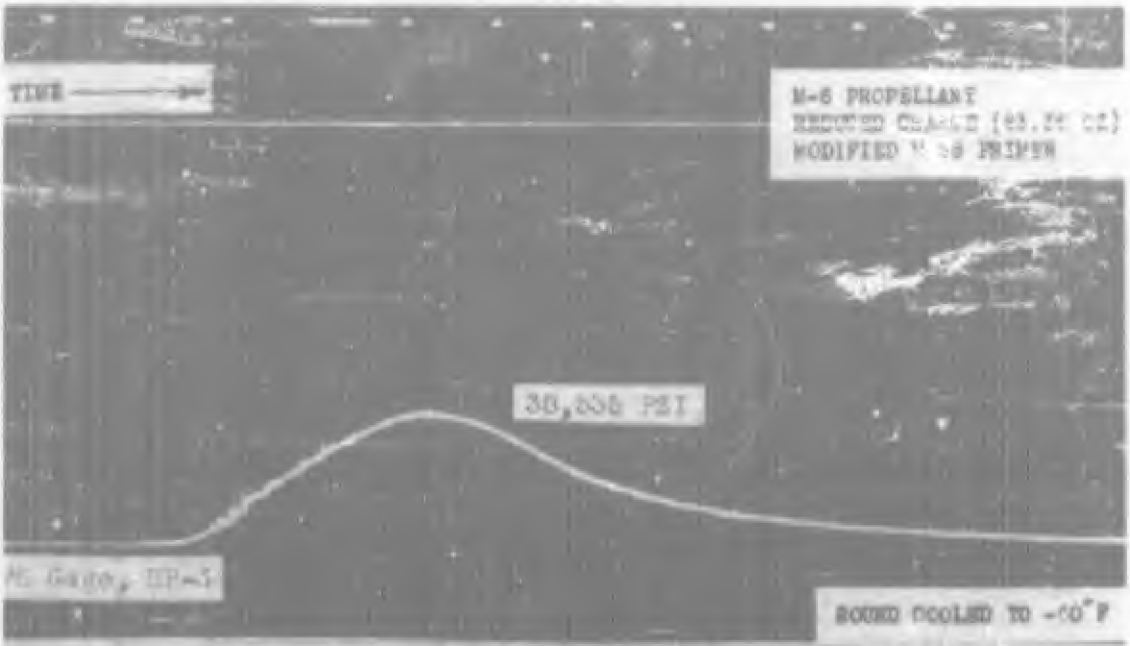
HIGH-SPEED MOTION PICTURES OF M-28 PRIMER VENTING
(INNER TUBE USED WITH CHARGE OF 150 GRAINS OF
FFFG BLACK POWDER)

FIGURE 17

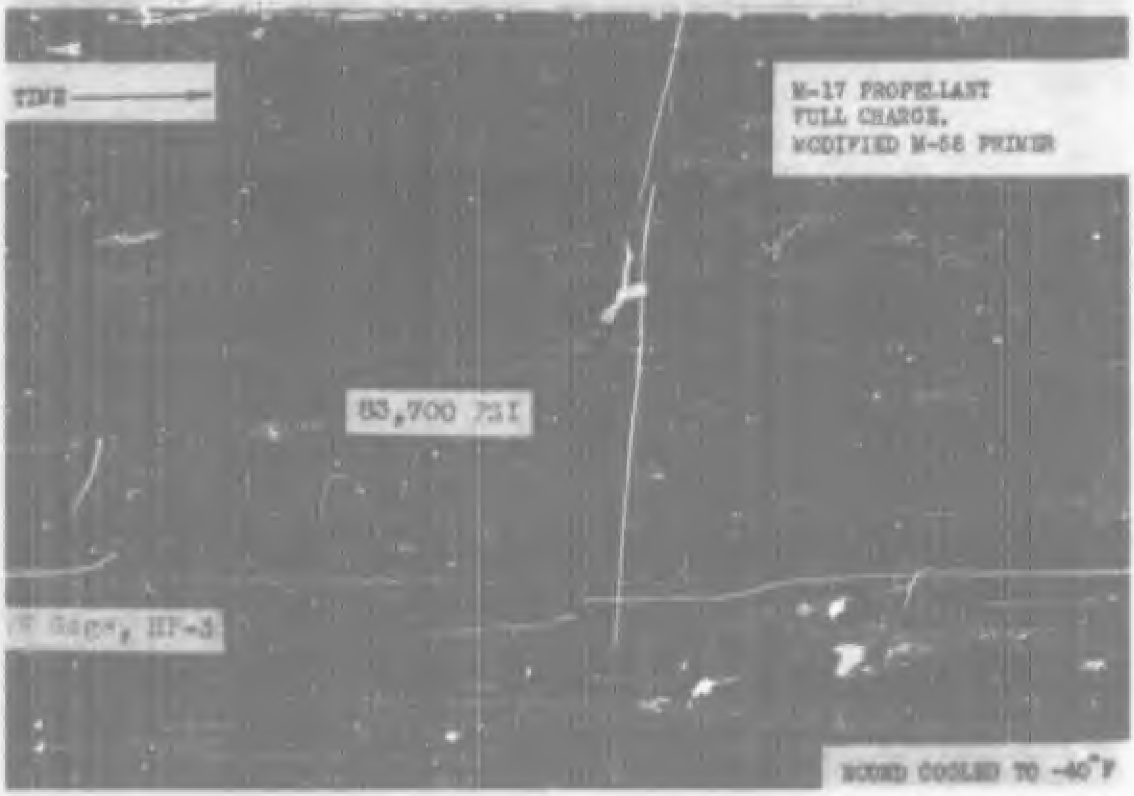


HIGH-SPEED MOTION PICTURES OF M-28 PRIMER (WITH TUBE) VENTING. CHARGE IS 150 GRAINS OF A-1 BLACK POWDER.

FIGURE 18

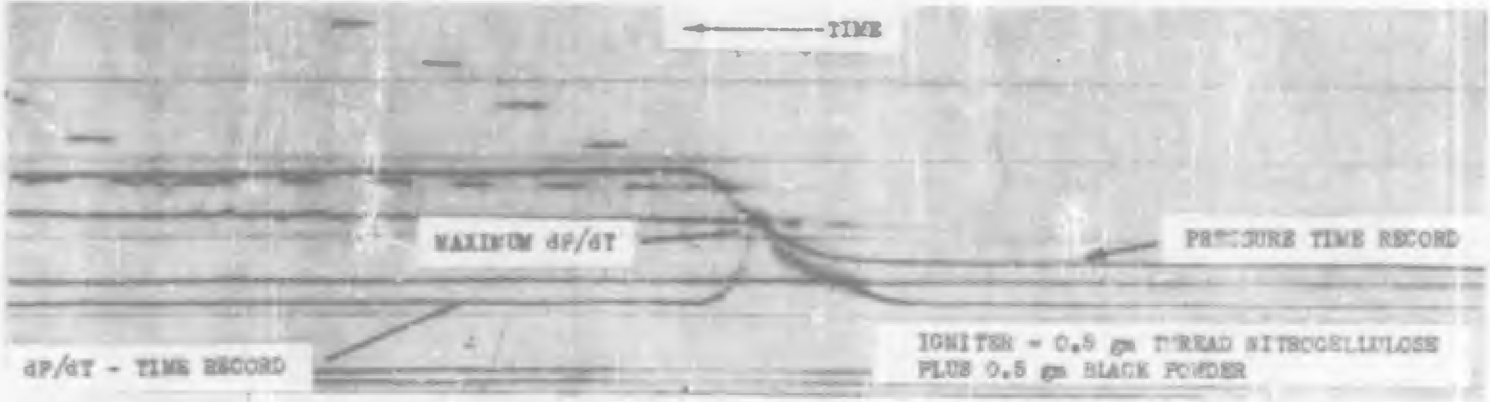


CHAMBER PRESSURE-TIME RECORD FOR 76MM T-91 GUN

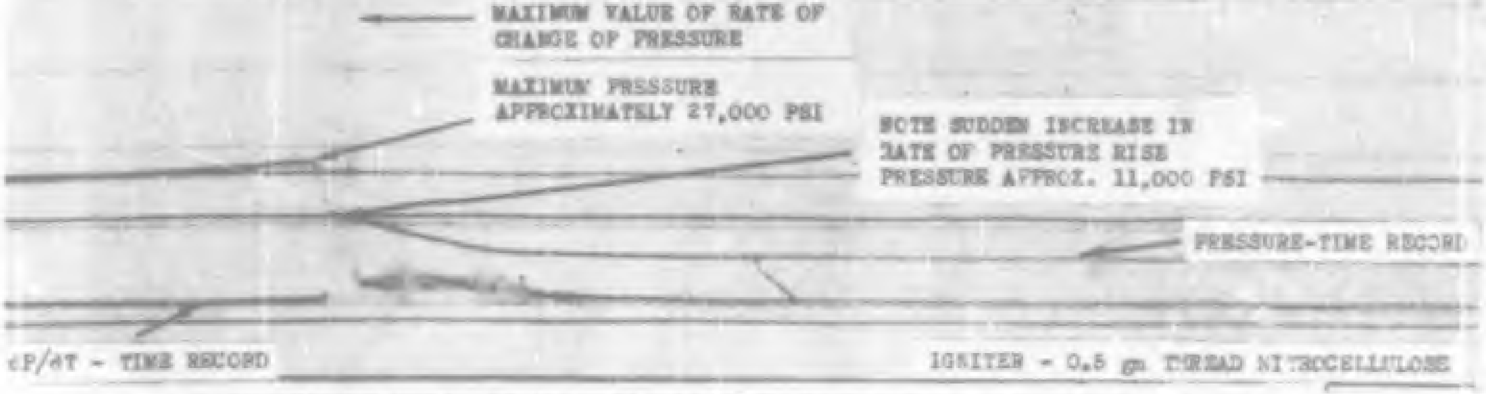


CHAMBER PRESSURE-TIME RECORD FOR 76MM T-91 GUN

FIGURE 19

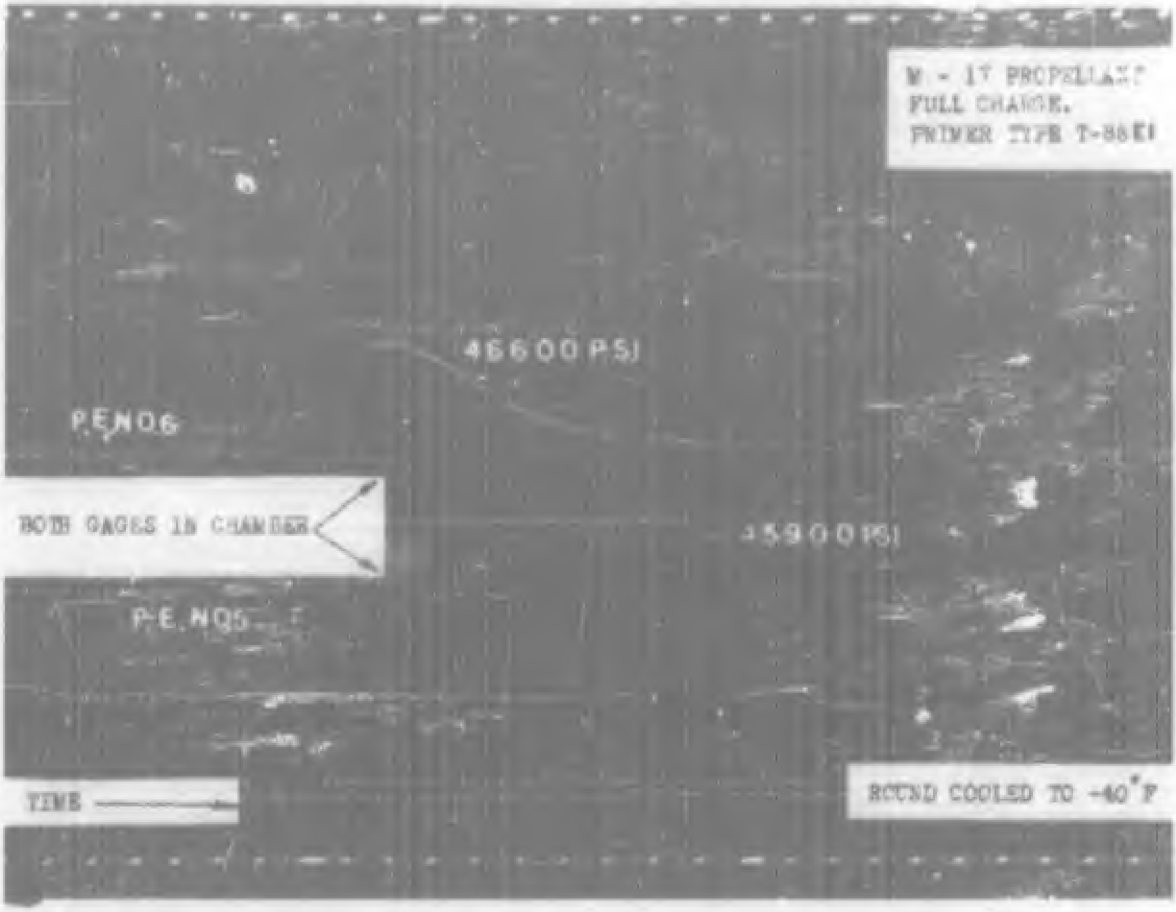


CLOSED CHAMBER RECORD SHOWING REGULAR BURNING OF M-17 PROPELLANT



CLOSED CHAMBER RECORD SHOWING IRREGULAR BURNING OF M-17 PROPELLANT LOT # MKA-6896

FIGURE 20



CHAMBER PRESSURE-TIME RECORD FOR 76MM T-91 GUN.

USING T88E1 PRIMER

FIGURE 21

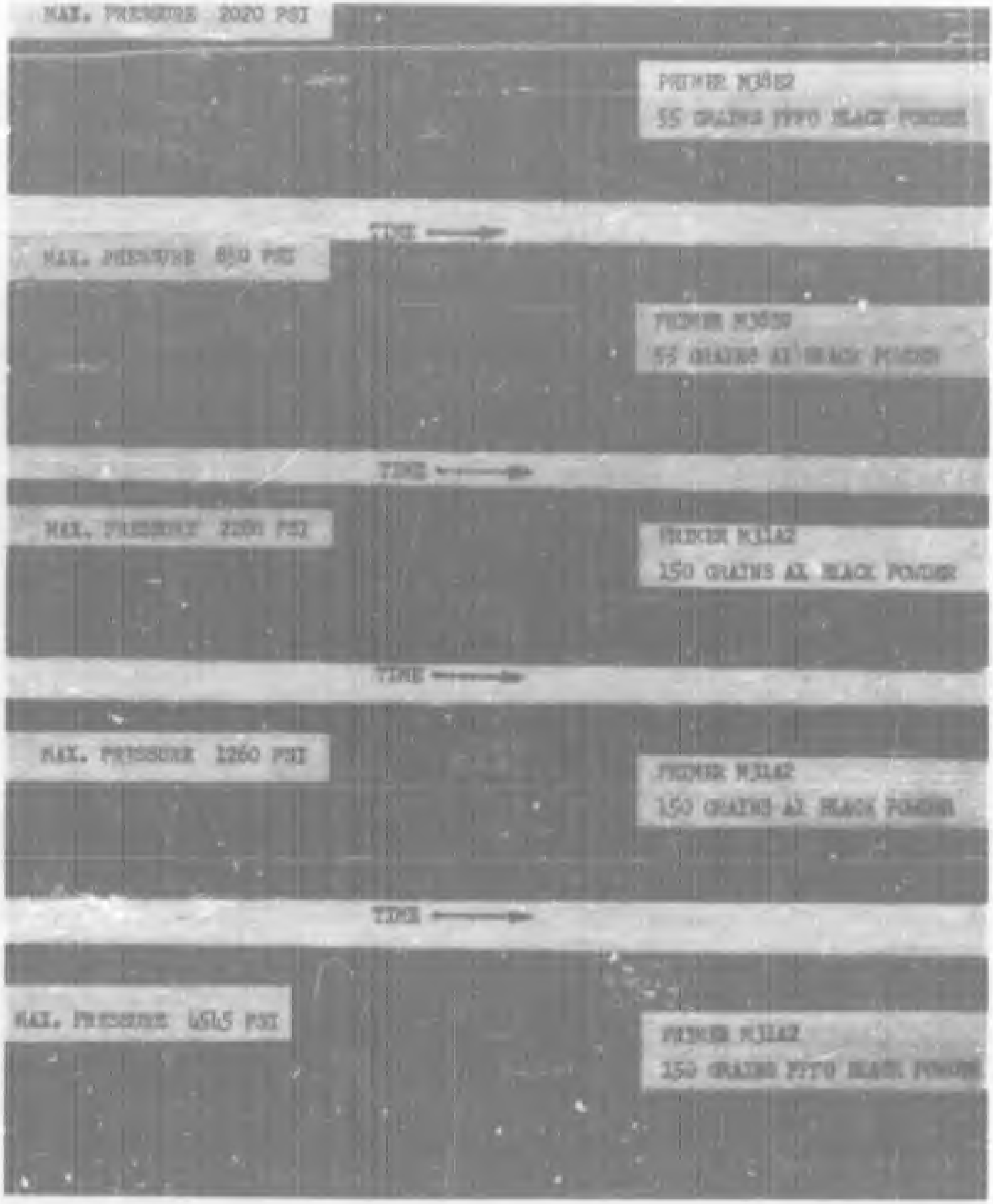
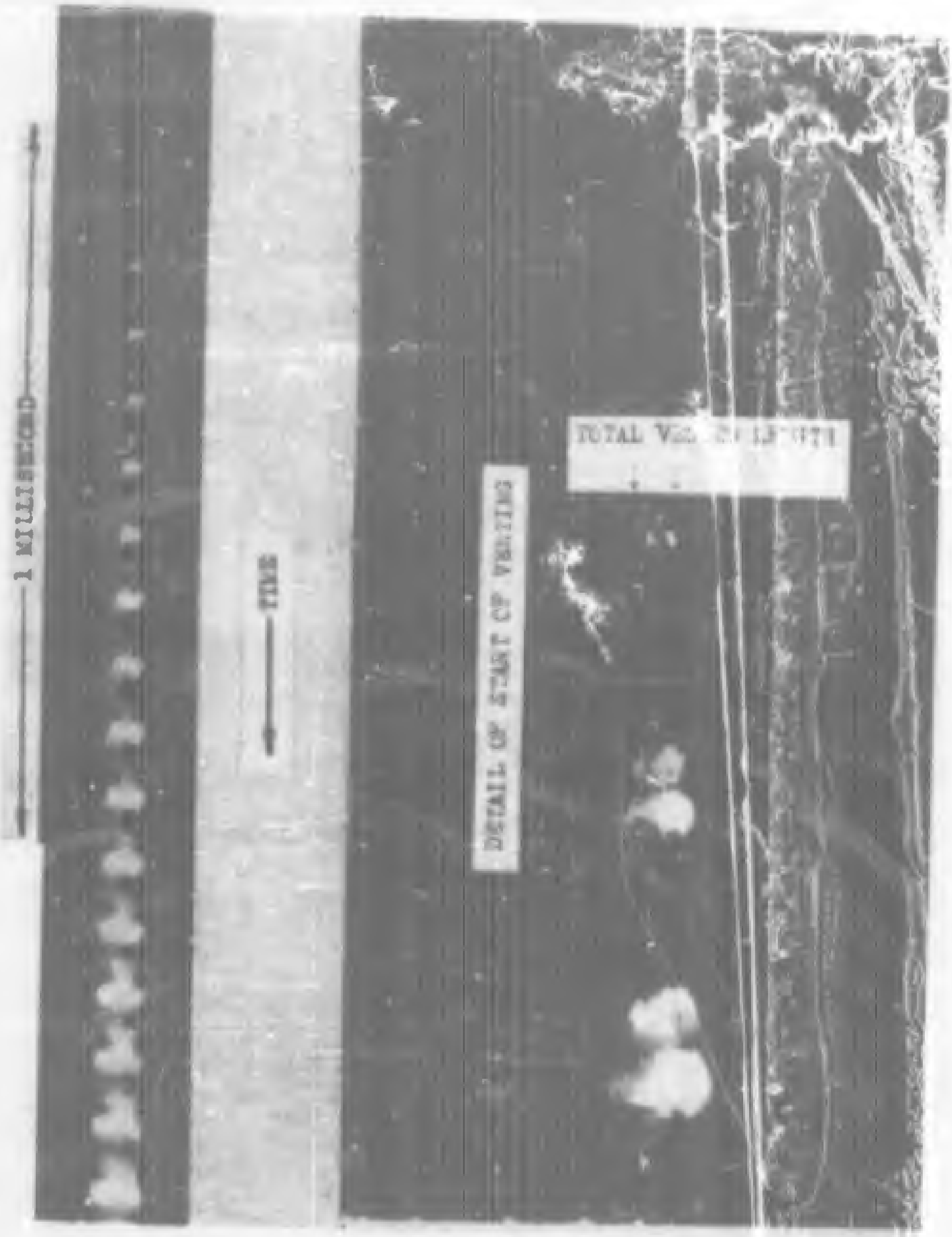


FIGURE 22

PRESSURE TIME RECORDS DERIVED FROM STATIC FIRING OF PRIMERS
(TIME INTERVALS ARE MILLISECONDS)



HIGH-SPEED MOTION PICTURES OF M-28 PRIMER
USING BRASS RUPTURE DISC

FIGURE 23

UNCLASSIFIED

UNCLASSIFIED