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Pressure Studies Of Artillery Primers Fired Statically (U)

EF- JUL 1996

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B A L L I S T I C R E S E A R C H L A B O R A T O R I E S

REPORT NO. 938

JUNE 1955

PRESSURE STUDIES OF ARTILLERY PRIMERS FIRED STATICALLY (U)

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A B E R D E E N P R O V I N G G R O U N D , M A R Y L A N D



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REPORT NO. 938

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Aberdeen Proving Ground, Md.
June 1955

PRESSURE STUDIES OF ARTILLERY PRIMERS FIRED STATICALLY

ABSTRACT

Characteristics of artillery primers are discussed with particular attention to pressure-time phenomena measured from static firing tests. Other aspects considered are the general nature of the burning of black powder, the nature of packing of granular beds, the mass discharge of product gases from primer tubes, and the times of various events occurring during primer functioning. Qualitative explanations are given for the various phenomena, and experimental results to verify these explanations are presented wherever possible.

It is hoped that this study will further the understanding of the functioning of present primers and provide a sound general basis for the design of future primers.

NOMENCLATURE

Throughout this report, gauge positions on primers and the times of various events will be represented by certain symbols. The gauge positions will be numbered in order, starting numerically at the breech ends of the primers. The actual locations of gauge positions for specific primers may be found from sketches presented in Fig. 2 through 5.

Time intervals measured from pressure-time records in milliseconds (ms) will be represented by the following symbols:

- T_1 - Time from firing pin impact to start of pressure rise.
- T_2 - Time from firing pin impact to maximum pressure.
- T_3 - Total time under pressure-time record (venting time).
- T_3' - Total time under pressure-time record above 200 p.s.i.

Time intervals measured from high-speed motion picture records will be represented as follows:

- T_a - Time from firing pin impact to start of venting.
- T_b - Time from initial venting until all vents discharge.
- T_c - Total venting time.

INTRODUCTION

The desirable characteristics of artillery primers have been discussed by a number of workers concerned with practical ignition problems. These characteristics have, in general, been discussed in qualitative terms, largely because sufficient quantitative data do not yet exist. Although firm quantitative foundations cannot be cited for many of these characteristics, they can be summarized in four general properties. One of these properties is that the primer should be capable of transferring sufficient energy to a propellant region to assure that the propellant begins to burn regularly and continues to burn after the effects of the igniter are no longer great. Details of the most desirable mechanism of energy transfer to a propellant cannot yet be fully specified. Another property which applies to many other components of weapon systems as well as to igniters is that of regularity or reproducibility. This characteristic means merely that an igniter of a given type will conform as closely as possible to some set pattern from firing to firing. A third characteristic reflects the desire of the theoretical interior ballisticians to cause all of the propellant grains in a gun charge to ignite as nearly simultaneously as possible. Because simultaneous discharge of energy cannot be realized in most instances, the fourth characteristic of symmetrical discharge of energy with respect to position in propellant regions is frequently accepted as a substitute for simultaneity which cannot be realized in practice.

A thoroughgoing study of primers, with a view to understanding the above four characteristics, would be extremely costly and difficult. In lieu of conducting the necessary experiments in complete weapons systems, one can learn a considerable amount of information by means of static firings of primers conducted in open air. This technique has been described in some detail in an earlier report (1), and was employed for the studies described herein.

The simplest possible apparatus which can be employed in a static evaluation of primers consists of a mount for holding the primer, a means of initiating the primer and methods of measuring quantitative data which describe the phenomena occurring. In the case of the set-up used at the Ballistic Research Laboratories the mount is a simple structure (Fig. 1) which holds a primer at the percussion element. All of the primers which have been evaluated by the Ballistic Research Laboratories are percussion primers which are initiated by the impact of a falling pendulum on a simple firing pin. This pin is insulated electrically so that information can be obtained about the instant of firing pin impact on the primer head. Pressure-time relationships of phenomena occurring inside the primer are measured by means of resistance pressure gauges used in conjunction with cathode ray tube recording instruments. Additional information about times at which certain events occur can be obtained by means of high-speed motion picture photography; the method is one of the simplest possible, namely, that of photographing the primer under self-illumination in a darkened room. This report describes a number of

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experiments which have been conducted on static tests of primers using pressure-time information and photographic measurements to obtain the basic data.

Some of the tests which are described here have brought out specific points that require additional investigation. One of these points is of prime importance to this discussion, namely, that artillery primers which are filled with granular black powder leave much to be desired as test devices for ignition studies. There is, for example, considerable variation in pressure-time relationships for primers which are nominally of the same type. Much of this lack of reproducibility can be traced to the characteristics of black powder. Black powder which is employed in primer systems is a granular material of random shape and of fairly wide variation in particle size. The surface condition of the black powder may vary widely, as may the density of individual grains. There have been some strong indications that black powder may burn in such a manner that the pressure index of burning varies considerably with pressure. At a pressure of approximately 2000 to 3000 p.s.i., for example, the pressure index in a power burning equation may change from approximately 0.5 to almost unity. This variability in the pressure index may account in part for the difficulty one encounters in attempting to control the burning of black powder in a primer body which discharges its combustion gases. Even if black powder does burn with a low pressure index, there still is another factor which may explain the irreproducibility in pressure-time relationships. This fact is that all of the black powder in a primer body does not ignite simultaneously, and hence additional surface for burning is brought into play as the combustion gases at one end of the primer flow to the end of the primer in which the black powder has not yet begun to burn. The result is equivalent to a high and variable pressure index. This same lack of reproducibility introduces confusion into a study such as that being reported here. Despite these difficulties, much has been learned about the burning of granular black powder, and data related to these phenomena are presented with qualitative explanations. It is hoped that portions of these data will assist materially in the design of new types of artillery primers. Additional work on materials other than black powder will be reported separately.

PRESSURE PHENOMENA IN PRIMER TUBES

Gas Flow in Packed Beds

In order to understand pressure-time phenomena in conventional primers, one must inquire about the packing of granular beds, the flow of gases through these beds and the effects of certain variables on this flow under the conditions existing in primer tubes. In an attempt to study some of these problems, an experimental primer was designed so that many important features of the bed could be varied at will in a downstream section having pressure gauges at each end (gauge positions 2 and 3 in Fig. 2a). This primer has a black powder charge next to the initiator, followed by a section of inert material and then by the section to be studied. For initial experiments, the section to be scrutinized was loaded with inert material only, in order to eliminate the effect of gases which would have evolved in this section by the burning of a combustible material. The inert material was crushed rock, screened to the granulation of grade A-1, grade A-3a or FFFG black powder. (See Table I for particle sizes of these black powder granulations). Observations were made on the extent of forced packing of the bed which was caused by upstream gases, rate of pressure rise and pressure drop in this section for various powder types. The effect of vent holes in this section could also be determined. In later experiments an auxiliary charge of black powder was added to this reference section in order to study the commencement of burning and the effect of this burning on all of the measured quantities. Too few firings have been made during this test to permit sound quantitative conclusions as to pressure drops to be expected and times for gas flow through given lengths of powder beds; however, the expected trends were observed, and are described below.

After firing, both the A-1 and A-3a inert powder beds were left packed very tightly near the reference sections of the primers, the inert particles being crushed and packed together to form dense conglomerates which greatly restricted gas flow. Indeed, the material in these sections had to be picked loose for removal. The extreme packing was localized, however, and in many cases when the muzzle end of the primer was sawed off after firing, the inert material could be poured out easily. The powder beds were compressed about 25 to 50 percent of their original lengths during the firing period. When primers containing inert material of FFFG size were fired, much of the material was blown through the primer body vents, whose diameters were about six times the diameter of the inert particles.

It was found that the addition of vent holes to the test section has a great effect upon the results obtained when A-1 inert material was used. When FFFG inert material was used, however, severely restricted gas flow was the controlling factor, so that increases in downstream vent area had little effect upon upstream conditions.

When an auxiliary charge of grade A-1 black powder was used to fill the reference section, the results were much different. The auxiliary charge

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appeared to ignite almost immediately after the upstream gases reached that section. The rates of pressure rise were much greater in the reference section than when no auxiliary charge was used. When grade A-3a or FFFG black powder was used as the auxiliary charge, it did not ignite in any primer tested. In these cases the restriction to flow through the fine inert material was great enough to prevent ignition. (Note that a pair of vents allows gas to escape from the main charge section). In every case the auxiliary charge of black powder was compressed to about 50 percent of its original length. The charge was left packed very tightly and had to be picked loose for removal. Both the inert material and the black powder were crushed so that some of each was pulverized to very fine powder, but with some large unbroken pieces remaining. Thus it appears that hot gases are the cause of ignition and that impact and frictional effects, such as would be imposed during the packing period, are of minor importance.

Closed-End Primers Uniformly Side-Vented Along Entire Lengths

Primers of this type (powder charge occupying the entire primer length) usually ignite at the breech end so that the pressure rises there first and a flame front moves downstream from that region. The rate of pressure rise is generally lowest at the breech end and increases at downstream positions along the primer tube. The maximum pressures attained at each point also increases along the primer.

Packing of the powder bed caused by upstream pressures is probably the reason for the trends noted above. When ignition first occurs, the gases can flow out through nearby vents and also along the primer tube through the loosely packed powder bed. As the flame front moves downstream the degree of packing increases so that the gases cannot flow readily through the powder bed. As packing occurs, the individual black powder particles are probably crushed so that the total burning surface is increased, thereby causing higher mass burning rates and consequently higher pressures at downstream positions.

Another observation is that the speed of the flame front decreases as it moves downstream; this observation also could be explained as a result of increased packing of the powder bed. Although the flame front speed decreases, the mass burning rate is greater, owing to an increase in loading density caused by packing at the forward end.

An example of a primer filled with black powder and having vents uniformly spaced along its length is the standard M28 (Fig. 3a). This primer generally burns at low pressures because of its high ratio of vent area to charge weight. In the case of one lot of these primers which was studied, average maximum pressures measured at four points along the primer varied from about 1080 psi at the breech end to about 1300 psi at the muzzle end. As was observed from pressure-time records, the average time for the flame front to travel a distance of 7 1/2 inches from the first gauge position (near the breech end) to the most forward gauge position was 4.6 ms. The time interval between start of pressure rise and

[REDACTED]

maximum pressure at a given gauge position (a function of the rate of pressure rise) ranged from 3.9 ms near the breech end to 1.8 ms at the muzzle end of the primer. Total times of venting varied from 9.8 ms at the breech end to 4.2 ms at the muzzle end. The rate at which the flame front moved downstream varied from about 180 feet per second between the first two gauge positions (nearest to the breech end) to about 100 feet per second between the last two gauge positions, for an average of about 140 feet per second over the whole primer length. It is believed that the gases flow down a primer between the primer wall and the powder bed more readily than through the packed bed itself, so that there is actually no clear-cut flame front traveling through the powder bed.

All of the above figures are average values for six rounds. Results for the individual rounds may be found in Table II; a reproduction of a typical pressure-time records may be found in Fig. 6.

When the black powder charge was reduced in an M28 primer, variations from round to round for all of the measured quantities were greatly increased. For charges of 200 grains the maximum pressure varied from 290 psi for one position to 1520 psi for another position on the same primer. The time interval from firing pin impact to start of pressure rise (T_1) also varied greatly. The value of T_1 for the gauge position nearest to the breech end was 0.8 ms for one firing and 32.5 ms. for another. These increased round-to-round variations resulting from reductions in powder charges probably reflect the random manner in which the powder bed may be oriented when the igniter gases strike it and the ways it may pack during the combustion process. In instances where the maximum pressures are very high, the total venting time is short, while for low pressures the opposite is true. This indicates that in some cases much of the black powder is ignited at once so that the rate of evolution of gas is great. An illustration of this point may be found in modified M28 primers containing 100 grains of grade A-1 black powder, which showed maximum pressures of about 250 psi and venting periods in the order of 30 ms. Another modified M28 primer with a 150-grain charge exhibited a maximum pressure of about 2600 psi and a venting period of less than 10 ms. Typical pressure-time data for M28 primers with reduced charges may be found in Table III.

Multiple Venting

Certain primers have been observed to discharge gases during several periods of the firing process. This phenomenon will be referred to herein as multiple venting. When multiple venting occurs, the flame front appears to travel down the primer tube in the usual manner with the resulting discharge of gaseous and solid products. After the flame front has traveled the length of the primer, pressures along the primer drop so low that they cannot be measured, and no indication of gas discharge can be observed on camera records. After a dormant period, the venting process takes place again. As many as three ventings have been observed for some primers.

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Since multiple venting has been observed only with FFFG black powder, one concludes that it is associated with the particle size of the powder. For this fine powder the grains may be so small relative to the vent hole size that they are easily carried away in the gas stream. After gas evolution reaches a certain stage, the rate at which burning particles are carried out the vents may be greater than the rate at which the flame front moves through the remainder of the powder bed. If this effect is sufficiently strong, the number of burning particles will decrease so that the pressure drops and the burning rate decreases. This process could then continue until gas evolution is so low that burning stops, to be resumed by some hot particles remaining in the primer tube. An illustration of pressure-time records illustrating this phenomenon can be found in Fig. 7. Experiments with inert beds in primer tubes indicate that much FFFG black powder is blown out the vents during a firing. Larger particles show much less ejection and also virtually no tendency toward multiple burning.

When multiple venting occurs, maximum pressures are reduced greatly because only a portion of the powder charge is consumed during each period of venting. The percentage of the powder burned during the first venting varies greatly from round to round, and thus values of the maximum pressures vary excessively. The effect of multiple venting on maximum pressures is illustrated by modified M28 primers (200 grains of FFFG black powder). In one instance where multiple venting did not occur, a maximum pressure of 7400 psi was observed. For a primer where multiple venting occurred the maximum pressure was only 2000 psi. (The peak pressure of 7400 psi indicates how much higher pressures may become when FFFG is used in lieu of grade A-1 black powder. The maximum pressure observed in an M28 primer with 200 grains of A-1 was slightly greater than 1500 psi).

When multiple venting occurs, no significant change is observed in times for the various events of the first venting period. The only difference of note is that the ignition delay, T_1 , is slightly increased. The time between successive venting periods, if they occur in M28 primers with FFFG black powder, is in the order of 10 to 20 ms. Pressure-time data for M28 primers with FFFG black powder may be found in Table IV.

It should be mentioned here that for M28 primer tubes, which have very close spacing of vents, approximately 18% of the total vent area is restricted by the four pressure gauges and their housings during static firing tests; recorded pressures are probably in error by being slightly high because of this vent restriction. In the case of other primers to be described subsequently, separate gauge holes are drilled into the primer bodies. All of the vents are free to discharge, therefore, and the early portions of pressure-time relationships determined for these primers should duplicate the initial behavior of the primer in a weapon system.

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Primers with Powder Charges Retained in Unvented Sections by Movable Diaphragms

This type of primer has some distinct operational advantages over primers with the powder charge occupying the whole length, and is commonly used in artillery weapons.

Maximum pressures in the unvented sections of primers with paper diaphragms were found to depend on the length of the powder column to a power greater than unity, for the examples considered. Average values for maximum pressures at the breech ends of primers having the same internal diameter and using grade A-1 black powder were 1660 psi for charges of 100 grains, 6650 psi for 225 grains and 16,650 psi for 270 grains. These pressures were recorded for M58 primers with reduced charges, FVE primers (BRL designation for primers used to study the effect of free volume) and M40 primers, shown in Figs. 4a and 4b and Fig. 2b respectively. Pressure-time data for these primers may be found in Tables V, VI and VII. Breech end pressures in the standard M58 primer (400 grains) are only about 12,620 psi; however, the vented section extends back into the powder region in this primer and hence prevents the build-up of higher pressures in this region. See Fig. 4a for the schematic diagram and Table VIII for pressure-time data.

The time interval from the instant of firing pin impact to start of pressure rise (T_1) at the breech end of diaphragm primers varies little with the powder charge. The interval between firing pin impact and maximum pressure (T_2) also varies little with powder charge, but the actual rates of pressure rise are greater, for greater charges, since higher pressures are attained. If the charge section (portion between the initiator and diaphragm) is lengthened, but with the powder charge remaining constant so that the loading density is reduced, maximum pressures are reduced and ignition delay (T_1) is increased correspondingly until misfires are encountered.

It has long been known that the addition of vent holes to the unvented portion of this type of primer will greatly reduce maximum pressures all along the primer. A series of rounds was fired to determine the magnitude of this reduction in pressure. For a standard M58 primer, pressures range from approximately 12,000 psi at the breech end to about 3000 psi at the muzzle end. The addition of six 0.140 inch vents near the initiator (0.092 in^2) reduced breech pressures to about 6000 psi (50 percent reduction) and reduced muzzle end pressures to less than 200 psi. When six 0.059 inch vents (0.16 in^2) were added, pressures near the breech end were affected very slightly, while muzzle pressures were reduced to about 2000 psi (30 percent reduction). See Table IX for results.

[REDACTED]

Every experimental primer with an unvented section and a paper retaining diaphragm has exhibited extremely high rates of pressure rise and oscillatory pressure-time curves for positions near the diaphragm. The rate of pressure rise is essentially vertical in most cases for the drum camera speeds used ($1/4$ to $3/8$ inch per ms). This effect has been observed at positions several inches to the rear of the diaphragm. A possible explanation for this phenomena is the accumulation and subsequent rapid decomposition of incompletely reacted gaseous combustion products following rupture of the diaphragm. If the reactions of these gases proceed rapidly only at high temperatures and pressures, the rapid motion of the diaphragm and the sudden cooling owing to expansion of the gases would exert a strong retarding influence. The effect might be similar to that found in the effect of projectile motion in a gun on retarding the decomposition of the nitric oxide, evolved by burning propellant, which subsequently reacts with violence after having accumulated to an appreciable extent. Experiments in primers suggest that the same thing occurs when a paper diaphragm moves suddenly. When a group of copper pellets was added near the diaphragm, the pressure-time curves became much smoother. Also, when a flash tube was added to the initiator to effect ignition near the diaphragm, the rate of pressure rise was greatly reduced. Reproductions of pressure-time records for these three types of primers are shown in Fig. 8.

It can be asserted for open-end primers that the values of maximum pressures decrease steadily with position along the vented section. Some standard primers exhibit very low pressures near the open end. When a metal plug was added to the forward end of this type of primer, very high pressures were observed in the vicinity of the plug. The magnitude of pressures measured at these closed ends is a function of the primer length, the powder charge remaining constant.

For a given type of primer one can choose a length for which these pressures will be a maximum. It is possible in the case of short primers that powder particles do not have time to attain any appreciable velocity before striking the closure. For very long primers, most of the gas and solid particles are discharged through side vents before unburnt particles reach the muzzle end. For intermediate lengths, however, the powder-gas mixture probably attains appreciable momentum by the time the metal plug is reached. Upon striking the closure the gas mixture will be compressed so that its temperature and pressure rise. It is also quite possible that unburnt particles are crushed during the process so that the burning surface and, therefore, the rate of gas evolution is greatly increased. Gas velocities determined from high-speed motion pictures vary from about 250 to about 2000 feet per second when the vented length is varied from 3 to 9 inches in an FVE primer containing charges of 225 grains of A-1 black powder. (See data for gauge position 4 in Table X for pressures at closed ends of primers.)

A closed-end primer whose vent diameters vary along its length is the T88E1. A diagram of this primer may be found in Fig. 5 and pressure-time data in Table XI.

[REDACTED]

Experiments confirm the prediction that the pressures on the plug at the muzzle end of a closed-end primer are actually greater than pressures recorded with the gauge mounted perpendicular to the direction of gas flow (as they were for pressure measurements along the rest of the primer). To check this point, several rounds with reduced charges were fired with gauges screwed into the open ends to replace the metal plugs used with closed-end primers. In this case the axis of the gauge was parallel to the direction of gas flow down the primer. Another gauge was placed in the usual manner as close to the muzzle end as possible, so that pressures in the two directions could be compared. Although results indicated no direct correlation with gas velocities measured, the pressures in the direction of gas flow were always greater than the pressures measured perpendicular to the flow and in some instances they were almost twice the magnitude of the latter. Results of five rounds are shown in Table XII. Data for primers with full charges are not available.

Gas velocities measured in the unvented sections appear to be less than 500 feet per second for all diaphragm primers tested, and the velocity increases steadily as the paper diaphragm is approached. Values for the velocity of gas flow down primer tubes may be found in Table XIII. Results calculated from pressure-time records varied greatly from round to round, while results from high-speed motion pictures were much more uniform, and probably are more reliable.

Double-Tube Primers

The so-called double-tube primers have been used with some success in attempting to approach symmetrical or simultaneous gas discharge. This type of primer (Fig. 3b) is equipped with a tube extending from the initiator down the axis of the primer tube for the purpose of carrying the initiator gases and discharging them at any desired position or positions along the primer. The inner tubes are usually of metal, but other materials have been used.

Previous work on double-tube primers has been reported in earlier papers (1,2,3). Additional study has been made of a model using a primer body vented its entire length with the inner tube open at the forward end and terminated at approximately mid-primer. (The tube is anchored at one end by a press fitting in the flash port of the initiator). These primers have been tested with black powder charges of from 100 to 300 grains of both FFFG and A-1 granulations. The pressures and venting times for primers using FFFG black powder are rather erratic because of multiple venting, a phenomenon which appears to be associated with the small size of the particles rather than with the inner tubes.

The double-tube primer functions best at high densities of loading of the black powder where the tube best serves its intended purpose of providing a free channel for the initiator gases to flow the length of the primer. For reduced charges where free flow of the initiator gases

[REDACTED]

is possible in the ullage space, an inner tube of small internal diameter serves no worthwhile purpose, and may actually be more a hindrance than a help. Experimental results bear out this point. The use of an inner tube in a fully loaded primer (300 grains of FFFG) that is vented its entire length reduces the period from initial venting until all vents are active from 4.3 ms to 2.7 ms. However, when the charge is reduced to 100 grains of FFFG in the same primer, periods varying from 1.5 to 2.0 ms are required to vent the entire length. In contrast to this, a conventional type of primer with a charge of 100 grains requires but 0.7 ms to vent its length,

In a double-tube primer, with 300 grains of FFFG, venting of the gases (as indicated by initial rise of pressure) started first near gauge position 3 (Fig. 3b) and progressed in both directions from this point. The flame front reached gauge position 1 at the breech end in approximately 1.4 ms, but encountered more difficulty in moving from position 3 to position 4, requiring 2.7 ms to reach this point. (The distance from gauge position 3 to positions 1 and 4 were 5.25 inches and 2.25 inches respectively.) The reason for the greater ease of gas flow toward the breech end of the primer can probably be accounted for by the manner in which particles pack next to a smooth surface. It has been mentioned earlier (1) that a flame front travels more rapidly between the powder bed and the primer body than through the tightly packed powder bed. The extension of the tube, therefore, probably aided gas flow by providing an additional path of this sort leading toward the breech end, whereas no such central path existed toward the muzzle end.

The maximum pressures observed in double-tube primers containing FFFG black powder are very erratic, varying greatly from round to round and even from muzzle to breech in a given primer. The variation in pressure along a given primer is probably a direct effect of the packing of the fine FFFG particles. (Conclusions about the effect of an inner tube on the maximum pressures are hard to draw on the basis of the meager results obtained, but the double-tube primers exhibit the lower pressures). See Table XIV for data on double tube primers with FFFG black powder.

Double-tube primers loaded with A-1 black powder show a reduced gas flow problem at the expense of ease of ignition (Table XVI.). Primers of the fully vented type with a double tube and full charge of A-1 black powder operate very well at room temperature, requiring a period of less than 0.5 ms to vent the entire length of the primer. The total time of venting is moderate and the maximum pressures recorded are twice as high as those observed in the standard M28. The higher pressures are probably due to a higher loading density when the inner tube is used. In addition, more powder ignites and burns per unit time than in the case of the standard primer.

When the black powder charge is reduced to 200 grains of A-1 granulation, ignition difficulties are encountered even at room temperature. Experimental primers showed time delays between initiator impact and start of venting of more than 25 ms and maximum pressures less than 1000 psi for all gauge positions. This condition is not unexpected, however, since it also occurs in the standard M28 primer for reduced charges. When the charge in the double-tube primer was reduced further to 100 grains of A-1 black powder, all rounds misfired. Apparently, with low loading densities, the initiator gases expand with a corresponding drop in temperature so that ignition does not occur. In addition, the large free volume allows the black powder particles to be blown away from the region of highest energy of initiator gases.

Originally, the double-tube primer was designed to provide an efficient means of transporting the initiator gases from the breech end of the primer to a predetermined position downstream. With ignition taking place at mid-primer, one would expect that, since the travel of the flame front would be reduced by a factor of 2, the time to vent the total length of the primer should also be reduced by this factor. The original design was workable using A-1 black powder and a fairly high density of loading. However, since the design failed in low temperature firings because of misfires, FFFG black powder was employed as a means of presenting more surface area to the initiator gases. While this was a workable change, it increased the restriction to gas flow in the powder bed. To overcome the faults apparent in the use of either granulation of powder, it was decided that an improved double-tube primer would need a powder of fairly large particle size and a booster in conjunction with the initiator. Another solution would be an inner tube vented its entire length to eliminate the flow problem associated with packed beds. Accordingly, a double tube primer embodying these principles has been tested. This primer has a 5/16-inch inner tube vented the entire length of the primer. A 5-grain booster charge of FFFG black powder is held in the inner tube near the initiator with a paper wad. The main charge consists of 100 grains of FFFG black powder (Fig. 3c). This primer is very fast in venting its entire length and shows no indication of multiple burning. The pressures are high and the pressure-time curves are rather rough, probably owing to the vigorous ignition system. (Table XV). A larger granulation of black powder in the primer would probably reduce the pressure level to a more acceptable value.

PRIMER INITIATORS

Initiators in standard artillery primers are usually of three types: percussion, electric or percussion-electric. The first is actuated by the impact of a firing pin, the second by means of an electrical device such as the discharge of a condenser and the third by either of these two methods. In the typical case the gases from the detonation of the initiator flow through a small orifice and expand into that region of the primer occupied by the primer charge. This report is concerned with the percussion type exclusively, although, in their effect on the burning of the black powder, the three types are similar.

The time interval between firing pin impact and emission of gases from a standard 1-grain initiator is about 250 microseconds. The initiator gases then vent for about 500 microseconds. In an experimental primer equipped with a window for observation, it was observed photographically that the venting period of the initiator was followed by a dormant period before the black powder began to burn (1). During this dormant period the temperature of the gases is apparently so low that they cannot be seen on high-speed motion picture records. Pressure-time measurements taken from primers confirm this observation. There is a short period after firing pin impact before the pressure rises due to initiator gases. The pressure from the initiator gases exists for about a millisecond in primers with grade A-1 black powder and then drops almost to zero before rising again as a consequence of the burning of the black powder charge.

The magnitude of the pressure rise caused by the initiator gases depends, of course, upon the free volume available in the primer body. In an M28 primer about 1 inch of the tube is free of black powder if the charge is positioned toward one end. The pressures at position 1 caused by standard 1-grain initiators in M28 primers vary from about 150 psi to 500 psi. When 2-grain initiators were used with an M28 primer the pressures observed were between 800 psi and 1200 psi, which pressures are evident on pressure-time records for gauge position 1 only. Figure 6 shows the initial pressure rise at position 1 for a standard M28 primer.

The effect of initiator gases upon powder beds has been studied qualitatively by using loosely packed inert material in M28 primer tubes. For the few primers fired there was no significant difference in the packing of the inert material (crushed rock screened to the size of grade A-1 black powder) by 1-grain and 2-grain initiators. In both instances the inert bed was moved forward about 1/4 inch, and the bed was scorched and packed so that for removal it had to be picked loose in a section about 1 1/2 inches long. The effect of increased initiator charge on ignition delay (T_1) and rates of pressure rise seems to be negligible with conventional primer charges.

When a flash tube or inner tube is added to a standard 1-grain initiator, the ignition delay (T_1) is increased directly proportional to

[REDACTED]

the length of the inner tube and inversely proportional to the temperature of the tube. In a test of two M58 primers with inner tubes and 375 grains of grade A-1 black powder at -70°F , one misfire occurred. The other primer exhibited a very long delay between firing pin impact and an audible report from the primer. Chances of misfires occurring at low temperatures can be lessened by using 2-grain initiators in double-tube primers.

GAS DISCHARGE FROM PRIMERS

General

The desirability of sufficiency of a primer, or discharge of the proper amount of igniter gases to a propellant bed, has been mentioned earlier. Thus, although no conclusive quantitative data are available about the energy necessary for proper ignition of particular weapon systems, it is desirable to have some method of measuring or judging the amount of igniter gases discharged from primers so that correlation with gun firing tests can be made. In the ideal case, the transfer of energy to a propellant bed should be as uniform as possible to every region of the bed. Therefore, variations in rates of gas discharge along primers ought to be considered in static tests so that over-all effects can be compared in gun firing tests.

An expression for the mass rate of gas discharge from an orifice or vent is available from simple rocket theory. This expression may be written as follows:

$$\frac{dm}{dt} = AC_D P$$

where:

$\frac{dm}{dt}$ = the rate of gas discharge, lbs (mass) per second,

A = the area of the vent, in ²

P = the stagnation pressure at the vent entrance, lbs
(force) per in²

C_D = the discharge coefficient, lbs (mass) per lb (force
per second, or sec⁻¹

The above equation may be integrated to obtain an expression for m, the total mass burned. The new expression is

$$m = AC_D \int P dt.$$

[REDACTED]

This equation permits the experimental determination of C_D , since total m and A for all of the vents are known for a given primer and $\int P dt$, or gas impulse in lb-sec per in², can be determined from static firing tests (the area under the pressure-time curves). (In these experiments no effort has been made to state the equivalent rate of energy release. This point is deferred to the conclusion of experiments on a variety of igniter materials which include black powder).

In using the above equation for determining gas discharge, certain assumptions are made. Some of these assumptions are:

- a) The products of combustion are perfect gases so that the discharge coefficient is a constant.
- b) The vent area is the actual area of the holes in a primer body. Actually, the vena contracta for a square-edged orifice is slightly less than the cross-sectional area of the orifice.
- c) The pressures measured and recorded on the pressure-time records are stagnation pressures.

If one wishes only relative comparisons among primers, the first assumption may require only that the characteristics of the gases remain the same from round to round.

Since A and C_D are constants, a simple way to illustrate the variation in gas discharge along a primer is to plot gas impulse versus position along the primer tube. This has been done in order to compare various types of primers and to study the effect of variables such as characteristics of black powder charge and primer length.

Closed-End Primers Uniformly Side-Vented Along Entire Lengths

The ideal primer, with uniform discharge of gases per unit length, would exhibit a constant gas impulse at all positions along the primer. Side-vented primers fully packed with grade A-1 black powder burn in a cigarette fashion, starting from the breech end. Although maximum pressures occur at the muzzle end, maximum venting takes place at the breech end, because the total venting time is greater there. The graph of gas impulse (ordinate) versus position (abscissa) is concave upward with a maximum value of impulse at the breech end, (or wherever else ignition occurs). In some of the tests the point of maximum discharge of gases occurred well downstream from the breech end. It is believed that ignition also took place downstream in these instances, as indicated on pressure-time records). An example of uniformly vented closed-end primers is the standard M28, for which graphs of gas impulse versus position may be found in Fig. 9.

[REDACTED]

When the powder charge is reduced, no change occurs in the shape of the curve of gas impulse versus position. The curve is, of course, closer to the abscissa, indicating less discharge at every position along the primer.

When FFFG black powder is used in this type of primer, multiple venting often occurs and round-to-round variations are more marked. However, the curve of gas impulse usually shows maximum venting at the igniter end or at any other position where the black powder charge first ignites. The curve is again concave upward and approaches the abscissa asymptotically at forward positions. If multiple venting occurs, the curve for the first venting is closer to the abscissa than for complete burning, since only a portion of the charge burns during this initial period. The second and third ventings, if they occur, exhibit curves that tend progressively with successive ventings to slant in the opposite direction, i.e., more venting toward the muzzle end. If the curves for all of the periods of ventings from one primer are added, the curve obtained (Fig. 10) is more nearly horizontal than curves for any single period of venting.

As the charge of FFFG black powder is reduced, the curve of gas impulse becomes more nearly parallel to the abscissa and may show maximum venting at the muzzle end. This shift in the point of maximum discharge probably occurs because the powder bed is more easily ignited along its entire length and does not pack at the muzzle end so readily for the reduced charges. An example is a modified M28 primer containing FFFG black powder (See Fig. 11).

Primers with Powder Charges Retained in Unvented Sections by Movable Diaphragms

Primers of this type generally show great variations in gas discharge along the tube. A typical plot of gas impulse versus position for the vented portion of a primer, approaches the abscissa asymptotically with maximum gas discharge at vents nearest the unvented section, neglecting discharge from the open forward end. As was mentioned earlier, the effect of increasing the charge in this type of primer is that of increasing the pressure greatly in the unvented section and the variations in pressure along the primer. A reduction of the charge produces a primer that has little variation in gas discharge along the length, but the total gas discharge becomes very low. Examples of primers with great variation along the vented section are the standard M40 and standard M58 primers. (See Fig. 12 and 13). A primer showing relatively low pressures and little variation in gas discharge with length is the modified M58 primer with a reduced black powder charge. Curves of gas discharge for primers with 100 grains and 150 grains of grade A-1 black powder may be found in Fig. 14.

[REDACTED]

Added length to an open-end primer of this type should increase resistance to gas flow past the point of addition and cause higher upstream pressures and, therefore, greater gas discharge from upstream vents. Experimental results indicate the opposite is true, however. As the primer length was increased, a given upstream vent showed slightly less gas discharge. Fig. 15 shows this effect for experimental primers with charges of 225 grains of grade A-1 black powder held in the unvented section by a paper diaphragm; the primers varied in length from 11 1/4 inches to 17 1/4 inches.

When a metal plug is used to close the muzzle end of the primer, maximum gas discharge usually occurs at the muzzle end, apparently owing to the piling up of gases and resultant high pressures associated with closed-end primers. Since high pressures occur in the unvented portion of these primers, the amounts of gas discharged are also great at the first vents beyond the unvented section. As the length of the vented section is shortened, the piling up action at the closed end is felt farther upstream so that gas discharge is greater near the unvented section for short primers than for long primers. For longer primers, gas discharge decreases with distance beyond the unvented section and then begins to increase again as the closed end is approached. Of the examples studied, the 15 3/4-inch primer fell between the two extremes and exhibited fairly uniform gas discharge. The example studied was the closed-end FVE primer with varied vented length. (Fig. 4b). Graphs of gas impulse versus position may be found in Fig. 16.

A closed end primer of this type with the vent diameters varied along its length is the T88E1 primer (Fig. 5). It should be pointed out that the vented region extends back into the powder section in this example.

A plot of gas impulse versus position for the T88E1 primer may be found in Fig. 17. Since the vent area varies with position, a correction must be applied to this plot in order to indicate the actual variation of gas discharge along the primer. A value of 0.0166 sec.^{-1} has been assumed for C_D (See section on "Empirical Determination of Orifice Discharge Coefficients" below) in the relationship $m = AC_D \int P dt$.

A bar graph of gas discharge from each pair of vents in the primer is presented in Fig. 18, which shows that one can partially control the variation of gas discharge along a primer by a suitable disposition of vent area.

Double-Tube Primers

When an inner tube is added to a primer which is vented along its entire length, so that ignition takes place at the mid-primer position, an improvement in the variation of gas discharge along the primer is accomplished. For primers which are fully packed with A-1 black powder, a plot of gas impulse versus position curves downward slightly for the breech end and tips up for the muzzle end of a primer. The concavity

[REDACTED]

of the forward end of the curve, indicating more gas discharge there, is probably due to the greater amount of powder at the forward end of the primer. If the inner tube ran the entire length of the primer, so that the powder per unit length of primer were constant, the curve would probably bend down at both ends and maximum gas discharge would be indicated at the mid-primer position or point of ignition.

Smaller charges (if they ignite) exhibit essentially the same curve shapes as full charges but with somewhat reduced impulse. An example of this primer is shown in Fig. 3b; amounts of gas discharged for charges of 200 and 300 grains are shown in Fig. 19.

If FFFG black powder is used in double-tube primers, multiple venting is encountered. Discharge of gases is greatest at mid-primer or any other point of ignition. When and if subsequent ventings take place, gas discharge at the ends increases relative to gas discharge at mid-primer. If the curves for all ventings are added, the gas impulse is more nearly uniform with position, and the maximum remains at the point of ignition. As the charge of FFFG black powder is reduced in double-tube primers, the variation in gas discharge along the primer may decrease, and the point of maximum gas discharge moves toward the muzzle end. The maximum discharge still occurs near the mid-point of the primer, however. Data for gas discharge are plotted in Fig. 20 and 21.

Since the amount of gas discharged from a primer is essentially a pressure-time relationship, the same amount of gas discharge, energy-wise, could be realized from a low-pressure, long-duration discharge as from a high-pressure, short-duration discharge. Therefore, it is reasonable to state that other factors concerning primer performance, such as maximum pressure and sequence and length of vents, must be considered in order fully to evaluate a given primer design.

Empirical Determination of Orifice Discharge Coefficients

As mentioned earlier the coefficient of discharge C_D for black powder may be calculated from the results of static firing tests of artillery primers by using the expression:

$$m = AC_D \int P dt$$

As would be expected, since many assumptions must be made and since an imperfect gas is involved, the calculated values of C_D also vary greatly. The effects of variation from a perfect gas (4) are:

- 1) Friction decreases C_D
- 2) Heat loss increases C_D

3) Incomplete reaction increases C_D

4) Unburnt powder in the gas increases C_D

The method used for estimating values of C_D was that of plotting a graph of $\int P dt$, gas impulse, versus position for a particular primer and of finding values of $\int P dt$ for each individual vent in that primer. The average value of $\int P dt$ for all of the vents was then substituted for $\int P dt$ in the above equation. The total area for all the vents was used for A , and the original charge of black powder in the primer (pounds mass) was used for m . The average value of C_D was 0.018 sec^{-1} for M28 primers (Fig. 3a) and 0.015 sec^{-1} for experimental closed-end primers with unvented sections (FVE type primer shown in Fig. 4b). The average value calculated for all of the primers tested was 0.0166 sec^{-1} , and the standard deviation of C_D was 0.0032 . Although these values of C_D are approximate, they will be used here to make an estimate of the amounts of gas discharged through the open ends of open-end primers.

Estimating End Venting From Open-End Primers

Given a value of C_D for black powder, it is possible to calculate what fraction of the original charge is discharged through the open forward end of a primer. The method used is simply that of calculating the fraction of the original primer charge that is discharged through the side vents and of assuming that the rest is discharged through the open end. This method is similar to that described above for calculating C_D , except that here C_D is known and m is calculated. A value of 0.015 sec^{-1} was assigned to C_D , since it was obtained from primers similar in design to the open-end primers.

The results of the calculations indicate that as the vented length of the primer is increased and the charge is held constant, less mass is discharged from the open end. This would be expected, since longer primers allow greater chance for side venting before the gases (which, of course, carry some solid particles) reach the open end. Open-end FVE primers illustrated in Fig. 4b show this trend. The amount of end venting varied from 41 percent for the shortest (12 3/4 inches) to 18 percent for the longest primers (17 1/4 inches).

As the charge is increased the fraction of products vented through the open end decreases. Examples showing this are the modified M58 with a reduced charge (Fig. 4a), and the 15 3/4-inch FVE primer. For the modified M58 primer and a charge of 100 grains of grade A-1 black powder, about 52 grains, or 52 percent, of the charge was discharged from the open end. When the charge was increased to 150 grains, the amount end-vented increased to 53 grains, or 35 percent, of the original charge.

[REDACTED]

Other primers showing this phenomena are the standard M40 (Fig.2b) and the open-end 17 1/4-inch FVE primer (similar in length to the M40 but with only 225 grains of black powder). The FVE primer discharged about 40 grains, or 18 percent, of its charge out the muzzle end. The M40 primer end-vented about 45 grains in one case and 25 grains in another, or 17 and 9 percent of its 270-grain charge, respectively.

Several primers with reduced loading densities in the unvented powder bed section were also tested. These were the modified M58 primers with charges of 100 grains and 150 grains in a section long enough (7 1/2 inches) to hold 225 grains of grade A-1 black powder. In general, these loosely packed primers showed longer times for the various events and lower maximum pressures than the primers with closely packed beds. The primer with the lowest loading density (100 grains of A-1) exhibited a very long ignition delay. With this in mind, the results of end venting are considered. The 100-grain primer end-vented about 32 grains. The 150-grain primer indicated about 50 grains end-vented, a fraction about the same as for packed bed primers. It should be realized that only one each of these last two primers has been tested. The above results may be found in Table XVII.

SUMMARY AND CONCLUSIONS

The most desirable characteristics of any primer system are reproducibility, simultaneity and/or symmetry of discharge, and sufficiency. This ideal primer can be approached but probably never attained using black powder.

Because of certain properties of black powder it is impossible for it to operate in a reproducible manner at all times. Since the burning rate exponent, n , apparently increases from about 0.5 to 1.0 at about 2000 or 3000 psi, primers operating at or above this range will show great variations among rounds. Furthermore, the shape, size and strength of black powder particles vary from sample to sample so that irregularities in the way it packs and breaks up during firing will inevitably occur. With smaller granulations packing becomes worse and the possibility of multiple venting arises. Hence, the better black powder primer from the standpoint of reproducibility would be one operating below 3000 psi, with large enough particles (relative to the vent hole size) that multiple venting would not occur and packing would not be extreme. Certain other steps such as the addition of inner tubes can also be taken to aid the flow problem.

Static firing tests have shown that simultaneity can be approached but that it has not been achieved in standard black powder primers. The problem is associated with the flow problem in packed beds. The double-tube primer vents its length quickly in alleviating this problem, but is costly to fabricate. Simultaneity can also be approached at the expense of reproducibility by increasing foiling paper strength and, therefore, pressures. The diaphragm type primer offers another solution by venting

[REDACTED]

quickly, but gas discharge varies greatly from breech to muzzle end in open-end primers of this type.

The sufficiency of igniter systems has not been stressed in this work, but it may be stated that black powder has a sufficiently low flame temperature that standard primers may be inadequate for some propellant systems.

Uniformity in the amount of gas discharged from primers appears to be connected directly with flow problem in packed beds. The use of inner tubes corrects this condition somewhat. Certain diaphragm primers with closed ends can also be made to discharge energy evenly in specific instances, but reproducibility is poor in these primers.

As indicated above, many of the problems associated with black powder primers are due to the flow problem inherent in beds of granular black powder. One way to alleviate the flow problem is to use a material that can be extruded in stick form. The use of these sticks in standard primer tubes of the M28 type would provide natural channels for gas flow along the primer. One material that can be extruded into strands and yet has most of the desirable properties of black powder is a mixture of potassium nitrate, sulfur and charcoal in nitrocellulose as a binder. Small amounts of certain other ingredients are added to aid ignition. Metals and oxidizers may be added to this mixture if desired. Preliminary experiments on a number of potential substitutes for black powder have been conducted and the results indicate that the use of extruded materials offers real potentialities.

A detailed description of some other advantages and disadvantages of black powder may be found in other works (5).

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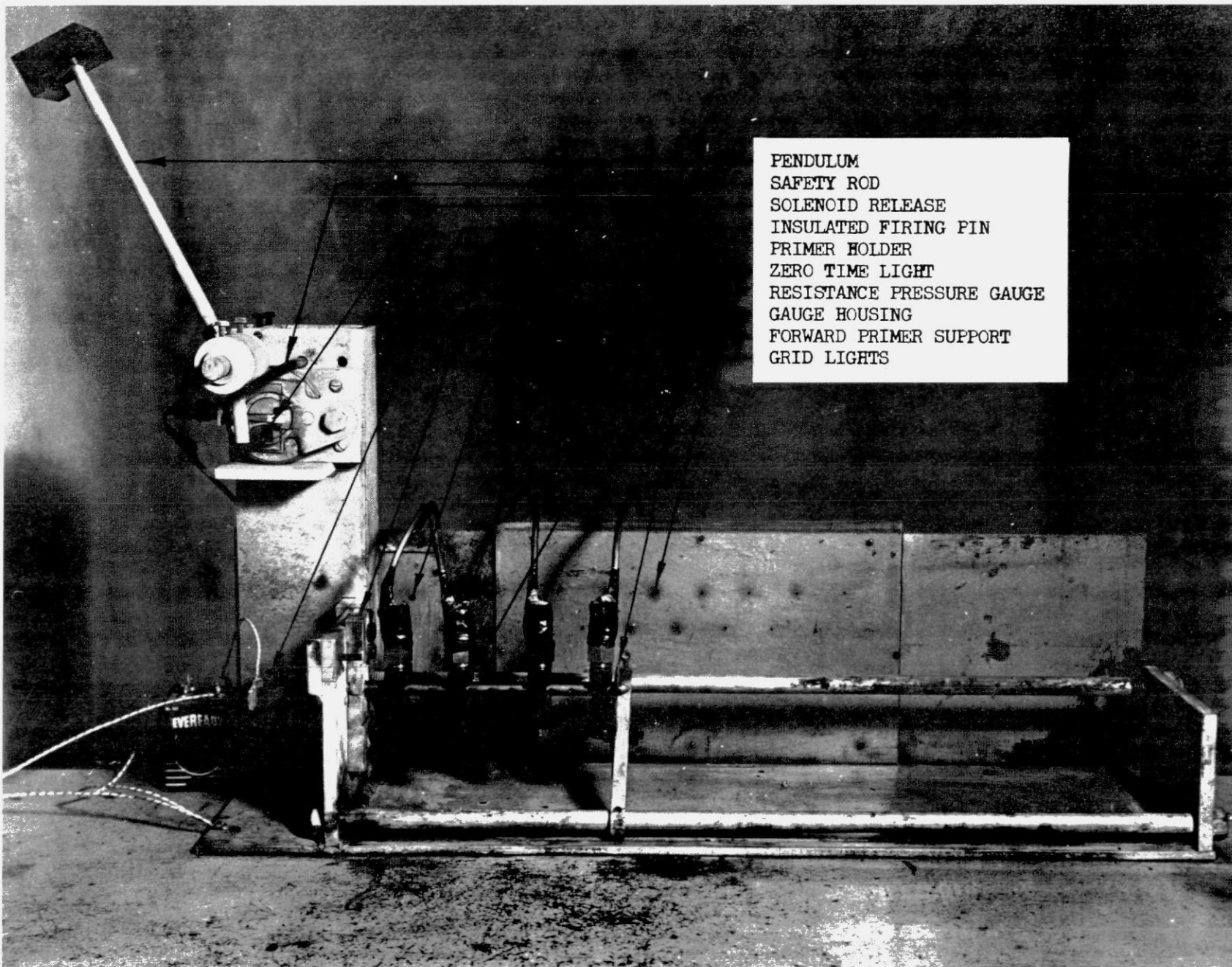


Figure 1. Static Firing Mechanism.

CONFIDENTIAL

CONFIDENTIAL

EXPERIMENTAL PRIMER FOR STUDY OF FLOW IN PACKED BEDS

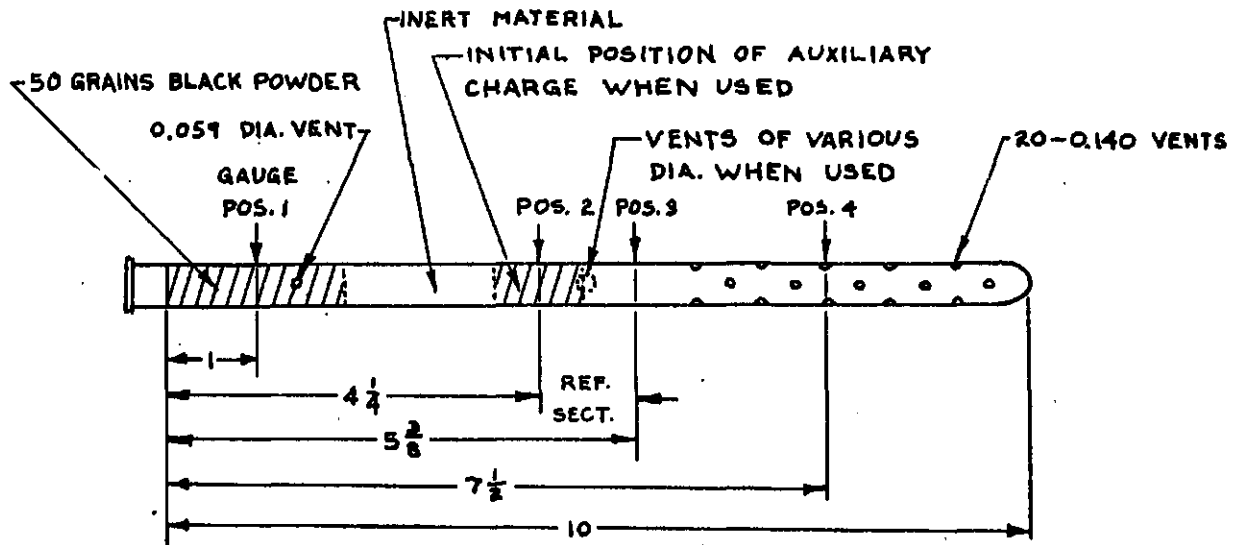


Fig 2a

STANDARD M40

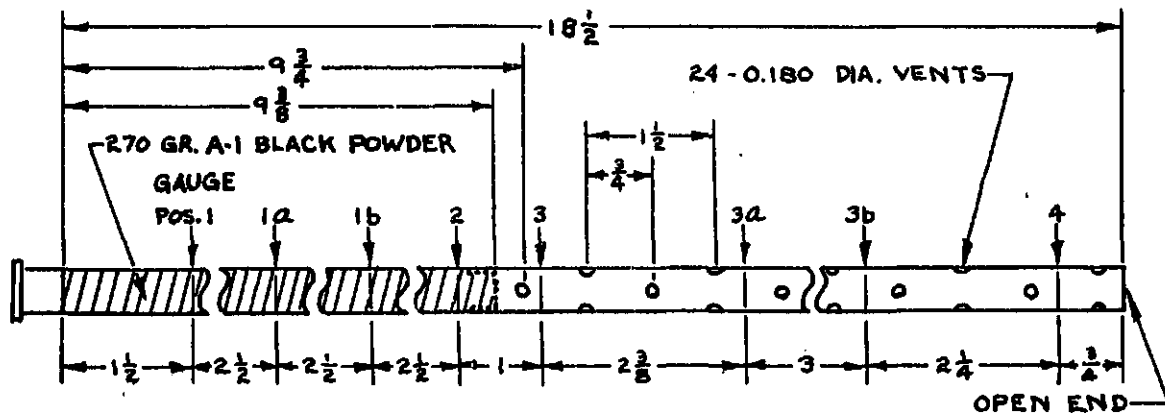


Fig. 2b

STANDARD M28

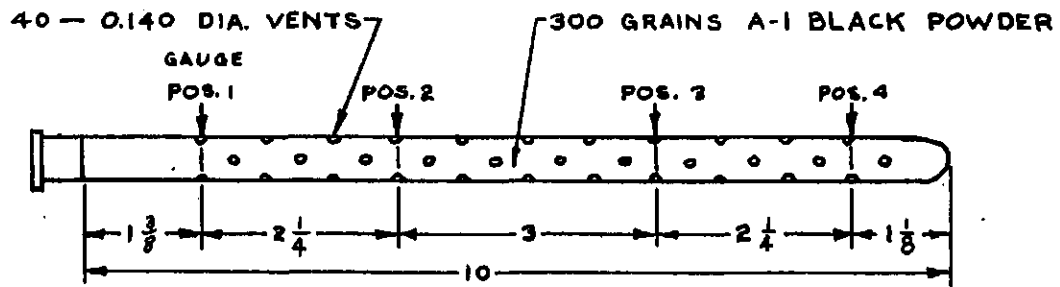


Fig. 3a

MODIFIED M28 (DOUBLE TUBE)

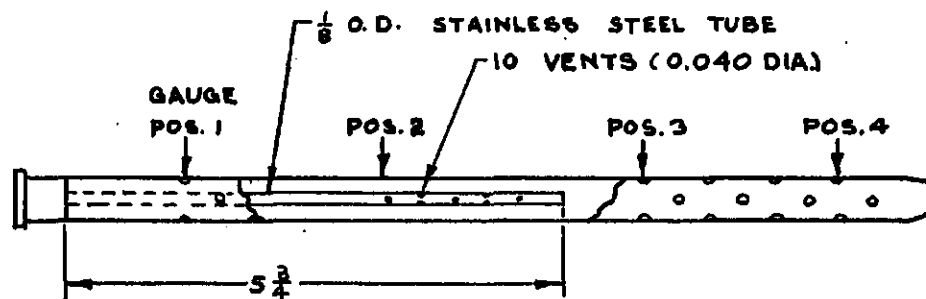


Fig. 3b

DOUBLE TUBE PRIMER WITH BOOSTER

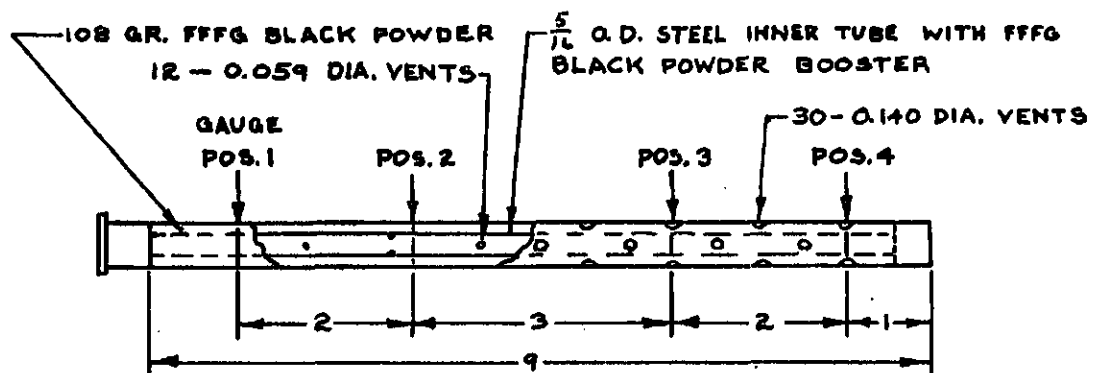
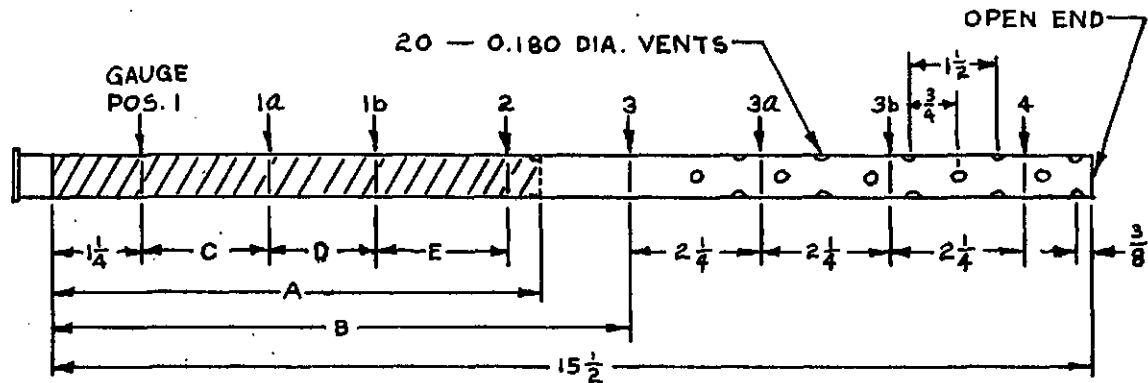


Fig. 3c

STANDARD AND MODIFIED M58 PRIMERS



TYPE:

STANDARD M58 (400 GR. A-1 BLACK POWDER)

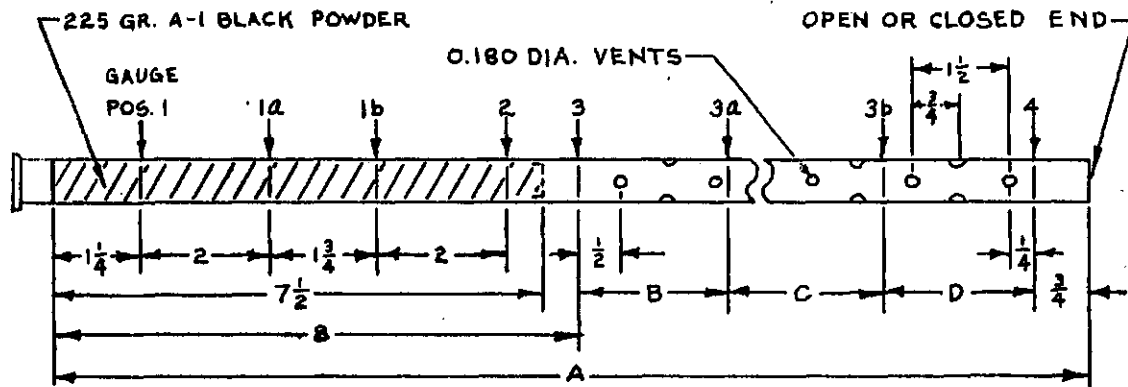
150 GR. A-1 BLACK POWDER

100 GR. A-1 BLACK POWDER

A(IN.)	B(IN.)	C(IN.)	D(IN.)	E(IN.)
14	8 $\frac{1}{4}$	2 $\frac{1}{4}$	2 $\frac{1}{4}$	2 $\frac{1}{4}$
3 $\frac{1}{4}$	7 $\frac{1}{4}$	1 $\frac{1}{4}$	1 $\frac{1}{4}$	1 $\frac{1}{4}$
3 $\frac{3}{4}$	7 $\frac{3}{4}$	1 $\frac{1}{2}$	1 $\frac{1}{2}$	1 $\frac{1}{2}$

Fig. 4a

FVE PRIMER (BRL DESIGNATION)



A(IN.)	B(IN.)	C(IN.)	D(IN.)	NO. OF VENTS
11 $\frac{1}{4}$	2 $\frac{1}{2}$	-	-	6
12 $\frac{3}{4}$	4	-	-	10
14 $\frac{1}{4}$	1 $\frac{3}{4}$	2 $\frac{1}{4}$	1 $\frac{1}{2}$	14
15 $\frac{3}{4}$	2 $\frac{3}{8}$	2 $\frac{3}{8}$	2 $\frac{1}{4}$	18
17 $\frac{1}{4}$	3 $\frac{1}{8}$	3	2 $\frac{3}{8}$	22

Fig. 4b

T88E1 PRIMER

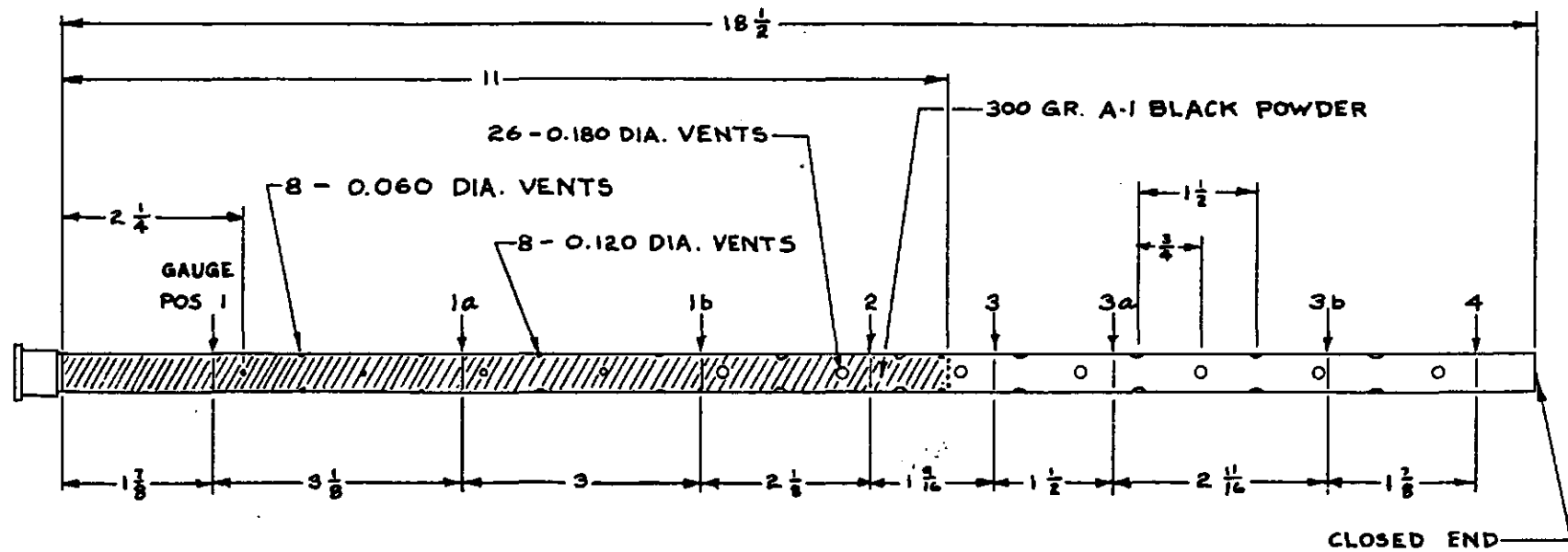
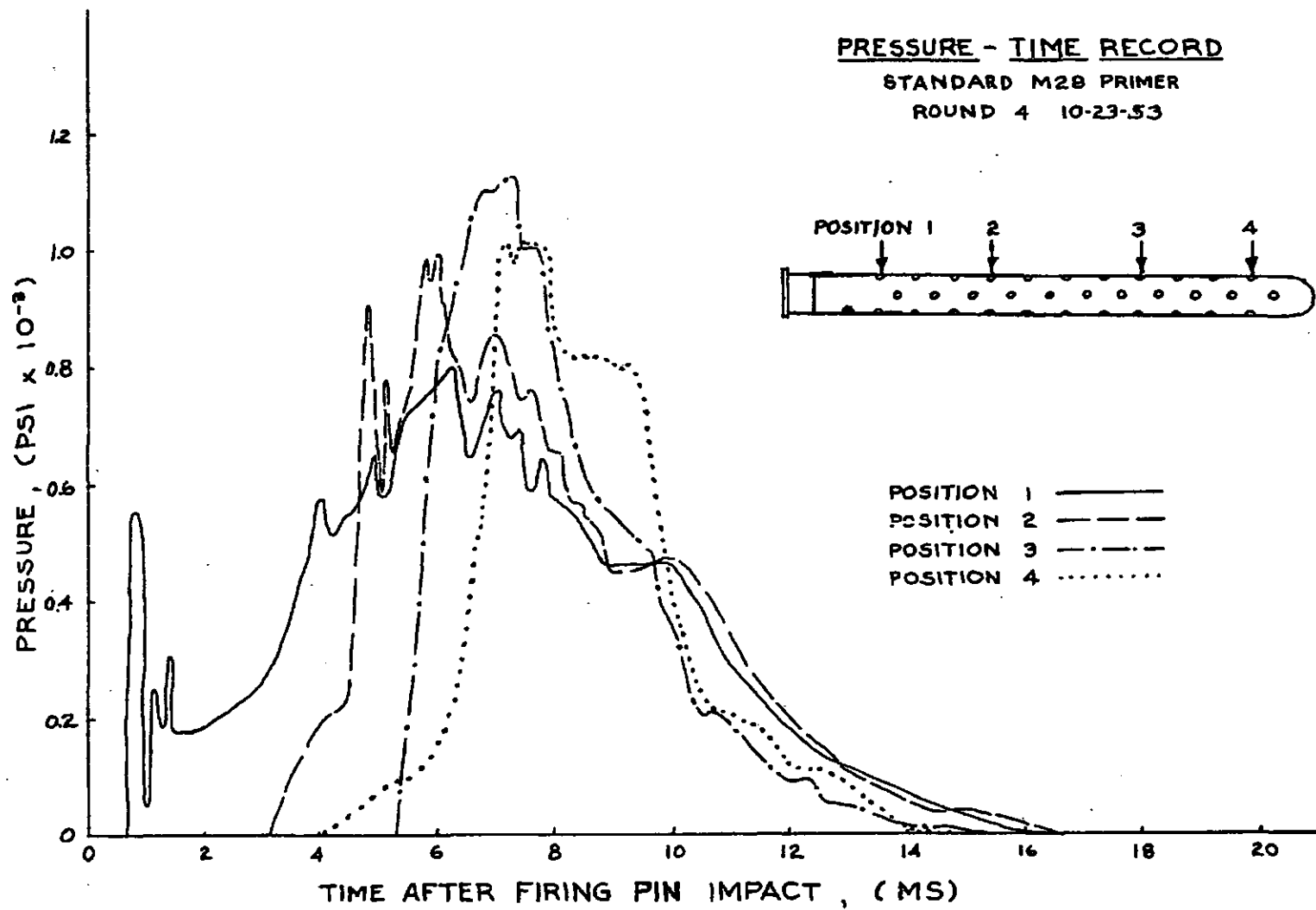


FIG. 6



MULTIPLE VENTING

PRESSURE-TIME RECORD

FOR MODIFIED M28 PRIMER (300 GRAINS FFFG BLACK POWDER)
ROUND 2 11-12-53

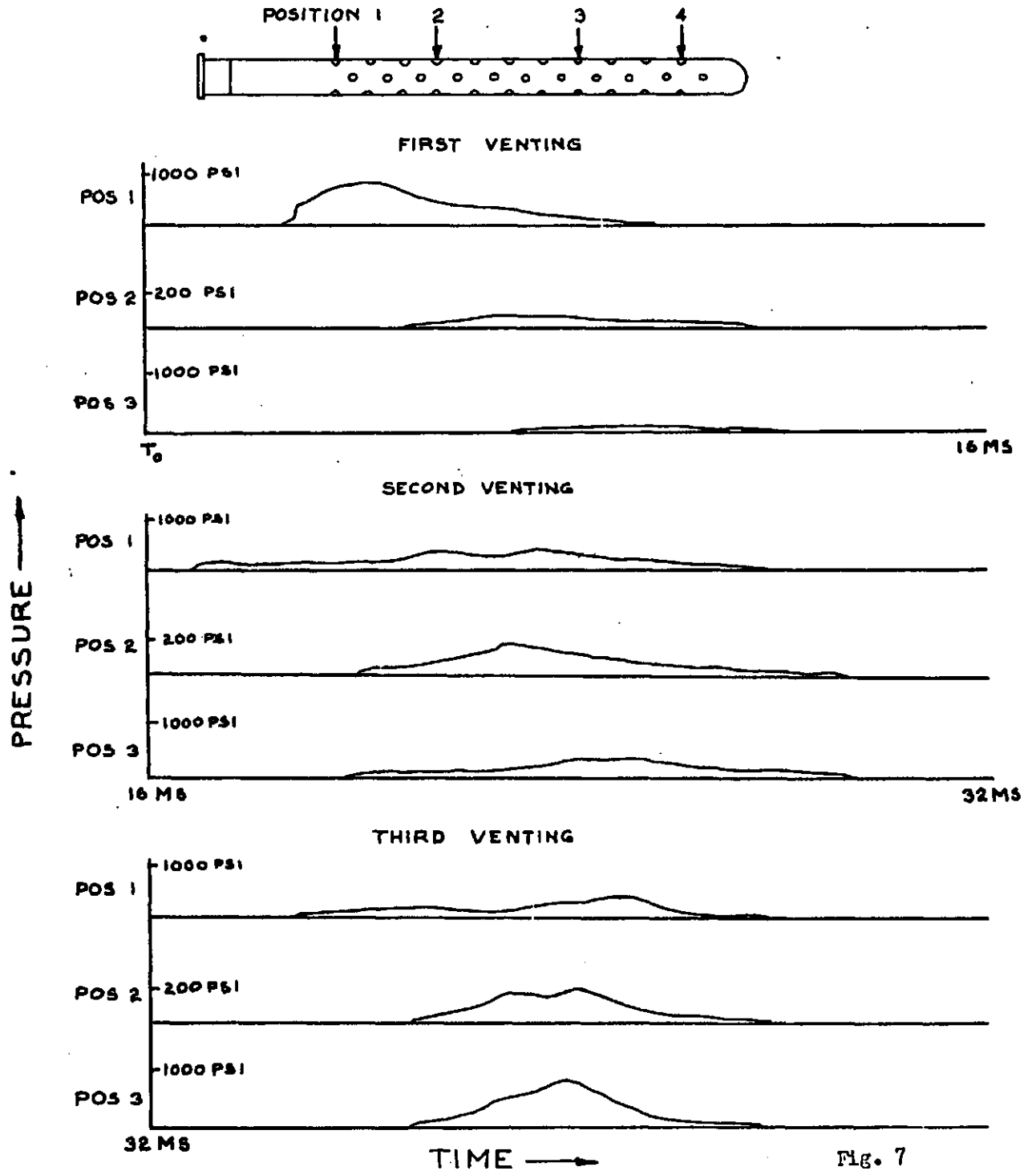
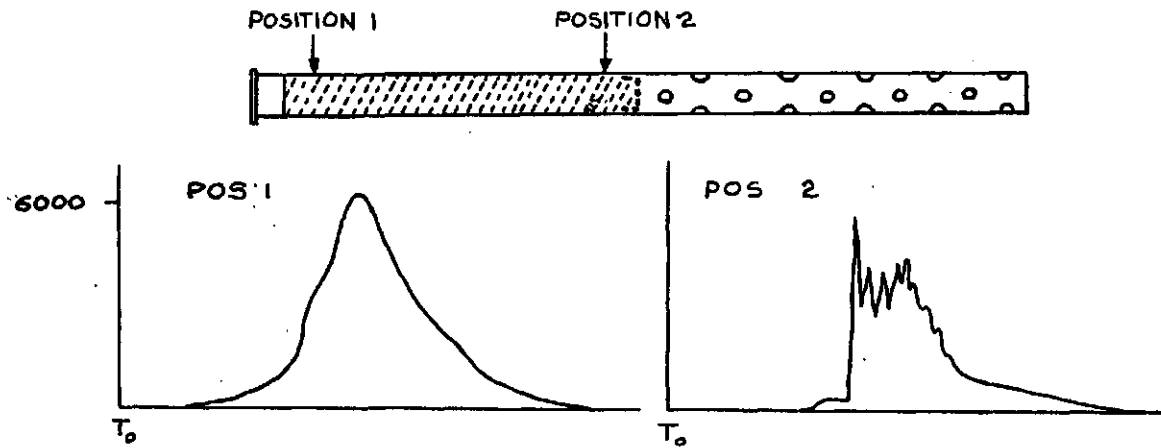


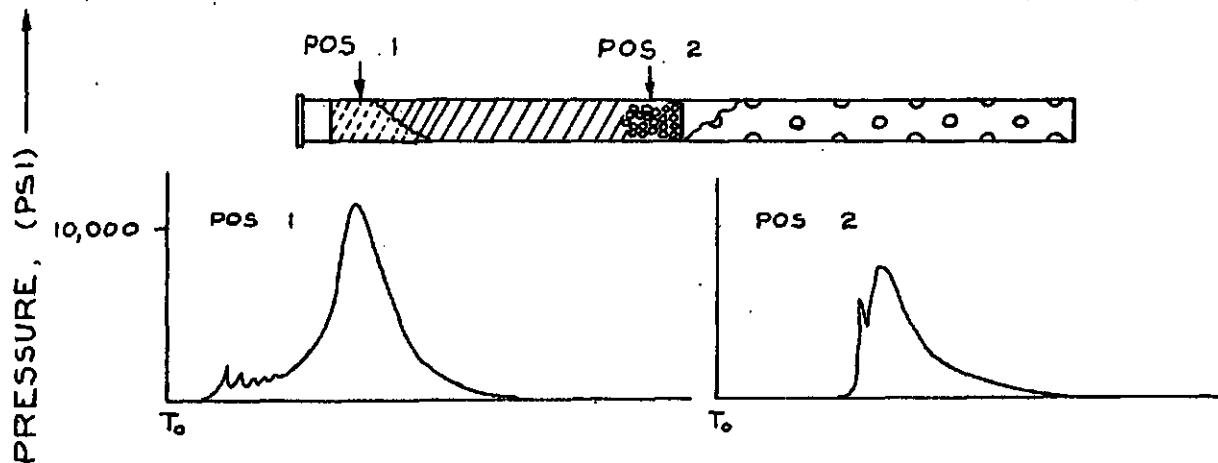
Fig. 7

PRESSURE-TIME RECORDS

FVE PRIMER



MODIFIED FVE PRIMER (COPPER PELLETS ADDED NEAR DIAPHRAGM)



MODIFIED FVE PRIMER (INNER TUBE ADDED)

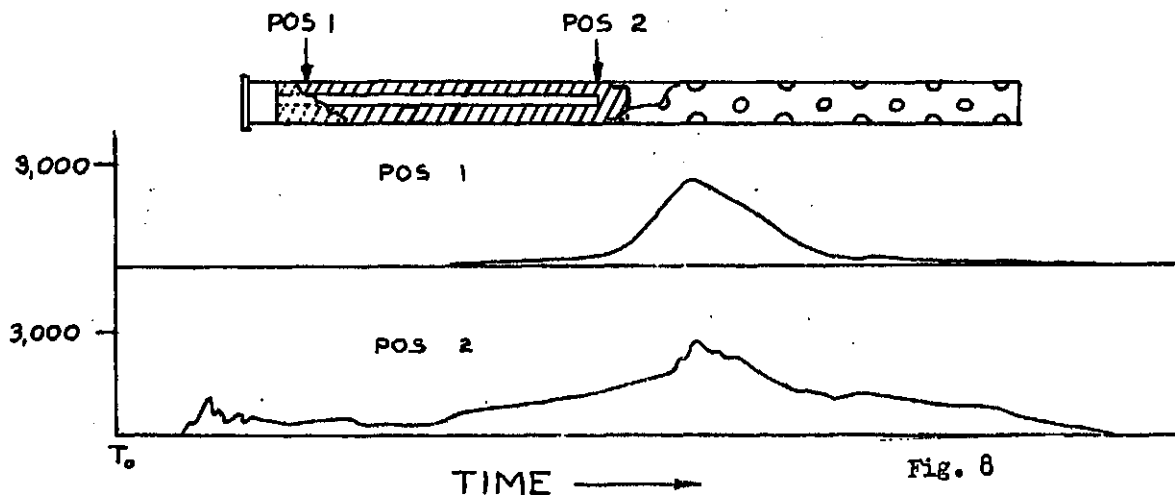


Fig. 8

GAS IMPULSE VERSUS POSITION

M28 PRIMERS

GRADE A-1 BLACK POWDER

DISTANCE



- STANDARD M28 (300 GRAIN CHARGE)
- ① STANDARD M28 (300 GRAIN CHARGE)
- ⊖ MODIFIED M28 (200 GRAIN CHARGE)
- ⊖ MODIFIED M28 (200 GRAIN CHARGE)

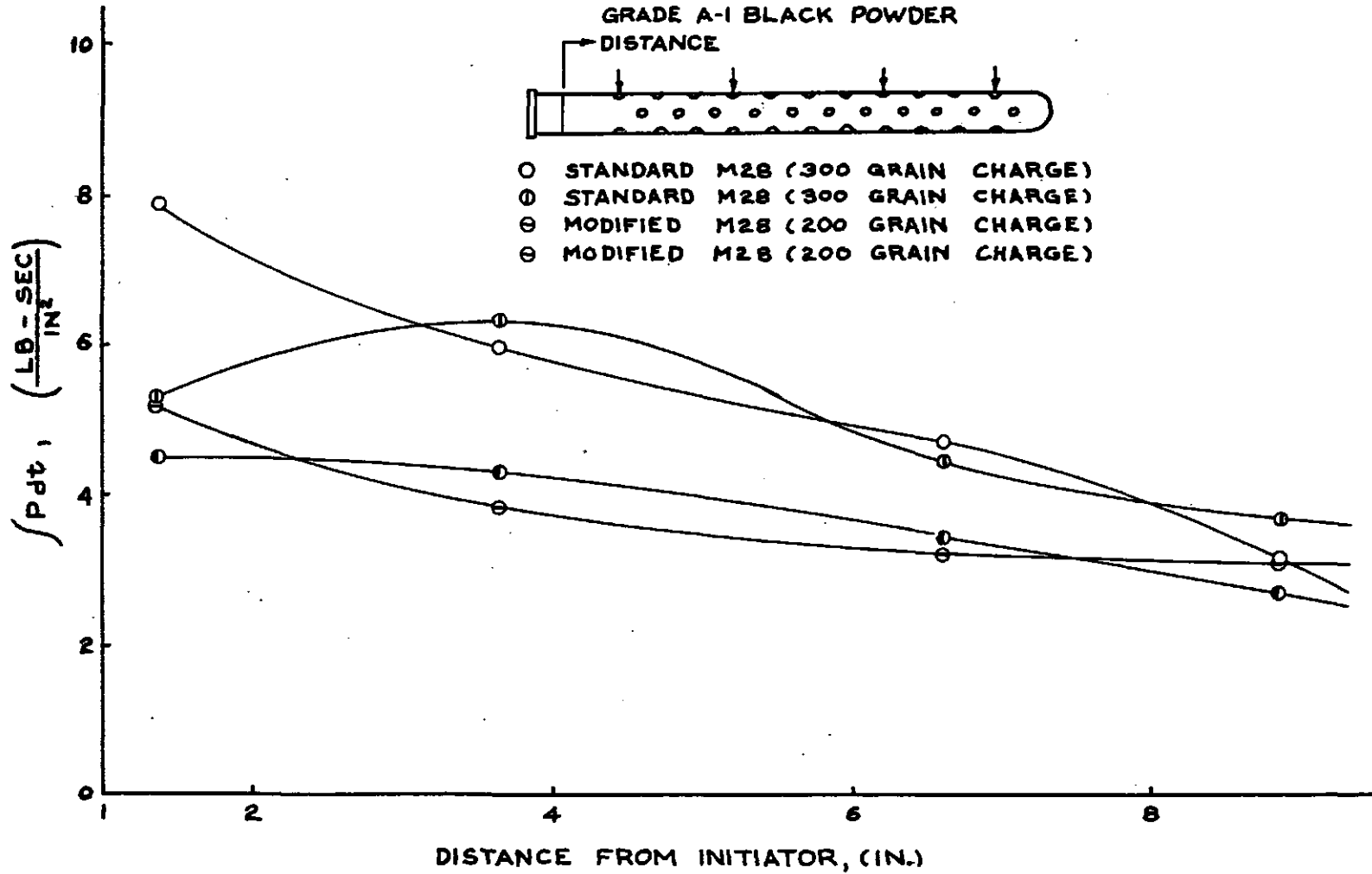
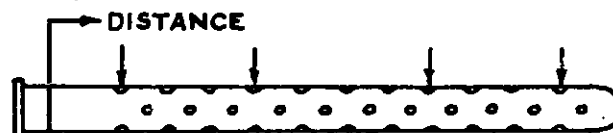


Fig. 9

GAS IMPULSE VERSUS POSITION

MODIFIED M28 PRIMERS
(300 GRAINS FFFG BLACK POWDER)



- FIRST VENTING
- ⊖ SECOND VENTING
- ⊗ THIRD VENTING
- SUMMATION OF THREE VENTINGS

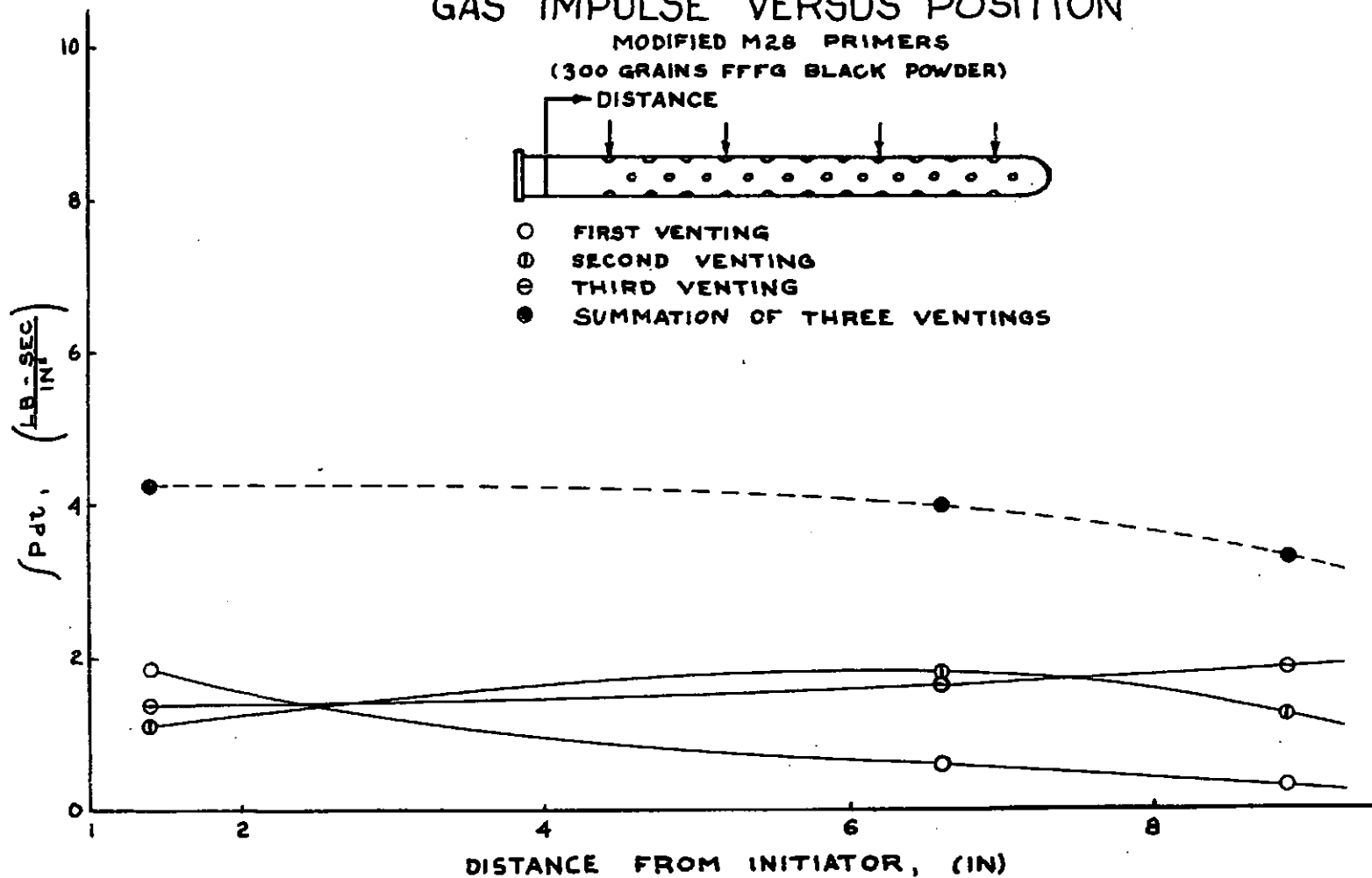


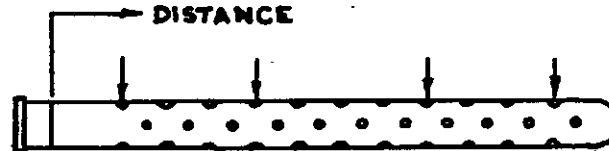
Fig. 10

GAS IMPULSE VERSUS POSITION

MODIFIED M28 PRIMERS

(FFFG BLACK POWDER)

DISTANCE



- 200-GRAIN CHARGE
- ① 150-GRAIN CHARGE (FIRST VENTING)
- ⊖ 150-GRAIN CHARGE (SECOND VENTING)
- 150-GRAIN CHARGE (SUMMATION OF TWO VENTINGS)
- ◊ 100-GRAIN CHARGE

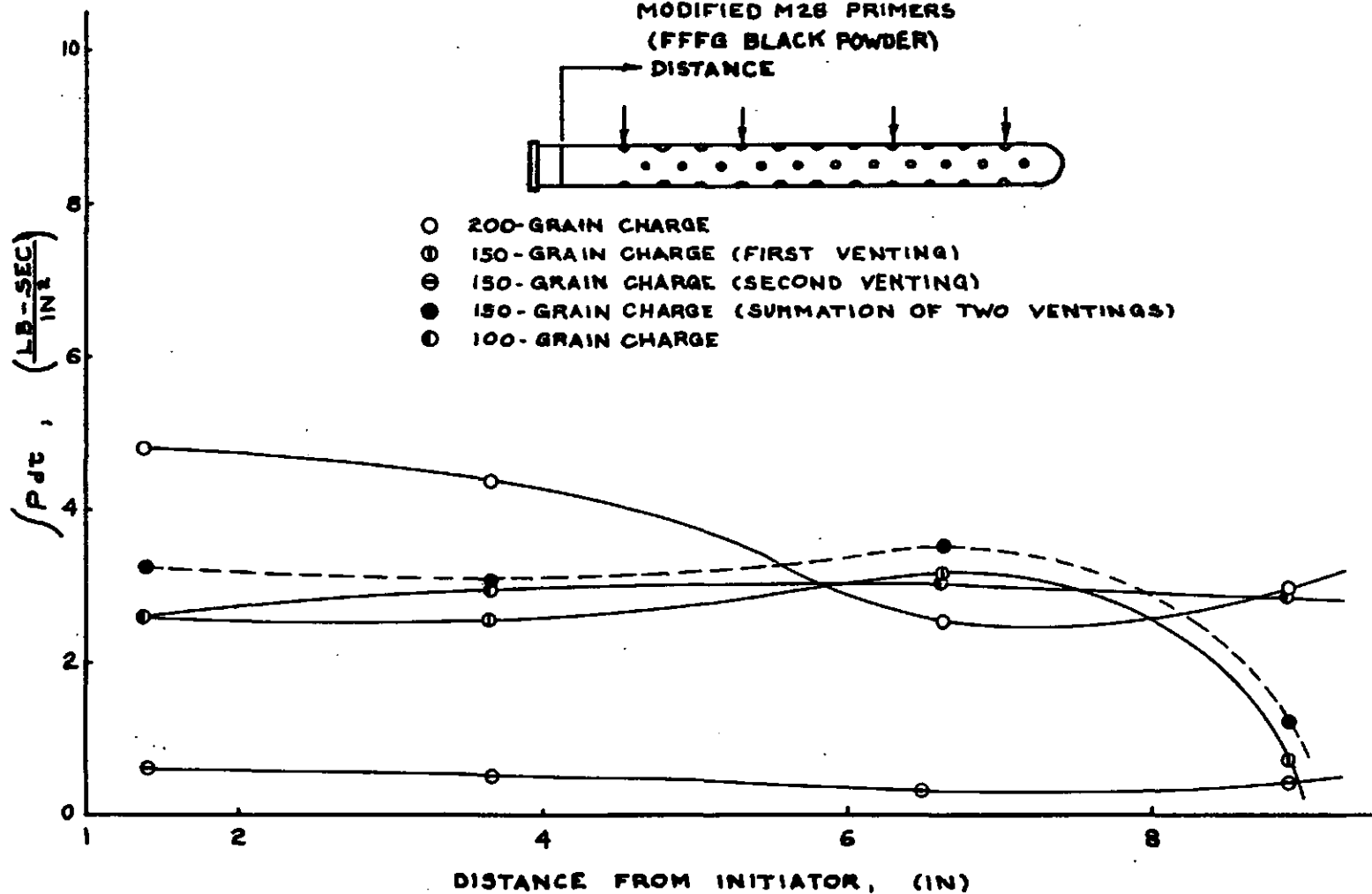


Fig. 11

GAS IMPULSE VERSUS POSITION

STANDARD M40 PRIMERS

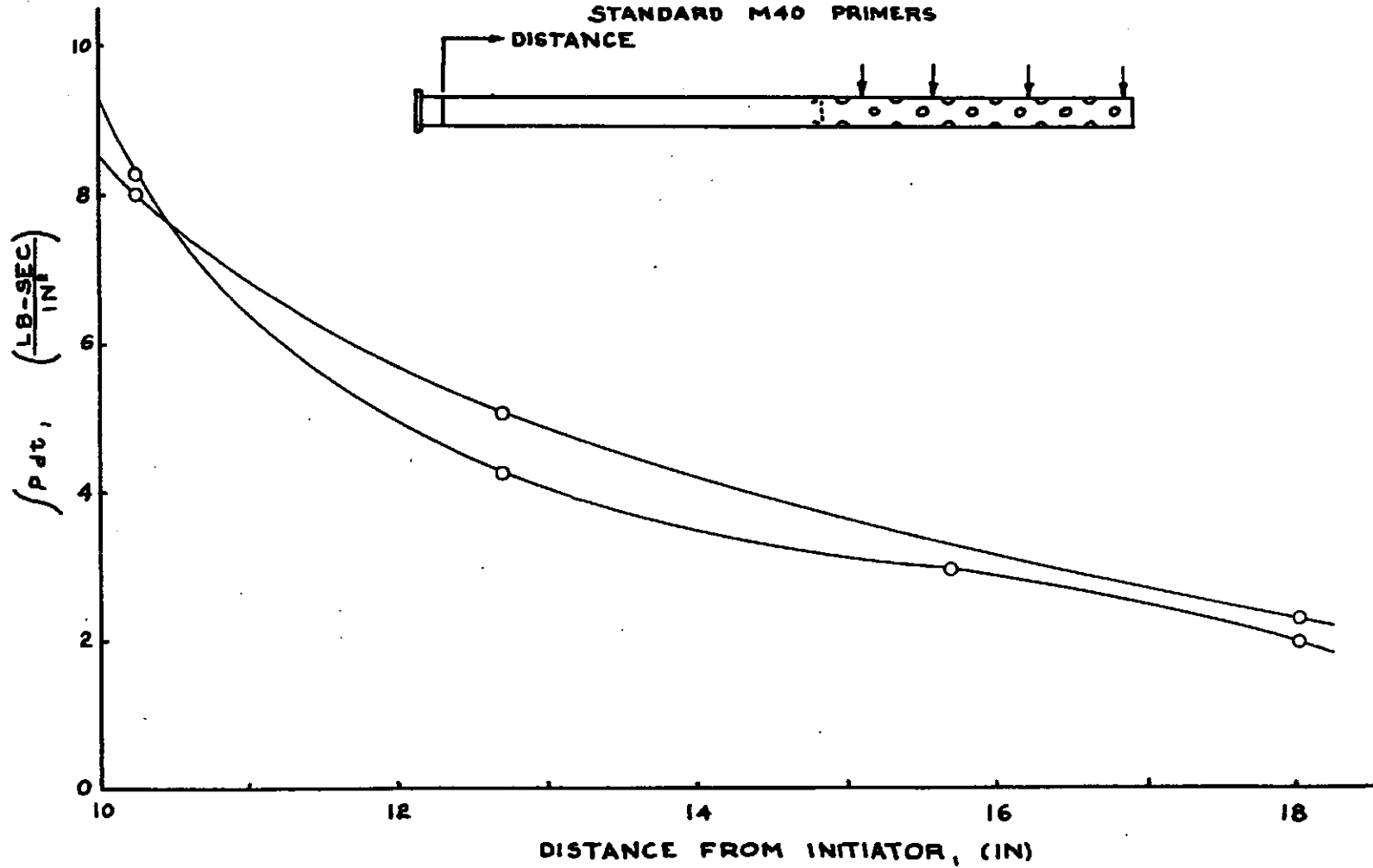


FIG. 12

GAS IMPULSE VERSUS POSITION M58 PRIMERS

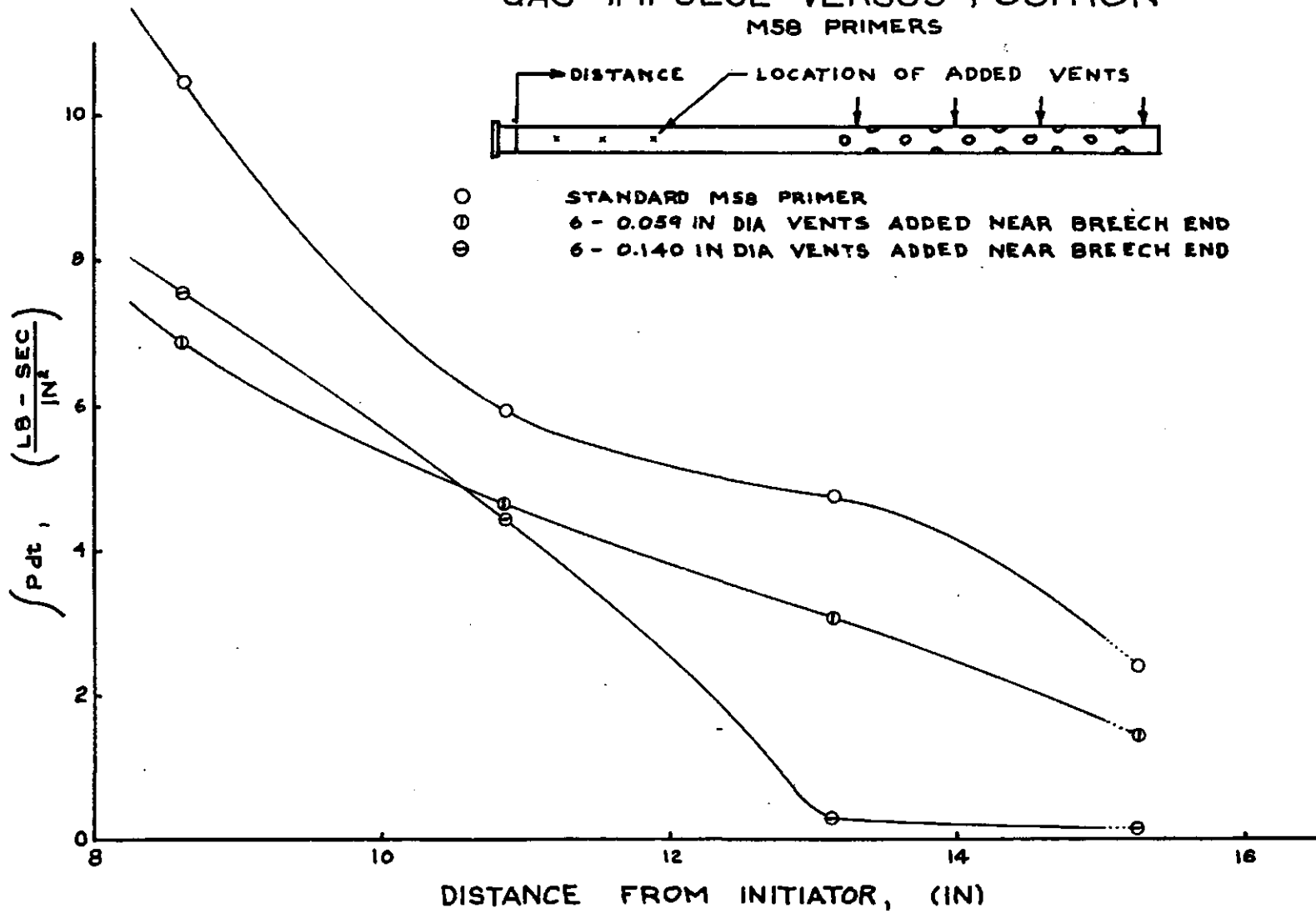


FIG. 13

GAS IMPULSE VERSUS POSITION MODIFIED MSB PRIMERS (REDUCED CHARGES OF GRADE A-1 BLACK POWDER)

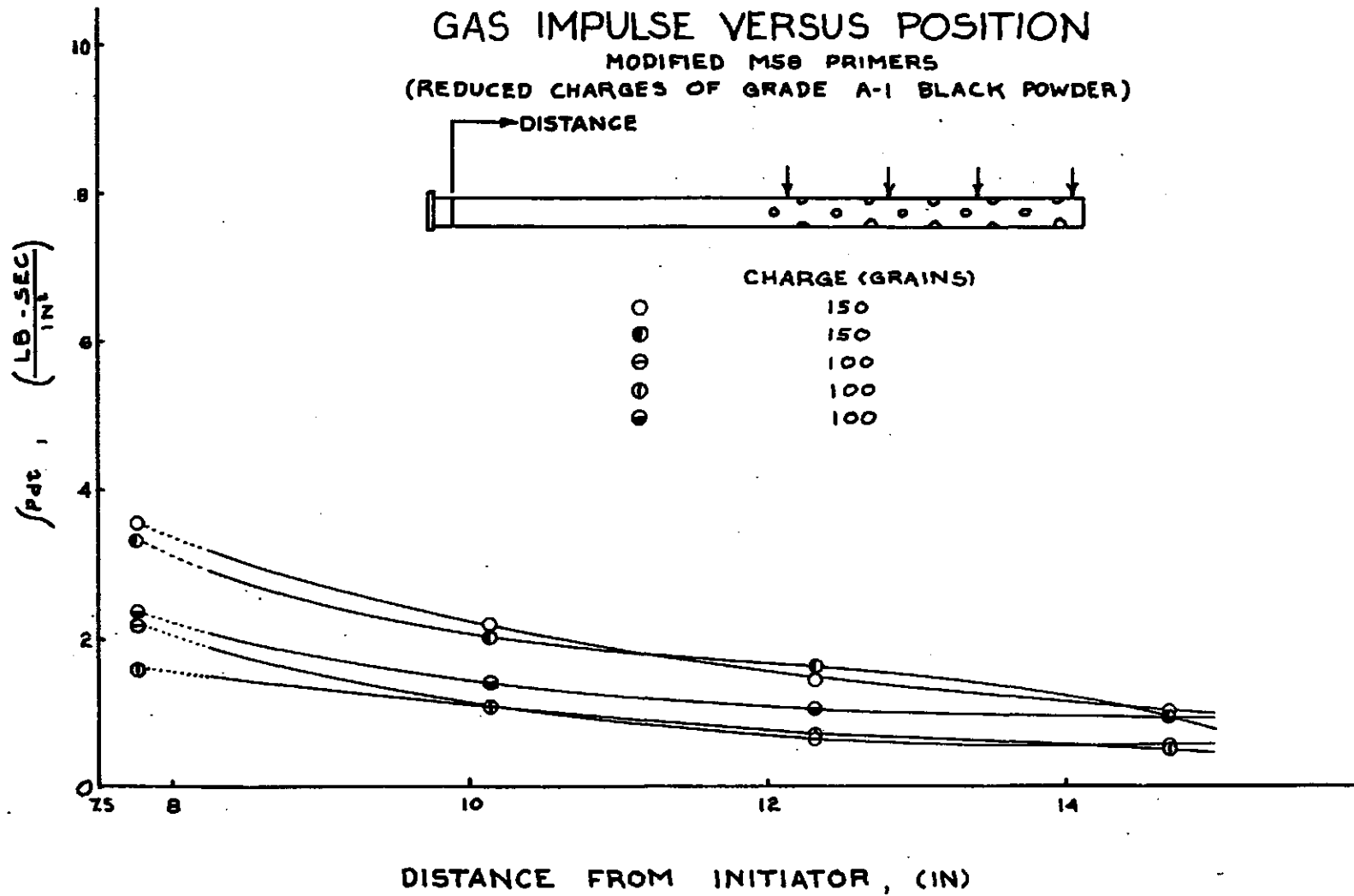


Fig. 11

GAS IMPULSE VERSUS POSITION

FIVE OPEN END PRIMERS
225 GRAINS GRADE A-1 BLACK POWDER

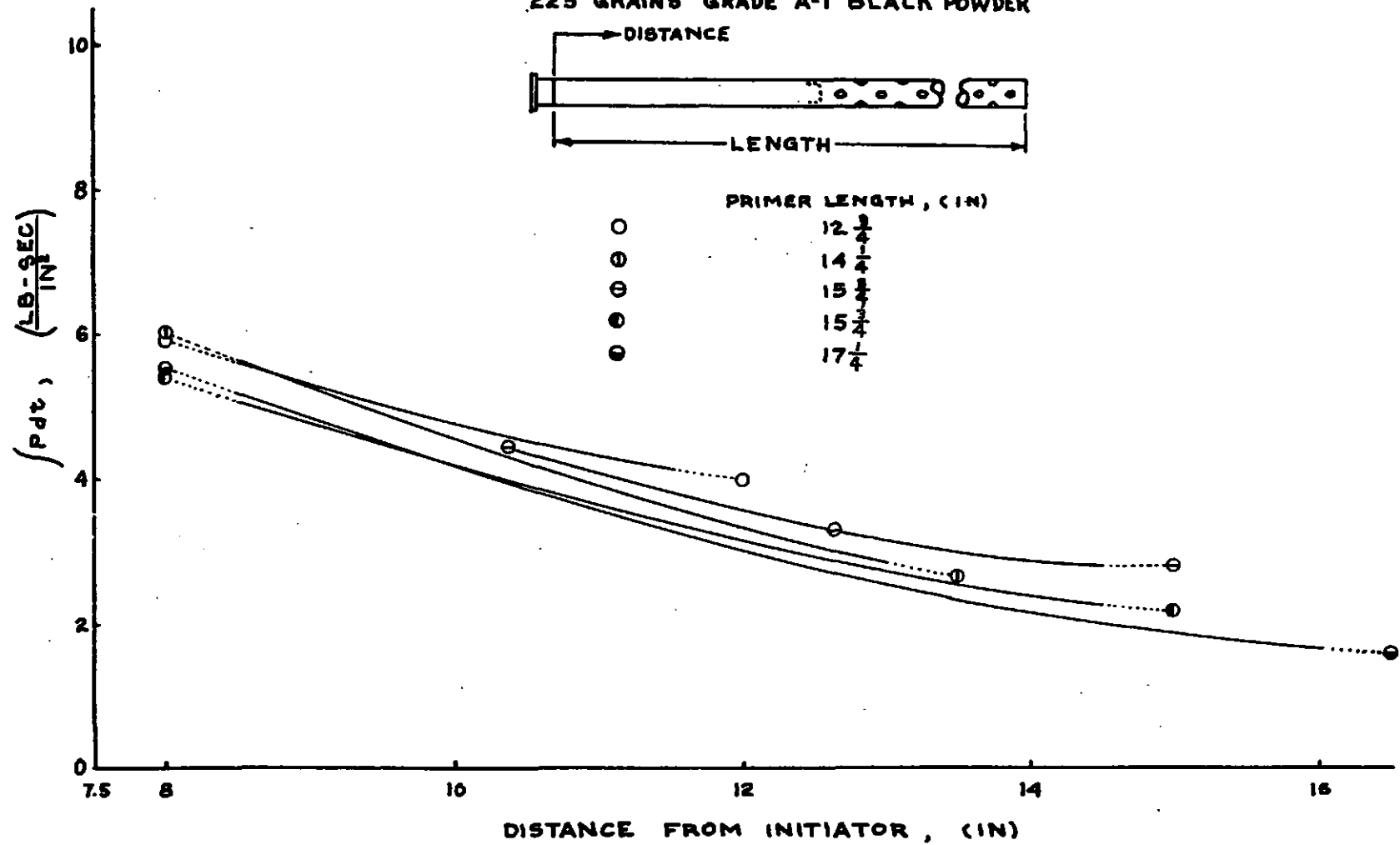


FIG. 15

GAS IMPULSE VERSUS POSITION

FIVE CLOSED END PRIMERS
2.25 GRAINS GRADE A-1 BLACK POWDER

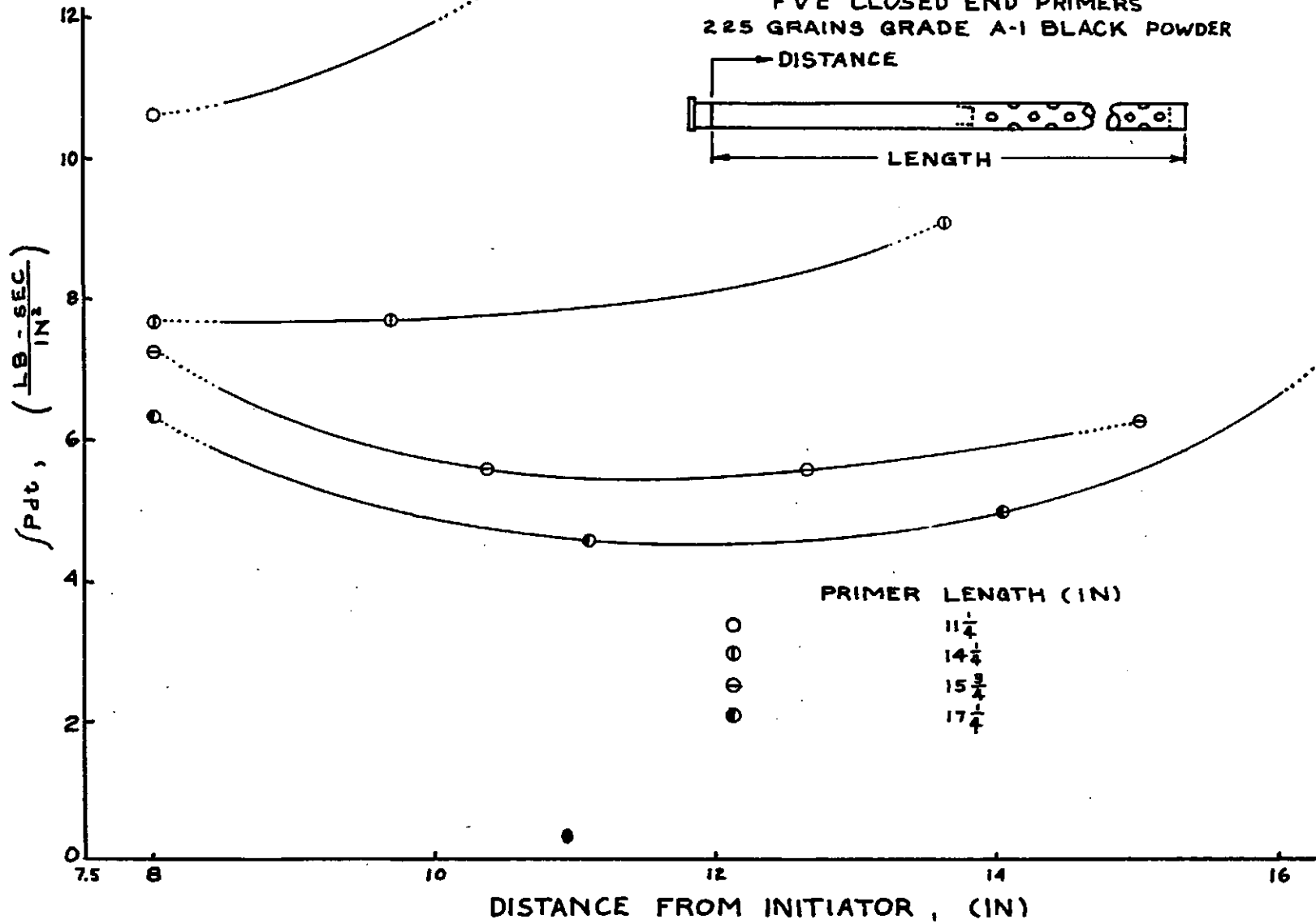
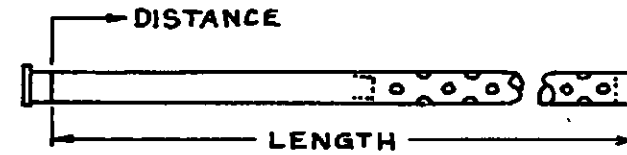
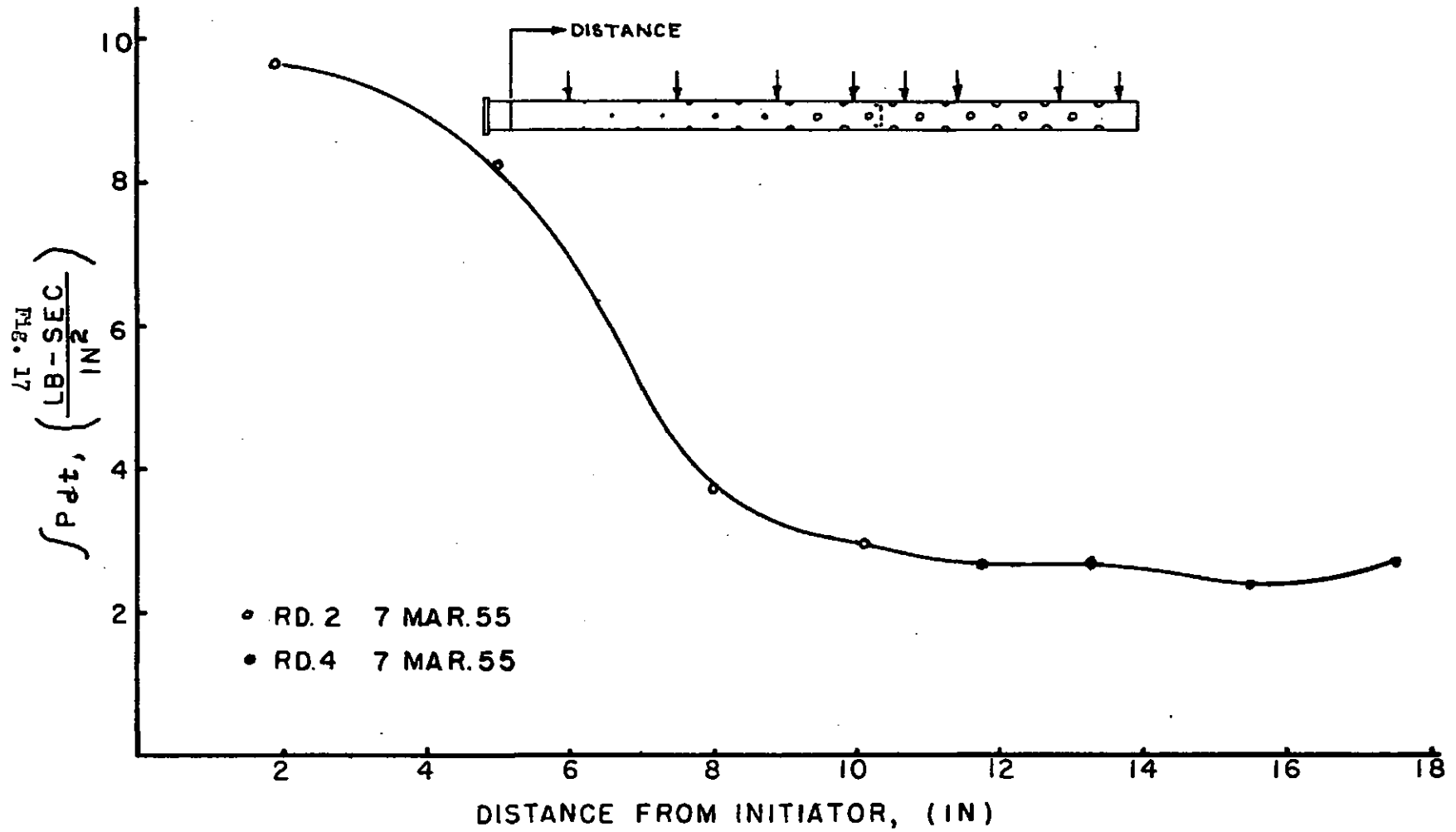


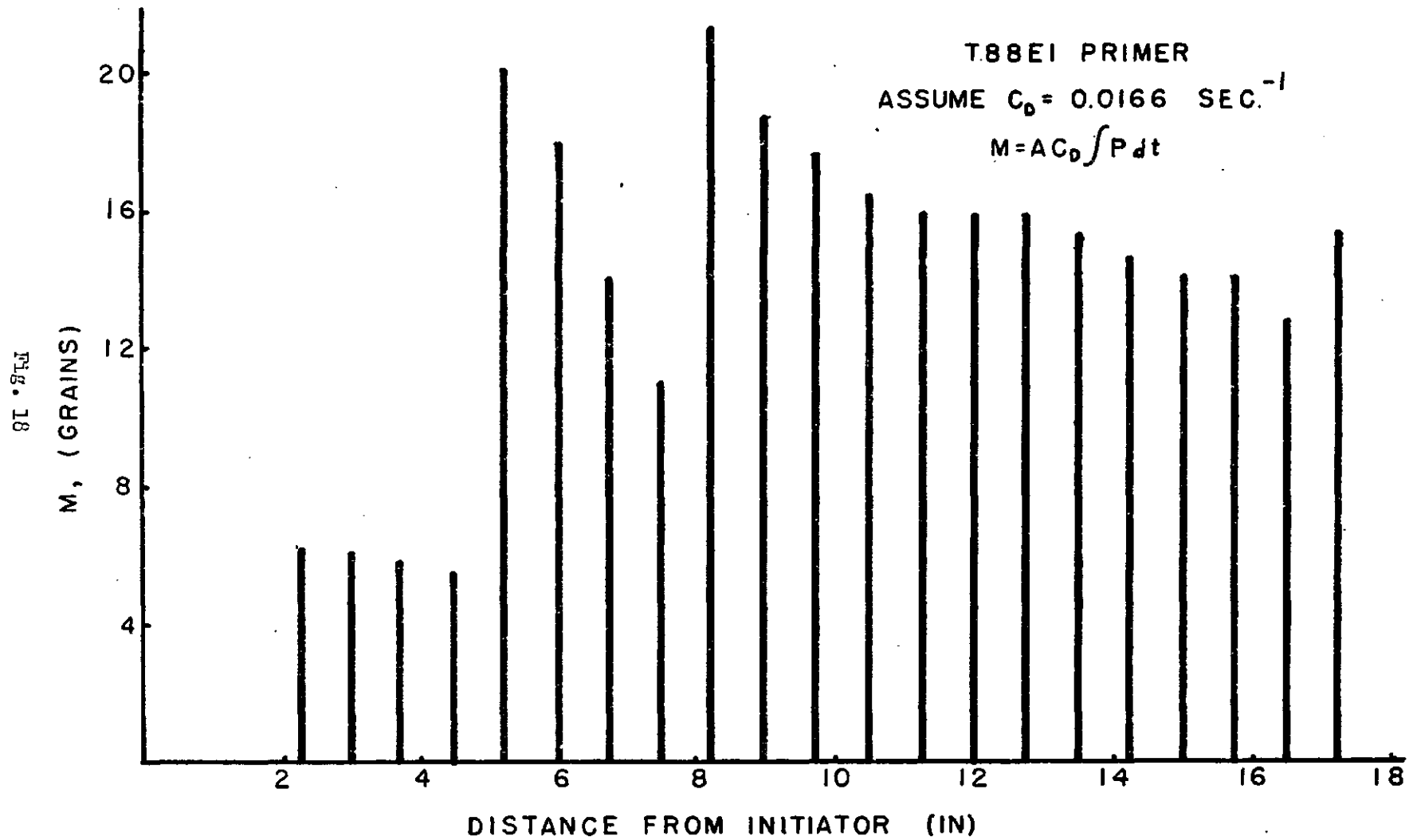
FIG. 16

GAS IMPULSE vs. POSITION

T88E1 PRIMER



MASS DISCHARGE OF GASES



GAS IMPULSE VERSUS POSITION

M28 DOUBLE TUBE PRIMERS
GRADE A-1 BLACK POWDER

DISTANCE



- 300 - GRAIN CHARGE
- ① 200 - GRAIN CHARGE

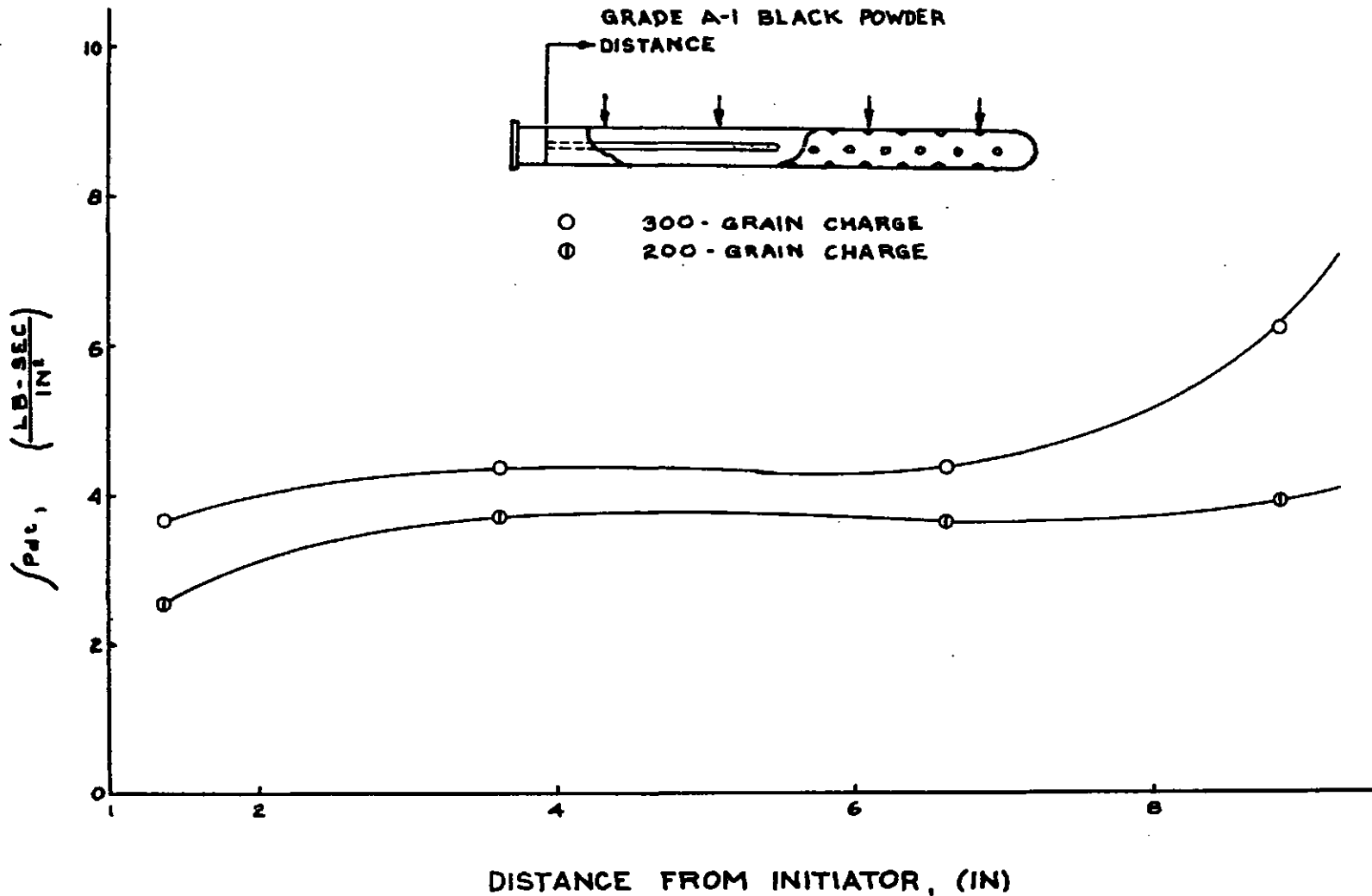


FIG. 19

GAS IMPULSE VERSUS POSITION

M28 DOUBLE-TUBE PRIMER
300 GRAINS FFFG BLACK POWDER

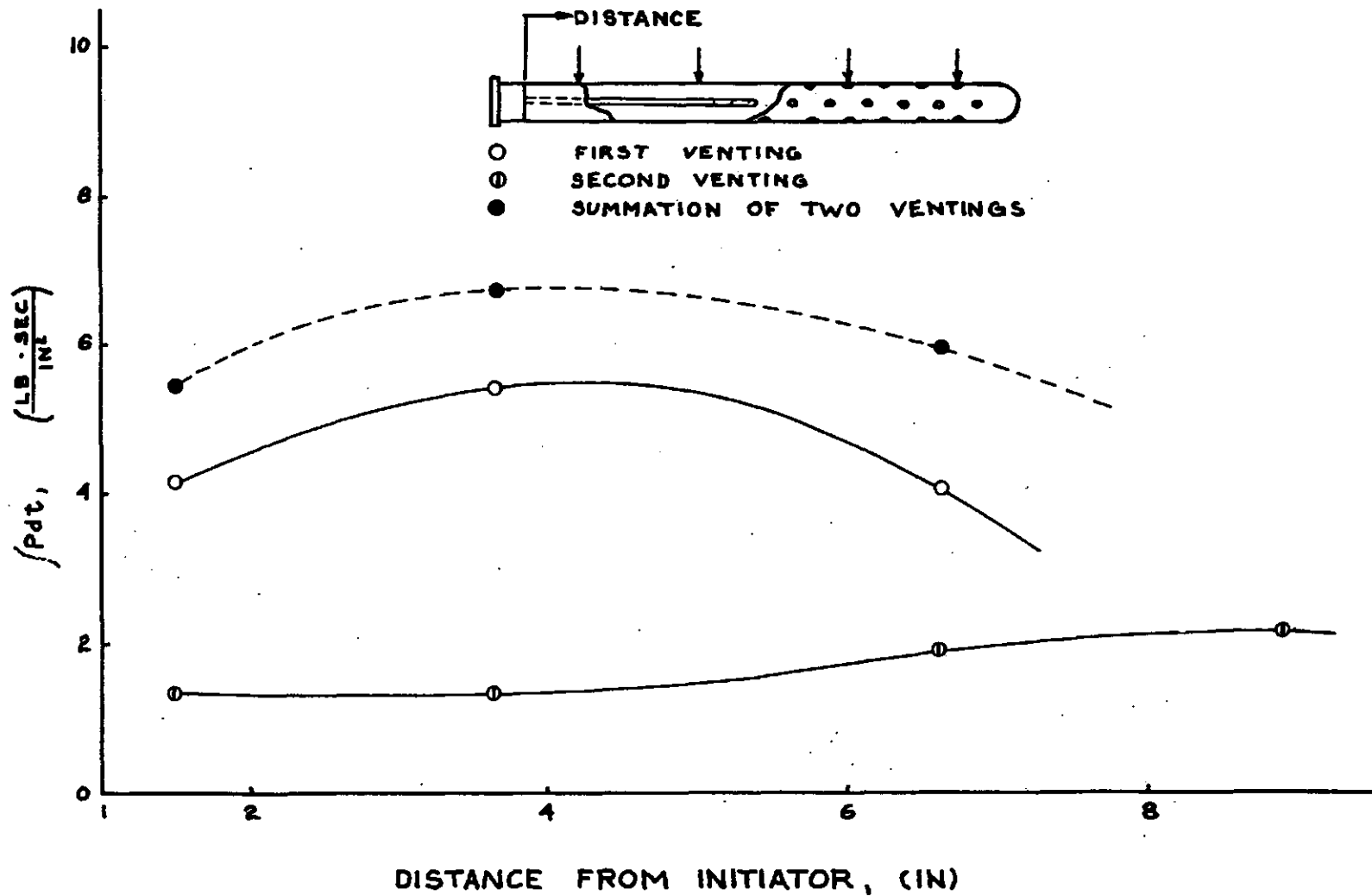


Fig. 20

GAS IMPULSE VERSUS POSITION

M28 DOUBLE-TUBE PRIMERS

FFFG BLACK POWDER



- 200-GRAIN CHARGE (FIRST VENTING)
- ◐ 200-GRAIN CHARGE (SECOND VENTING)
- 200-GRAIN CHARGE (SUMMATION OF TWO VENTINGS)
- ⊖ 150-GRAIN CHARGE
- ◑ 100-GRAIN CHARGE

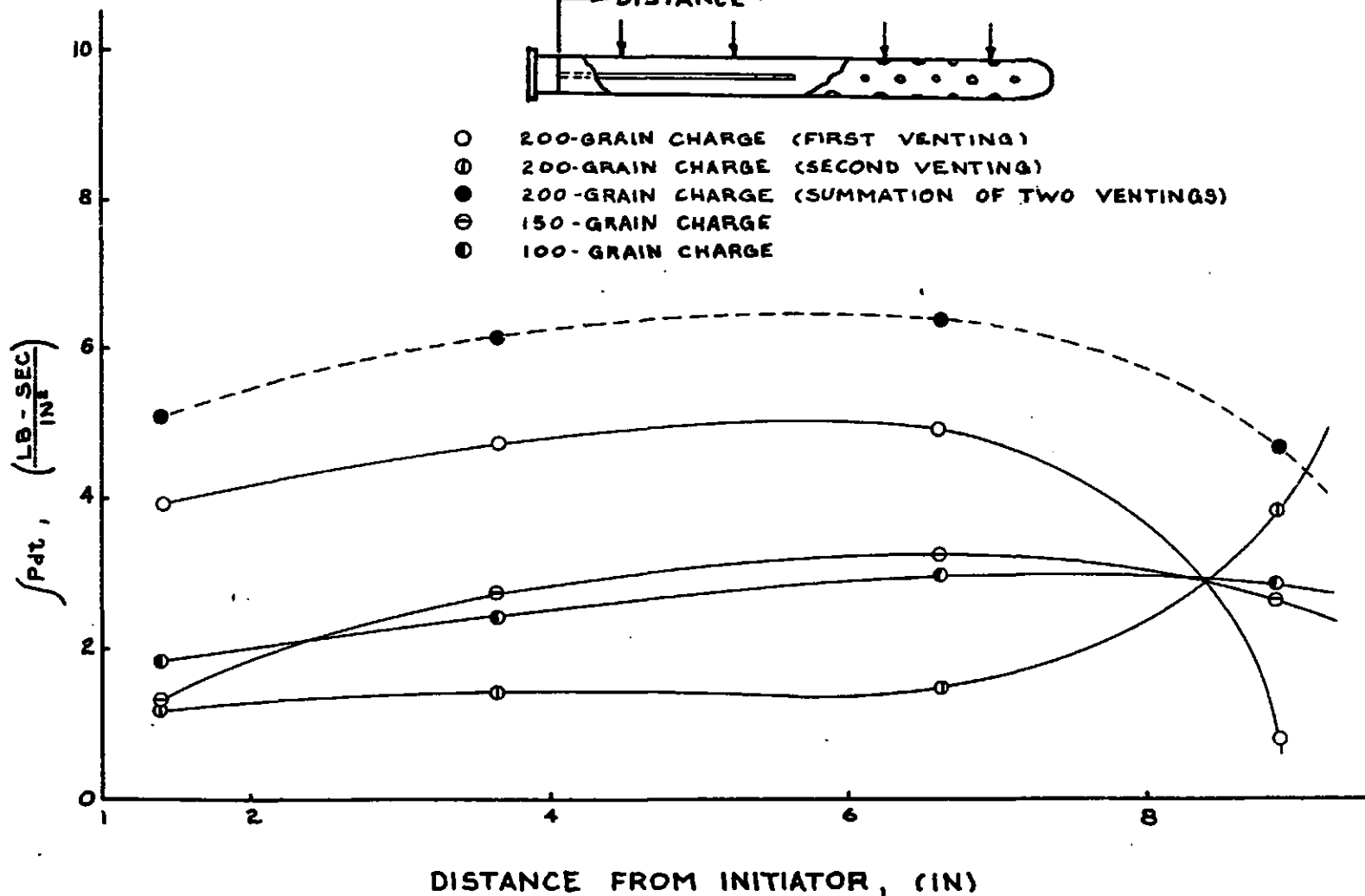


FIG. 21

45

[REDACTED]

TABLE I - BLACK POWDER GRANULATIONS *

Grade A-1

- a) A maximum of 3.0 percent may be retained on a screen having openings of 0.185 inch square (sieve size No. 4).
- b) A maximum of 5.0 percent may pass through a screen having openings of 0.093 inch square (sieve size No. 8).

Grade A-3a

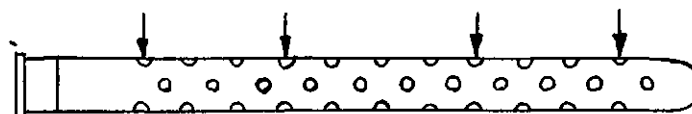
- a) A maximum of 3.0 percent may be retained on a screen leaving openings of 0.065 inch square (sieve size No. 12).
- b) A maximum of 5.0 percent may pass through a screen having openings of 0.033 inch square (sieve size No. 20).

FFFG

- a) A maximum of 3.0 percent may be retained on a screen having openings of 0.033 inch square (sieve size No. 20).
- b) A maximum of 5.0 percent may pass through a screen leaving openings of 0.012 inch square (sieve size No. 50).

*Data taken from "JAN-P-223A, 12 Jan 1949, National Military Establishment Specification: Powder, Black".

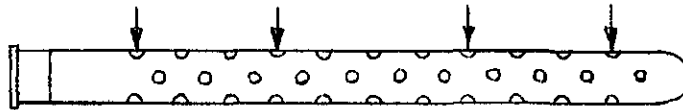
TABLE II- STANDARD M28 PRIMERS*



DATE	ROUND NUMBER	GAUGE POSITION	MAXIMUM PRESSURE (psi)	T ₁ (ms)	T ₂ (ms)	T ₃ ¹ (ms)
10-19-53	1	1	860	0.9	5.2	8.7
		2	1050	1.3	5.0	6.9
		3	1300	1.5	5.4	4.0
		4	1380	4.8	6.6	2.5
10-19-53	2	1	1595	2.0	3.4	5.2
		2	1260	0.9	2.9	6.6
		3	1315	4.2	5.3	3.0
		4	2640	3.4	5.1	4.0
10-23-53	1	1	980	0.8	8.2	15.0
		2	960	1.2	8.2	8.4
		3	1130	7.4	10.4	5.9
		4	1130	9.7	10.6	4.7
"	2	1	1190	1.6	5.9	7.6
		2	1250	0.9	5.9	7.2
		3	1300	2.6	6.6	5.3
		4	1740	4.8	7.3	4.3
"	3	1	1140	1.5	7.7	10.9
		2	1290	4.1	7.7	6.8
		3	1600	3.0	7.7	5.8
		4	1190	5.5	8.0	4.6
"	4	1	770	0.7	5.6	11.3
		2	970	3.2	6.3	7.9
		3	1120	5.2	7.4	5.4
		4	1050	4.9	7.0	5.1

* Note: 8 of 16 vent holes were covered by gauge housings.

TABLE III - MODIFIED M-28 PRIMERS*
(Reduced Charges of Grade A-1 Black Powder)

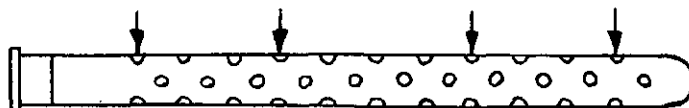


DATE	ROUND NUMBER	CHARGE (GRAINS)	GAUGE POSITION	MAXIMUM PRESSURE (psi)	T ₁ (ms)	T ₂ (ms)	T ₃ ¹ (ms)	T ₃ (ms)
10-21-53	1	200	1	1490	0.8	6.8	13.4	
			2	720	0.9	6.7	9.0	
			3	800	5.1	7.7	6.6	
			4	940	5.9	7.1	5.7	
"	2	200	1	520	1.1	6.8	10.2	
			2	700	3.4	7.7	8.3	
			3	980	1.4	7.6	5.2	
			4	1000	6.2	7.8	4.6	
"	3	200	1	900	32.5	43.1	9.7	
			2	470	33.0	41.4	6.4	
			3	1520	29.0	42.2	15.3	
			4	290	31.4	41.4	2.5	
8-27-54	3	150	1	1960	0.7	4.0	9.5	
			2	1750	2.6	3.5	2.3	
			3	1720	0.8	3.9	4.6	
			4	2580	3.2	3.8	2.7	
11-3-53	1	100	1	100	5.4	9.4		19.4
			2	No Record				
			3	150	6.3	10.9		35.3
			4	160	4.2	14.4		36.0
8-18-54	1	100	1	235	0.9	14.3		22
			2	480	1.0	14.1		23
			3	800	11.0	14.5		32.7
			4	900	12.8	15.0		23.1
"	2	100	1	315	0.9	1.1		29
			2	250	1.4	1.6		33
			3	250	1.3	3.2		37
			4	200	1.5	4.1		33.8

*Note: 8 of 44 vent holes were covered by gauge housings.

TABLE IV - MODIFIED M28 PRIMERS*

(FFFG Black Powder)



DATE	ROUND NUMBER	CHARGE (GRAINS)	GAUGE POSITION	MAXIMUM PRESSURE (psi)	T ₁ (ms)	T ₂ (ms)	T ₃ ¹ (ms)	T ₃ (ms)
11-12-53	2	300	1	800**	2.7	4.5	4.3	10.3
				450	16.6	24.0	5.0	11.5
				430	35.8	42.0	2.6	9.0
			2	No Record				
			3	50	5.0	7.9	-	7.5
				200	20.0	23.2	-	9.2
				225	37.3	40.4	-	8.0
			4	60	7.0	9.0	-	7.0
				325	20.7	25.4	4.1	9.5
				810	37.3	40.3	4.2	7.0
11-6-53	2	200	1	7400	1.3	1.7	1.9	3.0
			2	6300	1.2	1.5	2.7	4.1
			3	4250	1.5	1.7	1.8	4.0
			4	4000	1.4	1.8	1.7	3.6
"	1	200	1	2000**	4.1	5.2	2.7	6.0
				100	21.0	26.0	-	9.0
			2	1800	3.9	5.2	2.6	4.1
			3	No Record				
11-4-53	4	150	1	No Record				
			2	1400**	4.8	7.5	3.4	8.5
				75	19.4	22.2	-	9.0
				1300	5.8	7.3	3.5	4.8
			3	150	19.6	22.6	-	6.5
				1800	3.0	6.8	3.7	8.5
				150	19.2	21.9	-	6.2
			4	380	7.1	8.3	1.9	6.0
				140	19.5	22.5	-	7.0
11-3-53	3	100	1	1800	1.1	6.2	3.0	11.5
			2	1700	1.2	6.2	3.9	11.5
			3	--	0.8	5.4	-	10.5
			4	2350	1.5	5.1	2.4	10.4

TABLE IV (Cont'd)

DATE	ROUND NUMBER	CHARGE (GRAINS)	GAUGE POSITION	MAXIMUM PRESSURE (psi)	T ₁ (ms)	T ₂ (ms)	T ₃ ¹ (ms)	T ₃ (ms)
11-4-53	1	100	1	5400	1.0	1.5	1.8	4.6
			2	3100	1.2	1.7	1.6	2.3
			3	2700	1.2	1.7	1.5	4.5
			4	3200	1.7	2.1	1.5	4.5

*Note: 8 of 44 vent holes were covered by gauge housings.

**Multiple Venting

TABLE V - MODIFIED M58 PRIMERS

(Reduced Charge of Grade A-1 Black Powder)



DATE	ROUND NUMBER	CHARGE GRAINS	GAUGE POSITION	MAXIMUM PRESSURE (psi)	T ₁ (ms)	T ₂ (ms)	T ₃ (ms)
6-15-54	2	100	1	1350	2.7	7.5	5.8
			1a	1270	2.8	5.3	5.2
			1b	1540	2.5	6.2	4.2
			2	1060	2.7	6.0	3.7
6-24-54	3	100	1	1970	1.3	1.4	4.2
			1a	1905	1.7	1.8	4.0
			1b	1680	1.9	2.0	3.5
			2	1550	2.2	2.5	2.8
6-15-54	3	100	3	1100	2.3	2.5	3.1
			3a	950	2.3	2.4	2.7
			3b	870	2.6	2.9	2.2
			4	450	2.6	2.8	1.4
6-24-54	4	100	3	1620	2.5	2.5	2.7
			3a	1290	2.8	2.8	1.9
			3b	900	2.4	2.7	1.7
			4	600	3.2	3.2	1.1
6-15-54	4	150	1	4750	1.0	2.8	5.4
			1a	4880	1.3	2.8	5.0
			1b	4870	2.1	2.8	6.5
			2	4150	2.3	3.3	4.6
6-25-54	6	150	1	4550	1.1	2.5	6.4
			1a	4060	1.6	2.3	6.0
			1b	4940	2.1	2.1	5.0
			2	4400	2.2	2.3	4.5
6-15-54	5	150	3	3550	2.7	2.9	6.6
			3a	2900	3.0	2.8	2.6
			3b	2930	3.1	3.4	3.3
			4	1130	3.3	3.3	2.8
6-24-54	6	150	3	3550	2.7	2.7	5.0
			3a	3280	2.6	2.6	8.0
			3b	1550	2.9	3.2	4.0
			4	No Record			

TABLE VI - OPEN END FVE TYPE PRIMERS

225 Grains Grade A-1 Black powder



DATE	ROUND NUMBER	LENGTH (in)	GAUGE POSITION	MAXIMUM PRESSURE (psi)	T ₁ (ms)	T ₂ (ms)	T ₃ (ms)
12-11-53	1	11 1/4	1	4300	1.8	3.8	4.8
			2	3550	2.7	3.8	5.2
			3	2500	2.9	3.6	5.2
			4	No Record			
"	2	11 1/4	1	5280	1.9	4.1	5.9
			2	3950	2.7	4.2	6.5
			3	3100	3.2	4.1	5.3
			4	2100	3.6	4.2	3.8
"	3	12 3/4	1	8000	1.6	4.1	6.5
			2	5520	2.3	4.0	6.0
			3	3900	3.4	3.8	4.6
			4	2700	3.6	4.3	4.3
12-14-53	1	12 3/4	1	5500	-	-	-
			2	4150	2.6	3.1	4.7
			3	3100	2.9	3.4	4.6
			4	No Record			
"	2	14 1/4	1	6300	1.3	3.9	5.9
			2	4300	3.0	4.7	5.8
			3	3200	3.3	4.0	4.3
			4	1650	3.6	4.1	4.0
"	3	14 1/4	1	5500	1.0	3.2	5.2
			2	4450	2.3	2.6	4.6
			3	3900	2.5	2.9	4.2
			4	2600	2.9	2.9	3.6
"	4	15 3/4	1	6930	1.1	3.4	5.8
			2	4640	1.8	3.3	5.3
			3	3460	2.7	3.4	4.5
			4	1450	3.2	3.8	3.5

TABLE VI (Cont'd)

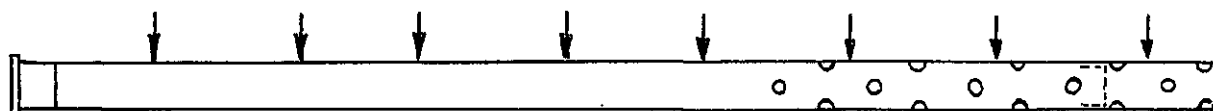
DATE	ROUND NUMBER	LENGTH (in)	GAUGE POSITION	MAXIMUM PRESSURE (psi)	T ₁ (ms)	T ₂ (ms)	T ₃ (ms)
12-14-53	5	15 3/4	1	6310	1.1	3.6	6.1
			2	4380	2.3	3.6	5.8
			3	3750	3.0	3.6	5.3
			4	2250	3.5	3.6	2.8
"	6	17 1/4	1	5600	1.1	3.3	5.5
			2	4290	2.5	2.9	5.0
			3	2840	2.5	3.0	5.3
			4	1090	3.0	3.7	4.0
"	7	17 1/4	1	5960	1.0	3.2	6.5
			2	6680	2.6	2.9	5.1
			3	4100	2.8	3.3	5.0
			4	2000	3.3	3.4	4.0
5-5-54	3	15 3/4	1	7230	1.2	3.8	6.5
			1a	7650	2.1	3.7	5.4
			1b	6550	2.7	3.4	6.0
			2	No Record			
5-6-54	2	15 3/4	3	-	3.0	-	-
			3a	3870	3.3	3.3	3.5
			3b	3100	3.5	3.5	4.0
			4	2400	3.7	4.0	4.0

TABLE VII - STANDARD M40 PRIMERS



DATE	ROUND NUMBER	GAUGE POSITION	MAXIMUM PRESSURE (psi)	T ₁ (ms)	T ₂	T ₃	T ₃ '
5-20-54	2	1	15600	1.0	3.4	5.7	4.9
		1a	14600	2.0	3.5	3.5	4.1
		1b	13750	2.4	3.3	6.0	3.8
		2	No Record				
"	3	1	16550	1.3	3.9	6.5	5.4
		1a	16200	2.5	3.7	5.0	4.1
		1b	13730	2.9	3.5	5.5	3.8
		2	8230	3.1	4.0	4.5	3.3
6-4-54	2	1	17800	1.7	2.9	5.0	4.7
		1a	16700	2.6	3.2	5.0	4.0
		1b	15250	2.7	3.3	4.5	3.5
		2	-	3.0	-	4.5	3.4
6-8-54	1	3	10600	2.6	2.7	4.0	2.8
		3a	7500	2.8	2.9	4.0	2.6
		3b	8400	2.9	3.1	3.0	2.2
		4	3240	3.1	3.2	2.5	1.7
"	2	3	11450	2.7	2.7	3.0	2.9
		3a	7500	2.9	3.2	3.0	2.7
		3b	No Record				
		4	2860	2.9	3.2	3.0	2.1

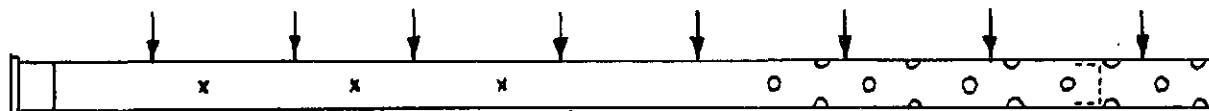
TABLE VIII - STANDARD M58 PRIMERS



DATE	ROUND NUMBER	GAUGE POSITION	MAXIMUM PRESSURE (psi)	T ₁ (ms)	T ₂ (ms)	T ₃ (ms)	T ₃ ' (ms)
11-1-54	5	1	12220	1.4	4.3		5.5
		1a	11220	1.5	4.1		5.7
		1b	10060	2.9	3.1		4.0
		2	7830	3.5	3.6		3.3
11-15-54	9	3	8250	2.6	2.9		3.0
		3a	7160	2.8	3.1		2.1
		3b	6780	--	--		--
		4	5250	3.4	4.0		1.5
3-7-55	6	1	11250	1.2	3.4	4.6	
		1a	11500	1.5	3.4	4.9	
		1b	10450	2.34	3.4	3.6	
		2	8350	2.86	3.15	2.9	
"	7	1	13500	1.2	3.86	6.0	
		1a	12700	1.47	4.0	5.1	
		1b	10700	2.8	4.0	4.0	
		2	7800	3.4	3.9	2.8	
"	8	1	13500	1.2	3.6	4.8	
		1a	13100	1.5	3.7	4.8	
		1b	10500	2.2	3.75	3.8	
		2	8360	3.1	3.4	2.4	
"	9	3	7000	2.9	3.35	2.1	
		3a	8000	3.12	3.35	2.3	
		3b	4200	3.35	3.7	1.7	
		4	1680	3.70	3.9	1.4	
"	10	3	8580	3.3	3.6	3.6	
		3a	7130	3.6	3.7	2.4	
		3b	4550	3.8	4.1	1.9	
		4	2820	3.9	4.1	1.5	
"	11	3	6250	3.5	4.15	2.5	
		3a	6410	3.9	4.3	3.2	
		3b	5660	4.25	4.45	2.1	
		4	1740	4.38	4.60	1.6	

TABLE IX - MODIFIED M58 PRIMERS

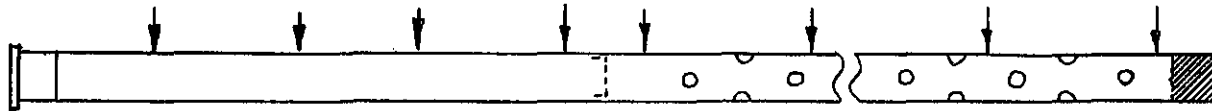
(Vents Added Near Breech End)



DATE	ROUND NUMBER	ADDED VENTS		GAUGE POSITION	MAXIMUM PRESS. (psi)	T ₁ (ms)	T ₂ (ms)	T ₃ (ms)
		NUMBER	DIA. (in.) DISTANCE FROM INITIATOR (in.)					
11-1-54	3	4	0.059	2 and 4	1	12570	0.7	2.9
					1a	9850	2.1	2.8
					1b	No Record		
					2	8850	2.4	2.6
"	4	6	0.059	2, 4, and 6	1	11670	0.5	3.0
					1a	10350	1.3	3.0
					1b	9720	2.1	3.0
					2	7750	2.5	2.6
11-15-54	8	6	0.059	2, 4, and 6	3	7500	2.6	3.0
					3a	6250	2.7	3.0
					3b	5000	3.0	3.2
					4	2100	3.3	3.4
11-1-54	6	2	0.140	2	1	9500	1.2	5.0
					1a	8850	1.5	5.2
					1b	8060	3.5	5.0
					2	6780	4.4	4.5
"	9	4	0.140	2 and 4	1	6980	0.9	3.5
					1a	6250	1.8	3.6
					1b	6360	2.6	3.2
					2	6060	3.1	3.3
"	10	6	0.140	2, 4, and 6	1	6380	0.5	3.8
					1a	5900	1.5	2.6
					1b	6520	2.0	2.1
					2	6080	2.4	2.6
"	12	6	0.140	2, 4, and 6	3	5720	3.1	3.2
					3a	3240	3.3	3.7
					3b	220	7.0	7.5
					4	170	7.5	8.0

TABLE X-CLOSED END FVE TYPE PRIMERS

225 Grains Grade A-1 Black Powder

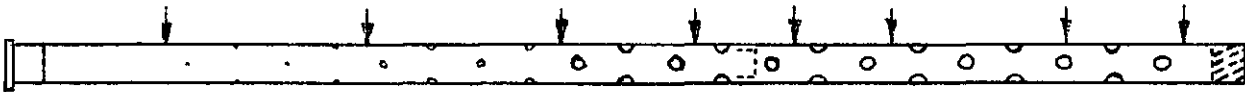


DATE	ROUND NUMBER	LENGTH (in.)	GAUGE POSITION	MAXIMUM PRESSURE (psi)	T ₁ (ms)	T ₂ (ms)	T ₃ (ms)
1-7-54	3	11 1/4	1	8600	1.4	3.6	9.5
			2	6700	2.6	3.5	9.0
			3	5780	2.8	3.6	7.3
			4	5600	3.0	3.7	7.6
1-8-54	2	11 1/4	1	8350	0.7	3.2	6.5
			2	7900	2.3	2.7	6.0
			3	4530	2.5	2.7	5.3
			4	2500	2.6	2.6	4.5
"	3	12 3/4	1	4200	2.5	6.1	8.0
			2	3000	3.7	5.9	7.0
			3	2240	5.0	5.8	7.2
			4	4650	5.5	5.5	6.8
"	4	12 3/4	1	5960	0.8	3.7	8.0
			2	4650	2.9	3.7	10.0
			3	3600	3.0	3.5	6.5
			4	6280	3.2	3.3	7.0
"	5	14 1/4	1	No Record			
			2	5350	2.3	2.3	5.5
			3	3030	2.4	2.6	5.0
			4	8200	2.2	2.3	5.5
"	6	14 1/4	1	5830	1.0	3.7	6.5
			2	6450	3.0	3.1	10.0
			3	3600	3.2	3.7	5.3
			4	No Record			
9-2-54	4	14 1/4	3	4020	2.5	2.7	6.0
			3a	4005	2.9	3.4	5.5
			3b	6700	3.1	3.4	5.0
			4	5130	3.1	3.4	5.0

TABLE X (Cont'd)

DATE	ROUND NUMBER	LENGTH (in.)	GAUGE POSITION	MAXIMUM PRESSURE (psi)	T ₁ (ms)	T ₂ (ms)	T ₃ (ms)
1-12-54	1	15 3/4	1	7600	0.9	2.8	7.5
			2	4750	2.5	2.5	5.5
			3	7130	2.6	2.6	5.5
			4	No Record			
"	2	15 3/4	1	7850	0.7	2.6	6.5
			2	6900	2.2	2.5	6.5
			3	3800	2.3	2.5	6.5
			4	11250	2.6	2.6	6.5
5-6-54	3	15 3/4	3	4000	3.9	5.0	4.5
			3a	3250	4.2	4.9	4.0
			3b	3630	4.4	5.0	4.0
			4	4280	4.5	4.6	4.5
5-13-54	3	15 3/4	1	11000	-	-	-
			1a	10350	-	-	-
			1b	7200	-	-	-
			2	6500	-	-	-
9-2-54	5	15 3/4	3	4890	3.2	3.5	9.1
			3a	3705	3.6	3.6	8.0
			3b	4075	3.4	4.0	7.4
			4	5730	3.4	3.7	8.0
1-7-54	1	17 1/4	1	No Record			
			2	No Record			
			3	2180	3.4	4.0	6.5
			4	3480	4.0	4.5	5.5
"	2	17 1/4	1	No Record			
			2	8220	2.0	2.0	5.8
			3	6450	2.0	2.2	7.0
			4	No Record			
9-2-54	6	17 1/4	3	3680	3.8	4.4	5.0
			3a	2410	3.9	4.4	4.0
			3b	3780	4.3	5.0	4.0
			4	5710	4.4	4.8	3.5

TABLE-XI-T88E1 PRIMER



DATE	ROUND NUMBER	GAUGE POSITION	MAXIMUM PRESSURE (psi)	T ₁ (ms)	T ₂ (ms)	T ₃ (ms)
2-14-55	5	1	6945	1.46	1.94	3.5
		1a	6885	2.46	2.88	2.9
		1b	6120	2.97	3.33	2.6
		2	3760	3.19	3.52	-
2-15-55	1	3	5140	2.84	2.95	1.73
		3a	5580	2.93	3.14	1.68
		3b	5420	3.09	3.47	1.74
		4	10630	3.12	3.25	1.64
"	2	3	5300	3.28	3.37	3.0
		3a	4730	3.42	3.62	3.0
		3b	5710	No Record		
		4	5010	3.7	3.85	2.5
"	3	3	2820	4.49	4.57	19.11
		3a	2760	4.73	4.96	17.04
		3b	2585	5.08	5.55	12.01
		4	967*	5.21	5.32	20.
3-2-55	1	3	2245	3.7	4.0	1.4
		3a	3225	3.8	3.93	1.35
		3b	5200	4.08	4.40	1.57
		4	1570	4.4	4.7	0.8
"	2	1	4660	1.33	3.5	4.4
		1a	4460	2.42	3.5	3.1
		1b	4940	3.3	3.65	2.4
		2	4175	3.8	3.9	1.9
"	3	3	-	3.85	3.95	1.8
		3a	2600	4.05	4.2	1.8
		3b	2115	4.35	4.5	2.1
		4	398*	4.35	4.4	0.6

TABLE-XI- (Cont'd)

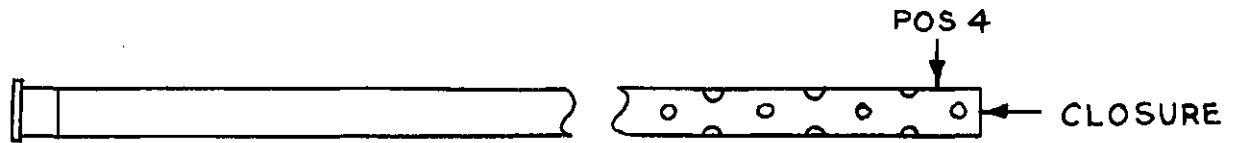
DATE	ROUND NUMBER	GAUGE POSITION	MAXIMUM PRESSURE (psi)	T ₁ (ms)	T ₂ (ms)	T ₃ (ms)
3-7-55	2	1	5350	1.4	3.22	4.2
		1a	5120	2.6	3.22	2.6
		1b	5030	3.22	3.57	2.6
		2	3440	3.58	3.74	1.95
"	3	1	4460	2.1	4.9	5.3
		1a	4020	3.34	4.7	3.7
		1b	3400	4.35	4.7	2.7
		2	2250	4.9	5.0	2.2
"	4	3	3320	3.33	3.7	2.3
		3a	2220	3.45	3.7	2.0
		3b	3450	3.7	4.0	1.7
		4	7770	3.7	4.0	1.35
"	5	3	1900	4.9	5.0	1.7
		3a	2020	5.1	5.3	1.7
		3b	1570	5.5	5.6	1.0
		4	2390	5.6	5.7	1.0

* In these cases the pressure gauge port was believed to have been partially blocked by the paper blow-out diaphragms.

TABLE XII - STAGNATION PRESSURES AT PRIMER CLOSURES

MODIFIED PRIMERS

(Reduced Charges of Grade A-1 Black Powder)



DATE	ROUND NUMBER	TYPE	CHARGE (GRAINS)	MAXIMUM PRESSURE (PSI) POSITION 4	CLOSURE
10-27-54	3	M58	100	2590	2780
"	4	M58	150	2580	4580
"	5	M58	200	5780	7700
"	6	M40	100	1800	3270
11-1-54	2	11 1/4" FVE	100	1480	2740

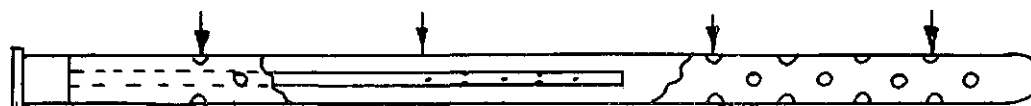
TABLE XIII - FLAME FRONT VELOCITIES IN PRIMERS

Average Values in Feet Per Second

PRIMER TYPE	From P-t Records		From Camera Records
	Unvented Section	Vented Section	Vented Section
11 1/4 inch open-end FVE	550	595	
12 3/4 " " " "	738	1667	
14 1/4 "	326	1310	
15 3/4 "	1278	1113	1114
17 1/4 "	330	1496	
11 1/4 inch closed-end FVE	350	2600	245
12 3/4 "	317	1167	501
14 1/4 "	2495	-	844
15 3/4 "	315	832	1139
17 1/4 "	-	1288	1958
Standard M40	489	2397	1337
Standard M58	273		
Modified M58 (150gr Charge)	398	938	883
Modified M58 (100gr Charge)	364	1527	705

[REDACTED]

TABLE XIV - MODIFIED M28 PRIMERS*
(Double Tube Primer with FFG Black Powder)



DATE	ROUND NUMBER	CHARGE GRAINS	GAUGE POSITION	MAXIMUM PRESSURE (psi)	T ₁ (ms)	T ₂ (ms)	T ₃ (ms)
11-9-53	3	300	1	1550**	No Record		
				400	No Record		
			2	2100	No Record		
				550	" "		
			3	2550	" "		
				600	" "		
			4	No record			
				730	" "		
11-12-53	1	300	1	2130	3.2	3.6	5.6
			2	3100	2.2	2.5	7.0
			3	2620	1.8	1.9	5.6
			4	80	4.5	7.2	12.5
11-9-53	1	200	1	1400**	10.7	11.4	8.3
				200	25.6	271.3	3.2
				340	28.2	30.3	4.7
				1550	11.1	11.5	8.5
			2	250	24.0	27.5	4.6
				470	28.6	30.4	4.5
				2050	10.9	11.9	9.5
				290	24.9	27.7	9.0
			4	950	-	31.0	-
				150	14.8	17.8	5.0
				260	25.0	27.3	10.0
				520	-	30.1	-
11-9-53	2	200	1	1510**	4.3	5.6	10.0
				No Record-		-	-
			2	1700	5.3	5.5	7.0
				No Record-		-	-
			3	2180	4.2	5.4	10.0
				100	17.0	22.5	10.0
			4	520	7.0	10.0	8.2
				130	20.0	23.2	7.7

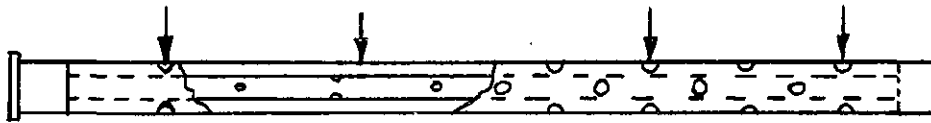
TABLE XIV - (Cont'd)

DATE	ROUND NUMBER	CHARGE GRAINS	GAUGE POSITION	MAXIMUM PRESSURE (psi)	T ₁ (ms)	T ₂ (ms)	T ₃ (ms)
11-4-53	3	150	1	1280	4.8	5.9	5.0
			2	1700	4.3	5.8	5.0
			3	2350	3.3	5.4	6.2
			4	1130	4.3	5.1	4.3
11-4-53	2	100	1	650	23	26	9.0
			2	600	22.3	25.6	9.0
			3	700	21.0	25.6	11.5
			4	580	21.3	25.7	10.3

* Note: 8 of 44 vents holes were covered by gauge housings.

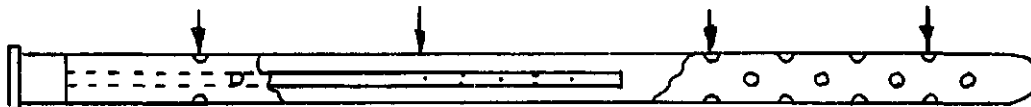
** Multiple Venting

TABLE XV - PRIMER, 5/16" DOUBLE TUBE - WITH BOOSTER
FFFG BLACK POWDER



DATE	ROUND NUMBER	CHARGE (GRAINS)	GAUGE POSITION	MAXIMUM PRESSURE	T ₁ (ms)	T ₂ (ms)	T ₃ (ms)
9-2-54	3	108	1	4080	0.8	0.9	4.1
		(5-Grain Booster)	2	5105	0.5	1.0	4.8
			3	8000	1.1	1.3	5.2
			4	9200	1.2	1.6	4.5

TABLE XVI - MODIFIED M28 PRIMERS *
(Double Tube Primers with Grade A-1 Black Powder)



DATE	ROUND NUMBER	CHARGE (GRAINS)	GAUGE POSITION	MAXIMUM PRESSURE (psi)	T ₁ (ms)	T ₂ (ms)	T ₃ (ms)
8-30-54	5	300	1	3180	1.6	3.3	7.5
			2	2560	1.5	3.5	9.0
			3	2320	1.4	3.9	7.0
			4	3385	1.7	3.8	10.0
8-30-54	6	200	1	300	26.7	30.9	18
			2	690	27.2	30.1	16.5
			3	890	26.3	30.8	17
			4	710	27.3	31.5	20
8-30-54	7	100		Misfire			
11-3-53	2	100		Misfire			

* Note: 8 of 44 vent holes were covered by gauge housings.

TABLE XVII - ESTIMATED END VENTING FROM OPEN-END PRIMERS



DATE	ROUND NUMBER	PRIMER TYPE	CHARGE (GRAINS)	SIDE VENTING (GRAINS)	END VENTING (GRAINS)	END VENTING (PERCENT)
12-11-53	3	FVE 12 3/4 inch open end	225	133.2	92.8	40.8
12-14-53	2	" 14 1/4 in open end	225	158	67	29.8
"	5	" 15 3/4 in open end	225	171.4	53.6	23.8
"	7	" 17 1/4 in open end	225	185.5	39.5	17.6
6-8-54	1	Standard M40	270	225	45	16.7
"	2	" "	270	245	25	9.3
6-24-54	4	Modified M58*	100	49.5	50.5	50.5
6-15-54	3	" "	100	46.2	53.8	53.8
6-15-54	5	Modified M58*	150	97	53	35.4
6-25-54	5	Modified M58**	100	68.5	31.5	31.5
6-25-54	4	Modified M58**	150	99.7	50.3	33.6

* Reduced Charge Tightly Packed.

** Reduced Charge Loosely Packed, (Powder Section Lengthened).

[REDACTED]

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